

AGRICULTURE & FOOD eNEWSLETTER

ISSN: 2581-8317

**VOLUME 07 - ISSUE 06
JUNE 2025**

**MONTHLY ONLINE MAGAZINE IN
AGRICULTURE, HORTICULTURE, FOOD
TECHNOLOGY AND ALLIED SUBJECTS**

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INDEX

Agriculture & Food: e-Newsletter

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Volume 07 – Issue 06 – JUNE 2025

Article id.	Title of article	Page no.
71000	Melatonin: An Emerging Biomolecule in Horticultural Crops	01
71001	Companion Planting for Natural Pest Control: Harnessing Nature's Allies in Agriculture	03
71002	Insect Apocalypse: A Silent Threat to Global Farming	06
71003	Hydroponics - The Future of Agriculture	10
71004	Recently Advance Development Approaches in Tomato (<i>Solanum lycopersicum</i> L.) Breeding	13
71005	Intelligent Packaging and Storage Technologies for Shelf-Life Extension of Tea Products	17
71006	Advances in Artificial Intelligence for Assessing Fish Freshness	21
71007	Advances in Tea Beverage Processing: Traditional Roots to Hybrid Innovations	25
71008	Advanced Post-Harvest Practices for Prolonging the Shelf Life of Cut Flowers	29
71009	Study on Post-Harvest Treatments to Extend Vase Life of Cut Carnations: Focus on Sucrose Pulsing and Silver Thiosulphate (STS) Treatments	36
71010	Biological Control of Plant Diseases: A Review	39
71011	Jeevamrit Application in Marigold (<i>Tagetes</i> spp.): A Review on Growth, Yield, and Sustainable Production	43
71012	Recently Advance Development Approaches in Tomato (<i>Solanum lycopersicum</i> L.) Breeding	46
71013	Biometrical Techniques in Plant Breeding	49
71014	Nano Fertilizers: The Next Revolution in Crop Nutrition	52
71015	Drone-Based Pest Surveillance: A Game Changer for Insect-Pest Monitoring	55
71016	Rainfed Agriculture: Traditional Adaptation Strategies in Water-Scarce Regions	58
71017	Integration of IoT and AI Technologies in Urban Vertical Farming for Sustainable Vegetable Production	62
71018	Ergot Disease in Bajra (Pearl Millet): Symptoms and Management	65
71019	Blister Blight of Tea: Symptoms and Integrated Disease Management	67
71020	Low Poly Tunnels: Uses and Recent Advances in Vegetable and Ornamental Applications	69
71021	Comprehensive Nursery Raising Techniques in Vegetables	72
71022	Management of Bacterial Wilt of Tomato	75
71023	Li-Fi Technology in Horticulture: A Smart Solution for Future Farming	76
71024	Soil Health and Management	79
71025	Startup Ecosystem and Investment Trends in Hydroponics Agritech	82
71026	Synthetic Biology for Engineered Plant Metabolites: Unlocking New Frontiers in Drug Discovery	86
71027	Carbon Farming: A New Income Stream for Farmers	89

INDEX

Agriculture & Food: e-Newsletter

Volume 07 – Issue 06 – JUNE 2025

www.agrifoodmagazine.co.in

71028	Advances in Raceway Aquaculture System	92
71029	Recirculatory Aquaculture Systems (RAS)	97
71030	Open Crop Residue Burning: Cause, Impact, and Mitigation	101
71031	Mapping Plant Health: How GIS and QGIS are Transforming Plant Disease Assessment in Agriculture	105
71032	A Case Study on Multicollinearity in Agricultural Data: Causes, Consequences, and Detection	108
71033	Role of Herbal Additive in Aquaculture	111
71034	Storage Entomology: Insect Pests in Stored Products	116
71035	From Algorithms to Animals: Integrating AI into India's Livestock Sector for Inclusive Growth	119
71036	Documentation and Preservation of Indigenous Technical Knowledge (ITK) for Better Knowledge Management in Agriculture	122
71037	Medicinal And Nutritional Values of Goat Milk	125
71038	Goat Milk: A Versatile Dairy Alternative with Unique Health Benefits and Functional Properties	130
71039	Revolutionizing the Food Industry with Blockchain: Enhancing Transparency, Traceability and Trust	135
71040	Terraforming Through Agriculture for a Long-Term Vision	138
71041	Push-Pull Strategy: A Game-Changer in Integrated Pest Management	141
71042	White Fly as Vectors: Uncovering Their Role in Plant Disease Transmission	144
71043	Rice Blast Disease: A Growing Concern for Food Security	146
71044	Mites as Vectors: Uncovering Their Role in Plant Disease Transmission	149
71045	Disease Detectives: Using Remote Sensing and GIS to Monitor Crop Health	152
71046	Harvesting Opportunities: Agro Eco-Tourism as a Path to Sustainable Rural Entrepreneurship	156
71047	Sowing the Seeds of Change: Urban Agriculture for a Greener Future	159
71048	Biofertilizers: A Natural Solution for Improving Soil Fertility	162
71049	Boosting Crop Potential: The Benefits of Bio-Stimulants in Agriculture	166
71050	Blockchain in Agriculture: Enhancing Transparency, Security, and Efficiency	169
71051	Kewda Source of Liquid Gold	172
71052	Synergy Between Environment Sustainability and Crop Growth Efficiency	175
71053	Soil-Plant Dynamics: A Key to Maximize Crop Productivity	179
71054	Nutritional and Sustainable: Plant-Based Beverages	181
71055	Regenerative Agriculture: Building Healthy Soils for Future Generations	184
71056	Women Empowerment through Fruit Processing and Marketing in Rural India	188
71057	Regenerative Agriculture: Building Healthy Soils for Future Generations	192

INDEX

Agriculture & Food: e-Newsletter

Volume 07 – Issue 06 – JUNE 2025

www.agrifoodmagazine.co.in

71058	Evaluation of Herbicide Efficacy in Non-Crop Situations	196
71059	The Science of Ripening in Vegetables: Ethylene Role and Changes During Ripening	199
71060	Insight on Major Fungal Diseases of Some Medicinal Plants	203
71061	Insight on Bacterial Diseases of Medicinal Plants	207
71062	Insight on Viral Diseases of Medicinal Plants	210
71063	Incubating Rural Agripreneurs through RKVY-RAFTAAR	213
71064	Smart Logistics and Cold Chain Management in Perishables	216
71065	Stress: Navigating Environmental Stress on Cropping - Strategies for Boosting Crop Resilience	219
71066	Sustainable Aquaculture: Ensuring a Resilient Future for Global Seafood	222
71067	Aquaculture and Biodiversity: Balancing Production and Conservation	226
71068	Biofertilizers: A Natural Path to Restoring Soil Fertility	230
71069	Digital Twin in Vegetable Farming	232
71070	Sangri - A Popular Humble Bean of Desert Rajasthan in Pursuit of GI Tag	234
71071	Antimycotic Innovation: Revolutionary Biomaterial Packaging Extends Postharvest Fruit Viability	236
71072	Leveraging E-NAM and Digital Mandis for Direct Marketing	239
71073	Environmental Impact Assessment of Recirculating Aquaculture Systems	243
71074	Soil Carbon and Carbon Credits: Can Farmers Earn by Saving Soil?	247
71075	Nanotechnological Innovations for Sustainable Plant Disease Suppression	250
71076	Tiny Tenants: Endosymbionts - How they Power the Insect World?	253
71077	Why Are Whiteflies So Invasive in India?	259
71078	Sustainable Agriculture Practices	261
71079	Panchagavya: A Low-Cost Organic Input for Sustainable Crop Production	264
71080	Jeevamrutha: A Step Towards Sustainable Crop Production and Chemical-Free Farming	268
71081	Boosting Crop Yields Organically: The Use of Humic Acid in Modern Agriculture	272
71082	Seaweed Extract: A Natural Bio-Stimulant for Sustainable Agriculture	275
71083	Plant Vaccines: Can We Immunize Crops Against Diseases?	278
71084	Role of Nano-Formulation in Persistence and Dissipation of Pesticide Residues	280
71085	Value Addition of Organic Produces to Marketable, Higher-Value Products	283
71086	Boosting Sugarcane Seedling Production by Single Eye Bud Sett Cutter	286
71087	AI and Machine Learning: Transforming Insect Identification and Crop Protection	289
71088	Climate-Resilient Fruit Crops: Innovations in Breeding and Sustainable Management	292

INDEX

Agriculture & Food: e-Newsletter

Volume 07 – Issue 06 – JUNE 2025

www.agrifoodmagazine.co.in

71089	Jute's Homeland: The Science behind its Affinity for Bengal's New Alluvial Zone Green Gold	296
71090	Biosensors for Food Quality and Safety Assessment	301
71091	Importance of Biofortification in Vegetable Crops	304
71092	Karyotaxonomy in Fishes and its Importance	307
71093	Vegetables as Natural Antioxidant Sources	313
71094	Forest-Based Livelihood: Pathways to Resilience and Sustainability	316
71095	Importance of Mulching in Crop Production	320
71096	Role of Pseudomonas spp. in Disease Management Towards Sustainable Agriculture	322
71097	Heavy Metals Removal Using Natural Based Polymer	325
71098	The Vital Role of Bees and Insects in Pollination of Cucurbit Vegetables	327
71099	Comprehensive Guide to Production Technology of Solanaceous Vegetables (Tomato, Brinjal, Chili and Capsicum) – With Special Focus on Rainy Season Cultivation	330
71100	High-Tech Nurseries: Bridging the Gap between Agronomy and Climate-Smart Agriculture	333
71101	Sowing Sustainability: A Guide to Carbon Neutral Gardening Practices	337
71102	The Burning Issue: Understanding Open Crop Residue Burning's Impact and Mitigation Strategies	341
71103	Eco-Friendly Textile for Sustainable Growth	343
71104	From Mulberry to Marketplace: Exploring the Potential of Seri-Tourism	346
71105	The Role of Nutrition in Non-Alcoholic Fatty Liver Disease: A Review of the Evidence	350
71106	Conservation Agriculture: Future for Modern Agriculture	353
71107	Bee Venom Therapy: From Venom to Medicine	355
71108	Sustainable Urd-bean Production in Changing Climatic Conditions	357
71109	Bio-Input Resource Centres for Natural Farming	359
71110	Ohmic Heating: A Revolutionary Technology in Food Processing	362
71111	Role of UAV Integrated with Machine Learning in Agriculture	365
71112	Signal Pathways in Nematophagous Fungi-Nematode Interactions: Implications for Biocontrol	368
71113	Comprehensive Guide to Biofertilizers: Formulations, Applications, and Usage Guidelines	372
71114	Biodynamic Seed Treatment: Unravelling the Ecological Principles of Beejamrutham	378
71115	LoRa Communication for Agriculture 4.0	381
71116	Wetland and Carbon Sequestration	385
71117	Post Harvest Nutritional Facts and Value Addition of Litchi Fruit (<i>Litchi chinensis</i>)	388
71118	The Health Benefits and Risks of Drinking Honey with Lemon and Hot Water: A Natural Wellness Elixir	391

INDEX

Agriculture & Food: e-Newsletter

Volume 07 – Issue 06 – JUNE 2025

www.agrifoodmagazine.co.in

71119	India's Blue Economy: Transforming the Coastal Resources into Opportunities	393
71120	Cyborg Botany: Engineering Plant-Machine Interfaces for Precision Agriculture	396
71121	Small Hive Beetle (SHB): A Growing Threat for Global Beekeepers	399
71122	Shrimping for Gold - India's Lucrative Shrimp Farming Business	403
71123	Turning Trash into Treasure: How Agricultural Waste is Fueling the Future with Biobutanol	408
71124	Optimization of Working Parameters for a Tractor-Mounted Coconut Basins Lister Cum Fertilizer Dispenser	410
71125	Remote Sensing in Agriculture	412
71126	Importance of Agripreneurship Facilitation Center (AEFC) at Krishi Vigyan Kendras and Other Government Institutions	415
71127	Production Technology of Onion Under Saline Soil Conditions	417
71128	Socioeconomic Characterization of Recreational Fisheries in India	420

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Melatonin: An Emerging Biomolecule in Horticultural Crops

Article ID: 71000

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Introduction

The world's population is currently 7.7 billion and is projected to increase to 8.5 billion by 2030 and 9.7 billion by 2050 (United Nations, 2019). Horticultural crops are major sources of proteins, carbohydrates, vitamins, minerals, fiber, fats, micronutrients, and antioxidants in human nutrition. The shift towards population growth and healthier diets has led to an increased demand for horticultural crops. The crop quality and food safety is negatively affected by the abuse of agrochemicals by growers in pursuit of high yields and profits threatening environmental and human health through the food chain. Also, climate change and other abiotic and biotic stresses seriously affect horticultural production and will potentially increase in the future (Parajouli et al., 2019; Wheeler and Barun, 2013). Different phytohormones are produced by plants to mitigate the adverse effects of these stresses. One such phytohormone is melatonin (MEL), which, being a potential bio-stimulator, helps to govern a wide array of functions in horticultural crops.

Structure and Occurrence of Melatonin

Melatonin (*N*-acetyl-5-methoxytryptamine, MT or Mel), is a highly conserved molecule, which has a structure similar to auxin as an indole tryptamine. It was initially found (Lerner et al., 1958) in the pineal gland of the cow brain and was named melatonin because it acted as a skin-lighting agent in frogs. Later, Jackson (1967) detected a small amount of melatonin in the endosperm cells of Hydrangea lily. Dubbels et al. (1995) extracted melatonin from plants by gas chromatography/mass spectrometry for the first time. Since then, melatonin has been detected in many horticultural plants like tomato (*Solanum lycopersicum*), cucumber (*Cucumis sativus*), Chinese cabbage (*Brassica rapa* var. *glabra*), grape (*Vitis vinifera*), apple (*Malus pumila*), logan and banana (*Musa nana*).

Function of Melatonin in Horticultural Crops

Melatonin is a pleiotropic molecule with many diverse effects in living organisms. Because of its diverse biological functions, the term 'phytomelatonin' was proposed in 2004. Recent studies have demonstrated numerous potential functions of melatonin in multiple aspects of horticulture, including molecular breeding, vegetative reproduction, virus-free plant production, food safety and horticultural crop processing. Melatonin can also influence key plant processes such as parthenocarp, autophagy and arbuscular mycorrhizal symbiosis. Numerous examples in horticultural crops have demonstrated that the development of new crop varieties and the use of melatonin as a PGR, preservative, and antimicrobial agent have great potential to address grand challenges in the horticultural industry. Field trials have shown the promise of melatonin for regulating fruit set and fruit ripening, promoting fruit postharvest preservation, and improving abiotic/biotic stress resistance. The optimal melatonin dosage, application method, and duration appear to differ among different species and plant parts. Three application parameters should be considered in order to apply melatonin effectively: concentration, method, and processing time.

Table 1. Phytomelatonin effects and response elements in different abiotic stress (Wang et al., 2024):

Stress	Phytomelatonin effects	Response elements
Heat stress	Activate the heat stress-related regulatory network and enhance antioxidant enzyme activities	HSFs, HSPs, POD, CAT, SOD, RBOH

Cold stress	Increase the expression of cold-response genes and cooperate with other phytohormones	ICE, CBF, miRNAs, CDPKs, bHLHs, DREBs, WRKYs, MYBs, NCEDs
Drought stress	Synergistic promotion with other phytohormones and ROS scavenging	NCEDs, CYP707s, WRKYs, DREBs, MYBs
Salt stress	Activate the H ⁺ pump and enhance the ion homeostasis	Na ⁺ -K ⁺ transporters, APX, CAT, POD, TRXs, PET and D1 protein, SLAC, MYBs; ABF; AREB, MAPK
Heavy metal toxicity stress	Reduce accumulation of heavy metal in plants and enhance antioxidant enzyme activities	MT1, IRT1, Nramp1, PT2, PT8, Lsi1, SGT1
UV stress	Activate the key components of UV-B signaling pathway	COP1, HY5, HYH, RUP1/2, GPXs
Oxidative stress	Scavenges the ROS and alleviates direct oxidative stress	APX, CAT, POD, SOD
Waterlogging stress	Optimize metabolism in roots and regulate hypoxia-related genes	ACO, ACS, ADC, DAO, SAMDC, SPDS, SPMS

Conclusion and Future Thrusts

The use of melatonin as a novel eco-friendly agrochemical and the development of new crop varieties have great potential to meet agricultural challenges. However, melatonin has significant untapped potential, and many of its possible benefits to the horticultural industry remain unclear. Therefore, potential applications of melatonin should be tested through field trials. For effective translation of melatonin to the horticultural industry, it will be critical to gain a better understanding of several challenges associated with its use, including the identification of effective melatonin concentrations and the development of economically viable melatonin sources. In the future, the development of crop varieties with increased melatonin production or modified melatonin signaling will undoubtedly give rise to new paradigms for the application of melatonin in horticultural crops in a changing environment.

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Companion Planting for Natural Pest Control: Harnessing Nature's Allies in Agriculture

Article ID: 71001

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Abstract

Companion planting is an age-old agricultural practice that involves the strategic placement of different plant species in proximity to enhance growth, deter pests, and promote biodiversity. This method leverages natural plant relationships to reduce reliance on chemical pesticides, thereby fostering sustainable farming practices. Recent scientific studies have elucidated the mechanisms by which companion plants contribute to pest management, including acting as trap crops, emitting repellent volatiles, and attracting natural enemies of pests. This article delves into the science behind companion planting, highlighting its efficacy in natural pest control and its role in sustainable agriculture.

Keywords: Companion planting, volatile organic compounds, repellents, trap crops.

Introduction

Modern agriculture faces the dual challenge of increasing food production while minimizing environmental impact. Chemical pesticides, though effective, have led to issues such as pest resistance, environmental degradation, and health concerns. Companion planting emerges as a viable alternative, offering a natural means to manage pests and enhance crop productivity.

Companion Plants Altering Host Plant Selection

Search behavior and the selection of vital resources for insects such as aphids can be divided into three steps: habitat location, host location, and host acceptance. During these three steps, positive and negative external stimuli interact also with the internal factors of the insect, allowing for the acceptance or rejection of the host plant. Generally, visual (colors, contrasts) and olfactory stimuli are involved in aphid host-finding.

Olfaction is typically the major sensory modality during the first two steps, while chemoreception dominates the third. Some Companion Plants are known to release chemicals that may affect the movement, feeding, and reproductive behavior of aphids. Strategies using this type of CP have been developed to disturb the process of HP selection either directly on aphids by affecting their habitat and host selection (masking, repellency), or indirectly by modifying HP acceptability by aphids.

Mechanisms of Pest Control through Companion Planting

1. Trap Crops: Trap crops are planted near the main crop to lure pests away. For example, mustard is often used alongside cabbage to attract pests like diamondback moths and flea beetles, sparing the main crop from damage. Once the pests are concentrated on the trap crop, they can be controlled more easily using targeted methods.

2. Repellent Plants: Certain plants naturally produce chemicals that repel insect pests. For instance, marigolds emit compounds that deter nematodes and aphids, while basil planted near tomatoes can repel whiteflies and mosquitoes. These aromatic plants mask the scent of host crops, making it harder for pests to locate their targets.

3. Attracting Beneficial Insects: Many flowering plants attract predators and parasitoids that feed on pests. Sweet alyssum, for example, attracts hoverflies, whose larvae consume aphids. Similarly, dill, fennel, and coriander attract parasitic wasps that help control caterpillar and aphid populations. This promotes a natural balance in the field.

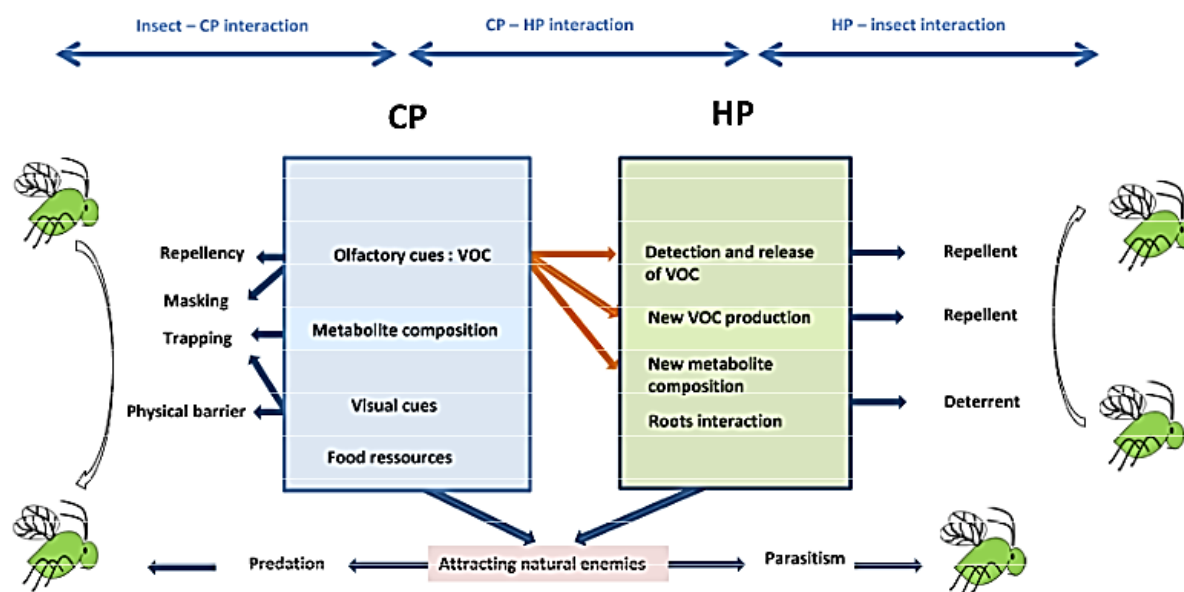


Fig.1. Potential interactions between companion plants, aphids, natural enemies, and host plants. Interactions and mechanisms described are based on the available literature. CP: companion plant, HP: host plant, VOC: volatile organic compound.

4. Habitat Diversification: A diverse plant environment creates niches for beneficial insects and reduces the likelihood of pest outbreaks. Intercropping—growing two or more crops together—breaks the uniformity that pests exploit. A classic example is the “Three Sisters” planting used by Native Americans: corn, beans, and squash, which support each other both physically and ecologically.

Examples of Effective Companion Planting

Main Crop	Companion Plant	Benefit
Tomatoes	Basil, Marigold	Repels aphids, whiteflies
Cabbage	Dill, Nasturtium	Attracts predators, distracts pests
Corn	Beans, Squash	Nitrogen fixation, ground cover
Carrots	Onions	Repels carrot flies
Lettuce	Chives, Garlic	Repels aphids, enhances flavor

Scientific Evidence and Case Studies

Recent studies have provided strong support for the effectiveness of companion planting:

1. A study by the International Centre of Insect Physiology and Ecology (icipe) found that push-pull technology—a form of companion planting—significantly reduced stem borer infestations in maize and increased yields by over 50%.
2. Researchers at the University of California demonstrated that planting mustard alongside lettuce significantly decreased populations of aphids and thrips, reducing the need for pesticide applications.
3. In pear orchards, intercropping with aromatic plants like basil (*Ocimum basilicum*) and summer savory (*Satureja hortensis*) has led to significant reductions in aphid populations. Similarly, in cotton fields, bordering with alfalfa (*Medicago sativa*) has increased predator populations, effectively controlling aphid infestations.

Species of Aphid	Host Plant	Companion Plants	Proposed Mechanisms
<i>Myzus persicae</i>	<i>Capsicum annuum</i>	<i>Allium schoenoprasum</i>	Masking odors Repellency Reduces the attractiveness of hosts
<i>Brevicoryne brassicae</i>	<i>Brassica oleracea</i> Bently F1	<i>Tagetes patula nana</i> <i>Calendula officinalis</i>	Repellency
<i>Myzus persicae</i>	<i>Nicotiana tabacum</i>	<i>Allium sativum</i>	Repellency Deterrent effect
<i>Myzus persicae</i> <i>Aphis gossypii</i>	<i>Solanum tuberosum</i>	<i>Allium sativum</i>	Repellency Reduces the attractiveness of hosts
<i>Myzus persicae</i>	<i>Capsicum annuum</i>	<i>Ocimum basilicum</i> <i>Rosmarinus officinalis</i> <i>Lavandula latifolia</i>	Repellency Reduces the attractiveness of hosts
<i>Brevicoryne brassicae</i>	<i>Brassica oleracea</i>	<i>Allium cepa</i>	Reduces host-finding ability
<i>Brevicoryne brassicae</i>	<i>Brassica oleracea</i>	<i>Secale cereal</i>	Reduces host-finding ability
<i>Aphis fabae</i>	<i>Vicia faba</i>	<i>Satureja hortensis</i> <i>Ocimum basilicum</i>	Deterrent effect Repellency
<i>Aphis citricola</i>	<i>Pyrus communis</i>	<i>Satureja hortensis</i> <i>Ocimum basilicum</i>	Repellency
<i>Lipaphis erysimi</i>	<i>Brassica napus</i>	<i>Allium cepa</i> <i>Allium sativum</i>	Repellency Deterrent effect Disrupts behavior
<i>Macrosiphum rosivorum</i>	<i>Rosa chinensis</i>	<i>Tagetes patula</i>	Repellency Allelopaty change
<i>Rhopalosiphum padi</i>	<i>Hordeum vulgare</i>	<i>Cirsium vulgare</i>	Allelopaty change Reduces the attractiveness of hosts

Fig. 2. Altering effect of companion plants on host plants and the different mechanisms involved (Issa et al., 2017).

Challenges and Considerations

While companion planting offers many benefits, it also requires careful planning:

- 1. Space and Competition:** Some companions may compete for nutrients or space.
- 2. Timing:** Synchronizing the growth cycles of main and companion plants is essential.
- 3. Pest Spill over:** Improper use of trap crops may increase pest pressure if not managed well.

Conclusion

Companion planting blends tradition and science, offering a sustainable, low-cost approach to pest management. By understanding and harnessing natural interactions between plants and insects, farmers can reduce chemical use, improve crop health, and foster biodiversity. As agriculture moves toward more regenerative practices, companion planting stands out as a key component of resilient farming systems.

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Insect Apocalypse: A Silent Threat to Global Farming

Article ID: 71002

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Abstract

Insects, essential for pollination, pest control, and soil health, are experiencing a rapid global decline, leading to significant implications for agriculture and food security. Recent studies have shown alarming decreases in insect populations, with some regions reporting up to 75% declines in flying insect biomass. The primary drivers of this decline include pesticide use, habitat loss, climate change, and pollution. As insects disappear, crops lose vital pollinators, natural pest control diminishes, and soil health deteriorates, all of which impact agricultural yields and food production costs. The economic value of insect-driven ecosystem services is immense, with pollination alone worth billions of dollars annually. In this article, we explore the causes of insect decline, the critical roles insects play in farming, and the potential consequences for global food security. We also discuss potential solutions, such as agroecological practices, habitat preservation, and policy reforms, to reverse this trend and ensure the sustainability of farming systems. The loss of insects is a growing crisis, but through informed action, it is not too late to protect these tiny yet indispensable creatures.

Keywords: Insect decline, global warming, habitat loss, pollination.

Introduction: A Silent Decline

Look around a summer field today, and you might notice something missing: the hum of bees, the flutter of butterflies, the buzz of beetles. Insects, often overlooked or misunderstood, are quietly disappearing across the globe. This dramatic decline—sometimes called the “**insect apocalypse**”—has serious implications, especially for agriculture. Insects are not just bugs in the dirt—they are essential to farming, food production, and ecosystems. Losing them could disrupt our entire food system.

Once a symbol of vibrant fields and thriving nature, insects are quietly vanishing—and many of us hardly noticing. Their disappearance has been likened to a silent spring: fewer bees on blossoms, fewer butterflies on the breeze, and less of the familiar hum that once filled meadows and farmland. While this might seem like a minor concern, the reality is far more serious. Insects form the backbone of many ecosystems and play essential roles in global food production. Their alarming decline is not only an ecological crisis but also a growing threat to agriculture and food security.

The Evidence for Insect Decline

Studies around the world show alarming trends:

1. A comprehensive review by Sánchez-Bayo & Wyckhuys (2019) estimated that over 40% of insect species are declining, and one-third are endangered.
2. In Germany, a long-term study found a 75% decline in flying insect biomass in protected areas over 27 years (Hallmann et al., 2017).
3. In Puerto Rico's tropical rainforests, insect populations have plummeted by up to 98%, along with the reptiles and birds that depend on them (Lister & Garcia, 2018).
4. Similar patterns have been observed in the UK, Netherlands, Puerto Rico, and parts of the U.S.

This decline is not limited to one species or region—it's global and affects pollinators, decomposers, and pest predators alike.

Why are Insects Disappearing?

Agricultural Intensification: Modern farming practices prioritize high yields over biodiversity. This includes:

- a. Monoculture crops that eliminate plant diversity.
- b. Heavily mechanized land use that destroys habitats.
- c. Frequent tilling and pesticide spraying that kill beneficial insects.

2. Pesticides and Herbicides: Insects face constant exposure to toxic chemicals—particularly neonicotinoids, which impair their nervous systems even in tiny doses. These pesticides:

- a. Disrupt foraging behavior in bees.
- b. Reduce reproductive success in pollinators and predators.

3. Habitat Loss and Fragmentation: Urban development, road construction, and deforestation strip away the natural areas insects need to survive. Many insects are specialists—they require specific plants, soil conditions, or microhabitats. Without them, they simply vanish.

4. Climate Change: Rising temperatures, changing rainfall patterns, and extreme weather events affect insect life cycles and distributions. Some species are unable to migrate fast enough or adapt to rapid changes, especially in mountain or tropical regions.

5. Light and Noise Pollution: Artificial lights confuse nocturnal insects like moths and fireflies, disrupting their reproduction and predator-prey interactions. Urban noise can interfere with acoustic communication used by some species, such as crickets.

6. Invasive Species: Non-native plants and predators can displace or kill native insects.

Impacts on Farming

Pollination at Risk: About 75% of global food crops depend on animal pollination, and insects—especially bees—are responsible for the majority of it. Declines in pollinators have led to:

- a. Reduced yields in crops like apples, almonds, berries, and cucumbers.
- b. Lower fruit quality and nutritional value.
- c. Increased costs as farmers turn to manual pollination or managed bee colonies.

Natural Pest Control Disrupted: Ladybugs, lacewings, wasps, and spiders help control agricultural pests. Their decline means:

- a. Greater reliance on chemical pesticides.
- b. Resurgence of pest outbreaks due to lack of predators.
- c. A vicious cycle of pesticide use, harming more beneficial insects.

Soil Health and Decomposition Affected: Detritivores like beetles, ants, and flies help break down organic matter, recycle nutrients, and aerate soil. Their decline leads to:

- a. Poorer soil fertility.
- b. Slower nutrient cycling.
- c. Less resilient farm ecosystems.

The Economic Cost of Insect Loss

The economic value of insect pollination alone is estimated at \$235–\$577 billion globally each year (IPBES, 2016). Natural pest control and soil health services provided by insects are harder to quantify, but are undeniably vast.

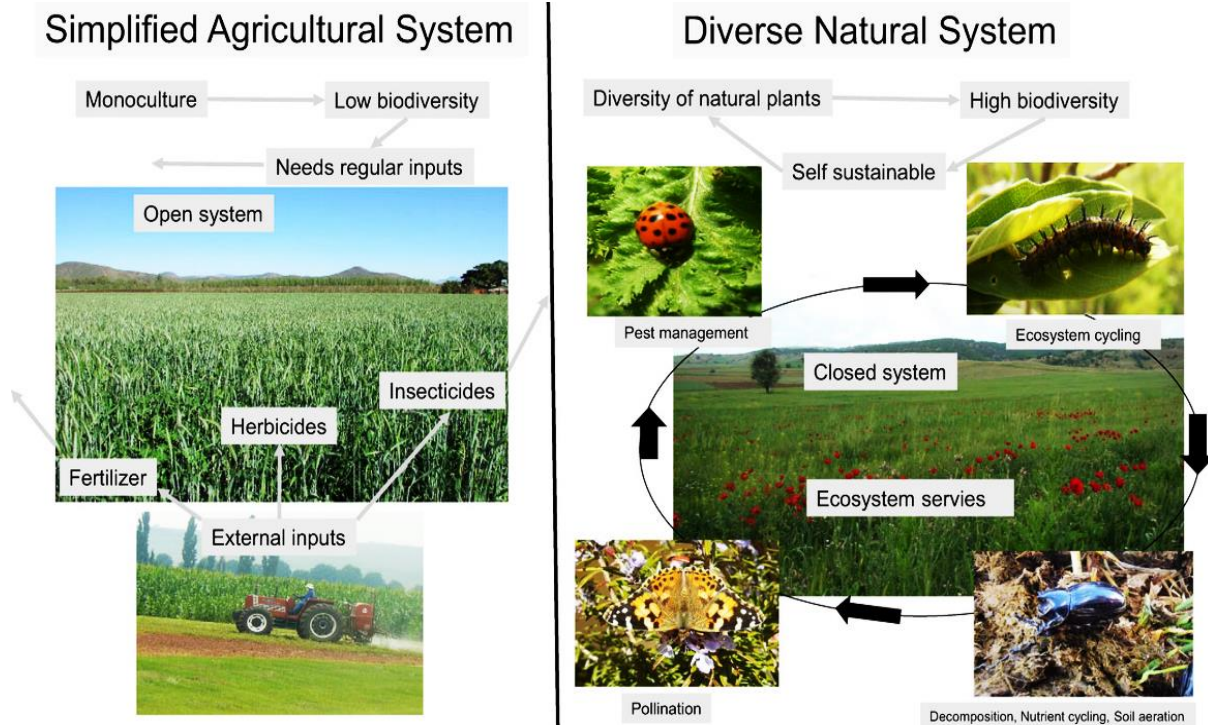


Fig. 1. Comparison of a simplified agricultural system and a diverse natural system (Jankielsohn, 2023).

As Insect Populations Dwindle

1. Yields decrease.
2. Farm input costs rise.
3. Food prices go up.
4. Rural livelihoods suffer.

Ultimately, food security, nutrition, and sustainability are at risk.

A Tipping Point for Agriculture

The decline of insects isn't just an environmental issue—it's a threat to food security. In 2020, Dainese et al. found that biodiversity loss on farms reduces crop yields and stability. Insects provide ecosystem services worth billions of dollars annually. Without them, farming becomes more difficult, expensive, and less sustainable.

What Can Be Done? Toward Insect-Friendly Farming

We're not powerless. A global shift in how we farm and build landscapes can reverse the trend.

1. Agroecology & Regenerative Farming

- a. Rotate crops and diversify plantings to support insect life.
- b. Integrate wildflowers and native plants to provide food and shelter.
- c. Reduce pesticide use and focus on biological control.

2. Preserve Wild Spaces

- a. Protect native vegetation near farms.
- b. Rewild field margins, hedgerows, and riparian buffers.

3. Policy and Research

- a. Ban or restrict harmful pesticides based on scientific evidence.
- b. Invest in long-term insect monitoring programs.
- c. Support incentives for pollinator-friendly practices.

4. Public Involvement

- a. Grow pollinator gardens.
- b. Choose organic and local produce.

c. Advocate for sustainable agriculture.

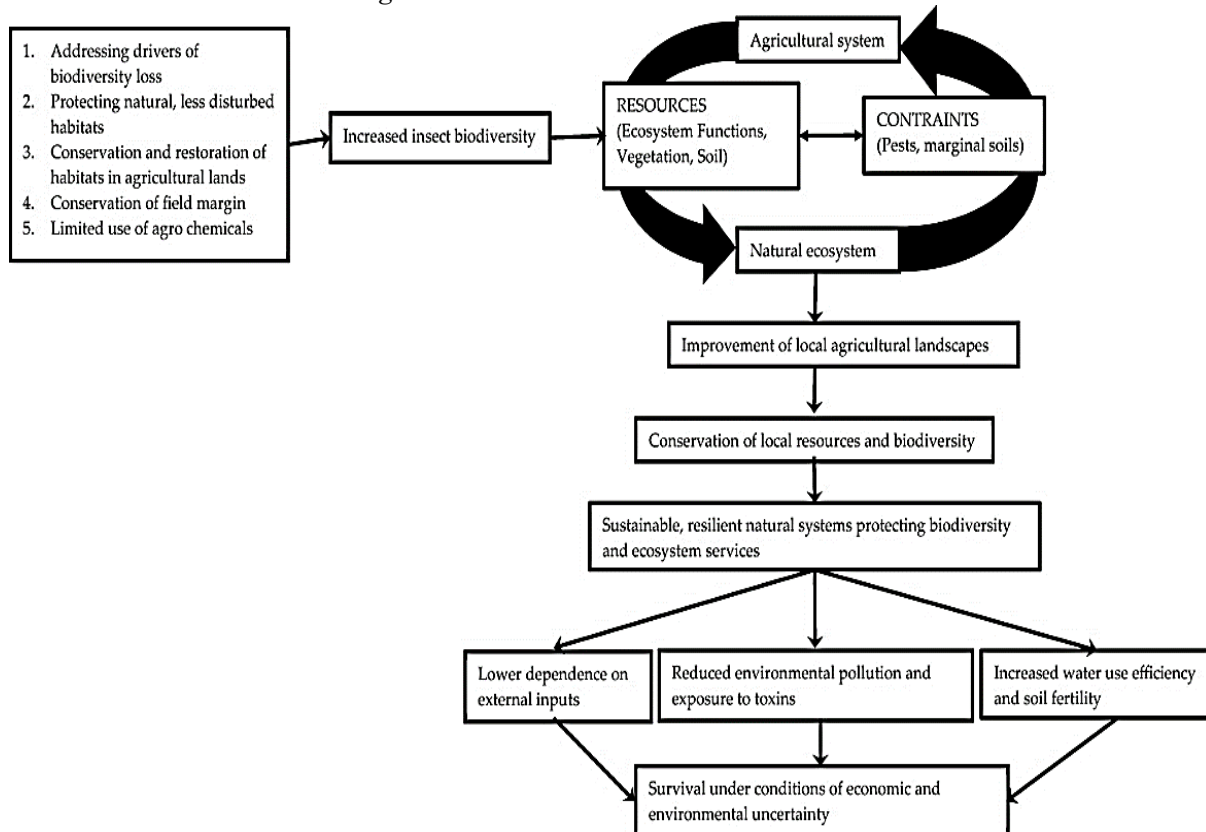


Fig. 2. Holistic approach to changing of agricultural systems to ensure sustainable systems (Jankielsohn, 2023).

Conclusion: Small Creatures, Huge Impact

Insects may be small, but their role in farming is colossal. Their decline is not just an ecological warning—it is an agricultural emergency. If we lose our insects, we risk losing the foundation of global food production. By rethinking how we farm, manage landscapes, and value biodiversity, we can turn this crisis around. The time to act is now—before the buzz truly fades forever.

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Hydroponics - The Future of Agriculture

Article ID: 71003

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Introduction

Growing of plants without soil in a nutrient media contains the complete nutrition for plant which includes subtracts like clay balls, coco-pit, vermiculite as a soil replacement.

These hydroponic models are mainly used by small farmers, hobbyists, and commercial growers. Urban dwellers are showing interest in hydroponic farming, where plants are grown in a nutrient medium without the use of soil and pesticides.

Soilless farming is not a new practice in the world; it has long been practiced in desert countries such as Israel, where hydroponic farming is most common. However, with the increasing use of pesticides, teachers have begun to turn to organic hydroponics. Cities like Bengaluru, Hyderabad, and Delhi are the biggest hubs for this business.

Following the outbreak of the COVID-19 pandemic, health has become a major concern for all animals in the world, leading everyone to seek healthy food. This has increased the demand for hydroponics.

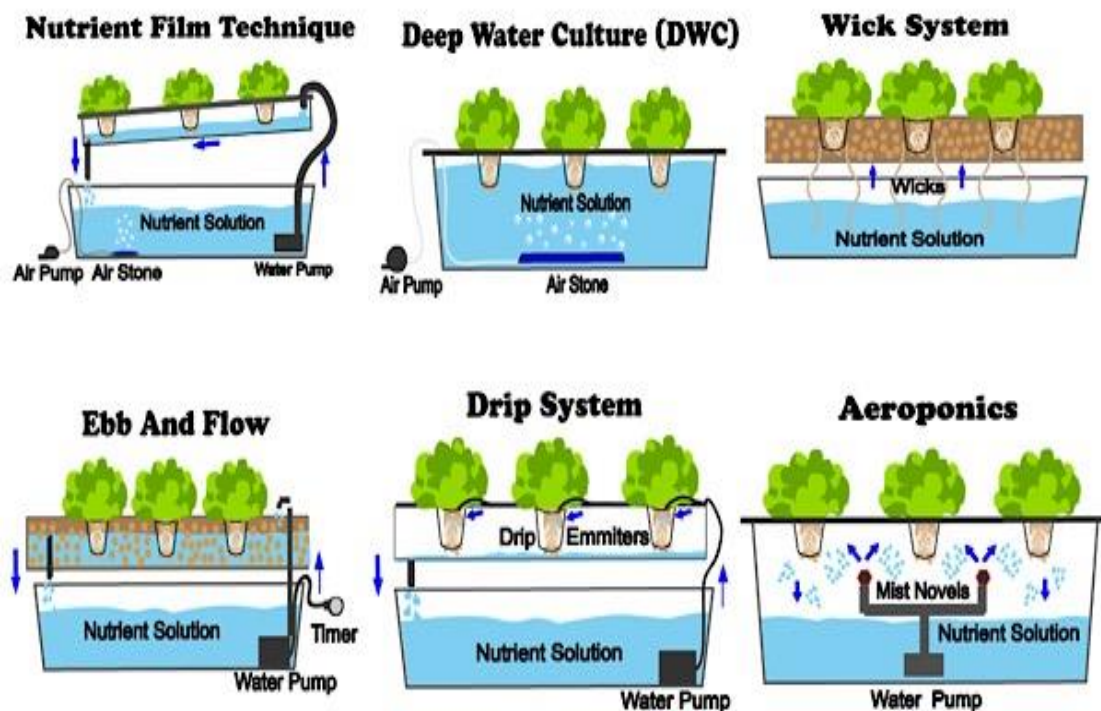


Nutrient Film Technique

Here plants /seedlings are placed slantly over a nutrient solution tank. Here continuous flow of nutrient media is observed. So, the plants can easily uptake the nutrients from that water.

Deep Water Culture

Plants are directly placed in the nutrient tank. Roots are fully dipped in nutrient media. Air stone is placed in the nutrient tank for supply of air to the plants.



Wick System

A string is made up of cotton and nylon helps in absorbing the nutrient media and helps seedlings to grow.

EBB And Flow

In this system a timer is placed which helps the plants absorb the nutrients periodically. seedlings are placed in the pots filled with cockpit /soil balls and kept in trays these trays are called EBB trays.

Drip System

In this system a pump is placed in the nutrient media pipes having drippers supplies the nutrient media continuously. Most preferred system of hydroponics.

Aeroponics

In this system a mist sprayer is placed for continuous supply of nutrients to the plants. Which sprays the nutrient media on coco pits/soil balls.

Advantages	Disadvantages
No soil involved	Time consuming
Saves water	Expensive
Zero weed	Requires some expertise
Free from pesticides	Threats of system failure
Doesn't depend on outer climate	Quantity of yield

Conclusion

Yes, it takes some time to bring awareness in the countries like India at the farmer level but the future going to be different where Agri lands converting to commercial plots bringing scope for hydroponics at homely level too.

It may be expensive today, once corporate takes step into it we may see the downhill of prices. Once we see the health benefits from the source then the expensive is not a matter today.

it may be trend today to grow a hydroponics plant but tomorrow it is necessary to grow hydroponic plant in each and every home.

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Recently Advance Development Approaches in Tomato (*Solanum lycopersicum* L.) Breeding

Article ID: 71004

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Abstract

The cultivated tomato (*Solanum lycopersicum* L. $2n = 2x = 24$) is one of the most widely cultivated vegetable crops due to its wider adaptability, high yielding ability and enormous demand by consumers. Due to its simplicity tomato is to modify and how diverse its population exists, cultivated tomatoes have been utilized in genetic studies. The hybridization process, together with pedigree selection, has been the most significant breeding approach used for improving tomato. The back cross method of breeding has been the most effective technique for transferring desired traits from wild species to domesticated varieties. It has been observed that breeding techniques like pedigree method and single descent method work well when combined with molecular techniques. The production of boosted varieties with increased qualitative attributes has been demonstrated through the transfer of genes from uncultivated into cultivated cultivars, utilizing tomato as an example. To address the country's growing population, breeders must produce high-yielding cultivars using both traditional breeding and plant biotechnology technologies. Marker-Assisted Selection may be a useful method for tomato breeding.

Introduction

Tomato comes under solanaceous group of vegetable, its grown in open field as well as protected cultivation. There are around 3000 species of solanaceous vegetables. Tomatoes originated in Peru and were first domesticated in Mexico due to the abundance of both cultivated and wild tomato relatives in the area (Rick, 1969). The wild tomato type has a very wide range of genetic variability, particularly when it comes to self-incompatible species like *S. chilense* and *S. peruvianum*. The plants have indeterminate or determinate type, alternate leaves with small leaflets. It is soft and hairy when young and hard, woody and branched when mature. It has a strong tap root system. Cultivated tomato is a self-pollinated crop as the stigma is inside the anther cone but in case of some wild forms the stigma is exerted outside the anther cone which leads to cross pollination.

Tomato demand continues to rise, but production is impacted by various diseases and pressures (both biotic and abiotic). Tomato production and development are limited by a variety of conditions, including drought, temperature, salt and insect and pest infestations. Plant breeding focuses on creating qualitative traits, disease-resistant and stress-tolerant cultivars.

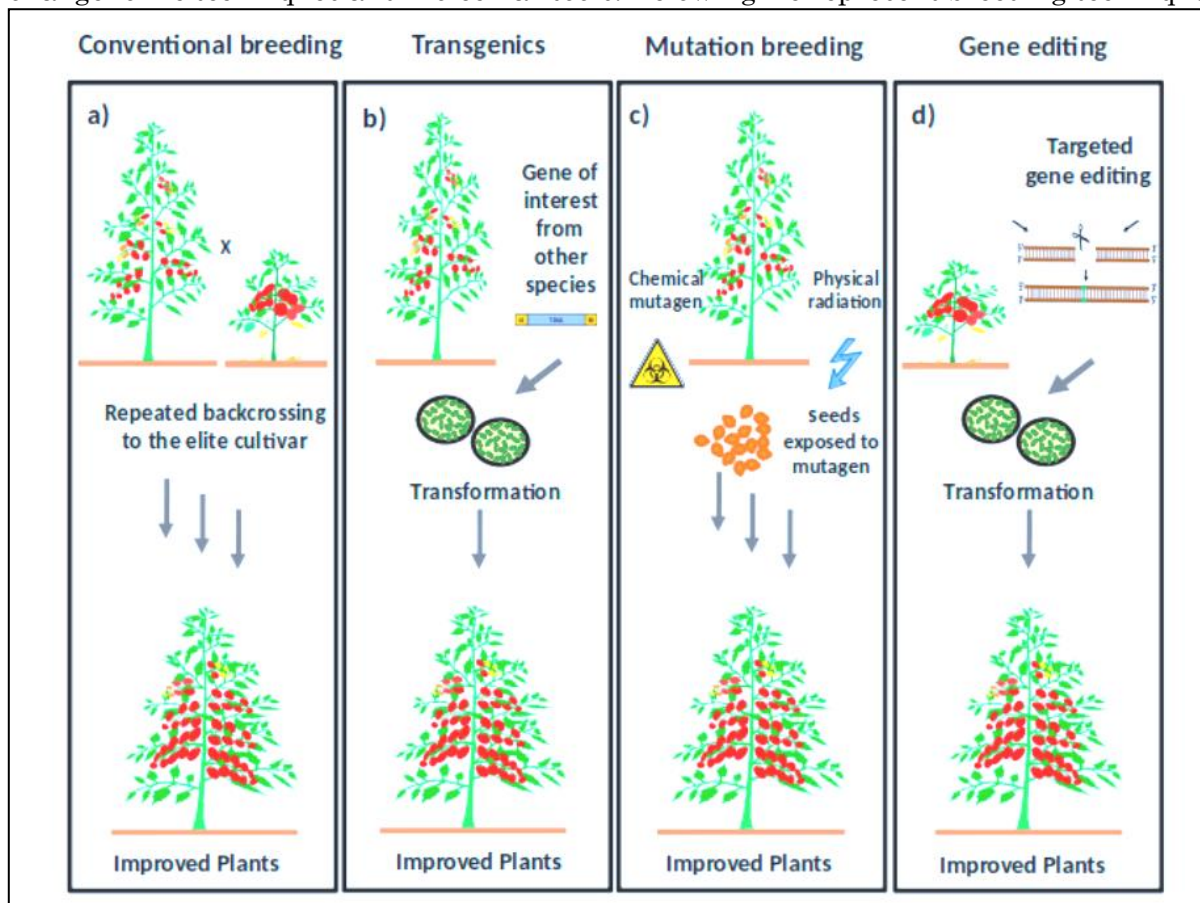
Genetic engineering can help generate disease-resistant crops. Improving tomato crops is crucial for overcoming production limitations.

Floral Morphology

Tomato has perfect flowers, having viable male and female parts. In tomato anthesis starts around 6 a.m. and finally the flower opens around 11 a.m., dehiscence of anther occurs between 8 to 11 a.m. Pollen remains viable from 2 to 5 days. Stigma of the flower remains receptive 16 to 18 hours before anthesis up to 6 days after anthesis. The reproductive biology and production of appreciable quantity of seeds per fruit provide ample opportunity for manifestation of heterosis in tomato. In tomato emasculation for controlled pollination must be done nearby one day prior to opening of the flower to avoid the self-pollination. The stigma appears to be fully receptive at this stage, thus allowing pollination immediately after emasculation. Emasculation of flower is done between 55 and 65 days after planting. Pollen grains are collected before it is shed. When the corolla of the emasculated flower turns bright yellow, the stigma is ready for pollination. For 3-5 weeks repeat the pollination 2-3 times a week. Usually, fruit starts to enlarge after successful pollinations are visible within one week (Fentik *et al.*, 2017).

Tomato Breeding

The development of molecular biology and bioinformatics has offered wide scope for improving the effectiveness of traditional plant breeding programmes. Advances in genomics and genetics improved the understanding of structural and functional aspects of plant genomes. Among the fruit bearing plants, tomato has been selected preferably to study the fruit development process and significant improvement in the understanding of the molecular basis of fruit set and development has been made due to advances in functional genomic techniques and molecular tools. Below figure represent breeding techniques:



Methods of Tomato Breeding

Hybridization and pedigree selection are the most common breeding techniques for improving tomato varieties. Back cross breeding is the preferred approach for transferring beneficial features from wild species to cultivated kinds that have not been improved.

Introduction

Introducing a genotype or a group of genotypes of plants into new agro climatic condition where they have not been grown before. These evaluated plants if meets the standards are directly released as a variety or used in hybridization for crossing. There are varieties which are introduced from the foreign countries called as exotic varieties and these varieties are used to improve the existing varieties. IARI and other institutes introduced many varieties are Roma, Labonita, Sioux, Marvel, Best of All and Money maker.

Pure Line Selection

In this method many phenotypically superior plants are selected and these plants are further harvested individually. The best progeny after evaluation is selected from the population and is released as a variety. Ex: Arka Vikas, Arka Saurabh, Arka Alok and Arka Ahuti.

Mass Selection

Mass selection involves selection of many phenotypically superior plants. This process of harvesting and bulking is repeated till the desired characters are obtained. The original population from where the

superior plants are selected would have been a mixture of several pure lines and the plants selected would be homozygous. The final population which is obtained from the selected plants would be more uniform than that of the original population for easily observable characters which are governed by one or few major genes like presence of awns, plant height and seed colour. Ex: Pusa Ruby, Arka Meghali, Arka Ashish.

Pedigree Method

This method involves making a controlled cross followed by several successive generations of single plant selection. The aim is to develop at least one new variety from a single cross. Pedigree would describe the parents, grandparents, great grandparents and so on. This method makes a controlled crosses followed by single plant selection. Single plant selection is initiated in F_2 and is continued through successive generations till F_6 . This method produces new varieties faster than mass selection (Kalloo 2012).

Backcross Method

Hybrid and the progenies in the successive generation are repeatedly backcrossed to one of the parents. This method desirable gene transfers for resistance to diseases like, early blight resistance, Bacterial wilt resistance and nematode resistance. This method is used for development of isogenic lines, multiline and Root Knot Nematode lines are derived from *S. peruvianum*.

Mutation Breeding

Also called variation breeding, is a method that uses physical radiation or chemical means to induce spontaneous genetic variation in plants to develop new crop varieties. "Mutation" is the source of most genetic variation and the motor of evolution. Ex: Pusa Lal Meeruti, S-12, PKM-1 and Maruthan.

Heterosis Method

Hybrids are more popularised and in demand among cross-pollinated crops but it has been achieved successfully in several self-pollinated crops too such as tomato even though the heterozygote advantage has not been unequivocal. The F_1 hybrids have some favourable traits such as uniformity and better resistance to diseases but their economic advantages over standard checks have not been as high as in cross-pollinated crops. The F_1 hybrids development in self-pollinated crops largely follows scheme used for cross-pollinated species (Jiang 2018). Ex: Arka Vishal, Kashi Sharad, Arka Vardan, Arka Rakshak, Pusa Hybrid-1, Pusa Red Plum, Hisar Anmol.

Biotechnology in Breeding of Tomato

Still today to satisfy and fulfil the requirements of future, conventional breeding methods are largely exploited. Also, the genetic diversity and variability present among the cultivated and wild relatives of tomato help in achieving the success. Although traditional methods of breeding are time consuming and labour intensive, there is no choice left for appropriate breeding purposes. Thus, developing and utilising genetically-transformed plants, commercial applications are coming into picture. The in vitro culture is used successfully in different biotechnological applications including the clonal propagation of high value commercial varieties, virus-free plants and genetic transformation. The first commercially developed genetically modified tomato cultivar is Flavr Savr. It was developed after 10 years of intensive research work by the Calgene Company in 1992.

Speed Breeding

Researchers found that extending photoperiods using LED lighting and adjusting growth chamber conditions considerably reduced the time required to conduct tomato breeding programs. This rapid breeding cycle resulted in speedier selection and creation of tomato varieties with desired features, including disease resistance, fruit quality and yield.

Conclusion

Conventional breeding may not be sufficient to meet future demands. This requires tremendous advances in molecular genetics and the application of molecular marker techniques. To improve tomato breeding, it is recommended to mix conventional and current plant breeding methods, such as molecular marker selection and marker-assisted selection, which can be effective tools.

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Intelligent Packaging and Storage Technologies for Shelf-Life Extension of Tea Products

Article ID: 71005

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Abstract

Tea (*Camellia sinensis*), prized for its aroma, flavor, and health-promoting properties, is highly sensitive to environmental factors such as moisture, oxygen, temperature, light, and volatile compound loss. These factors accelerate chemical degradation and microbial contamination, leading to reduced shelf life and quality deterioration. Conventional packaging methods offer limited protection and lack real-time quality monitoring capabilities. Recent advances in intelligent packaging and storage technologies provide innovative solutions to preserve tea quality and extend shelf life. Intelligent packaging systems—including time-temperature indicators (TTIs), freshness and humidity indicators, gas sensors, and RFID/QR codes—offer real-time data on environmental and product conditions. Complementary storage techniques such as cold storage, modified atmosphere storage, vacuum sealing, controlled humidity, and light-protected environments help minimize biochemical and microbial degradation. Emerging smart storage systems integrated with IoT and cloud-based platforms enhance traceability and enable predictive shelf-life management. Despite their potential, challenges like high cost, regulatory gaps, and consumer acceptance must be addressed. This review highlights the current developments, applications, and future prospects of intelligent packaging and storage solutions for enhancing the shelf life and safety of tea products.

Keywords: Intelligent packaging; Shelf-life extension; Time-temperature indicators (TTIs); Modified atmosphere storage (MAS); IoT-based smart storage; Gas sensor.

Introduction

Tea (*Camellia sinensis*) is one of the most widely consumed beverages globally, valued for its distinctive flavor, aroma, and health benefits. It contains a rich profile of bioactive compounds such as catechins, theaflavins, and flavonoids, which contribute to its antioxidant, anti-inflammatory, and therapeutic properties. However, the quality of tea deteriorates over time due to its sensitivity to environmental factors like moisture, oxygen, temperature, light, and volatile compound loss. These factors lead to chemical degradation, microbial contamination, and loss of aroma and color, ultimately shortening the product's shelf life. Conventional packaging materials, while effective in providing physical protection, lack the ability to monitor and respond to real-time changes in product quality. In response to these limitations, intelligent packaging and advanced storage technologies have emerged as innovative solutions for quality preservation and shelf-life extension of tea. Intelligent packaging integrates indicators, sensors, and data carriers to monitor environmental conditions and product status. Meanwhile, storage strategies such as modified atmosphere packaging (MAP), cold storage, and humidity control help in slowing down degradation processes. This review explores the developments in intelligent packaging and modern storage technologies applied to tea products, emphasizing their role in maintaining freshness, safety, and consumer acceptability.

Tea Product Shelf-Life: Influencing Factors

The shelf-life of tea is influenced by:

- 1. Moisture Content:** Hygroscopic in nature, tea easily absorbs moisture, leading to microbial growth and chemical changes.
- 2. Temperature and Relative Humidity (RH):** Elevated storage temperature and RH accelerate oxidation and microbial proliferation.

3. Oxygen Exposure: Promotes oxidation of polyphenols, affecting taste and color.

4. Light: UV and visible light degrade sensitive compounds.

5. Volatile Compound Loss: Tea's aroma is volatile and can dissipate or undergo chemical transformation.

Proper packaging and storage solutions are crucial to mitigating these factors.

Components of Intelligent Packaging for Tea

1. Time-Temperature Indicators (TTIs): TTIs are small devices that change color based on the duration and temperature to which the tea has been exposed. This is especially important for green teas, which are sensitive to heat and oxidative degradation. For example, a study by Ahmed et al. (2020) found that TTI labels were effective in detecting spoilage risk in green tea stored under fluctuating temperatures.

2. Freshness Indicators: Freshness indicators respond to the presence of volatile amines or aldehydes produced during tea degradation. These indicators change color when these gases accumulate, indicating potential quality loss. Such systems are suitable for herbal and flavored teas, where aroma and freshness are critical.

3. Humidity Indicators: Since tea is hygroscopic, moisture ingress can lead to microbial growth and clumping. Humidity indicators (like cobalt chloride-based or halochromic dyes) visually reflect moisture exposure inside the packaging.

4. Gas Sensors: Tea oxidation and microbial activity can alter the gas composition in the package. Gas sensors (such as metal oxide semiconductor-based sensors) can detect oxygen, carbon dioxide, or volatile organic compounds (VOCs) that indicate spoilage or aroma loss.

5. RFID and QR Codes: Radio Frequency Identification (RFID) and Quick Response (QR) codes are used for real-time traceability and data sharing. They enable retailers and consumers to access storage history and shelf-life estimation based on embedded sensors.

Active Packaging Technologies

1. Oxygen Scavengers:

a. Function: Absorb residual oxygen inside the package.

b. Importance in Tea: Oxygen promotes oxidation of catechins and volatile aroma compounds, degrading flavor and color.

c. Application: Iron-based oxygen absorbers are commonly used in tea sachets and canisters to maintain a low-oxygen environment.

d. Example: Oxygen scavenger sachets in green tea packages help retain color and antioxidants.

2. Moisture Absorbers (Desiccants):

a. Function: Absorb excess humidity to prevent moisture-induced spoilage.

b. Importance in Tea: Tea is hygroscopic and readily absorbs moisture, leading to microbial growth and clumping.

c. Materials: Silica gel, calcium chloride, and molecular sieves.

d. Application: Placed inside secondary packaging (e.g., tins or foil pouches) to keep RH below critical levels (usually <50%).

3. Antimicrobial Packaging:

a. Function: Inhibit or kill microorganisms on the product surface or inside the package.

b. Mechanisms:

i. Releasing natural antimicrobials (e.g., essential oils, organic acids).

ii. Coating packaging films with antimicrobial agents.

c. Potential Use for Tea: Prevent mold growth in high-humidity environments, especially for herbal and loose-leaf teas.

d. Limitation: Not yet widely adopted in tea due to regulatory and sensory concerns.

4. Ethylene Scavengers:

a. Function: Absorb ethylene gas to slow down aging and spoilage.

b. Relevance to Tea: Less critical for dried tea, but useful when tea is stored near fresh produce during distribution.

c. Materials: Potassium permanganate-based scavengers.

5. Aroma-Enhancing/Releasing Systems:

a. Function: Either absorb undesirable odors or release pleasant aromas to enhance perceived freshness.

b. Application in Tea: Some premium teas may include aroma-releasing systems to reinforce brand identity or sensory appeal.

c. Innovation: Microencapsulated aroma releasers embedded in packaging films.

Advanced Storage Technologies for Tea

1. Cold Storage: Cold storage involves maintaining tea at low temperatures (typically between 4°C and 10°C) to inhibit chemical reactions and microbial activity. Green tea, in particular, benefits from refrigeration due to its higher content of unoxidized catechins and chlorophyll, which degrade faster at room temperature. A study by Zhou et al. (2017) demonstrated that green tea stored at 5°C retained higher levels of epigallocatechin gallate (EGCG) and better color and aroma profile over 12 months compared to samples stored at ambient temperatures.

2. Modified Atmosphere Storage (MAS): MAS involves replacing the air surrounding tea with a controlled gas mixture—commonly nitrogen or carbon dioxide—to limit oxidative degradation and microbial growth. Nitrogen flushing is particularly effective for black and green teas as it displaces oxygen, thereby preventing the oxidation of polyphenols and volatile oils. In a study by Muthumani and Kumar (2014), nitrogen-flushed packaging of black tea at ambient temperature maintained better sensory and chemical quality for up to 9 months compared to tea stored in air-packed containers.

3. Vacuum Storage: Vacuum storage involves removing air from packaging to create a low-oxygen environment. This method is particularly useful for long-term storage of teas that are highly sensitive to oxidation, such as white and green teas. By limiting oxygen exposure, vacuum packaging minimizes color change, loss of aroma, and degradation of bioactives. Liang et al. (2021) found that vacuum-sealed green tea retained more than 85% of its original catechin content after 6 months of storage, as compared to only 60% in air-packed counterparts.

4. Desiccated and Controlled Humidity Storage: Tea is hygroscopic and rapidly absorbs moisture from its environment, leading to caking, microbial contamination, and off-flavors. Desiccated storage environments—using silica gel or molecular sieves—maintain relative humidity (RH) below 50%, ensuring tea stays dry and microbiologically stable. Controlled Humidity Chambers (CHCs) use humidistats to maintain optimal RH levels (~40–50%) in large-scale storage facilities. These systems are especially important in regions with high ambient humidity.

5. Smart Storage with IoT Integration: Smart storage solutions equipped with Internet of Things (IoT) sensors allow real-time monitoring and remote management of storage parameters like temperature, humidity, and gas concentration. Data collected from these sensors can be analyzed using cloud-based platforms or AI algorithms to predict shelf-life and send alerts when conditions deviate from the optimum. This technology is being piloted by premium tea manufacturers in Japan and Taiwan for export-quality tea storage and logistics. Integration with blockchain ensures traceability and quality assurance throughout the supply chain.

6. Light-Protected Storage: Light, especially UV rays, accelerates the degradation of chlorophyll and volatile aroma compounds in tea. Advanced storage units use UV-blocking materials or opaque containers to shield tea from light. Packaging with light-filtering properties is also employed to extend shelf-life.

Challenges and Limitations

Despite potential benefits, several challenges hinder widespread adoption:

1. Cost: High cost of sensors and integration technologies.

2. Consumer Acceptance: Concerns about the safety and effectiveness of embedded components.

3. Regulatory Compliance: Lack of standardized guidelines for intelligent packaging in food applications.

4. Material Compatibility: Ensuring packaging does not interact adversely with tea components.

Conclusion

Intelligent packaging and advanced storage technologies offer promising solutions to overcome the limitations of conventional methods in maintaining the quality and extending the shelf life of tea products. Their integration into the tea industry can enhance product safety, traceability, and consumer satisfaction. However, economic feasibility, consumer awareness, and regulatory support are critical for their mainstream adoption. Future research should focus on cost-effective sensor integration, sustainable materials, and predictive quality monitoring systems tailored to the specific requirements of different types of tea.

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Advances in Artificial Intelligence for Assessing Fish Freshness

Article ID: 71006

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Abstract

Fish is a highly perishable yet nutritionally valuable food commodity, demanding accurate and timely assessment of its freshness to ensure food safety and minimize postharvest losses. Traditional methods such as sensory evaluation, microbiological testing, and chemical assays like total volatile basic nitrogen (TVB-N) are often destructive, subjective, and time-consuming. Recent advancements in Artificial Intelligence (AI) have led to the development of non-invasive, rapid, and reliable tools for fish freshness detection. By integrating machine learning (ML) and deep learning (DL) algorithms with advanced sensing technologies—including hyperspectral imaging, electronic nose, computer vision, spectroscopy, and electronic tongue—AI systems can objectively analyze spoilage indicators such as odor, texture, and color changes. Convolutional Neural Networks (CNNs) and other models like SVM and 3D-CNN have demonstrated high accuracy in classifying freshness across different fish species and storage conditions. Despite promising results, challenges such as limited datasets, model interpretability, environmental variability, and high implementation costs persist. Future research should focus on developing standardized datasets, explainable AI models, edge computing integration, and multimodal sensing systems. Overall, AI-enabled freshness detection holds immense potential for transforming seafood quality monitoring by enhancing accuracy, ensuring safety, and enabling real-time, on-site applications from catch to consumer.

Keywords: Fish Freshness; Machine Learning (ML); Deep Learning (DL); Hyperspectral Imaging (HSI); Electronic Nose (E-nose); Spectroscopy.

Introduction

Fish is a highly nutritious but perishable food product that begins to spoil rapidly after harvest due to microbial growth, enzymatic activity, and oxidation, posing significant concerns for food safety, quality assurance, and market value. Traditional fish freshness evaluation methods—such as sensory inspection, chemical assays (e.g., total volatile basic nitrogen, TVB-N), and microbiological analysis—are often labor-intensive, subjective, time-consuming, and destructive in nature. With the growing demand for more objective, rapid, and non-invasive quality assessment tools, Artificial Intelligence (AI) has emerged as a transformative solution. By integrating AI with imaging, spectroscopy, and sensor-based technologies, researchers have developed systems capable of analyzing spoilage indicators like color changes, odor emissions, and texture degradation with high precision. Machine learning (ML) and deep learning (DL) algorithms, especially convolutional neural networks (CNNs), can classify fish freshness with minimal human intervention. These AI-driven approaches not only improve accuracy and repeatability but also offer potential for real-time, on-site applications in markets, cold chains, and processing units. As the seafood industry advances toward smart quality monitoring, AI-enabled freshness detection tools hold promise for reducing postharvest losses, enhancing food safety, and ensuring consumer confidence.

AI Techniques for Fish Freshness Detection

Artificial Intelligence (AI) has revolutionized the process of fish freshness evaluation by enabling rapid, non-destructive, and objective decision-making based on complex data inputs. The core AI techniques employed in fish freshness detection can be broadly classified into **machine learning (ML)** and **deep learning (DL)** approaches, which are integrated with data from sensors, images, or spectral signals.

1. Machine Learning (ML) Techniques: Machine learning algorithms are widely used to extract patterns from data collected through sensors or analytical instruments and classify the freshness state of fish. Some commonly used ML methods include:

a. Support Vector Machines (SVM): SVM is effective for binary classification tasks such as distinguishing between fresh and spoiled fish. For instance, Lin et al. (2020) used SVM on electronic nose data to classify freshness of tilapia with 92.4% accuracy.

b. Random Forest (RF): RF is a robust ensemble learning method based on decision trees. It has been successfully used in conjunction with image features and spectral data for multiclass classification of fish freshness (Wang et al., 2019).

c. K-Nearest Neighbors (KNN): KNN, being a simple distance-based classifier, has been applied in fish freshness detection using biochemical indices, where the freshness grade was predicted with high reliability (Zhang et al., 2018).

d. Artificial Neural Networks (ANN): ANN models simulate brain-like computation for non-linear pattern recognition. They have been applied to electronic nose and spectroscopy data for predicting freshness levels and spoilage duration of fish such as cod and salmon (Cheng et al., 2021).

In many studies, **dimensionality reduction techniques** like Principal Component Analysis (PCA) are used before feeding the data into ML classifiers, thereby enhancing accuracy and reducing computational complexity (Huang et al., 2019).

2. Deep Learning (DL) Techniques: Deep learning has brought significant improvements in freshness detection, particularly for image-based or high-dimensional spectral data. Among DL techniques, **Convolutional Neural Networks (CNNs)** are the most dominant.

a. Convolutional Neural Networks (CNNs): CNNs are adept at automatically extracting spatial features from images and have been extensively applied to classify fish freshness based on visual cues such as eye clarity, skin color, and gill condition. For example, Chen et al. (2022) used a CNN model on images of fish heads to assess freshness and achieved classification accuracy of over 95%.

b. 3D-CNN and Recurrent Neural Networks (RNNs): For hyperspectral imaging data, 3D-CNN models have been utilized to analyze both spatial and spectral dimensions of fish tissue. A study by Cheng and Sun (2015) applied 3D-CNN to hyperspectral images of grass carp fillets and accurately predicted spoilage progression over 7 days.

c. Transfer Learning and Pretrained Models: Transfer learning using pretrained models like VGGNet, ResNet, and MobileNet has been effective in reducing training time and improving accuracy, especially in scenarios with limited labeled data (Rahman et al., 2021).

Unlike traditional ML, deep learning models often do not require handcrafted features. Instead, they learn relevant features directly from raw data, which enhances their adaptability across different fish species and storage conditions.

Sensing Technologies Integrated with AI

AI-based fish freshness detection systems rely heavily on the quality and type of input data derived from various sensing technologies. These sensors provide objective, real-time, and non-destructive measurements of spoilage indicators such as chemical composition, texture, odor, and visual features. The fusion of advanced sensors with AI algorithms enhances the system's ability to accurately classify and predict fish freshness. Key sensing technologies integrated with AI include:

1. Hyperspectral Imaging (HSI): HSI combines imaging and spectroscopy to collect both spatial and spectral information across hundreds of narrow wavelength bands. This technique enables the detection of subtle biochemical changes in fish tissue that occur during spoilage. When processed using machine learning or deep learning models, HSI data can effectively classify different freshness levels. For instance, Cheng and Sun (2015) employed 3D-CNN models on hyperspectral data to monitor spoilage in grass carp fillets over time with high classification accuracy. Spectral features such as absorption bands related to water, proteins, and lipids are often used for freshness prediction.

2. Electronic Nose (E-nose): An electronic nose mimics the human olfactory system by using sensor arrays to detect volatile organic compounds (VOCs) released during microbial spoilage. Different sensors (e.g., metal oxide semiconductors) respond to compounds such as ammonia, trimethylamine (TMA), and sulfur-containing gases. The resulting signal patterns can be analyzed using machine learning algorithms such as ANN, SVM, or PCA-SVM to predict freshness levels. For example, Huang et al. (2019) developed an E-nose system coupled with PCA and SVM that successfully classified cod samples by spoilage stage.

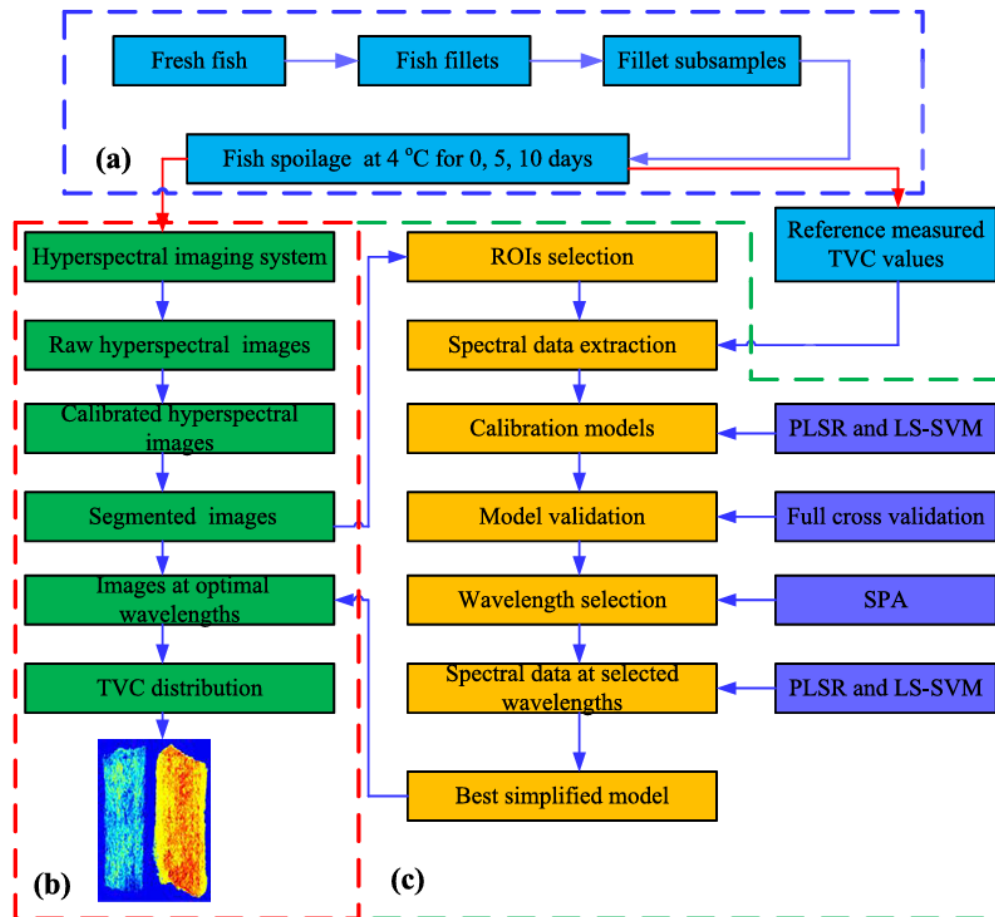


Fig. 1. Main steps of determination of TVC (total viable count) value in grass carp fillet by hyperspectral imaging technique, (a) fish subsample preparation; (b) image processing analysis; (c) spectral processing analysis (Source: Cheng and Sun, 2015)

3. Computer Vision Systems: Computer vision systems use digital cameras to capture visual cues of fish such as eye clarity, gill color, skin brightness, and texture. These features deteriorate in predictable ways during spoilage. Deep learning models, especially convolutional neural networks (CNNs), are highly effective in analyzing these images for freshness classification. Chen et al. (2022) applied a CNN to classify fish freshness from smartphone-captured images and achieved over 95% accuracy. This approach is attractive due to its simplicity, cost-effectiveness, and scalability.

4. Spectroscopy (NIR, FTIR, Raman): Spectroscopic methods such as near-infrared (NIR), Fourier-transform infrared (FTIR), and Raman spectroscopy are widely used for non-destructive chemical fingerprinting. These techniques detect molecular vibrations and are sensitive to changes in protein, lipid, and water content during spoilage. Spectral data, when processed through machine learning models like partial least squares regression (PLSR) or SVM, can accurately estimate freshness indicators such as total volatile basic nitrogen (TVB-N) and pH. Wang et al. (2019) successfully used FTIR spectroscopy combined with SVM for spoilage detection in mackerel.

5. Electronic Tongue (E-tongue): Electronic tongues use sensor arrays to detect taste-related attributes such as sourness, saltiness, and bitterness, which change during spoilage. Although less common than E-nose or spectroscopy, E-tongue systems integrated with AI have been applied in research settings for distinguishing freshness stages in fish fillets with promising results (Rahman et al., 2021).

Challenges in AI-Based Freshness Detection

Despite significant progress, several challenges limit widespread application:

1. Data Limitations:

- High-quality, annotated datasets are scarce.
- Generalization is difficult across species and storage conditions.

2. Model Interpretability:

- a. Deep learning models are often considered “black boxes.”
- b. Lack of interpretability hampers adoption in regulatory frameworks.

3. Environmental and Sample Variability:

- a. Lighting conditions, camera quality, and fish variability affect model performance.
- b. Calibration and standardization remain key hurdles.

4. Cost and Accessibility:

- a. High-end sensors (e.g., HSI) and computing infrastructure are expensive.
- b. Affordable and portable solutions are still under development.

Future Perspectives

1. Standardized Datasets: Creating large, open-access datasets across multiple fish species and spoilage stages can improve model generalizability and benchmarking.

2. Edge AI and IoT Integration: Embedding AI models in edge devices (smartphones, IoT sensors) can enable real-time, on-site freshness detection for fish vendors, consumers, and processors.

3. Explainable AI (XAI): Research into explainable AI will help enhance trust and transparency in model decisions, enabling regulatory and industrial adoption.

4. Multimodal Sensing: Combining multiple sensor inputs (vision, gas, spectroscopy) with AI models can provide more robust predictions, especially in variable field conditions.

Conclusion

AI-enabled systems for fish freshness detection represent a promising frontier in smart food quality assessment. By integrating machine learning, deep learning, and non-destructive sensing, these technologies offer fast, objective, and reliable alternatives to traditional methods. Continued research focusing on model accuracy, interpretability, and cost-effective deployment will be crucial for commercial success. AI has the potential to revolutionize quality assurance in the seafood industry, ensuring safety, reducing waste, and enhancing consumer trust.

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Advances in Tea Beverage Processing: Traditional Roots to Hybrid Innovations

Article ID: 71007

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Abstract

Tea, a globally cherished beverage, has evolved from its traditional artisanal roots into a diverse industry shaped by technological innovation and changing consumer demands. This article explores the progression of tea beverage processing—from classic methods involving manual plucking, withering, and drying to modern hybrid techniques integrating automation, novel extraction, and formulation technologies. Traditional processing methods preserve tea's unique flavor and bioactive properties but often suffer from limitations in scalability and consistency. In response, advances such as ultrasound-assisted, microwave-assisted, and supercritical fluid extraction have enhanced bioactive yield and processing efficiency. Functional formulations now incorporate nutraceuticals, probiotics, and natural sweeteners, aligning with health-conscious consumer trends. Hybrid innovations like cold brewing, high-pressure processing, and encapsulation technologies further improve shelf life, flavor stability, and bioavailability. Packaging has also advanced, with smart and sustainable options enhancing product quality and traceability. Additionally, the tea industry is increasingly embracing eco-friendly practices, such as waste valorization and renewable energy usage. Despite these advancements, challenges persist in maintaining flavor integrity, managing high processing costs, and navigating regulatory complexities. This review highlights current innovations and outlines future prospects for developing high-quality, functional, and sustainable tea beverages that harmonize tradition with modern science.

Keywords: Cold brew tea; Hybrid technologies; Supercritical fluid extraction; Flavor enhancement; Nano-encapsulation; Oolong tea.

Introduction

Tea, derived primarily from the leaves of *Camellia sinensis*, is the second most consumed beverage globally after water, with a cultural and economic significance that spans centuries. Originating in ancient China, tea has evolved from a traditional brew to a versatile and dynamic product found in various forms, including loose leaves, tea bags, and ready-to-drink (RTD) formulations. Its appeal lies not only in its unique flavor and aroma but also in its well-documented health benefits, including antioxidant, anti-inflammatory, and cardioprotective properties. Traditionally, tea processing involves artisanal methods such as hand-plucking, natural withering, manual rolling, and sun drying. These techniques, while effective in preserving flavor and cultural heritage, are often labor-intensive, time-consuming, and prone to variability in quality. As global demand for tea grows and diversifies, there has been a pressing need to enhance processing efficiency, standardization, and scalability without compromising sensory and nutritional quality.

In response, significant technological advancements have emerged, including mechanical harvesting, automated rolling systems, and innovative extraction methods such as ultrasound-assisted and supercritical fluid extraction. Additionally, consumer preferences have shifted towards functional and health-oriented beverages, driving innovations in tea formulation, packaging, and delivery systems. The modern tea industry also faces increasing pressure to adopt sustainable practices in sourcing, production, and packaging.

These evolving dynamics have led to the emergence of hybrid innovations—an amalgamation of traditional techniques with cutting-edge technologies—that are redefining tea beverage processing. This review explores the journey of tea processing from its traditional roots to the latest hybrid innovations. It highlights key developments in extraction technologies, formulation strategies, packaging, and

sustainability initiatives, offering insights into current challenges and future opportunities in the global tea sector.

Traditional Tea Processing Methods

Tea processing involves a sequence of steps including plucking, withering, rolling, oxidation (fermentation), and drying. The methods differ based on the type of tea:

- 1. Green Tea:** Involves minimal oxidation. After plucking and withering, leaves are steamed or pan-fired to deactivate enzymes before rolling and drying.
- 2. Black Tea:** Undergoes full oxidation. Leaves are rolled to rupture cell walls and then allowed to oxidize fully before drying.
- 3. Oolong Tea:** Partially oxidized; processing is intermediate between green and black tea.
- 4. White Tea:** Minimally processed; young leaves are simply withered and dried.

These methods rely heavily on manual labor, artisanal knowledge, and specific climatic conditions. While they preserve the natural compounds and flavors, traditional techniques often lack consistency and scalability.

Technological Advancements in Tea Processing

- 1. Mechanical Processing and Automation:** Modern tea factories employ automated plucking machines, controlled withering chambers, and rotary rollers to standardize production. These advancements enhance efficiency, reduce labor dependency, and improve hygiene.

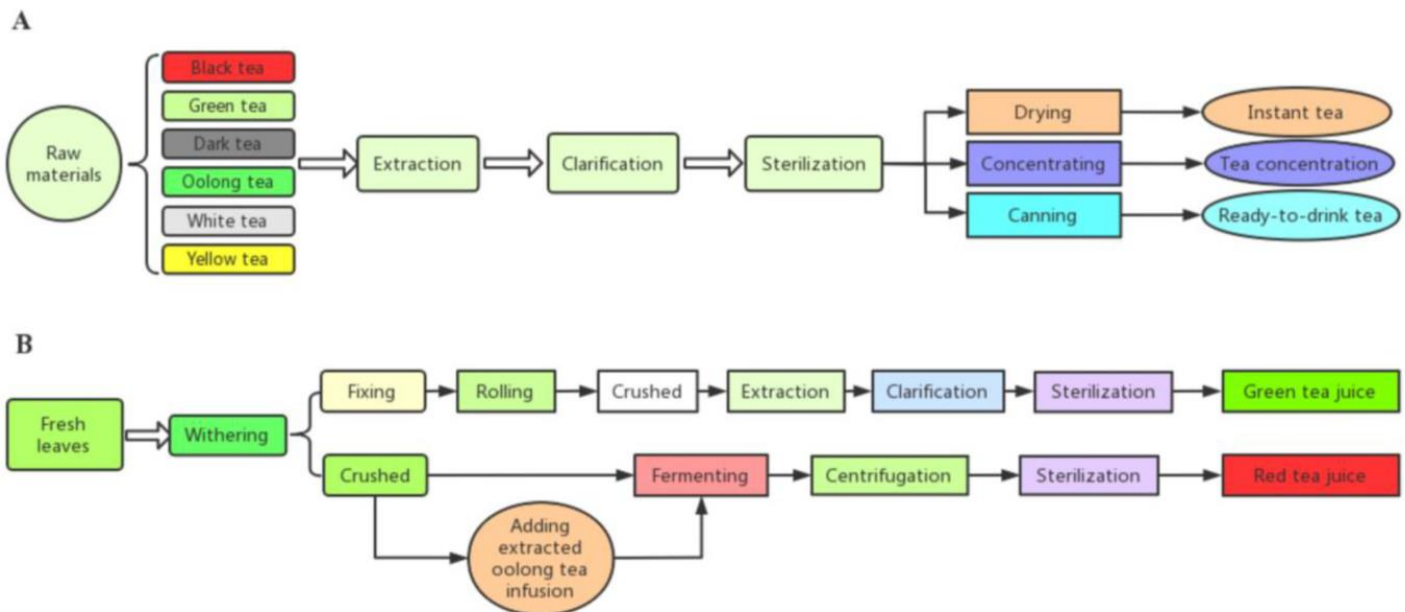


Fig. 1. Main manufacture process of tea beverages (A) and fresh tea juice (B) (Source: Liang et al., 2021).

- 2. Advanced Extraction Techniques:** The shift towards RTD and functional teas has necessitated improved extraction methods for bioactive compounds:

- a. Ultrasound-Assisted Extraction (UAE):** Enhances the release of polyphenols and catechins by disrupting cell walls.
- b. Microwave-Assisted Extraction (MAE):** Increases yield and reduces extraction time using microwave energy.
- c. Supercritical Fluid Extraction (SFE):** Utilizes supercritical CO₂ to extract high-value components without solvents.

- 3. Membrane Technologies:** Membrane filtration (microfiltration, ultrafiltration, nanofiltration) is increasingly used for clarification, concentration, and purification of tea extracts, maintaining quality and bioactivity.

Formulation Innovations in Tea Beverages

1. Functional and Nutraceutical Teas: Tea beverages are now being fortified with vitamins, minerals, herbal extracts (e.g., ginseng, turmeric), and probiotics. These additions target health-conscious consumers seeking specific health benefits such as stress relief, immunity boosting, and weight management.

2. Flavor Enhancement and Stabilization: Flavor encapsulation (e.g., spray drying, coacervation) and natural flavor modulators are used to preserve aroma and taste. Stabilizers, emulsifiers, and antioxidants prevent sedimentation, phase separation, and oxidation during storage.

3. Sugar Reduction and Natural Sweeteners: Given the health risks of high sugar consumption, industry players are adopting natural sweeteners like stevia, monk fruit, and erythritol. Enzyme-based sugar conversion techniques are also gaining attention.

Hybrid Processing Technologies

1. Cold Brew and High-Pressure Processing (HPP): Cold brew tea, steeped at low temperatures for extended periods, offers smoother taste and better retention of antioxidants. HPP, a non-thermal pasteurization method, extends shelf life without compromising nutritional and sensory qualities.

2. Fermentation and Biotransformation: Probiotic fermentation using lactic acid bacteria and yeast transforms tea into kombucha and other fermented beverages. This process enhances functional properties and introduces novel flavors.

3. Nano and Micro-encapsulation: These techniques protect sensitive tea bioactives (e.g., EGCG) during processing and delivery, improving bioavailability and stability in RTD formulations.

Packaging and Shelf-Life Extension

1. Smart and Sustainable Packaging: Modern tea packaging incorporates oxygen scavengers, UV blockers, and biodegradable materials. Smart packaging technologies, such as freshness indicators and QR codes for traceability, are being adopted.

2. Aseptic and Retort Packaging: Aseptic packaging allows tea beverages to be stored at room temperature with extended shelf life. Retort pouches are used for tea concentrates and herbal decoctions.

Sustainability and Environmental Impact

Sustainability has become a central theme in tea processing. Initiatives include:

1. Adoption of renewable energy sources in tea factories.
2. Water reuse and waste valorization (e.g., tea waste used as compost or biochar).
3. Certification systems like Rainforest Alliance and Fair Trade to ensure ethical sourcing.

Challenges and Future Perspectives

Despite significant advancements, several challenges remain:

1. Maintaining flavor and nutritional quality during processing.
2. High costs associated with advanced technologies.
3. Regulatory hurdles for novel ingredients and health claims.
4. Future research is expected to focus on personalized nutrition, AI-based process optimization, blockchain for traceability, and development of zero-waste tea processing systems.

Conclusion

Tea beverage processing has witnessed remarkable transformation, blending age-old traditions with modern science. Innovations in extraction, formulation, packaging, and sustainability are redefining the industry landscape. Continued research and development, guided by consumer preferences and environmental imperatives, will shape the next generation of tea beverages.

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Advanced Post-Harvest Practices for Prolonging the Shelf Life of Cut Flowers

Article ID: 71008

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Introduction

Flowers are among the most captivating elements of nature, forming a crucial part of the reproductive cycle in many plants. Due to their aesthetic appeal, many flowers are considered premium commodities and are actively traded both locally and internationally. While cultivating high-quality flowers in large quantities is essential, equally vital is ensuring their proper handling post-harvest.

This article focuses on the post-harvest handling of cut flowers such as roses, gerberas, chrysanthemums, and orchids to maximize their shelf life. Although each flower species may require specific handling methods, the fundamental principles of extending their post-harvest life—preserving strength, texture, color, and visual appeal—are generally consistent.

Cut flowers are highly perishable and prone to significant losses after harvest. Inefficient storage and packaging practices can lead to market losses of 20–40% (Jawaharlal et al., 2006). Proper storage is vital not only for meeting market demand and enabling bulk transport but also for extending the selling period of high-value flowers (Goszczynska and Rudnicki, 1988). Because storing flowers in isolation may cause damage, appropriate packaging and pulsing treatments are essential.

Post-harvest management determines the quality and longevity of flowers from harvest to final use. Effective practices should aim to minimize moisture loss, preserve nutrients, prevent chemical degradation, and protect against physical damage—all of which help maintain the flower's visual appeal that consumers value.

In today's society, flowers play a role in nearly every celebration—be it inaugural events, national holidays, or special days like Teacher's Day, Mother's Day, Valentine's Day, and Friendship Day. They are also used to convey emotions: roses symbolize love, red roses or carnations express feminine affection, irises convey messages, snapdragons imply presumption, daffodils stand for regard, marigolds for sorrow, lotuses for purity, and lilies for luxury.

This widespread use underscores the significant role flowers play in daily life. With rising demand, attention is increasingly directed toward improving aspects like vase life. Traditionally, flowers were evaluated by physical traits like color, bloom size, stem length, foliage quality, and overall appearance. However, longevity after harvest has now become a critical quality parameter.

Post-harvest management is key because the market value of flowers is closely tied to their visual quality. In any marketing system, quality assurance is crucial for profitability—especially for perishables like flowers. To consumers, the quality of flowers also reflects social status and personal dignity.

Factors Affecting Post-Harvest Life of Spike During Storage Temperature

Temperature influences the metabolic activities of plants. Low temperature during storage or shipment period reduces the entire metabolism in the tissues, slows down the respiration, transpiration, ethylene production and action and retards the multiplication of bacteria and fungi.

Humidity: Cut flowers should be kept at 90-92 % relative humidity for maintaining turgidity i.e. beneficial for prolonging the vase life of cut flower during post- harvest (Doi *et al.*, 2000).

Water: Water is essential to maintain the turgidity of spikes of cut flower. Slightly acidic water checks the growth of harmful bacteria and fungi.

Air exchange: The associated biochemical and physiological changes associated with the post-harvest quality of flowers are largely affected by O₂ and CO₂ levels. So, altering the levels of these two can enhance the vase life by large extent.

Microbial activity: Fungi and bacteria cause rotting and thereby deteriorate flower quality. Effective management of these pathogens can extend shelf life of cut flower to a large extent. Celikel and Reid, 2002, confirmed that vascular plugging in cut flowers caused by bacterial colonies development is the major reason for lesser vase life.

Ethylene: Ethylene is one of important plant growth regulator. It plays an important role in hastening the senescence of the flower. There are a number of inhibitors of ethylene action are used such as, Silver Thiosulfate, 2,5- Norbornadiene and 1- Methylcyclopropene (1-MCP). Exogenous ethylene in a large number of cut flower can be controlled by using the 1-MCP (Celikel and Reid, 2002). Hence, throughout entire storage period it is necessary to maintain uniform temperature, relative humidity, air circulation and sanitation of storage room.

Post-harvest handling of the crop is the most important aspect in getting the right value for the crop. A typical post-harvest management practice of flowers comprises of the following stages

Pre-cooling: It is required to bring down the temperature of the flowers down to a much lower temperature (around 10 °C but not below the recommended storage temperature) as soon as the harvesting is done. Buckets containing flower stems dipped in water or water solution of preservatives should be kept in a pre-cooling chamber.

One may prefer doing cleaning, de-leafing, and bunching after harvest and then pre-cool but it should be done as quickly as possible. Refer the points that follow to know more about them. This operation should be finished within six hours or less. Pre-cooling removes field heat quickly, arresting the metabolism/respiration and extends the life of the flowers.

Cleaning and De-leafing: The leaves from the lower portion of the stem are removed. All infected leaves are also removed. Precautions should be taken to prevent crop injury during these processes.

Grading, Sorting and Bunching: The grading of flowers should be done according to the stem length, bud size, stem thickness and opening of flowers. Depending on the requirement of a buyer, appropriate thumb rules should be applied for these processes. The requirement of grading could be different in Indian market than what it is in say, Netherlands. Bent neck, thorn damage flowers, disease and pest affected and thick stem should be rejected.

Storage Methods

Storage of flowers can be of following types.

1. Cold storage:
 - a. Wet storage
 - b. Dry Storage
2. Controlled atmosphere storage (CAS)
3. Low pressure storage (LPS)
4. Modified atmosphere storage (MAS).

Cold Storage

It facilitates the adjustment of flower stock to the market demand. It is the most economical and widely used method of flower storage.

Table 1: Pre-cooling Temperature of flower storage:

Sr. No.	Crop	Pre-cooling Temperature
1.	Anthurium	13 °C
2.	Alstroemeria	4.0 °C
3.	Chrysanthemum, Cymbidum, Paphiopedilum	0.5- 4 °C
4.	Dendrobium	5- 7 °C

5.	Gladiolus	4-5.0 °C
6.	Rose	1-2 °C
7.	Carnation	0.5- 1.0 °C
8.	Gerbera	4.0 °C

Source: Janick, 2011

Wet Storage

In this method spikes are dipped in water or some preservative solution during storage. The cut flowers are kept in water or preservatives solution at 3-4 °C for a short time. Carnation, Gerbera, Lily & Snapdragon can be best stored under this method (Singh *et al.*, 2007).

Table 2: Preservative temperature of during cut flowers storage:

Sr. No.	Flowers	Storage Temperature	Maximum Storage period
1.	Rose	2 °C	10 Days
		4 °C	4 Days
2.	Gladiolus	0.5-1.6 °C	10 Days
3.	Gerbera	4 °C	3-4 Weeks
4.	Lilium	0-2 °C	3 Weeks
5.	Tuberose	4-5 °C	4 Days
6.	Orchids	4 °C	2-3 Weeks
7.	Chrysanthamum	0.5-2 °C	12-15 Days

Source: Janick, 2011

Dry Storage

In this method fresh flowers are wrapped in plastic packaging or any other suitable packaging material to prevent the loss of moisture after harvesting & grading. Prior to storage flowers are treated with fungicide and pulsed with floral preservatives (Singh *et al.*, 2007).

Controlled Atmosphere Storage (CAS)

This is a storage method with lower level of O₂ with a higher level of CO₂ (up to 4%) in gas cool chambers with cooling system. This led to reduction in the physiological processes consisting of respiration and production of ethylene. (Singh *et al.*, 2009).

Modified Atmosphere Storage

Modified atmosphere storage (MAS) is less cumbersome and more economical than the controlled atmosphere and low-pressure storage. The storage response of flowers depends upon the maintenance of positive water balance in the stem and ultimate concentration of CO₂ and O₂ inside the packages during storage (Singh *et al.*, 2009). Considerable variations occur among flower species in their response to modified atmosphere conditions during storage (Goszczynska and Rudnicki, 1988).

Packaging

The flower buds should be wrapped with white or brown paper wrappers. The size of the wrappers depends upon the bud size and number of flowers per bunch. Using rubber bands of 2 into 4 in sizes below the bud and at the bottom of the stem help in minimizing transport injury and are recommended.

Packaging Material

A number of packaging material are used while placing flower spike for storage most frequently used are Polypropylene (PP), Low Density Polyethylene (LDPE), PO (Polyolefin), Cellophane, Butter paper, Newspaper, Banana leaves etc.

Qualities of Packaging Material

The requirement of attributes of packaging material with respect to floral product are flower quality maintenance, water loss reduction, protection from physical injury, convenient to use, traceability and

make the floral product easy to handle in transportation. The qualities of packaging material are strong enough, resistant to moisture, low cost or reusable, and finally friendly with packing line machinery. Selection of a suitable packaging material to create an optimal passive modification of CO₂ and O₂ levels is of utmost importance for storage of cut flowers (Patil and Singh, 2009).

Grading

During sorting, flowers damaged, infested with pest and diseases and defective are discarded. Good flowers are graded according to the bud size and stem length. Uniform buds with stem length of a particular grade range are bunched in 10, 15 or 20 number. Grading is normally done on the basis of flower quality judged by bud or bloom regularity, stem length and straightness. The grades prevailing in roses and gladioli in international trade are given below.

The flowers which are uniform in color, stem length and development are grouped together. Internationally recognized grades are as follows.

Gladiolus

Four grades are used on the basis of overall quality, length of spike and number of florets per spike (Staby *et al.*, 1978). While grading care should be taken to discard the bruised, broken, diseased and insect damaged flowers. Same grade flowers are bunched together and wrapped with cellophane paper to improve the display value.

The inner layer of package should also provide cushioning effect to the flowers. Some of the packaging material commonly used are cellophane paper, newspaper, fluted card board paper, polypropylene, polyethylene, craft paper and tissue paper either in the form of sleeves, cones, cups or simple wrapping over flowers. Corrugated cardboard boxes are commonly used for packaging of flowers.

Package should be labeled mentioning source, crop, variety, grade and number of flowers or bunches with handling tip. Singh *et al.*, in 2007, reported that Polypropylene packing in cold storage can keep the gladiolus spikes up to 10 days. Dastagiri *et al.*, (2014) observed that *Ornithogalum* spikes can be best stored up to 3 days at 4 °C in modified atmosphere packaging with cellophane.

Chrysanthemum

Most of the Standard chrysanthemums are placed in sleeves (50 gauges) and packed in display boxes measuring 91 x 43 x 15cm. They are placed in the boxes according to the grades. For bulk packing of the spray chrysanthemums, 10, 15 or 20 stems are placed in sleeves & packed in box measuring 80 x 50 x 23cm. It is wrapped in plastic and stored for 6-8 week at 0.5 °C. Recommended temperature for truck shipment is 2-4 °C. Azordin (600 ppm) treatment for half hour protect from pest and diseases. Pillow of corrugated paper under neck of large bloom prevents mechanical damage. Pulsing with different solution shows better keeping quality yet sucrose 2% + AgNO₃ (25 ppm) + citric acid (75 ppm) and sucrose (2%) + 8 HQC (500 ppm) are recommended best holding solution for bud opening and increased vase life of chrysanthemum. Slight acidic and biocidal nature of 8-HQC increase its efficiency as floral preservative (Gupta *et al.*, 2006).

Gladiolus

Storage of gladiolus below 1.6 °C proven detrimental and it also fail to open when taken out of long term storage. Though, 6-9 days storage is satisfactory, yet can be stored for 30 days under low pressure storage technology. Spikes when harvested for local market are submerged in water. Perforated card board or wooden box of 120 X 60 X 30 cm size is used for packing. It is recommended to put immediately on water after reaching distant market. Refrigerated van can keep quality for long distant shipment. Nelofar and Paul, (2008). reported that with increasing storage duration the quality and vase life of gladiolus decrease significantly. The spikes of gladiolus dry-stored in polyethylene sleeves showed considerable decline in post-storage vase life and opening of florets, with an increase in storage duration. The post-storage vase life, however, varied in different cultivars (Singh *et al.*, 2006). Polypropylene sheet reported to maintain high CO₂ and low O₂ level. Spikes harvested when 1-2 bud start showing colour exhibit less vase life than those when 4-5 start showing colour for 7 and 14 days but more for 21 days storage. Spikes of later could be dry stored with PP 100 and PP 200 for 7 days with vase life 7.67 and 6.67 days respectively (Singh *et al.*, 2008).

The spikes wrapped in cellophane and stored at 4°C for 48 hrs. exhibited better vase life than those wrapped in newspaper, Reason being decrease in water loss and a buildup of high relative humidity inside the cellophane packages Beura and Singh, (2003). Floret failed to open after 21 and 28 days of storage, floret size decline with increase in storage duration and was more in spikes stored in PP100 and PP 200 and maximum number of floret opening also decreased with storage duration (Singh *et al.*, 2008). The effect of wet packing of gladiolus on physiological loss in weight (g), vase life and floret size of gladiolus cv. 'Sylvia' and reported that the low temperature with a very and high relative humidity is favorable for decreasing the post-harvest losses in most of the cut flowers. The wet storage with sucrose at 3% for 48 hours was effective when wrapped with polyethylene at low temperature (10 °C) storage. However, the wet storage with sucrose 4% for 48 hours in storage as well at room temperature maintains the turgidity of flowers with the higher per cent floret display and vase life and also reduce the extra cost input for maintain the low temperature (Munsi *et al.*, 2011).

Narcissus

Vase life of Jonquil and Paper white cultivars of Narcissus decreased with increasing range of storage temperature. Dry storage of narcissus was found better at early stage but wet storage of narcissus was found better later. Respiration increase exponentially over temperature range 0-12.5 °C and vase life decrease exponentially with increasing storage temperature (Cevallos and Reid, 2000).

Carnation

Carnation is very sensitive to post harvest treatments and longevity can be doubled if handled carefully. It can be stored normally for 2 weeks but under low pressure condition upto 90 days. Stage of harvesting has great impact on ability to storage duration without deterioration of quality. Light bud stage can be stored for 20-24 week at 0-1.1 °C where as partial open for 6-10 weeks and fully open for 2-3 week. Flowers are packed in bunches and sleeved in plastic sheets or newspaper as per requirement of customer. Generally cardboard boxes having 122cm X 50cm X 30cm dimension are used. 10ppm 8-HQC + 2% sucrose was found best for improving longevity and quality, increased flower diameter, solution uptake and reduced fresh weight losses. Aluminium sulphate in vase solution is responsible for increasing vase life along with sucrose as it is known to check microbial growth. Combination of biocide and ethylene inhibitor alone or with sucrose tends to increase vase life, and improve flower quality (Bhatia *et al.*, 2002).

Gerbera

Use of germicide like 8-HQS reduce the population of microbes, and sucrose alone increase microbe population. Maximum vase life in gerbera as recorded in sucrose 3%+8- HQS 200 ppm or Sucrose 3% + Aluminium Sulphate 200 ppm along with better freshness, colour and least bent neck (Chakrabarty *et al.*, 2011).

Daisy (*Aster amellus*)

Daisy flowers showed maximum solution uptake, fresh weight and vase life in 0.4% 8-HQS (116.7%) and minimum fresh weight was found in distilled water. Other treatment used was Aluminium Sulphate (0.2 and 0.4%), 8-HQS (0.2%), sucrose (1 & 2 %), citric acid (100ppm) silver nitrate (0.003%) and distilled water (Patil *et al.*, 2009).

Effect of Different Storage and Pulsing

In all the three species of Iris, the enhanced vase life was recorded in scapes kept at 5°C under dry or wet storage as compared to the corresponding scapes kept at higher temperatures (10°C and room temperature). The postharvest performance of scapes was found to be better in scapes transferred to sucrose as compared to the corresponding scapes transferred to distilled water (Ahmad *et al.*, 2013).

Table 3: Different Storage temperature and pulsing rate of flower corps:

Sr. No.	Crop	Pulsing	Storage temperature	Storage life
1.	Rose	2-5% sucrose	0.5-2 °C	7-10 Days
2.	Chrysanthamum	2-5% sucrose	0.5-2 °C	12-15 Days

3.	Gladiolus	20% sucrose	4.0-5 °C	7-15 Days
4.	Gerbera	20% sucrose	4.0 °C	4 Weeks
5.	Orchid	-----	5-7 °C	-----
6.	Anthurium	-----	13 °C	-----
7.	Crossandra	-----	15-20 °C	-----
8.	Tuberose	20% sucrose	7-10 °C	10-12 Days

Use of Growth Regulators

Post-harvest life of flowers can be controlled by growth regulators. Water relation changes associated with flower senescence are also influenced by growth regulators. Auxin does not play much role in improving vase life.

Gibberellin helps in Delaying senescence. It promotes the opening of immature buds in gladiolus. Outer bracts of Gladiolus regulate production of alpha-amylase (Saeed *et al.*, 2013) reported that the application of GA3 at 25–50 mg/l renders the highest results for improving the vase life and quality of gladiolus cut flowers.

Cytokinins play important role in delaying senescence. Level of cytokinins decreases with ageing. BAP in holding solution delay senescence of Tuberose. Dip treatment of BA increases vase life of *Anthurium*. Mature coconut water is considered as a rich source of sugar, electrolytes and growth regulators such as auxin, gibberellins and cytokinin (Kumar *et al.*, 2022) observed that *Anthurium* cut flower variety wild pink when treated with 50 % Coconut water with 0.23 % NaOCl shows longest vase life (21 days). Coconut water has been successfully used to increase the post-harvest life of Gerbera (Nair *et al.*, 2000).

Ethylene a hydrocarbon gas, and commonly known as a ripening hormone induces senescence in many flowers. Some important effects of ethylene are: Sleepiness of petals in carnation, Epinasty in Poinsettia, Abscission of petals or whole flowers, Inhibition or promotion of bud opening in roses. Celikel *et al.*, 2002, studied the effect of 1-MCP and promalin on oriental lily and observed that 1- MCP play an important role in preventing post-harvest deterioration of buds and flowers caused by ethylene.

Transportation

The dimensions of the packaging box depend on the stem length, the number of stems, and the distance to the market. For transport, a 3 to 5 ply corrugated paper or fibreboard box is recommended. Flower bunches should be arranged in a row along the length of the box, with alternate bunches facing in opposite directions. The second layer should be placed in reverse orientation to the first. Bunches must be packed firmly to prevent unwanted movement during transit.

The boxes should be tightly strapped to ensure secure packaging. Loading should occur in shaded areas and be completed swiftly. During this process, flowers must not be moved directly from cold storage into direct sunlight. It is ideal to transport flowers in a refrigerated (reefer) container to maintain the storage temperature. While non-refrigerated transport is possible, it is important to remember that flowers have a short vase life—typically 1 to 3 days—after being removed from cold storage and should be used within this period."

Conclusion

Storage, packaging and transportation are indispensable for advancing vase life and sustaining quality of cut flower. Significant improvement among various cut flower species have been reported by manipulating stage of harvesting, supplying preservative and alternative food material, proper packaging, and storage conditions.

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Study on Post-Harvest Treatments to Extend Vase Life of Cut Carnations: Focus on Sucrose Pulsing and Silver Thiosulphate (STS) Treatments

Article ID: 71009

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Abstract

Carnation (*Dianthus caryophyllus* L.) is a prominent cut flower in the global floriculture market. The vase life of cut carnations is a critical quality parameter influencing consumer satisfaction and marketability. Post-harvest treatments, particularly sucrose pulsing and silver thiosulphate (STS) applications, have been extensively studied for their efficacy in prolonging vase life. This review consolidates current knowledge on the mechanisms and effects of these treatments, highlighting their roles in delaying senescence, maintaining floral quality, and extending vase life.

Introduction

The post-harvest longevity of cut flowers is a significant concern in the floriculture industry. Carnations, known for their aesthetic appeal and commercial value, are susceptible to rapid senescence post-harvest, primarily due to ethylene sensitivity and carbohydrate depletion. Implementing effective post-harvest treatments is essential to mitigate these issues and enhance vase life (Halevy & Mayak, 1981).



Senescence in cut flowers is characterized by wilting, discoloration, and petal drop, and is accelerated by the endogenous production of ethylene and the inability to sustain carbohydrate levels. The commercial handling of cut carnations thus necessitates strategies that either inhibit ethylene biosynthesis/action or improve carbohydrate availability to the flower tissues. Among various methods, chemical pulsing treatments using silver thiosulphate (STS) and carbohydrate sources like sucrose have shown promise in maintaining post-harvest quality (Nowak & Rudnicki, 1990).

Mechanisms of Senescence in Cut Carnations

Senescence in cut carnations is influenced by various physiological and biochemical factors:

- 1. Ethylene Production:** Carnations are ethylene-sensitive; endogenous ethylene accelerates petal wilting and abscission (Reid et al., 1983).
- 2. Carbohydrate Depletion:** Post-harvest, the depletion of stored carbohydrates leads to energy deficits, impairing cellular functions (Nichols, 1973).

3. Water Relations: Impaired water uptake due to vascular blockage affects turgidity and accelerates senescence (van Doorn, 1997).

Sucrose Pulsing: Enhancing Energy Supply

Sucrose pulsing involves treating cut flowers with a sucrose solution to replenish carbohydrate reserves:

- 1. Mechanism:** Sucrose serves as an energy source, maintaining metabolic activities and delaying senescence (Ichimura et al., 1999).
- 2. Application:** Pulsing with 20% sucrose at 22°C for 24 hours has shown to increase longevity and decrease ethylene sensitivity in carnations (Whitehead et al., 2003).
- 3. Benefits:** Improved floret opening, enhanced pigmentation, and extended vase life have been reported. Sucrose enhances the osmotic potential of petal cells, improving water uptake and turgor (Halevy & Mayak, 1981).

Silver Thiosulphate (STS): Ethylene Action Inhibition STS is an ethylene action inhibitor used to prolong the vase life of ethylene-sensitive flowers:

- a. Mechanism:** STS binds to ethylene receptors, preventing ethylene perception and subsequent senescence processes (Veen, 1979).
- b. Application:** Pretreatment with STS has been shown to extend the vase life of carnations significantly (Reid et al., 1983).
- c. Considerations:** Optimal concentrations (0.2-0.5 mM) and exposure times are critical to maximize efficacy without phytotoxic effects (Ichimura & Shimizu-Yumoto, 2007).

Combined Treatments: Synergistic Effects

Combining sucrose pulsing with STS treatment can have synergistic effects in prolonging vase life:

- 1. Eustoma Flowers:** STS plus sucrose treatments extended vase life more effectively than individual treatments (Shimizu & Ichimura, 2005).
- 2. Snapdragon Flowers:** Combined treatments promoted floret opening and extended vase life more than sucrose or STS alone (Ichimura et al., 2008).
- 3. Carnations:** Pretreatment with STS followed by sucrose pulsing improved vase life post-transportation (Ketsa et al., 1987).

Other Complementary Post-Harvest Treatments

- 1. 8-Hydroxyquinoline Citrate (8-HQC):** Used as a microbial suppressant and preservative to improve vase life (Ichimura & Shimizu, 2007).
- 2. Citric Acid and Chlorine Compounds:** Lower pH and prevent microbial growth in vase solutions (Liao et al., 2000).
- 3. Commercial Floral Preservatives:** Often include combinations of sugars, acidifiers, and biocides tailored to cut flower species (Nowak & Rudnicki, 1990).

Practical Implications and Recommendations

Implementing sucrose and STS treatments can significantly enhance the post-harvest quality of cut carnations:

- 1. Protocol Optimization:** Determining optimal concentrations and treatment durations is essential for maximum benefit.
- 2. Environmental Considerations:** Proper handling and storage conditions post-treatment are crucial to maintain flower quality.
- 3. Safety Measures:** Handling of STS requires caution due to its chemical nature; appropriate safety protocols should be followed.



Conclusion

Post-harvest treatments using sucrose pulsing and STS applications are effective strategies to extend the vase life of cut carnations. These treatments address the primary causes of senescence by replenishing energy reserves and inhibiting ethylene action. Combined or individual use of these treatments can significantly improve flower quality, reduce post-harvest losses, and increase commercial value. Continued research and optimization of treatment protocols will further enhance the longevity and quality of cut carnations in the floriculture industry.

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Biological Control of Plant Diseases: A Review

Article ID: 71010

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Summary

Plant diseases caused by fungi, bacteria, viruses, nematodes, and oomycetes pose a significant threat to global food security, resulting in substantial yield losses and economic setbacks. While conventional chemical pesticides have been used for disease suppression, their overuse has led to concerns such as pesticide resistance, environmental pollution, and health risks. As a sustainable alternative, biological control has gained attention, utilizing living organisms or their metabolites to suppress plant pathogens through various mechanisms. This review examines the principles, mechanisms, diversity, applications, and limitations of biological control agents in plant disease management, highlighting current advances and future prospects.

Introduction

The agricultural sector faces an ongoing battle against plant diseases, which can cause pre-harvest and post-harvest losses ranging from 20% to 40% in major crops, including rice, wheat, maize, and vegetables (Savary et al., 2019). The global dependence on synthetic agrochemicals has, over time, resulted in diminishing efficacy due to pathogen adaptation, ecological disruption, and increasing public concern regarding chemical residues in food and groundwater (Damalas & Eleftherohorinos, 2011).

Biological control offers a sustainable solution by leveraging naturally occurring or deliberately introduced antagonistic organisms or bioactive compounds to suppress plant pathogens. Unlike chemical control, biocontrol strategies integrate seamlessly with ecological processes, contributing to long-term soil health, enhanced biodiversity, and reduced chemical footprints.

Biological control operates through multiple, often overlapping, mechanisms:

- 1. Antibiosis:** Inhibition of pathogens via the production of antimicrobial compounds.
- 2. Competition:** Direct competition for limited nutrients and ecological niches.
- 3. Parasitism and Predation:** Physical attack and consumption or degradation of pathogens.
- 4. Induced Systemic Resistance (ISR):** Activation of plant immune responses for broad-spectrum resistance.

This review delves into these core mechanisms and explores the range of BCAs currently under research or in commercial use.

Mechanisms of Biological Control

1. Antibiosis: Antibiosis involves the secretion of biologically active metabolites, including antibiotics, volatile organic compounds (VOCs), siderophores, enzymes, and toxins, that inhibit or kill target pathogens.

a. *Pseudomonas* spp. produce a variety of antimicrobial metabolites, including 2,4-diacetylphloroglucinol (DAPG), pyoluteorin, pyrrolnitrin, and phenazines. These molecules disrupt pathogen metabolism, biofilm formation, and cell membrane integrity (Haas & Défago, 2005).

b. *Trichoderma* spp. secrete a broad spectrum of bioactive secondary metabolites such as gliotoxin, peptaibols, harzianolide, and viridin, which exhibit potent antifungal activity against soilborne pathogens (Vinale et al., 2008).

2. Competition for Nutrients and Niches: Competition is a fundamental strategy in microbial ecology and is often an underappreciated yet highly effective form of biological control. Beneficial microbes colonize infection courts, root surfaces (rhizosphere), or leaf surfaces (phyllosphere) more rapidly and efficiently than pathogens, denying them access to resources.

- a. Siderophore production by *Pseudomonas fluorescens* enables efficient iron sequestration, depriving competing pathogens of this essential micronutrient (Kloepper et al., 1980).
- b. Fast-growing fungi such as *Trichoderma* spp. effectively outcompete pathogens for space and resources in both soil and plant tissue.

3. Parasitism and Predation: Certain BCAs employ direct attack mechanisms on pathogens, either through parasitism or predation.

- a. **Mycoparasitism:** Species like *Trichoderma harzianum* employ a combination of enzymatic degradation (chitinases, glucanases, proteases) and physical coiling around the hyphae of plant-pathogenic fungi, leading to their disintegration (Harman et al., 2004).
- b. **Bacteriophages:** Highly host-specific viruses that infect and lyse pathogenic bacteria such as *Xanthomonas*, *Ralstonia*, and *Erwinia* species. Phage therapy in agriculture is emerging as a precise, residue-free plant disease management tool (Jones et al., 2007).

4. Induced Systemic Resistance (ISR): Some BCAs do not directly inhibit pathogens but instead "prime" the plant's immune system, enhancing its readiness to combat future infections.

- a. ***Bacillus* spp. and *Pseudomonas* spp.** can elicit ISR through the modulation of plant hormonal pathways, particularly involving jasmonic acid (JA), ethylene (ET), and salicylic acid (SA) (Pieterse et al., 2014).
- b. ISR-induced plants exhibit broad-spectrum resistance, which can persist for an extended period and protect against a wide range of pathogens.

Major Biocontrol Agents (BCAs)

1. Bacterial Biocontrol Agents:

- a. ***Bacillus* spp.:** Known for producing lipopeptides such as surfactin, iturin, and fengycin, which exhibit strong antifungal and antibacterial properties. *B. subtilis* is widely used as a seed coating and foliar spray against *Fusarium*, *Rhizoctonia*, and *Botrytis* species (Ongena & Jacques, 2008).
- b. ***Pseudomonas* spp.:** Recognized for root colonization and production of secondary metabolites that inhibit plant pathogens. Certain strains of *P. fluorescens* effectively suppress damping-off diseases caused by *Pythium* and *Rhizoctonia* (Weller et al., 2002).

2. Fungal Biocontrol Agents:

- a. ***Trichoderma* spp.:** Apart from its role in direct antagonism, *Trichoderma* also promotes plant growth through enhanced nutrient uptake and stress tolerance. Commercial formulations are widely used in both organic and conventional agriculture (Benítez et al., 2004).
- b. ***Ampelomyces quisqualis*:** A highly specialized hyperparasite of powdery mildew fungi, applied to reduce the pathogen's reproductive capacity and spread (Kiss, 2003).

3. Viral and Nematode-Based Biocontrol:

- a. **Bacteriophages:** Their high specificity makes them an attractive biocontrol tool against bacterial plant diseases, reducing reliance on copper-based bactericides (Balogh et al., 2010).
- b. ***Pasteuria penetrans*:** A spore-forming parasitic bacterium that attaches to and infects root-knot nematodes (*Meloidogyne* spp.), significantly reducing their population and subsequent crop damage (Stirling, 2014).

Application Methods of Biological Control

1. Soil Application: BCAs can be introduced into the soil through drenching, incorporation, or as part of organic amendments. This is particularly effective against soilborne pathogens such as *Rhizoctonia solani*, *Fusarium oxysporum*, and *Pythium* spp. (Larkin & Fravel, 1998).

2. Seed Treatment: Seed coating with BCAs offers protection during the vulnerable germination and seedling stages, establishing early rhizosphere colonization and offering preemptive defense against pathogens (Mancini & Romanazzi, 2014).

3. Foliar Spray: Application of bacterial or fungal suspensions to aerial parts of the plant enables effective management of foliar pathogens like powdery mildew, blight, and bacterial spots (Berg, 2009).

4. Biofumigation: Certain Brassicaceae crops, when incorporated into soil, release glucosinolate-derived isothiocyanates with broad-spectrum antifungal and nematicidal properties (Matthiessen & Kirkegaard, 2006).

Challenges in Biological Control

Despite its potential, the widespread adoption of biological control in agriculture faces several obstacles:

1. Environmental Variability: Fluctuations in soil temperature, pH, and moisture can significantly impact the survival and efficacy of BCAs in field conditions (Xu et al., 2011).

2. Regulatory Hurdles: Biopesticide registration processes are complex, region-specific, and often designed for chemical pesticides, delaying the commercial availability of BCAs (McSpadden Gardener & Fravel, 2002).

3. Limited Shelf Life: Many microbial formulations require specialized storage conditions to maintain viability and efficacy over time (Fravel, 2005).

Future Perspectives

Emerging technologies are poised to overcome existing challenges and unlock the full potential of biological control in plant disease management. Key areas include genetic engineering to enhance beneficial traits in biological control agents (BCAs), such as stress tolerance and antimicrobial metabolite production (Dunlap et al., 2019). Microbiome manipulation using advanced sequencing and metagenomics can also engineer plant-associated microbiomes for disease suppression (Berg et al., 2017). Furthermore, integrating biological control with modern tools like CRISPR/Cas-mediated plant resistance can create robust, multi-layered disease management strategies (Jinek et al., 2012).

Conclusion

Biological control represents a cornerstone of sustainable plant disease management. Its multi-faceted mechanisms—ranging from direct antagonism to the activation of plant defenses—offer environmentally safe alternatives to chemical pesticides. As scientific understanding of microbial ecology deepens and biotechnological advances enhance BCA performance, biological control will likely become an integral component of Integrated Pest Management (IPM) frameworks worldwide. Future research should focus on improving the formulation, delivery, and field performance of BCAs, as well as developing synergistic combinations with other biologicals, biostimulants, and conventional methods for effective, long-term plant protection.

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Jeevamrit Application in Marigold (*Tagetes spp.*): A Review on Growth, Yield, and Sustainable Production

Article ID: 71011

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Abstract

The growing demand for sustainable agriculture practices has led to increased interest in organic biofertilizers like Jeevamrit. Specifically in floriculture, marigold (*Tagetes erecta*) serves as an excellent model crop to evaluate the effects of natural amendments. This review compiles and analyses recent research findings on the impact of Jeevamrit applications on marigold growth, yield, and soil health. Drawing from recent studies by Bhadaraka *et al.* (2024) and Kaushal *et al.* (2024), along with ten critical references cited therein, this article explores how Jeevamrit contributes to the sustainable production of marigolds, emphasizing plant vigor, soil microbial activity, and eco-friendly farming benefits. The article also discusses the mechanisms, economic viability, and future research needs to establish Jeevamrit as a mainstream component of floriculture.

Introduction

Marigold (*Tagetes spp.*) is one of the most commercially significant floricultural crops in India and globally. It is valued for its ornamental beauty, cultural significance, and economic utility. Marigold is extensively used in social, religious, and commercial events due to its bright colours and robust nature. Medicinally, marigold extracts are known for their anti-inflammatory, antimicrobial, and antioxidant properties, enhancing its value in herbal and pharmaceutical industries (Rhama and Madhavan, 2011).

Sustainable cultivation methods are increasingly sought to balance productivity and environmental health. Among these, Jeevamrit is a fermented organic concoction made using cow dung, cow urine, jaggery, pulse flour, and soil is gaining attention as an alternative to synthetic fertilizers. As a low-cost, farm-prepared bio-input, Jeevamrit aligns with natural and regenerative farming systems (Kulkarni, 2019).

Jeevamrit and Soil Health Enhancement

Soil health forms the cornerstone of sustainable agriculture. A biologically active soil supports better nutrient availability and plant health. Jeevamrit enhances microbial diversity in the soil, including bacteria, fungi, and actinomycetes, which accelerate decomposition processes and nutrient cycling (Kaushal *et al.*, 2024). In marigold cultivation, higher microbial populations were recorded in Jeevamrit-treated soils: 18.27×10^5 cfu g⁻¹ for bacteria, 3.64×10^3 cfu g⁻¹ for fungi, and 3.12×10^3 cfu g⁻¹ for actinomycetes.

Jeevamrit creates a favourable rhizospheric environment by providing food for microbes and stimulating their growth. This biological activity enhances the availability of nitrogen, phosphorus, and potassium — the essential nutrients for plant growth. Furthermore, its acidic nature helps regulate pH, increasing nutrient bioavailability in alkaline soils (Kulkarni, 2019). According to Walkley and Black (1934), organic amendments like Jeevamrit also improve soil organic carbon, an essential parameter for fertility.

Growth and Yield Enhancement

African Marigold (*Tagetes erecta*): Bhadaraka *et al.* (2024) investigated the influence of 16 treatments of Jeevamrit, including drenching and foliar application combinations. The treatment involving Jeevamrit drenching @750 L/ha with a 15% foliar spray (T13) recorded the best results. The number of flowers per plant (82.33), flower yield per plant (528.49 g), yield per plot (5.57 kg), and yield per hectare (171.81 q/ha) were significantly higher than the control group.

The improved yield can be attributed to Jeevamrit's nutritional richness. Kumar *et al.* (2021) reported that Jeevamrit contains N (1.97%), P (0.172%), K (0.29%), Mn (47 ppm), and Cu (50 ppm). These nutrients,

combined with the microbial activity, enhance photosynthesis, increase food accumulation, and ensure efficient translocation of assimilates to reproductive organs, resulting in more and bigger flowers (Praveen *et al.*, 2021).

Marigold cv. Siracole: Kaushal *et al.* (2024) evaluated the use of Jeevamrit in propagating marigold cv. Siracole through cuttings. Cuttings derived from Jeevamrit-treated plants showed higher rooting percentage (77.62%), more roots per cutting (35.46), faster rooting (14.90 days), and higher survival rates (81.59%). The nutrient uptake in Jeevamrit-treated plants was also higher: 17.73 kg/ha N, 9.48 kg/ha P, and 15.03 kg/ha K.

Compared to chemical treatments, Jeevamrit offered better quality cuttings in terms of rooting efficiency and plant vigour. This is crucial for maintaining high-quality mother blocks in vegetative propagation, where uniformity and genetic fidelity are essential (Kim *et al.*, 2015).

Role in Sustainable Floriculture: The marigold industry faces the dual challenge of maximizing yield while ensuring environmental sustainability. Jeevamrit provides a holistic solution by enhancing soil fertility and reducing chemical dependency. The bio-input supports the goals of sustainable floriculture by improving soil microbial health, reducing input costs, and minimizing harmful residues. Kaushal *et al.* (2024) reported that plants grown under Jeevamrit-based natural farming produced 3.77% more marketable flowers compared to recommended chemical fertilizer doses. Additionally, its use lowered reliance on farmyard manure, thereby decreasing the carbon footprint and resource burden.

Mechanism of Action: The efficacy of Jeevamrit stems from its diverse microbial and nutrient composition. Cow dung and urine provide the primary microbial load, while jaggery and pulse flour act as energy sources for microbial growth. The fermentation process further enriches the microbial profile. The microorganisms decompose organic matter, solubilize minerals, and produce plant growth-promoting substances like auxins, gibberellins, and cytokinins. These enhance root development, nutrient absorption, and shoot growth. Palekar (2006) described Jeevamrit as a "living tonic" that revitalizes the soil food web. Rhama and Madhavan (2011) also noted the antifungal properties of cow urine, adding plant-protective benefits.

Moreover, Jeevamrit application has been shown to increase enzymatic activity in the soil, including phosphatases and dehydrogenases, which catalyse essential nutrient transformation processes (Tabatabai and Bremner, 1969).

Economic Viability: Economically, Jeevamrit represents a cost-effective alternative to synthetic inputs. It is farm-prepared, inexpensive, and readily available in rural settings. Bhadaraka *et al.* (2024) observed the highest benefit-cost ratio (2.38) in T13 (750 L/ha drenching + 15% foliar application), highlighting its profitability. By improving yield and reducing input costs, Jeevamrit enhances the net return per hectare. It also fosters input independence for small and marginal farmers, making it a powerful tool for inclusive agricultural growth.

Comparative Analysis with Chemical Inputs: While Jeevamrit shows clear advantages in sustainability and root quality, Kaushal *et al.* (2024) found that the highest cutting yield per plant (92.92) and per square meter (826.64) was recorded with benzyl adenine (BA) 100 ppm combined with NPK @ 30:20:20 g/m². This suggests that while Jeevamrit is excellent for quality and soil health, certain chemical growth regulators may temporarily outperform it in quantity.

However, when comparing long-term soil fertility, microbial health, and environmental impact, Jeevamrit outshines chemical fertilizers. It is ideal for farmers focusing on long-term sustainability rather than short-term yield maximization (Reddy and Menon, 2021).

Challenges and Future Prospects

Despite its benefits, Jeevamrit faces challenges. These include labor-intensive preparation, inconsistent composition due to variable raw materials, and lack of awareness or training among farmers. Moreover, Jeevamrit may not meet the immediate nutrient demands of high-yielding hybrid varieties under intensive farming. Future research should aim to standardize Jeevamrit formulations and dosages. Blending Jeevamrit with low-dose chemical inputs or bio-enhancers could create hybrid nutrient management systems that balance sustainability with productivity. Field trials in diverse agro-climatic zones and

different marigold cultivars will help fine-tune its application protocols. Additionally, extension services should promote farmer training in Jeevamrit preparation and usage. Government policies can also play a role in subsidizing organic inputs and recognizing their role in sustainable agriculture.

Conclusion

Jeevamrit offers a practical, affordable, and ecologically sound method to enhance marigold production. Its benefits in improving soil microbial diversity, boosting plant growth, and increasing flower yield make it a valuable asset in natural farming. As shown in the studies by Bhadaraka *et al.* (2024) and Kaushal *et al.* (2024), Jeevamrit holds promise not just for productivity but for the resilience and sustainability of floriculture systems. Strategic adoption of Jeevamrit, especially in combination with regenerative practices, can significantly reduce environmental impact while ensuring economic viability. With proper awareness and research support, Jeevamrit could become a cornerstone of future-ready floriculture.

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Recently Advance Development Approaches in Tomato (*Solanum lycopersicum* L.) Breeding

Article ID: 71012

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Abstract

The cultivated tomato (*Solanum lycopersicum* L. $2n = 2x = 24$) is one of the most widely cultivated vegetable crops due to its wider adaptability, high yielding ability and enormous demand by consumers. Due to its simplicity tomato is to modify and how diverse its population exists, cultivated tomatoes have been utilized in genetic studies. The hybridization process, together with pedigree selection, has been the most significant breeding approach used for improving tomato. The back cross method of breeding has been the most effective technique for transferring desired traits from wild species to domesticated varieties. It has been observed that breeding techniques like pedigree method and single descent method work well when combined with molecular techniques. The production of boosted varieties with increased qualitative attributes has been demonstrated through the transfer of genes from uncultivated into cultivated cultivars, utilizing tomato as an example. To address the country's growing population, breeders must produce high-yielding cultivars using both traditional breeding and plant biotechnology technologies. Marker-Assisted Selection may be a useful method for tomato breeding.

Introduction

Tomato comes under solanaceous group of vegetable, its grown in open field as well as protected cultivation. There are around 3000 species of solanaceous vegetables. Tomatoes originated in Peru and were first domesticated in Mexico due to the abundance of both cultivated and wild tomato relatives in the area (Rick, 1969). The wild tomato type has a very wide range of genetic variability, particularly when it comes to self-incompatible species like *S. chilense* and *S. peruvianum*. The plants have indeterminate or determinate type, alternate leaves with small leaflets. It is soft and hairy when young and hard, woody and branched when mature. It has a strong tap root system. Cultivated tomato is a self-pollinated crop as the stigma is inside the anther cone but in case of some wild forms the stigma is exerted outside the anther cone which leads to cross pollination.

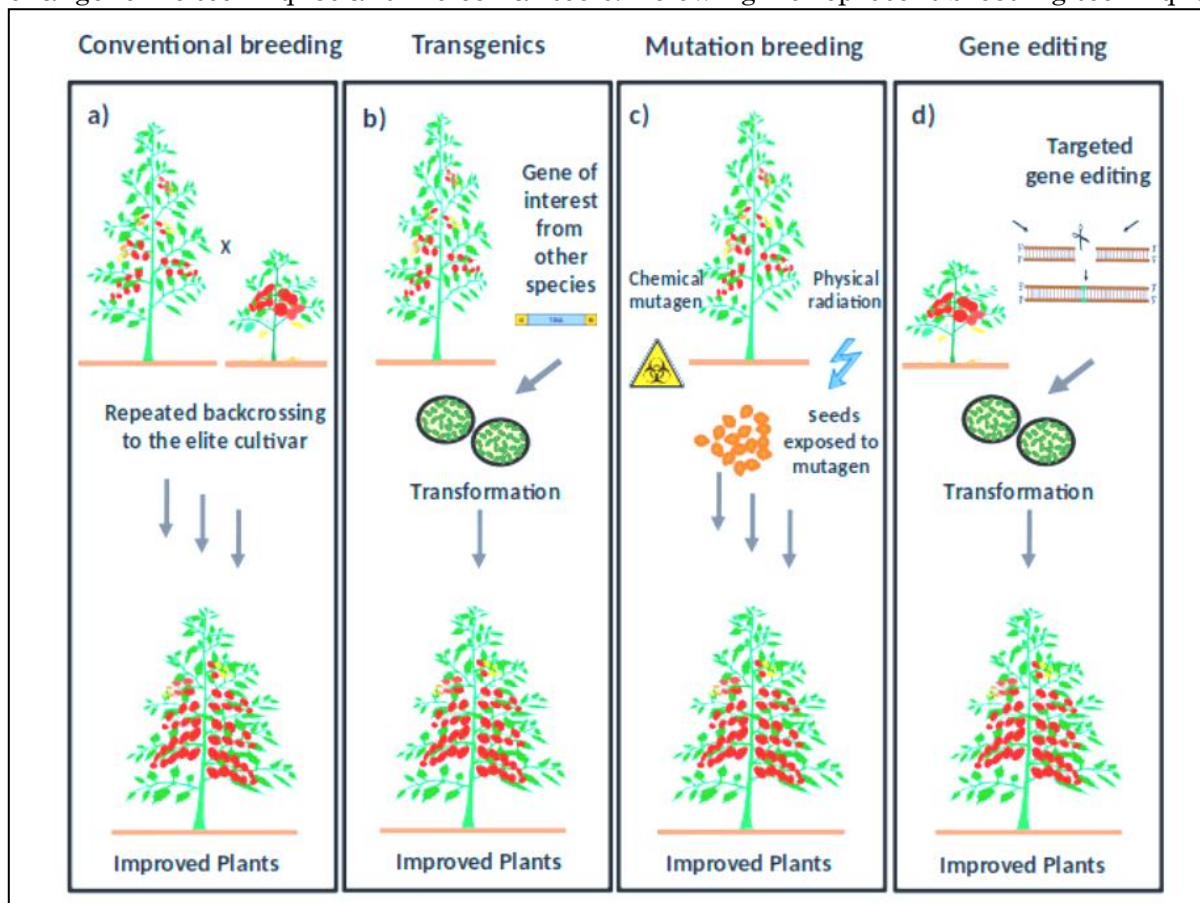
Tomato demand continues to rise, but production is impacted by various diseases and pressures (both biotic and abiotic). Tomato production and development are limited by a variety of conditions, including drought, temperature, salt and insect and pest infestations. Plant breeding focuses on creating qualitative traits, disease-resistant and stress-tolerant cultivars. Genetic engineering can help generate disease-resistant crops. Improving tomato crops is crucial for overcoming production limitations.

Floral Morphology

Tomato has perfect flowers, having viable male and female parts. In tomato anthesis starts around 6 a.m. and finally the flower opens around 11 a.m., dehiscence of anther occurs between 8 to 11 a.m. Pollen remains viable from 2 to 5 days. Stigma of the flower remains receptive 16 to 18 hours before anthesis up to 6 days after anthesis. The reproductive biology and production of appreciable quantity of seeds per fruit provide ample opportunity for manifestation of heterosis in tomato. In tomato emasculation for controlled pollination must be done nearby one day prior to opening of the flower to avoid the self-pollination. The stigma appears to be fully receptive at this stage, thus allowing pollination immediately after emasculation. Emasculation of flower is done between 55 and 65 days after planting. Pollen grains are collected before it is shed. When the corolla of the emasculated flower turns bright yellow, the stigma is ready for pollination. For 3-5 weeks repeat the pollination 2-3 times a week. Usually, fruit starts to enlarge after successful pollinations are visible within one week (Fentik *et al.*, 2017).

Tomato Breeding

The development of molecular biology and bioinformatics has offered wide scope for improving the effectiveness of traditional plant breeding programmes. Advances in genomics and genetics improved the understanding of structural and functional aspects of plant genomes. Among the fruit bearing plants, tomato has been selected preferably to study the fruit development process and significant improvement in the understanding of the molecular basis of fruit set and development has been made due to advances in functional genomic techniques and molecular tools. Below figure represent breeding techniques:



Methods of Tomato Breeding

Hybridization and pedigree selection are the most common breeding techniques for improving tomato varieties. Back cross breeding is the preferred approach for transferring beneficial features from wild species to cultivated kinds that have not been improved.

Introduction

Introducing a genotype or a group of genotypes of plants into new agro climatic condition where they have not been grown before. These evaluated plants if meets the standards are directly released as a variety or used in hybridization for crossing. There are varieties which are introduced from the foreign countries called as exotic varieties and these varieties are used to improve the existing varieties. IARI and other institutes introduced many varieties are Roma, Labonita, Sioux, Marvel, Best of All and Money maker.

Pure Line Selection: In this method many phenotypically superior plants are selected and these plants are further harvested individually. The best progeny after evaluation is selected from the population and is released as a variety. Ex: Arka Vikas, Arka Saurabh, Arka Alok and Arka Ahuti.

Mass Selection: Mass selection involves selection of many phenotypically superior plants. This process of harvesting and bulking is repeated till the desired characters are obtained. The original population from where the superior plants are selected would have been a mixture of several pure lines and the plants selected would be homozygous. The final population which is obtained from the selected plants would be more uniform than that of the original population for easily observable characters which are governed by

one or few major genes like presence of awns, plant height and seed colour. Ex: Pusa Ruby, Arka Meghali, Arka Ashish.

Pedigree method: This method involves making a controlled cross followed by several successive generations of single plant selection. The aim is to develop at least one new variety from a single cross. Pedigree would describe the parents, grandparents, great grandparents and so on. This method makes a controlled crosses followed by single plant selection. Single plant selection is initiated in F_2 and is continued through successive generations till F_6 . This method produces new varieties faster than mass selection (Kalloo 2012).

Backcross Method: Hybrid and the progenies in the successive generation are repeatedly backcrossed to one of the parents. This method desirable gene transfers for resistance to diseases like, early blight resistance, Bacterial wilt resistance and nematode resistance. This method is used for development of isogenic lines, multiline and Root Knot Nematode lines are derived from *S. peruvianum*.

Mutation breeding: Also called variation breeding, is a method that uses physical radiation or chemical means to induce spontaneous genetic variation in plants to develop new crop varieties. "Mutation" is the source of most genetic variation and the motor of evolution. Ex: Pusa Lal Meeruti, S-12, PKM-1 and Maruthan.

Heterosis Method: Hybrids are more popularised and in demand among cross-pollinated crops but it has been achieved successfully in several self-pollinated crops too such as tomato even though the heterozygote advantage has not been unequivocal. The F_1 hybrids have some favourable traits such as uniformity and better resistance to diseases but their economic advantages over standard checks have not been as high as in cross-pollinated crops. The F_1 hybrids development in self-pollinated crops largely follows scheme used for cross-pollinated species (Jiang 2018). Ex: Arka Vishal, Kashi Sharad, Arka Vardan, Arka Rakshak, Pusa Hybrid-1, Pusa Red Plum, Hisar Anmol.

Biotechnology in breeding of tomato: Still today to satisfy and fulfil the requirements of future, conventional breeding methods are largely exploited. Also, the genetic diversity and variability present among the cultivated and wild relatives of tomato help in achieving the success. Although traditional methods of breeding are time consuming and labour intensive, there is no choice left for appropriate breeding purposes. Thus, developing and utilising genetically transformed plants, commercial applications are coming into picture. The in vitro culture is used successfully in different biotechnological applications including the clonal propagation of high value commercial varieties, virus-free plants and genetic transformation. The first commercially developed genetically modified tomato cultivar is Flavr Savr. It was developed after 10 years of intensive research work by the Calgene Company in 1992.

Speed Breeding

Researchers found that extending photoperiods using LED lighting and adjusting growth chamber conditions considerably reduced the time required to conduct tomato breeding programs. This rapid breeding cycle resulted in speedier selection and creation of tomato varieties with desired features, including disease resistance, fruit quality and yield.

Conclusion

Conventional breeding may not be sufficient to meet future demands. This requires tremendous advances in molecular genetics and the application of molecular marker techniques. To improve tomato breeding, it is recommended to mix conventional and current plant breeding methods, such as molecular marker selection and marker-assisted selection, which can be effective tools.

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Biometrical Techniques in Plant Breeding

Article ID: 71013

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Biometrical techniques in plant breeding integrate statistical and mathematical approaches to analyze and enhance the genetic potential of crops. These techniques are essential for studying complex quantitative traits influenced by multiple genes and environmental factors. Fundamental methods such as analysis of variance (ANOVA) partition phenotypic variation into genetic, environmental, and interaction components, provide insights into traits inheritance. Regression and correlation analyses help in understanding the relationships between traits, while path analysis reveals the direct and indirect effects of various factors on crop performance, such as yield. Techniques like heritability estimation measure the genetic contribution to traits, aiding breeders in selecting those with higher genetic control. Diallel analysis identifies the combining abilities of parental lines, enabling efficient hybrid development. Genotype-environment interaction studies assess the stability and adaptability of genotypes across diverse conditions, with methods like AMMI providing a detailed understanding of performance consistency. Selection indices combine multiple traits into a single value, optimizing the improvement of economically important traits. Advanced multivariate techniques, including principal component analysis (PCA) and cluster analysis, simplify complex datasets, aiding in the identification of patterns and diverse genotypes for breeding. Genetic mapping and quantitative trait locus (QTL) analysis, supported by molecular markers, enable the identification of genomic regions controlling important traits, accelerating marker-assisted selection (MAS). These tools not only facilitate the development of high-yielding and disease-resistant varieties but also optimize breeding strategies by predicting genetic gain and selecting superior genotypes. By integrating biometrical techniques with genomic tools, breeders can enhance precision, efficiency, and adaptability, ensuring improved crop performance in diverse environments and contributing to agricultural sustainability. These techniques provide a comprehensive framework for analyzing genetic variation, improving plant traits, and achieving targeted breeding goals.

Introduction

Plant breeding is a science that seeks to develop new and improved plant varieties with desired traits, such as better yield, resistance to pests and diseases, improved nutritional quality, and enhanced adaptability to environmental stresses. Over the years, plant breeding has evolved with the integration of advanced biometrical techniques that aid breeders in making informed decisions, optimizing breeding strategies, and achieving faster, more reliable results. Biometrical methods involve the use of statistical and mathematical tools to analyze genetic data, assess the effectiveness of breeding programs, and predict the potential performance of new plant varieties.

This article explores the various biometrical techniques used in plant breeding, their applications, and how they have revolutionized the field by improving the precision, efficiency, and speed of breeding efforts.

Statistical Genetics in Plant Breeding

Statistical genetics plays a fundamental role in plant breeding. It involves the study of genetic variation within populations and the inheritance patterns of traits. Key statistical tools are used to estimate genetic parameters, predict breeding values, and assess genetic progress over generations. These methods allow breeders to quantify the relationship between genotype and phenotype, enabling better selection and breeding decisions.

1. Heritability Estimates: Heritability is a critical concept in plant breeding, as it quantifies the proportion of phenotypic variation in a population that is due to genetic factors. High heritability indicates that selection based on phenotype will be effective in improving the trait of interest. Breeders use statistical models to estimate heritability and determine whether a trait can be improved through selection.

Heritability estimates can be classified into broad-sense heritability (H^2) and narrow-sense heritability (h^2):

- a. Broad-sense heritability (H^2)** refers to the proportion of the total phenotypic variation due to genetic factors, including additive, dominance, and interaction effects.
- b. Narrow-sense heritability (h^2)** focuses only on the additive genetic variation, which is most relevant for selection because it predicts the potential response to selection in future generations.

2. Genetic Correlation and Association Studies: In plant breeding, traits often exhibit genetic correlations, meaning that improvements in one trait may result in changes in another. Genetic correlation analysis helps breeders understand how traits are related at the genetic level and can assist in selecting for multiple traits simultaneously.

Association studies, such as genome-wide association studies (GWAS), have become powerful tools to identify genetic markers linked to specific traits. These studies correlate phenotypic data with genetic markers (such as single nucleotide polymorphisms or SNPs) to pinpoint regions of the genome that influence desirable traits. This information can be used for marker-assisted selection (MAS), where breeders select individuals carrying favorable alleles for specific traits, speeding up the breeding process.

Quantitative Trait Loci (QTL) Mapping

Quantitative traits in plants, such as yield, disease resistance, and drought tolerance, are controlled by multiple genes, each contributing a small effect to the phenotype. Identifying these genes and understanding their interactions is essential for improving quantitative traits in crops. QTL mapping is a biometrical technique that enables the identification of chromosomal regions associated with quantitative traits.

1. Marker-Assisted Selection (MAS): QTL mapping involves crossbreeding plants with different genetic backgrounds, generating segregating populations, and then associating phenotypic data with genetic markers to identify the QTLs controlling the traits of interest. Once the QTLs are identified, markers linked to these loci can be used to screen large populations, reducing the time required for selection.

MAS is particularly useful for traits that are difficult or costly to measure in the field, such as resistance to pathogens or environmental stress tolerance. By selecting plants based on their genetic markers rather than waiting for the trait to express itself phenotypically, breeders can significantly accelerate the breeding process.

2. Genome-Wide Association Studies (GWAS): While QTL mapping focuses on a small number of loci with large effects, GWAS aims to identify a large number of smaller-effect loci distributed across the genome. GWAS uses high-density genetic markers, such as SNPs, across the entire genome to link genetic variation to phenotypic variation. This approach allows breeders to uncover complex traits controlled by many small-effect loci.

Breeding Value Estimation and Selection Methods

Breeding value refers to the genetic potential of an individual plant for passing on desirable traits to its offspring. In plant breeding, estimating breeding values allows breeders to select the best-performing individuals for further propagation.

1. Best Linear Unbiased Prediction (BLUP): BLUP is a statistical method used to estimate the genetic merit of individuals in a population. It accounts for both fixed effects (e.g., environmental factors) and random effects (e.g., genetic variance) in the model. BLUP is particularly useful for estimating the breeding value of plants in complex breeding programs where multiple traits are involved. The method provides unbiased predictions of genetic potential, improving the accuracy of selection.

2. Selection Indices: Selection indices combine multiple traits into a single selection criterion, allowing breeders to select plants that perform optimally across several traits. The index weights each trait according to its importance and the genetic correlation between traits. This method is commonly used in multi-trait selection programs, where breeders aim to improve several traits simultaneously (e.g., yield, quality, and disease resistance).

Selection indices are also helpful in managing trade-offs between desirable and undesirable traits. For example, if improving yield results in a reduction in disease resistance, breeders can adjust the weights of each trait in the selection index to strike an optimal balance.

Genomic Prediction and Genomic Selection

Recent advancements in genomics have led to the development of genomic selection, a cutting-edge biometrical technique that uses genomic information to predict the breeding values of individuals. This approach utilizes genome-wide markers to predict the genetic potential of a plant before it expresses the trait of interest.

1. Genomic Selection Models: Genomic selection models predict breeding values based on DNA markers distributed across the genome. The primary advantage of genomic selection is that it allows breeders to make selection decisions early in the breeding cycle, often at the seedling stage, long before the traits of interest are expressed in the field. This results in faster genetic gains and a reduction in the time and resources needed for traditional breeding methods.

2. High-Throughput Genotyping: High-throughput genotyping platforms, such as next-generation sequencing (NGS), enable the rapid and cost-effective generation of genetic data on large populations. Combined with genomic selection, these platforms allow breeders to assess the genetic potential of thousands of individuals in a single breeding cycle. This is especially beneficial for crops with long breeding cycles, such as tree species, where traditional selection methods can take many years.

Applications and Future Directions

Biometrical techniques have dramatically transformed plant breeding by increasing the efficiency and precision of breeding programs. The integration of advanced statistical models, genetic analysis tools, and genomic data has made it possible to improve crops at a faster pace, with more predictable outcomes. These techniques have opened the door to the development of crops that are more resilient to climate change, disease, and pests, which is crucial for ensuring food security in the face of global challenges.

In the future, the continued integration of big data, machine learning, and artificial intelligence into plant breeding will further enhance the ability to predict and select for desirable traits. The combination of biometrical techniques and modern genomic tools holds great promise for the next generation of crop varieties that can meet the demands of a growing global population.

Conclusion

Biometrical techniques in plant breeding are invaluable tools that enable breeders to make informed, precise, and efficient decisions. From statistical genetics and QTL mapping to genomic selection, these methods have revolutionized the breeding process, allowing for the development of superior plant varieties with desired traits. As technology continues to advance, the role of biometrical techniques will only become more crucial in shaping the future of plant breeding and ensuring sustainable agricultural productivity.

Nano Fertilizers: The Next Revolution in Crop Nutrition

Article ID: 71014

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Summary

The agricultural sector is under increasing pressure to enhance crop yield while reducing environmental impacts. Traditional fertilizers, although essential for crop growth, have contributed to nutrient loss, environmental pollution, and soil degradation. Nano fertilizers, a relatively new concept in agricultural science, are emerging as a sustainable solution. These fertilizers, engineered at the nanoscale, exhibit superior properties such as enhanced nutrient solubility, controlled release, and improved bioavailability, offering promising alternatives to conventional fertilizers. This review explores the various types of nano fertilizers, their mechanisms of action, methods of synthesis, benefits, challenges, and their potential role in revolutionizing crop nutrition.

Introduction

The global agricultural industry faces challenges related to inefficient fertilizer use, nutrient depletion, and environmental contamination. Conventional fertilizers often lead to nutrient leaching, soil acidification, and pollution of water bodies (Lin et al., 2009). As a solution, nano fertilizers have garnered significant attention due to their ability to increase nutrient efficiency, reduce environmental impact, and enhance crop productivity. Nanotechnology-based fertilizers, which involve the application of nanoscale materials to deliver nutrients more effectively, present an innovative pathway for precision agriculture (Panwar et al., 2012).

Nano fertilizers can be synthesized using various nanoparticles such as metal oxides, carbon nanotubes, and polymer-based materials that release nutrients in a controlled manner. The application of nano fertilizers promises to address the limitations of conventional fertilizers by offering sustained nutrient release, reducing the need for frequent applications, and minimizing nutrient loss to the environment (Klaine et al., 2008).

Types of Nano Fertilizers

Nano fertilizers can be classified based on their structure and function. The major types include:

- 1. Nanoparticle-Based Fertilizers:** These fertilizers contain nanoparticles such as metal oxides (e.g., zinc oxide, iron oxide), silica nanoparticles, or carbon-based nanoparticles. These particles either serve as carriers of essential nutrients or enhance nutrient availability in the soil (Kumar et al., 2020).
- 2. Encapsulation-Based Fertilizers:** Nutrients such as nitrogen, phosphorus, and potassium are encapsulated in nanomaterials like polymeric nanoparticles. This encapsulation allows for the controlled release of nutrients over time, ensuring that plants receive nutrients as needed, reducing wastage and minimizing environmental impact (Hafeez et al., 2015).
- 3. Nutrient-Loaded Nanocarriers:** These fertilizers use nanoparticles to deliver specific nutrients. For instance, nanocarriers loaded with nitrogen (N), phosphorus (P), or micronutrients ensure the slow, efficient release of these nutrients into the soil, thus enhancing uptake by plants and improving overall plant health (Kyriacou and Rouphael, 2018).
- 4. Nanocomposites:** These fertilizers are created by combining two or more nanomaterials to create a composite material that can better facilitate nutrient uptake and delivery to plants. Magnesium oxide

(MgO) nanoparticles combined with organic materials, for example, can improve nutrient availability in soils that are low in magnesium (Zheng et al., 2005).

Modes of Action

The effectiveness of nano fertilizers is primarily attributed to their unique modes of action:

- 1. Enhanced Nutrient Solubility and Uptake:** Nano fertilizers increase the surface area of nutrients, which enhances their solubility. This, in turn, improves nutrient availability in soil, making it easier for plants to absorb them (Panwar et al., 2012).
- 2. Controlled and Slow-Release Mechanism:** One of the key advantages of nano fertilizers is their ability to release nutrients gradually over time. This controlled release minimizes nutrient loss to the environment and ensures that nutrients are available to plants at their optimal growth stages (Lin et al., 2009).
- 3. Reduction in Nutrient Loss:** Due to their controlled release, nano fertilizers significantly reduce nutrient leaching and runoff, thus minimizing the environmental pollution commonly associated with conventional fertilizers (Kumar et al., 2020).
- 4. Increased Plant Stress Tolerance:** Some studies suggest that nano fertilizers may enhance plant tolerance to stress factors such as drought and high salinity. This is thought to be due to the increased nutrient uptake and improved physiological processes in plants treated with nano fertilizers (Kyriacou and Roupael, 2018).

Methods of Synthesis

Nano fertilizers can be synthesized through several methods, including:

- 1. Chemical Synthesis:** In chemical methods, nanoparticles are created by reducing metals or other inorganic salts into their nanoparticulate forms. This method is commonly used for synthesizing metal oxide nanoparticles, such as ZnO and Fe₂O₃ (Zheng et al., 2005).
- 2. Physical Synthesis:** Physical techniques like laser ablation, ball milling, and electrospinning are used to produce nanoparticles with specific properties that are ideal for agricultural applications (Hafeez et al., 2015).
- 3. Biological Synthesis:** Biological methods involve the use of microorganisms or plant extracts to synthesize nanoparticles. This eco-friendly approach can produce nanoparticles that are biocompatible and have fewer environmental risks (Klaine et al., 2008).

Advantages of Nano Fertilizers

Nano fertilizers offer several advantages over traditional fertilizers:

- 1. Enhanced Nutrient Use Efficiency:** By releasing nutrients in a controlled manner and increasing nutrient solubility, nano fertilizers significantly improve the efficiency of nutrient use, leading to better crop yields with reduced input requirements (Atha et al., 2012).
- 2. Environmental Sustainability:** The slow-release nature of nano fertilizers reduces the risk of nutrient runoff into water systems, thereby minimizing environmental pollution and helping maintain ecosystem balance (Panwar et al., 2012).
- 3. Improved Crop Yield and Quality:** Numerous studies have demonstrated that nano fertilizers improve crop growth, quality, and yield. This is due to the enhanced nutrient availability and the sustained release of essential nutrients (Lin et al., 2009).
- 4. Soil Health Preservation:** Nano fertilizers can help preserve soil health by reducing the accumulation of salts and other harmful substances that are typically a result of excessive use of conventional fertilizers (Kyriacou and Roupael, 2018).

Challenges and Limitations

While the benefits of nano fertilizers are clear, their widespread adoption faces several challenges:

1. Toxicity Concerns: The potential toxicity of nanoparticles to humans, animals, and the environment remains a critical concern. Although some nanoparticles are biocompatible, long-term studies are necessary to understand their impact on human health and ecosystems (Naderi and Sharaki, 2013).

2. High Production Costs: The cost of synthesizing nano fertilizers is still relatively high, which may pose a barrier to their adoption, especially among smallholder farmers in developing countries (Hafeez et al., 2015).

3. Regulatory and Safety Issues: There is a lack of standardized regulations and safety protocols for nano fertilizers. Clear guidelines and safety standards need to be established to ensure their safe use in agricultural systems (Atha et al., 2012).

Future Directions

The future of nano fertilizers lies in their integration with precision farming and smart agricultural systems. The combination of nano sensors and data analytics will enable real-time monitoring of nutrient levels, optimizing fertilizer application to minimize waste and improve crop health. Additionally, biodegradable nano fertilizers are likely to gain more attention as a safer and more sustainable alternative (Jakhar et al., 2022).

Conclusion

Nano fertilizers represent a significant advancement in agricultural practices, offering solutions to the inefficiencies and environmental concerns associated with traditional fertilizers. With ongoing research, improved synthesis methods, and regulatory frameworks, nano fertilizers have the potential to revolutionize crop nutrition, ensuring sustainable agricultural practices that can meet the growing global food demand.

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Drone-Based Pest Surveillance: A Game Changer for Insect-Pest Monitoring

Article ID: 71015

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Summary

The integration of drone technology into modern agricultural systems has ushered in a new era of pest surveillance, providing timely, accurate, and cost-efficient monitoring capabilities. As a transformative tool, drone-based pest surveillance bridges the gap between traditional scouting and precision agriculture by delivering real-time, high-resolution data over expansive terrains. This review explores the evolution, technological frameworks, applications, and strategic advantages of unmanned aerial vehicles (UAVs) in insect pest monitoring. Emphasis is placed on sensor technologies, artificial intelligence integration, ecological implications, regulatory frameworks, and future innovations. By analyzing current literature and real-world case studies, we underscore how drones are revolutionizing pest detection, enhancing integrated pest management (IPM), and fostering sustainable agricultural practices.

Introduction

Insect pests remain a persistent threat to global food security, causing substantial yield losses annually. Conventional monitoring techniques such as manual scouting, pheromone traps, and fixed-point sampling are often insufficient in large-scale or rapidly changing agricultural ecosystems (FAO, 2021). These methods lack spatial comprehensiveness and are prone to observer bias and time delays. The emergence of drone technology, or unmanned aerial vehicles (UAVs), offers a paradigm shift. Equipped with cutting-edge sensors and AI-powered analytics, drones facilitate high-frequency, high-resolution, and spatially explicit pest surveillance. These tools align seamlessly with the principles of Integrated Pest Management (IPM), enabling early intervention, reduced chemical use, and enhanced ecological stewardship (Guebsi et al., 2024; Vikaspedia, n.d.). In India and other agrarian economies, the adoption of drone-based surveillance is gaining momentum due to increasing awareness, supportive policies, and demonstrable field successes.

Technological Advancements in Drone-Based Pest Surveillance

1. Sensor Technologies:

- a. RGB Imaging:** Red-Green-Blue (RGB) cameras remain the baseline imaging system in drone surveillance. These sensors provide detailed color imagery that can visually detect defoliation, discoloration, and visible pest symptoms (HusFarm, n.d.). They are especially effective in identifying surface-level anomalies and are often integrated into entry-level drone models due to affordability.
- b. Multispectral and Hyperspectral Imaging:** These sensors capture data in multiple (multispectral) or hundreds of (hyperspectral) narrow spectral bands, extending into non-visible wavelengths such as near-infrared (NIR) and shortwave infrared (SWIR). These capabilities allow for early detection of biotic stress well before visual symptoms emerge, by identifying chlorophyll degradation and plant stress indicators (Soussi et al., 2024). Hyperspectral imaging, though expensive, offers unparalleled precision in diagnosing pest-induced physiological changes.
- c. Thermal Imaging:** Thermal cameras detect subtle changes in canopy temperature, which may indicate pest or pathogen activity that disrupts transpiration and water balance. Plants infested by borers, sap-sucking insects, or root feeders may exhibit localized heat signatures, enabling early isolation and treatment (Vikaspedia, n.d.).
- d. LiDAR and 3D Mapping:** Light Detection and Ranging (LiDAR) systems, though primarily used for structural mapping, are emerging in pest surveillance to model canopy height, leaf area index, and structural changes associated with pest infestation (Park et al., 2023). These can assist in understanding pest-host interactions in spatially complex agroforestry systems.

2. Data Processing and AI Integration: With advancements in machine learning (ML), drones have evolved from passive observers to intelligent scouts. Deep learning models such as convolutional neural networks (CNNs) can classify pest species from drone-acquired images, with accuracies exceeding 90% in some trials (Guebsi et al., 2024). AI also aids in quantifying damage levels and forecasting infestation trajectories.

Moreover, cloud-based platforms enable seamless integration of spatial datasets with GIS layers, enabling the generation of pest heatmaps, damage severity zones, and temporal progression models. Recent innovations include edge computing—where data is processed onboard the drone itself—enabling real-time decision-making even in remote, internet-deficient locations (Guebsi et al., 2024).

Applications in Pest Monitoring

1. Early Detection and Rapid Assessment: UAVs enable proactive management by detecting infestations before they escalate. For instance, in South Korea, UAV-assisted detection of *Spodoptera exigua* in soybean fields allowed for immediate localized treatment, thereby minimizing crop loss and chemical overuse (Park et al., 2023). Such rapid interventions are critical in managing invasive pests like *Helicoverpa armigera* and *Fall Armyworm (Spodoptera frugiperda)*, which spread rapidly across landscapes.

2. Site-Specific Pest Management: By overlaying drone imagery with GPS coordinates, pest hotspots can be georeferenced, enabling precision spraying or deployment of biological controls. This not only enhances the efficacy of control measures but also reduces environmental contamination and preserves beneficial insect fauna such as pollinators and parasitoids (Park et al., 2023).

3. Monitoring Pest Dynamics Over Time: Longitudinal surveillance using drones facilitates the tracking of pest populations across seasons and cropping cycles. By maintaining a time-series database, researchers can study pest life cycles, migration patterns, and correlate outbreaks with climatic variables (HusFarm, n.d.). This forms the basis of predictive pest modeling and early warning systems.

4. Integration with Crop Health Monitoring: Drones can be deployed to monitor both pest incidence and crop health indices such as NDVI (Normalized Difference Vegetation Index), EVI (Enhanced Vegetation Index), and PRI (Photochemical Reflectance Index). The correlation of these indices with pest pressures allows for nuanced insights into pest-crop interactions and helps fine-tune management thresholds.

Advantages of Drone-Based Pest Surveillance

1. Operational Efficiency: UAVs can scan over 100 hectares in under 30 minutes, significantly outpacing manual scouting teams (The Agrotech Daily, n.d.).

2. High Precision: AI-driven analytics and multi-sensor payloads ensure precise identification and geolocation of pest outbreaks (AVPL International, n.d.).

3. Cost-Effectiveness: Over time, drone use reduces labor, pesticide usage, and crop loss, leading to net savings despite high initial costs.

4. Sustainability: Promotes targeted chemical use, reduces environmental load, and supports conservation of biodiversity.

5. Data-Driven Decision Making: Facilitates informed decisions based on real-time and historical data, minimizing guesswork and improving IPM effectiveness.

Challenges and Limitations

1. Regulatory Hurdles: Despite their benefits, drones face legal restrictions in many regions. In India, DGCA regulations require drone registration, remote pilot licenses, and flight permissions under the Digital Sky platform (Vikaspedia, n.d.). These compliance burdens deter smallholder adoption.

2. Technical and Operational Constraints: Battery life typically limits drone flight to 20–40 minutes. High-resolution sensors add weight, further reducing endurance. Moreover, adverse weather—strong winds, rain, or fog—can severely disrupt drone operations. Processing terabytes of image data also demands robust IT infrastructure and trained personnel (Soussi et al., 2024).

3. Ethical and Privacy Concerns: The use of drones over private farmland raises concerns regarding surveillance, data ownership, and misuse. Transparent data policies, consent mechanisms, and anonymization protocols are essential to mitigate mistrust (Devitt et al., 2021).

Future Prospects

The future of drone-based pest surveillance is intrinsically linked with broader trends in digital agriculture. Key developments on the horizon include:

- 1. Autonomous Swarms:** Coordinated fleets of drones can autonomously scan large areas, communicate findings, and deploy treatments in real-time.
- 2. Onboard AI and Edge Computing:** Further miniaturization will enable onboard decision-making without cloud dependence, enhancing performance in remote regions (Guebsi et al., 2024).
- 3. Drone-Biological Hybrid Systems:** Future systems may carry and release biological control agents, linking pest detection with eco-friendly treatment in one step.
- 4. Predictive Analytics:** Integration with weather forecasts, soil data, and pest databases can enable risk forecasting, early alerts, and regional pest advisories.
- 5. Farmer-Friendly Interfaces:** User-centric applications, vernacular support, and mobile dashboards will democratize drone access for small and marginal farmers.

Conclusion

Drone-based pest surveillance represents a milestone in the journey toward smarter, sustainable agriculture. By fusing advanced sensing, artificial intelligence, and geospatial analytics, UAVs offer an unparalleled edge in detecting and managing insect pests. While infrastructural, regulatory, and ethical challenges persist, their benefits in terms of efficiency, precision, and sustainability are compelling. As technology matures and becomes more accessible, drone-based pest monitoring is poised to become an integral component of global pest management strategies, supporting food security and ecological resilience in the 21st century.

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Rainfed Agriculture: Traditional Adaptation Strategies in Water-Scarce Regions

Article ID: 71016

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Summary

Rainfed agriculture—farming that depends solely on natural precipitation—remains a linchpin in global food production, particularly in regions where irrigation infrastructure is limited and water availability is erratic. Across continents, traditional adaptation strategies have evolved over centuries to cope with water scarcity. These include soil moisture conservation, water harvesting, the use of drought-resistant cultivars, agroforestry, and mixed cropping systems. This review synthesizes the historical evolution and technical nuances of these methods, examines their socio-economic and environmental intersections, and discusses their potential integration with modern agro-technologies. It underscores that while traditional practices have underpinned community resilience, their amalgamation with scientific advancements is indispensable for achieving sustainable, climate-resilient agriculture in the twenty-first century.

Introduction

Rainfed agriculture encompasses farming systems that entirely rely on natural rainfall for crop water needs. Globally, it supports the livelihoods of vast populations, especially in semi-arid and arid regions where water scarcity is a routine challenge. Traditional farmers have, over millennia, refined a repertoire of adaptation strategies to mitigate water deficits, maintain soil fertility, and enhance productivity in the absence of extensive irrigation networks. In an era of climate change—where the intensity and distribution of rainfall are becoming more unpredictable—these indigenous practices hold critical insights for resilient agricultural development. This review provides an in-depth discussion of these strategies as well as their socio-economic, environmental, and policy dimensions (Altieri & Koohafkan, 2008).

Historical Context and Importance of Traditional Adaptation

Before modern irrigation technologies, communities in water-scarce regions depended on locally developed agricultural practices. Historical evidence from various parts of Asia, Africa, and Latin America reveals that the adaptive techniques were not only designed to maximize the use of available moisture but also to preserve soil health and ensure long-term sustainability. For instance, the extensive use of terracing, contour bunds, and small-scale water harvesting structures in the Upper Indus Basin has enabled centuries of agricultural activity despite having limited water resources. These traditional systems illustrate how indigenous knowledge and social institutions have converged to create effective water management infrastructures that remain relevant today.

Traditional Adaptation Strategies

1. Soil Moisture Conservation Techniques: Ensuring that soil retains sufficient moisture is fundamental to the survival of rainfed crops. Traditional methods in this domain include:

- a. Mulching:** By applying organic residues like crop stubble, leaves, or dung on the soil surface, farmers reduce evaporation, moderate soil temperature, and suppress weed growth. Mulching has been documented to improve water infiltration while enhancing soil organic carbon levels.
- b. Contour Plowing and Bunding:** Plowing along natural land contours slows down water runoff, increases infiltration, and minimizes soil erosion. Bunds or small earth embankments constructed along contour lines also help preserve soil moisture and prevent nutrient losses.
- c. Terracing:** In hilly terrains, terracing transforms slopes into a series of stepped flat surfaces, substantially reducing soil erosion and water run-off. Such systems—found historically in many mountainous regions—help retain water on the land for extended periods, facilitating crop growth during dry spells.

2. Water Harvesting and Management: Water harvesting techniques represent the cornerstone of traditional adaptation in water-scarce regions. Diverse systems have been developed to capture, store, and utilize rainfall:

a. Traditional Tanks and Reservoirs: In many parts of India and Africa, villages constructed earthen ponds, stepwells, and tanks that serve dual purposes—supplying water for agriculture and domestic needs while recharging groundwater aquifers. These structures often become vital community assets during prolonged dry periods.

b. Check Dams and Gabion Structures: Small-scale barriers built across ephemeral streams slow down the flow of surface water, facilitate infiltration, and reduce sediment transport. Their strategic placement in catchment areas has proven to be effective in enhancing groundwater reserves.

c. Roof Water Harvesting: Particularly important in rural settlements, the collection of rainwater from rooftops into storage tanks makes supplemental water available during critical growth periods. Although modern in construction, these methods are often based on traditional practices, adapted to current infrastructural designs (FAO, 2013).

3. Crop Diversification and Use of Drought-Resistant Varieties: Traditional farmers have long recognized the importance of crop diversification as a risk management strategy:

a. Selection of Drought-Tolerant Cultivars: Indigenous farmers frequently select and conserve crop varieties adapted to local conditions. Cereals like millets and sorghum, known for their inherent drought resistance, form the backbone of rainfed agriculture in many regions (Brush, 2004).

b. Intercropping Systems: Mixing drought-tolerant crops with legumes or other complementary species helps maximize the use of available moisture and nutrients. The intercropping of cereals with pulses, for example, not only stabilizes yields during dry spells but also enhances soil fertility through biological nitrogen fixation.

c. Temporal Diversification: Adjusting sowing and harvesting dates to coincide with periods of higher rainfall is another adaptive strategy. This practice, often based on traditional calendars and local climatic indicators, minimizes the risk of crop failure due to untimely drought.

Through such diversified planting systems, communities reduce dependency on a single crop and spread risk over multiple seasons, thereby ensuring some level of productivity even during adverse climatic conditions.

4. Agroforestry and Mixed Farming Systems: Agroforestry—the integration of trees with crops and livestock—has been a longstanding traditional practice with multiple benefits:

a. Microclimate Regulation: Trees act as windbreaks and moderate local microclimates, reducing evaporation rates from soil and crops (Garritty et al. 2010).

b. Soil Fertility and Moisture Retention: Trees enhance organic matter accumulation, improve soil structure, and facilitate water infiltration. The root systems of trees often help stabilize soils and prevent erosion.

c. Economic Diversification: Beyond agronomic benefits, agroforestry provides additional income streams from fruit, timber, and non-timber forest products. Mixed farming systems thereby enhance the economic resilience of rural communities in water-scarce regions.

The synergistic effects of agroforestry have been well documented in various studies, reinforcing the value of integrating traditional practices with modern sustainability paradigms 3.

5. Traditional Water Management Systems: Beyond immediate on-farm practices, many rural areas have a rich heritage of communal water management institutions and infrastructures:

a. Community-Managed Irrigation Networks: In several regions, the construction and maintenance of ancient irrigation canals, check dams, and water distribution systems have been managed collectively. These systems are based on local customary laws and reflect a deep reservoir of traditional ecological knowledge (Agarwal & Narain, 1997).

b. Local Governance and Conflict Resolution: Many traditional systems incorporate methods that ensure equitable distribution of scarce water resources. Community-based water management

has often included conflict resolution mechanisms, which, although informal, have maintained the social fabric necessary to support sustainable agriculture.

The success stories from such communal systems illustrate that traditional water management is not merely about physical infrastructure but also about the social institutions that support equitable and sustainable resource use 3.

Socio-Economic and Environmental Implications

Traditional adaptation strategies are deeply connected to the socio-economic well-being of rural populations, enhancing livelihoods by stabilizing agricultural yields and securing food and income. These practices promote biodiversity conservation through diverse cropping systems and agroforestry, contributing to ecosystem resilience. They also ensure resource sustainability through efficient local resource utilization and low inputs, improving soil health and reducing chemical fertilizer dependency. Furthermore, collective management of water resources fosters social equity and community cohesion, although modern interventions can sometimes disrupt these traditional mechanisms, highlighting the need to preserve and integrate indigenous knowledge in contemporary water management policies.

Challenges and Limitations of Traditional Strategies

Traditional adaptation strategies face significant challenges in the modern context, including climate change-induced rainfall pattern alterations and increased extreme weather events, which threaten the reliability of centuries-old structures and drought-resilient species (IPCC, 2021). Additionally, rapid urbanization and modernization risk eroding indigenous knowledge, as younger generations become less engaged in traditional practices. Institutional and governance issues, such as elite capture and inequitable resource access, also hinder sustainability, while structural barriers impede effective integration with modern agro-technologies. Bridging the knowledge gap and fostering interdisciplinary collaborations are crucial for optimizing water management under changing climatic conditions, requiring innovative research and policies that respect traditional wisdom while leveraging modern techniques.

Integration with Modern Technologies and Policy Directions

The future of rainfed agriculture depends on the synergistic integration of traditional practices with modern innovations, including precision agriculture and remote sensing, which leverage satellite technology and GIS for real-time monitoring of soil moisture, crop conditions, and weather patterns to optimize water use and predict stress periods, alongside the development of improved drought-resistant varieties through biotechnology and advanced breeding techniques like gene editing and marker-assisted selection to enhance traditional cultivars while preserving their desirable traits. Community-centric policy frameworks that support participatory water management, farmer education, climate information sharing, and incentives for maintaining traditional structures are essential, as are multi-stakeholder research initiatives involving agronomists, hydrologists, sociologists, and economists to develop holistic approaches merging indigenous knowledge with emerging technologies, ensuring resilient and sustainable agricultural systems in a changing climate.

Future Prospects and Research Recommendations

Looking ahead, several key areas require further investigation to strengthen rainfed agriculture, including longitudinal impact studies to assess the long-term sustainability and productivity of traditional practices under evolving climatic conditions, as well as systematic documentation of indigenous knowledge to preserve cultural heritage and refine climate adaptation models through collaborative research that treats local farmers as co-researchers. Additionally, comprehensive economic analyses comparing the cost-benefit ratios of traditional and modern practices can guide resource allocation and policy design, while adaptive policy frameworks—supported by pilot projects and demonstration sites—can foster iterative learning and the development of hybrid water management systems that integrate agro-technologies with traditional methods. These research avenues are critical for building resilient agricultural systems capable of withstanding climate.

Conclusion

Traditional adaptation strategies in rainfed agriculture are the product of centuries of empirical knowledge and local innovation. These methods—ranging from soil moisture conservation and water harvesting to crop diversification and agroforestry—not only sustain agricultural productivity in water-scarce regions but also enhance biodiversity and socio-economic resilience. However, facing unprecedented climatic challenges and rapid socio-economic changes, these traditions must evolve. Integrating modern agro-technologies with time-tested indigenous knowledge offers a promising pathway to bolster the resilience of rainfed systems, ensuring food security and sustainable development for future generations 2.

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Integration of IoT and AI Technologies in Urban Vertical Farming for Sustainable Vegetable Production

Article ID: 71017

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Summary

Urbanization and the increasing demand for fresh produce have led to innovative agricultural practices. One environmentally friendly way to grow vegetables in city centres is through urban vertical farming, which uses IoT and AI technology. Highlighting their roles in optimising resource utilisation, boosting crop yields, and assuring food security, this article investigates the integration of IoT and AI in vertical farming. It particularly focusses on India's urban agricultural scene.

Introduction

The rapid urbanization in India has resulted in limited agricultural land, necessitating alternative farming methods. One workable option is urban vertical farming, which entails cultivating plants in a series of stacked vertical levels. These systems can precisely monitor and adjust environmental conditions thanks to the Internet of Things (IoT) and artificial intelligence (AI), which improves agricultural output and makes better use of resources.

IoT in Urban Vertical Farming

IoT devices, such as sensors and actuators, play a crucial role in monitoring various parameters in vertical farming systems:

- 1. Environmental Monitoring:** Sensors track temperature, humidity, light intensity and CO₂ levels, ensuring optimal conditions for plant growth.
- 2. Soil and Nutrient Analysis:** IoT devices assess soil moisture and nutrient content, facilitating precise irrigation and fertilization.
- 3. Remote Monitoring and Control:** The operational efficiency of farmers can be enhanced by remotely accessing real-time data and controlling systems.

In India, companies like Shunya have developed platforms like Urja, which utilize IoT sensors to monitor hydroponic fodder production, adjusting conditions in real-time to optimize growth.

AI Applications in Vertical Farming

AI technologies complement IoT by analyzing collected data to make informed decisions:

- 1. Predictive Analytics:** AI models forecast crop yields and detect potential issues, allowing proactive measures.
- 2. Automated Decision-Making:** AI algorithms adjust lighting, temperature and nutrient delivery based on plant needs.
- 3. Disease Detection:** Timely interventions are made possible by computer vision systems that detect early indicators of plant illnesses.

A study by Chowdhury *et al.* (2023) emphasizes the role of AI in sustainable vertical farming, highlighting its potential in optimizing resource use and enhancing decision-making processes.

Integration of IoT and AI: A Synergistic Approach

The convergence of IoT and AI technologies creates a synergistic effect in vertical farming:

1. Enhanced Precision: Real-time data from IoT devices is analyzed by AI to fine-tune environmental conditions.”

2. Resource Optimization: AI-driven insights lead to efficient use of water, energy and nutrients.

3. Scalability: Automated systems reduce labor requirements, making vertical farming scalable in urban settings.

In Bangalore, the AutoGrow system developed by researchers at IIIT-Bangalore integrates AI and IoT to automate irrigation and nutrient delivery, significantly reducing water usage and labor costs (Bangalore Mirror).



Source: Asia Farming

Case Studies in India

1. Shunya's Urja Platform: Shunya's Urja platform leverages IoT sensors and AI algorithms to monitor and control hydroponic fodder production. Minimising the need for human involvement, the technology optimises growing conditions by adjusting environmental factors in real-time.

2. AutoGrow System by IIIT-Bangalore: The AutoGrow system automates vertical farming processes using AI and IoT technologies. It employs wick irrigation, reducing water consumption by up to 60% and utilizes AI to manage irrigation and nutrient delivery, enhancing efficiency and sustainability.

Challenges and Future Prospects

Despite the benefits, integrating IoT and AI in urban vertical farming faces challenges:

- a. High Initial Costs:** The setup of advanced systems requires significant investment.
- b. Technical Expertise:** Operating and maintaining these systems necessitates specialized knowledge.
- c. Data Security:** Ensuring the security of collected data is crucial.

Future prospects include:

- a. Affordable Solutions:** Development of cost-effective technologies to make vertical farming accessible to small-scale farmers.
- b. Policy Support:** Government initiatives to promote smart farming practices.
- c. Research and Development:** Continued innovation to enhance system efficiency and crop diversity.

Conclusion

A possible answer to India's unsustainable vegetable production might lie in urban vertical gardening that makes use of AI and the internet of things. By optimizing resource use and enhancing crop yields, these technologies can contribute significantly to food security in urban areas. Continued investment, research and policy support are essential to realize the full potential of smart vertical farming systems.

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Ergot Disease in Bajra (Pearl Millet): Symptoms and Management

Article ID: 71018

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Introduction

Ergot of bajra, caused by the fungal pathogen *Claviceps fusiformis*, is a devastating disease that affects pearl millet (*Pennisetum glaucum*). Historically, ergot has been recognized for centuries due to its association with contaminated grains leading to ergotism in humans and livestock. The disease's prevalence has been a recurring challenge for farmers, particularly in regions with warm and humid climates conducive to fungal growth. Yield losses due to ergot can range from 10% to 30% in severe outbreaks, occurs under highly favourable conditions of the pathogen. The replacement of grains by sclerotia also leads to a significant reduction in seed quality and viability, further compounding economic losses.

Symptoms

The symptom is seen by the exudation of small droplets of light pinkish or brownish sticky fluid (honeydew) that attract insects and aid in pathogen spread (Figure -1). The dark brown to black elongated sclerotia replace healthy grains in the panicle. Normal grain development halts as the fungus colonizes the ovary. Infected plants often show reduced vigor and compromised grain quality. Infected panicles may appear discoloured, with a characteristic dull or darkened appearance due to fungal colonization.



Figure:1 light pinkish sticky fluid (honeydew) exudates on panicle and honeydew substances sticky to the pearl millet leaf.

Management

Cultural Practices: Crop Rotation in Bajra cultivation in the same field to disrupt the pathogen's lifecycle. Use ergot-resistant or tolerant Bajra cultivars. Collect and destroy infected panicles to reduce sclerotia buildup. Time planting to avoid flowering during periods of high humidity.

Chemical Control: Treat seeds with systemic fungicides such as carbendazim or captan to minimize initial infections. Spray fungicides like propiconazole or tebuconazole during flowering to prevent pathogen

establishment. Bioagents like *Trichoderma harzianum* or *Pseudomonas fluorescens* can be used to suppress fungal activity. Apply organic amendments that promote beneficial soil microbes.

Post-Harvest Measures: Remove sclerotia from harvested grain to minimize contamination and toxic alkaloid spread and Store grain under dry conditions to inhibit fungal activity and preserve quality.

Conclusion

Ergot of bajra is a severe disease impacting yield and food safety. Integrated management practices are essential to mitigate the yield and economic losses caused by ergot, ensuring sustainable cultivation and safe consumption of bajra. Further research on resistant cultivars and advanced management strategies will bolster efforts to combat this disease effectively.

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Blister Blight of Tea: Symptoms and Integrated Disease Management

Article ID: 71019

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Introduction

Exobasidium vexans causes blister blight, a fungal disease that affects tea (*Camellia sinensis*) plants. It is one of the most damaging diseases to tea plantations, especially in areas with high humidity and rainfall. The disease predominantly affects young leaves and shoots, resulting in severe output losses and reduced tea quality. Blister blight is a serious limitation on tea production since it affects both yield and quality. Yield losses might range from 15% to 50%, depending on the severity of the outbreak and the management strategies used. The disease primarily affects young, harvestable leaves, which reduces the number of pluckable shoots. Controlling blister blight is crucial for sustainable tea farming because it can disrupt trade and earnings for nations that rely significantly on tea exports.

Symptoms

The initial symptoms on young leaves and shoots, tiny, translucent spots show up. These water-soaked, pale green dots become more noticeable in humid environments. Usually on the upper leaf surface, the translucent spots grow larger and form elevated blisters (Figure -1). Fungal spore masses cause blisters to appear white or pink. Brown necrotic patches were left behind when the blisters eventually ruptured. Defoliation may result from affected areas curling, distorting, or falling off. Similar lesions develop in young shoots, which in extreme situations may result in dieback. Consistent rainfall combined with warm, humid weather is ideal for blister blight growth. When the environment is right, the pathogen's airborne spores travel quickly and infect new growth.



Figure: 1 Elevated blisters symptoms on A) abaxial and B) adaxial surface of the Tea leaf

Management Strategies

Cultural Practices: Tea bushes should be regularly pruned to get rid of diseased areas and increase airflow. Control shade trees to increase sunshine penetration and lower humidity levels. To lower inoculum levels, remove and destroy diseased leaves and shoots.

Chemical Control: Apply copper-based fungicide copper oxychloride @ 0.1% or systemic fungicides like hexaconazole during early disease development. Implement a regular fungicide spray schedule during peak infection periods, especially in rainy seasons.

Biocontrol Agents: Antagonistic microorganisms such as *Trichoderma* spp. or bacterial strains like *Bacillus subtilis* to suppress fungal growth. Explore plant-based extracts with antifungal properties as eco-friendly alternatives.

Integrated Disease Management (IDM)

Combine cultural, chemical, and biological control measures for sustainable management of blister blight. Monitor environmental conditions to predict disease outbreaks and take timely action.

Conclusion

Blister blight is a major threat to tea production, particularly in humid regions. An integrated approach combining cultural practices, chemical treatments, and biological controls is essential for effective disease management. Research into resistant tea varieties and innovative control strategies will further strengthen efforts to combat this disease, ensuring the sustainability of tea cultivation.

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Low Poly Tunnels: Uses and Recent Advances in Vegetable and Ornamental Applications

Article ID: 71020

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Summary

Low poly tunnels are cost-effective, lightweight agricultural structures used for season extension, frost protection, and controlled-environment farming. They are particularly beneficial for growing vegetables and ornamentals, offering advantages such as affordability, easy installation, and scalability.

Recent innovations in polymer technology, including **IR-absorbing materials** (for better heat retention) and **light-diffusing films** (for uniform light distribution), have enhanced their efficiency. Additionally, advancements like **UV-blocking films and multi-layered covers** improve crop yields and reduce energy costs.

These tunnels are increasingly used in **urban farming and precision agriculture**, with ongoing research focusing on automation and material durability. Overall, low poly tunnels provide a sustainable and adaptable solution for modern horticulture, combining affordability with high-performance growing conditions.

Introduction

Low poly tunnels, a simplified and cost-effective alternative to traditional greenhouses, have gained popularity in agriculture and horticulture. These structures, characterized by their geometric, low-polygon (low poly) designs, offer a balance between affordability and functionality. They are widely used for growing vegetables, ornamentals, and specialty crops while providing protection from adverse weather conditions.

Recent advancements in materials, including infrared (IR) absorbers, light diffusers, and improved polymers, have enhanced the efficiency of low poly tunnels. This article explores their uses, advantages, material innovations, and recent developments in ornamental and vegetable cultivation.

Uses of Low Poly Tunnels

Low poly tunnels serve multiple purposes in modern agriculture:

Season Extension – By moderating temperature and humidity, these tunnels allow for early planting and extended growing seasons.



Frost Protection – They shield crops from frost, wind, and heavy rain, reducing crop losses.

Pest and Disease Management – The enclosed structure minimizes pest infestations and reduces fungal infections by controlling humidity.

Controlled Environment Agriculture (CEA) – Farmers can manipulate light, temperature, and moisture for optimal growth.

Urban and Vertical Farming – Their lightweight and modular design makes them suitable for rooftop gardens and small-scale urban farms.

Advantages of Low Poly Tunnels

Compared to traditional greenhouses and high tunnels, low poly tunnels offer several benefits:

Cost-Effectiveness – Lower material and construction costs make them accessible to small-scale farmers.

Ease of Installation – Their simple structure allows for quick assembly without specialized tools.

Durability – Modern UV-resistant polymers ensure longevity even in harsh climates.

Energy Efficiency – Improved insulation properties reduce heating requirements in colder regions.

Scalability – Farmers can expand or modify the tunnels based on crop requirements.

Polymer Innovations: IR Absorbers and Light Diffusers

Recent advancements in polymer technology have significantly improved the performance of low poly tunnels:

1. IR-Absorbing Polymers: Infrared (IR) radiation plays a crucial role in greenhouse heating. IR-absorbing polymers help:

Regulate internal temperatures by trapping heat during the day and releasing it at night.

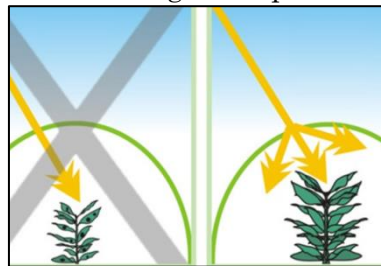
Enhance plant growth by maintaining optimal thermal conditions.

2. Light-Diffusing Polymers: Light diffusion ensures uniform light distribution, preventing hotspots and shadowing. Benefits include:

Improved photosynthesis efficiency due to even light dispersion.

Reduced plant stress by minimizing direct, harsh sunlight exposure.

Better crop quality with more consistent growth patterns.



Recent Advances in Ornamental and Vegetable Cultivation

1. Improved UV-Blocking Films: Advanced films that selectively block harmful UV rays while allowing beneficial wavelengths for plant growth. Extended lifespan of covers due to enhanced UV stabilization.

2. Multi-Layered Polymer Films: Films with anti-condensation properties to reduce dripping and fungal risks. Reflective inner layers to optimize light penetration.

3. Specialty Crop Adaptations

Ornamentals – Enhanced flower color and prolonged blooming periods due to optimized light spectra.

Vegetables – Higher yields in tomatoes, peppers, and leafy greens with tailored microclimates.

Conclusion

Low poly tunnels represent an efficient, scalable solution for modern agriculture, particularly in ornamental and vegetable production. With innovations in IR-absorbing polymers, light diffusion, and smart farming technologies, these structures are becoming more sustainable and productive. As research continues, we can expect further improvements in material science and automation, making low poly tunnels a cornerstone of future-proof farming.

By adopting these advancements, farmers can achieve higher crop quality, reduced environmental impact and greater economic returns.

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Comprehensive Nursery Raising Techniques in Vegetables

Article ID: 71021

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Introduction

Nursery raising is a crucial stage in vegetable production, ensuring healthy and vigorous seedlings for successful transplanting. Proper nursery management involves maintaining optimal temperature, preventing diseases, and controlling pests to produce high-quality seedlings. Early identification of diseases and pests, along with natural control methods, can significantly reduce crop losses. Additionally, transplanting seedlings at the right time ensures better establishment and higher yields. This article provides a detailed guide on nursery techniques, focusing on disease and pest identification, natural management strategies, and ideal transplanting practices.

Summary

A well-managed nursery is the foundation of successful vegetable cultivation. Key factors include maintaining proper temperature, preventing diseases like damping-off and leaf spot, and controlling pests such as aphids and cutworms. Early identification of these issues allows for timely intervention. Natural techniques, including biocontrol agents and organic sprays, help manage pests and diseases sustainably. Transplanting should be done when seedlings reach the right growth stage (typically 3-5 weeks) and under favorable weather conditions (early morning or late afternoon). This article covers all aspects of nursery management, from disease and pest control to best transplanting practices.

Nursery Raising Techniques

1. Selection of Site and Soil Preparation:

- Choose a well-drained, sunny location with wind protection.
- Use sterilized soil or cocopeat to prevent soil-borne diseases.
- Prepare raised beds (1m width, 15cm height) for better drainage.

2. Sowing Methods:

- Direct Sowing:** Suitable for large-seeded vegetables like beans.
- Seed Trays/Plug Trays:** Ideal for small-seeded crops like tomatoes and peppers.
- Optimal Sowing Depth:** Generally, 2-3 times the seed diameter.

3. Temperature Management:

- Warm-season crops (Tomato, Brinjal, Chilli):** Require 25-30°C for germination.
- Cool-season crops (Cabbage, Cauliflower):** Thrive at 18-22°C.
- Use **polyhouses or shade nets** to regulate temperature and humidity.
- Heating mats** can help in colder climates for better germination.

4. Irrigation and Humidity Control:

- Maintain consistent moisture without waterlogging.
- Use **mist sprayers** for delicate seedlings.
- Avoid overhead watering in the evening to prevent fungal diseases.



Table 1: Common Diseases in Vegetable Nurseries & Natural Management:

Disease	Identification	Causes	Natural Control Methods
Damping-off (Pythium, Rhizoctonia)	- Seeds rot before germination (pre-emergence). - Seedlings collapse at soil line (post-emergence). - White fungal growth on stems.	Overwatering, poor drainage, contaminated soil.	- Use sterilized soil/cocopeat. - Apply <i>Trichoderma</i> or <i>Pseudomonas</i>. - Avoid overcrowding.
Leaf Spot & Blight (Alternaria, Cercospora)	- Small brown/black spots on leaves. - Yellowing and leaf drop.	High humidity, poor air circulation.	- Neem oil or garlic-chili spray. - Baking soda solution (1 tsp + 1L water). - Remove infected leaves.
Powdery Mildew (Erysiphe)	- White powdery patches on leaves/stems. - Stunted growth.	High humidity, dry foliage.	- Milk spray (1:9 milk:water). - Sulfur dust or potassium bicarbonate.
Viral Diseases (TMV, CMV)	- Yellow mosaic patterns, leaf curling. - Stunted growth.	Spread by aphids, whiteflies.	- Use virus-free seeds. - Control vectors (neem oil, yellow sticky traps).

Table 2: Common Pests in Vegetable Nurseries & Natural Control:

Pest	Identification	Damage	Natural Control Methods
Aphids	- Tiny green/black/brown insects. - Sticky honeydew (sooty mold).	Sap-sucking, virus transmission.	- Neem oil or soap-water spray. - Release ladybugs/lacewings.
Whiteflies	- Small white flies (fly when disturbed). - Yellowing leaves.	Sap-feeding, virus spread.	- Yellow sticky traps. - Garlic-onion spray.
Cutworms	- Larvae hide in soil, cut stems at base.	Seedlings collapse overnight.	- Cardboard collars around stems. - Diatomaceous earth around plants.
Leaf Miners	- Squiggly white trails inside leaves.	Reduced photosynthesis.	- Remove infected leaves. - Neem oil spray.

Transplanting Time and Techniques

When to Transplant?

a. Ideal Seedling Age:

b. Tomato, Brinjal, Chilli: 4-5 weeks (4-6 true leaves).

c. Cabbage, Cauliflower: 3-4 weeks.

d. Cucurbits (Cucumber, Pumpkin): 2-3 weeks (avoid root disturbance).



Best Time for Transplanting:

Early morning or late afternoon to reduce transplant shock. Avoid hot, sunny periods.

Hardening Off Seedlings:

- Gradually expose seedlings to outdoor conditions **7-10 days before transplanting**.
- Reduce watering slightly to toughen stems.

Transplanting Method:

- Water seedlings well before uprooting.
- Dig holes slightly larger than root balls.
- Place seedlings at the same depth as in the nursery.
- Firm soil gently and water immediately



Conclusion

Effective nursery management involves proper disease and pest identification, natural control methods, and timely transplanting. By adopting organic practices and maintaining optimal growing conditions, farmers can produce healthy seedlings, ensuring better crop establishment and higher yields. Sustainable nursery techniques not only reduce chemical dependency but also promote long-term soil and plant health.

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Management of Bacterial Wilt of Tomato

Article ID: 71022

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Introduction

Tomato (*Solanum lycopersicum* L.) is the second most widely consumed fruit vegetable globally, after potato. Bacterial wilt of tomato, caused by *Ralstonia solanacearum*, is a highly destructive and prevalent soil-borne disease. It typically occurs under warm and humid conditions and can persist in the soil for extended periods.

Infected plants exhibit rapid wilting and death, usually without yellowing or leaf spotting. Internally, the stems show brown discoloration and decay. Diagnosis can be confirmed by placing a clean, cut section of an infected stem in clear water—within minutes, a white, milky stream of bacterial cells and slime will exude from the stem.

The pathogen thrives in acidic soils and causes substantial yield losses, ranging from 2% to 90% across various agro-climatic regions in India (Singh and Sinha, 2010). Using microbial antagonists is an emerging approach for managing bacterial diseases in plants. Thus, conducting a soil test before planting tomato seedlings is strongly recommended.

Management Strategies

Managing bacterial wilt in already infested soils is challenging. To minimize risk:

1. Avoid using diseased transplants and plant only in non-infested soils.
2. While soil fumigation can offer partial control, it does not completely eradicate the bacteria.
3. Promptly remove and destroy infected plants upon detection.

Seed treatment with antagonistic *Pseudomonas fluorescens* strains has been shown to significantly enhance seed germination and seedling vigour. Studies report reduced disease incidence in plants grown from *P. fluorescens*-treated seeds, even after challenge inoculation with *R. solanacearum* (Vanitha et al., 2009). Although developing resistant tomato varieties are effective, it is a time-consuming process that can result in interim yield losses. Grafting susceptible tomato scions onto resistant rootstocks is a practical interim solution, enabling sustainable production even in infested soils (Rivard et al., 2012). Crop resistance may be compromised over time due to the high genetic diversity of *R. solanacearum*. Intercropping and crop rotation strategies are limited by the broad host range of the pathogen. Plant growth-promoting rhizobacteria (PGPR) also exhibit biocontrol potential against soil-borne pathogens.

Conclusion

Soil acidification is a significant issue in modern agriculture, negatively impacting soil health and microbial communities. Applying lime to amend soil pH has been shown to improve soil conditions and reduce bacterial wilt incidence. Biocontrol strategies including microbial antagonists, resistant rootstocks, and grafting techniques offer sustainable and farmer-friendly approaches to mitigate the impact of bacterial wilt in tomato cultivation.

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Li-Fi Technology in Horticulture: A Smart Solution for Future Farming

Article ID: 71023

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The rapid advancements in technology have paved the way for smarter and more efficient farming practices, transforming how we grow and manage crops. Among the most promising innovations is Li-Fi (Light Fidelity) technology, a wireless communication system that uses visible light to transmit data. While Li-Fi has gained significant attention in areas like telecommunications and smart homes, its application in horticulture — the science of growing fruits, vegetables and ornamental plants is emerging as a revolutionary solution.

What is Li-Fi Technology?

Li-Fi is an advanced form of wireless communication that uses light waves instead of radio frequencies (used in Wi-Fi) to transmit data. The technology works by modulating the intensity of light emitted from a light source, such as an LED bulb, to send information at high speeds. Unlike Wi-Fi, which uses radio waves, Li-Fi operates in the visible spectrum, making it immune to interference from traditional radio frequencies.

Why Li-Fi in Horticulture?

Horticultural practices are constantly evolving to meet the growing demand for food, water conservation and sustainability. Li-Fi offers several key advantages that make it an ideal solution for modern farming.

1. Enhanced Control over Light for Plant Growth: Plants rely on light for photosynthesis and providing the right amount and quality of light is crucial for their growth. Traditional lighting systems often use a combination of light sources that can be difficult to control. With Li-Fi, horticulturists can harness the power of smart lighting systems to regulate light intensity, colour and duration with pinpoint accuracy.

Li-Fi can be integrated into smart greenhouses, where sensors and data analytics adjust the light environment in real time. For instance, different plant species may require specific wavelengths of light at different times of the day. Li-Fi systems could automate this process, ensuring optimal conditions for plant growth, leading to higher yields and more efficient use of energy.

2. Real-Time Data Transmission for Precision Farming: In precision farming, every detail matters. Li-Fi can transmit real-time data from sensors placed throughout a greenhouse or field to a central monitoring system. These sensors might track soil moisture levels, temperature, humidity and nutrient content. Li-Fi's high-speed, interference-free communication ensures that this data is transmitted seamlessly and in real-time, enabling immediate action to optimize crop conditions.

For instance, a sensor could detect that the soil is becoming too dry. Using the data transmitted via Li-Fi, an automated irrigation system could kick in to water the crops, thus preventing crop stress or loss. This level of responsiveness is critical in minimizing resource waste and maximizing productivity.

3. Energy Efficiency and Sustainability: Li-Fi systems use energy-efficient LED lights, which already consume far less energy than traditional lighting. The ability to replace traditional Wi-Fi communication with Li-Fi technology also reduces the power required for transmitting data, creating a more energy-efficient system overall. This is a win-win scenario for sustainable farming practices.

Moreover, by reducing reliance on radio frequency-based communication, Li-Fi can help reduce electromagnetic pollution, which is especially useful in environments like greenhouses where electromagnetic interference could impact plant health.

4. Improved Connectivity in Remote Areas: Many farms, especially in rural or remote areas, struggle with limited or unreliable internet connectivity. Li-Fi provides an alternative by using light, which can be easily transmitted over long distances within enclosed spaces like greenhouses. For example, in regions where WiFi infrastructure is sparse or non-existent, Li-Fi could offer a reliable way for farmers to connect devices, manage systems and collect data.

Practical Applications of Li-Fi in Horticulture

1. Smart Greenhouses: Smart greenhouses are revolutionizing the way we grow crops by integrating sensors, automated systems and advanced data analytics. Li-Fi could play a central role in such systems by providing high-speed communication between sensors, irrigation systems, climate control mechanisms and monitoring systems.



For example, Li-Fi-enabled sensors can send real-time data about environmental conditions such as light levels, humidity, and temperature to a central system, which can then adjust heating, cooling, or watering protocols. This automated and data-driven approach optimizes resource use and creates ideal growing conditions for plants.

2. Controlled Environment Agriculture (CEA): Li-Fi can further benefit controlled environment agriculture (CEA), which involves growing crops indoors or in highly controlled environments, like vertical farms. These systems often rely on artificial lighting to simulate sunlight. By incorporating Li-Fi into the lighting system, CEA systems can enhance both plant growth and communication between various devices used in the farming process.

For instance, Li-Fi could ensure real-time communication between the sensors monitoring nutrient levels and the automation systems that adjust nutrient delivery, further enhancing the precision and efficiency of these operations.

3. Smart Irrigation Systems: Water conservation is one of the most significant challenges in modern agriculture. By using Li-Fi to transmit data from soil moisture sensors, smart irrigation systems can be made more efficient. Li-Fi enables real-time communication, ensuring that water is applied only when needed and in the right amounts, minimizing waste.

4. Data-Driven Pest and Disease Management: Li-Fi could also support more effective pest and disease management. By transmitting data from pest monitoring sensors, the system can alert farmers to the presence of pests or diseases, allowing them to take swift, targeted action. This reduces the need for widespread pesticide use, promoting a more sustainable approach to pest management.

Challenges and Considerations

While Li-Fi has immense potential in horticulture, there are some challenges to consider:

Infrastructure Costs: Implementing Li-Fi systems requires upgrading lighting infrastructure and installing sensors, which can involve upfront costs.

Limited Range: Li-Fi operates in the visible light spectrum, so its range is limited to the areas where light can reach. This may restrict its use in large open fields or areas with inconsistent lighting.

Integration with Existing Systems: Integrating Li-Fi with other farm management systems may require additional technical expertise and compatibility adjustments.

The Future of Li-Fi in Horticulture

As more farms adopt smart farming technologies, Li-Fi's role in horticulture is poised to grow. Its ability to provide high-speed, interference-free communication combined with its energy efficiency and precision makes it an ideal solution for future farming systems. As infrastructure becomes more affordable and

accessible, Li-Fi has the potential to transform farming practices worldwide, contributing to more sustainable, productive, and connected agricultural practices.

In conclusion, Li-Fi technology presents a unique opportunity to revolutionize horticulture. By enabling better control over environmental factors, facilitating real-time data communication, and promoting energy-efficient farming practices, Li-Fi can be an essential part of the future of smart farming. The potential to create more sustainable and efficient agricultural practices could not only transform how we farm but also play a crucial role in feeding a growing global population in an environmentally responsible way.

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Soil Health and Management

Article ID: 71024

Renuka Sharma

Healthy soil is the foundation of productive, sustainable agriculture.

Soil works for you if you work for the soil by using management practices that improve soil health and increase productivity and profitability immediately and into the future. A fully functioning soil produces the maximum amount of products at the least cost. Maximizing soil health is essential to maximizing profitability. Soil will not work for you if you misuse it. Managing for soil health (improved soil function) is mostly a matter of maintaining suitable habitat for the numerous of creatures that involve the soil food web. This can be accomplished by disturbing the soil as little as possible, growing as many different species of plants as practical, keeping living plants in the soil as often as possible, and keeping the soil covered all the time. Managing for soil health allows producers to work with the land – not against – to reduce erosion, maximize water infiltration, improve nutrient cycling, save money on inputs, and ultimately improve the resiliency of their working land.



Management Practices to Improve Soil Health

1. Reduce Inversion Tillage and Soil Traffic: Excessive tillage is harmful to soil health in a number of ways. Tillage increases oxygen in the soil, stimulating microbial activity, and results in the decomposition of organic matter. Tillage also disrupts soil aggregates, exposing particles of organic matter that had been physically protected within aggregates to microbial consumption. If additions of organic matter are not sufficient to counteract the losses from decomposition, organic matter levels will decline over time, reducing soil health. Inversion tillage also reduces the soil coverage provided by crop residues, leaving soil more exposed to erosion.

Common Primary Tillage Implements:

Moldboard Plow: Inverts the soil to cover residues, terminate cover crops and perennial sod, and destroy weeds.

Disk Plow:

- a. Concave disks mounted in a group cut residue and invert soil laterally, loosening soil and mixing residue into the soil
- b. Soil disturbance and residue incorporation depends on the size, shape, and tilt angle of the disks

Chisel Plow:

- a. Curved shanks with chisel points are dragged through the soil without inversion
- b. Loosens surface soil, mixes some residue into the soil
- c. Soil disturbance and residue incorporation depends on the width and twist of chisel points.

2. Increase Organic Matter Inputs: To maintain or increase soil organic matter levels, inputs of organic matter must meet or exceed the losses of organic matter due to decomposition. Healthy crops can be a valuable source of organic matter, and crop residues should be returned to the soil to the coverage possible. Incorporation of cover crops or perennial crops and judicious additions of animal and green manure and compost can also be used to increase or maintain soil organic matter. Soil organic matter content can be monitored over time if you request an organic matter analysis when submitting soil fertility samples to your soil testing laboratory. Be sure that your organic matter comparisons over time are based on data from the same lab or from labs that use the same procedure for organic matter analysis, as results can differ significantly between analysis methods.

3. Use Cover Crops: Cover crops contribute numerous benefits to soil health. They keep the soil covered during the winter and other periods of time when crops are not growing, reducing the risk of erosion. The biomass produced by cover crops is usually returned to the soil, enhancing organic matter levels. Cover crops with taproots can create macro pores and improve compaction. Fibrous-rooted cover crops can promote aggregation and stabilize the soil. Species of cover crops that host mycorrhizal fungi can sustain and increase the population of these beneficial fungi. Legume cover crops can add nitrogen to the soil through nitrogen fixation. Cover crops can retain nitrate and other nutrients that are susceptible to leaching losses.

4. Reduce Pesticide Use and Provide Habitat for Beneficial Organisms: Beneficial insects that contribute to biological control or pest organisms can be harmed by the application of broad-spectrum insecticides. Farms aping is a whole-farm, ecological approach to increase and manage biodiversity with the goal of increasing the presence of beneficial organisms. Farms aping methods include the use of insectaries plants, hedgerows, cover crops, and water reservoirs to attract and support populations of beneficial organisms such as insects, spiders, amphibians, reptiles, bats, and birds that parasitize or prey on insect pests. Farms capes placed in contours between fields, steep ditches, or places that are easily eroded give stability to the soil. Farms aping can also be used as a filter strip to prevent water runoff and soil erosion. Plants used in farms capes contribute to healthy soil by adding organic matter, the base of the soil food web.

5. Rotate Crops: Diverse crop rotations will help break up soil borne pest and disease life cycles, improving crop health. Rotations can also assist in managing weeds. By growing different crops in time and space, pests that thrive within a certain crop are not given a chance to build their populations over time. Rotating crops can also help reduce nutrient excesses.

6. Manage Nutrients: Carefully planning the timing, application method, and quantity of manure, compost, and other fertilizers will allow you to meet crop nutrient demands and minimize nutrient excesses. Healthy, vigorous plants that grow quickly are better able to withstand pest damage. However, over fertilizing crops can increase pest problems. Increasing soluble nitrogen levels in plants can decrease their resistance to pests, resulting in higher pest density and crop damage.

Maintaining a soil pH appropriate for the crop to be grown will improve nutrient availability and reduce toxicity. Maintaining adequate calcium levels will help earthworms thrive and improve soil aggregation.

Using diverse nutrient sources can help maintain soil health. Manure and compost add organic matter as well as an arrangement of nutrients, but using just compost or manure to meet the nitrogen needs of the crop every year can result in excessive phosphorus levels in the soil. Combining self-effacing manure or compost additions to meet phosphorus needs with additional nitrogen inputs from legume cover or forage crops in a crop rotation can help balance both nitrogen and phosphorus inputs.

Managing Nutrients in Soil

Nitrogen (N) Management:

- a. Nitrate nitrogen is susceptible to leaching losses because the negative charge of the molecule is not held by cation exchange sites of soil particles. Leaching occurs mainly in the fall, winter, and early spring.
- b. Nitrogen in urea-containing fertilizers and manure is susceptible to volatilization losses as ammonia gas when not incorporated into the soil.
- c. Nitrate nitrogen can be lost to the atmosphere through conversion into nitrous oxide and nitric oxide gases by microorganisms in warm, poorly aerated soil.
- d. Nitrogen losses can be minimized with appropriate timing and application of fertilizers and manures and by using cover crops to limit leaching losses in the winter.

Phosphorus (P) Management:

- a. Phosphorus is tightly bound to soil particles and does not easily diffuse through the soil.
- b. Mycorrhizal fungi can assist plant roots in P acquisition in low-P soils.
- c. Adding organic matter can mask the P binding sites on soil particles, increasing P availability.
- d. Phosphorus can accumulate to excessively high levels when P inputs in manure and fertilizer exceed P removal by crops; this can occur in soil that receives annual manure applications at rates to supply crop nitrogen needs.
- e. Erosion can transport soil particles with high levels of P into waterways where P can become a pollutant.

Startup Ecosystem and Investment Trends in Hydroponics Agritech

Article ID: 71025

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Abstract

Hydroponics, a resource-saving and soil-less agricultural method, is quickly becoming an efficient solution to world agricultural challenges, especially in urban and resource-limited settings. This article examines the dynamic startup ecosystem within hydroponic agritech, how new startups are revolutionizing food production with controlled-environment agriculture. It investigates recent trends in investment, revealing growing interest among venture capitalists, impact investors, and governments in funding sustainable agri-innovation. Key advantages like superior water efficiency, pesticide-free crops, and cultivation throughout the year are fueling adoption, though challenges like steep setup costs and low consumer awareness continue to remain obstacles. The article also looks at the function of technology, policy support, and future opportunities, situating hydroponics as a keystone of contemporary agrifood systems and urban sustainable agriculture.

Introduction

Conventional farming is rapidly changing due to the intersection of sustainability, food security, and technological innovation. Perhaps the most promising trend in this space is hydroponics, a soilless form of farming that enables crops to develop in nutrient-dense water solutions. As climate change, land degradation, and urbanization place greater pressure on global food systems, hydroponics is proving to be a sustainable solution to traditional farming.

In India and globally, agritech startups are playing the lead role in creating scalable hydroponic models. This article explores the development of the hydroponics startup ecosystem, examines investment trends, and talks about the future direction of this fast-growing industry.



Source: Kr Asia

Evolution of the Hydroponics Agritech Ecosystem

Hydroponics itself is not a new idea, but its business uptake has come into focus quite recently with advancing technology and changing consumer behavior. Urban consumers are looking for fresh, pesticide-free produce, and hydroponics offers the facility to produce crops in controlled atmospheres, sometimes in urban environments with little or no land and water usage.

The Indian startup ecosystem for hydroponics includes:

- 1. Nutrifresh (Maharashtra):** Supplies pesticide-free vegetables and traceable farming systems.
- 2. Eeki Foods (Rajasthan) and Agrowave:** Grow crops all year-round using climate-controlled chambers.
- 3. Future Farms (Chennai):** Sells hydroponic kits, systems, and support to commercial and home consumers alike.
- 4. UrbanKisaan (Hyderabad):** Cultivates and distributes hydroponic vegetables to customers in urban locations.

These startups are using IoT, AI, data analytics, and automation to maximize water and nutrient supply, control environmental conditions, and enhance yield forecasting.

Investment Trends: Fueling Growth

1. Increasing Venture Capital Interest: Hydroponics startups are becoming more popular among investors interested in the high-tech and sustainability potential of the venture. From 2020 to 2024, investment in agritech worldwide was over \$30 billion, with hydroponics capturing a significant portion.

Major investment highlights:

1. Nutrifresh received \$5 million in pre-series funding from investors such as Green Frontier Capital.
2. Eeki Foods raised \$6.5 million in a round led by General Catalyst.
3. UrbanKisaan got seed funding from Y Combinator and other angel investors.
4. Jungle Ventures and Omnivore have shown continued interest in controlled-environment agriculture startups.



Source: Inc42

2. Impact Investing and ESG Alignment: Many hydroponics ventures align with Environmental, Social, and Governance (ESG) goals, making them attractive to impact investors. Firms like Incofin and Aavishkaar Capital focus on investments that promote sustainable agriculture, resource efficiency, and urban food resilience.

Government and Institutional Support

India's policy landscape is becoming more supportive of agritech innovation. Multiple government initiatives provide support to hydroponics startups:

1. Policy Initiatives:

- Rashtriya Krishi Vikas Yojana (RKVY-RAFTAAR): Provides up to ₹25 lakh grants to agritech startups.
- Startup India Mission: Includes tax relief, access to funds, and incubation facilities.
- National Bank for Agriculture and Rural Development (NABARD): Through its venture fund division NABVENTURES, it provides capital to innovative startups.

2. Incubation & Research Support: Startups are cooperating with ICAR, IARI, and state agricultural universities to reinforce research on hydroponic nutrient formulation, disease management, and diversification of crops.

Centres of Excellence (such as the Indo-Israel Centre in Haryana) promote high-end protected cultivation technologies, including hydroponics.

Key Benefits Driving Adoption

Hydroponics provides a compelling value proposition, especially for urban and peri-urban regions:

Advantage	Impact
80–90% water savings	Ideal for drought-prone regions
No soil required	Reduces dependence on land availability
Pesticide-free produce	Meets demand for clean, organic food
Year-round cultivation	Better control over market supply and pricing
Higher yield per square foot	Improves return on investment for urban farms

These advantages are particularly critical in cities like Delhi, Mumbai, Bengaluru, and Hyderabad, where land is scarce and food security is increasingly important.

Challenges Confronted by Hydroponic Startups

The promising future aside, hydroponic startups confront a number of challenges:

- Heavy Initial Capital Investment:** Establishing a commercial hydroponic farm may take ₹40–70 lakhs per acre as it requires infrastructure, climate control, and technology systems.
- Knowledge and Skill Gaps:** Farmers and agripreneurs have limited exposure to hydroponic systems. Specialized labor is needed to monitor nutrient levels, disease infections, and system maintenance.
- Market Education and Acceptance:** Consumer consciousness regarding hydroponically cultivated fruits and vegetables is low beyond metro areas. Price sensitivity would also affect sales unless backed by well-promoted health benefits.
- Logistics and Cold Chain:** Supply of fresh produce in a time-bound and quality-conserved condition calls for high capability supply chain and distribution networks—an aspect still in the formative stages.

The Road Ahead: Innovations and Expansion Opportunities

- Integration with Technology:** The future of hydroponics is in precision farming—applying AI, machine learning, and blockchain for:
 - Predictive yield modeling
 - Disease early warning systems
 - Nutrient optimization algorithms
 - Supply chain transparency.
- Franchising and Urban Farming Models:** Franchise-based models are being tried out by startups to grow fast. Rooftop farms, community farms, and container-based systems are becoming popular.
- Export Potential:** Since hydroponics guarantees standardization and uniformity, Indian startups have an opportunity to export exotic vegetables and herbs, particularly to Gulf nations and Southeast Asia.

Conclusion: A Sustainable Revolution in the Making

Hydroponics is more than a growing technique—it's a new farming philosophy based on efficiency, technology, and sustainability. As startups scale and innovate, they're redefining the food production story of India and the world. With increased consumer demand, investor support, and government recognition, hydroponics is destined to be an anchor of modern urban agriculture.

For entrepreneurs, scientists, and policymakers alike, the hydroponic agritech industry provides rich soil—literally and metaphorically—to influence the future of agriculture.

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Synthetic Biology for Engineered Plant Metabolites: Unlocking New Frontiers in Drug Discovery

Article ID: 71026

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Abstract

Limited access to vital medicinal compounds and low yields in their natural extraction are the two major drawbacks of the current pharmaceutical industry, for which the plant metabolites act as sustainable, promising solutions, as they have diverse therapeutic properties and are eco-friendly. Their natural biosynthesis often has limitations like yield, stability, and scalability. Synthetic biology brings new paradigms in tackling these restraints through engineering metabolic pathways, synthesizing novel enzymes, and improving genetic circuits. It embraces computational modeling, CRISPR-Cas technologies, and artificial promoters, further amplifying the efficacy of metabolite production.

Keywords: Metabolites, Pharmaceutical, Eco-friendly.

Introduction

Plant-derived metabolites have historically served as the most valuable resources for pharmaceutical purposes. Compounds such as morphine, artemisinin, and taxol have proven essential in treating pain, malaria, and cancer. A wide range of bioactive compounds used in folk medicines can treat some chronic and infectious diseases (Mickymaray, 2019). The extremely low abundance of natural plant products is the major drawback as there is a need for lump-sum production to meet the requirements. These chemicals are classified into alkaloids, terpenoids, benzoides, flavonoids, glucosinolates, phenylpropanoids, and cyanogenic glucosides (Croteau, 2000). Synthetic biology presents a powerful approach to overcoming these issues by utilizing genetic engineering tools to reprogram metabolic pathways. By reconstructing biosynthetic pathways in plants or microbial hosts, researchers can enhance metabolite yields, improve compound stability, and enable large-scale production.

Key Strategies in Synthetic Biology for Metabolite Engineering

1. Pathway Reconstruction: Redesigning and optimizing biosynthetic pathways, often in microbial hosts (like yeast or bacteria) or even in plants themselves, can significantly increase the production of these valuable compounds. Techniques such as gene stacking, synthetic promoters, codon optimization, and masking toxicity by protein fusions improve gene expression and pathway efficiency (Dziggel *et al.*, 2017).

For example, the artemisinin, which is originally isolated from the leaves of *Artemisia annua*, had the biosynthetic pathway successfully reconstructed in *Saccharomyces cerevisiae*, resulting in large-scale semi-synthetic artemisinin precursor production for anti-malarial drugs (Li *et al.*, 2016).

2. Metabolic Flux Optimization: The number of metabolites that can be processed by one or more steps per unit time (Stephanopoulos *et al.*, 1998). The most important plant systems are focused mainly on central carbon metabolism, such as photosynthesis, lipid biosynthesis, and cell wall formation. Hence, balancing the carbon flux within cellular pathways ensures enhanced metabolite accumulation (Shih and Morgan, 2020). Techniques like enzyme overexpression, knockdown of competing pathways, and dynamic gene regulation are used to improve metabolite yields.

For example, in Golden Rice, overexpression of key enzymes like phytoene synthase and downregulation of competing pathways enhanced the flux of β -carotene (Welsch and Li, 2022).

3. CRISPR-Cas Systems in Plant Metabolite Engineering: These systems enable precise genome editing for activating, silencing, or modifying target genes involved in metabolite synthesis.

For example, CRISPR-mediated editing of the *SmbZIP1* gene in *Salvia miltiorrhiza* resulted in increased tanshinone production, a valuable compound for cardiovascular treatments (Mu *et al.*, 2015).

4. Synthetic Promoters and Gene Circuits: Synthetic promoters allow precise control of gene expression by responding to specific stimuli that help targeted metabolite production. Gene circuits involving inducible switches and biosensors enhance pathway regulation, improving metabolic stability and compound yield.

For example, engineered circuits have been used in *Arabidopsis* to regulate water and nutrient acquisition by quantitatively controlling the root density (Brophy *et al.*, 2022).

5. Microbial Chassis for Metabolite Production: Engineered microbes such as *Escherichia coli*, *Saccharomyces cerevisiae*, and *Yarrowia lipolytica* act as a host for the plant-derived metabolites, ensuring faster growth and scalable metabolite production.

For example, yeast-based production of a potent anti-cancer drug such as taxol precursors has emerged as a sustainable alternative to traditional extraction from *Taxus* trees (Nowrouzi *et al.*, 2020).

Pharmaceutical Applications of Plant Metabolites

Property	Compounds	Reference
Anti-cancer	Vinblastine, Vincristine, Taxane derivatives, Lignan derivatives and Noscapine	Agarwal <i>et al.</i> , 2020, Martino <i>et al.</i> , 2017, Ardalani <i>et al.</i> , 2017
Anti-malarial	Artemisinin	Malhotra <i>et al.</i> , 2016
Cardiovascular treatments	Tanshinoes, Norarmepavine,	Zhou <i>et al.</i> , 2012, Morales <i>et al.</i> , 1998
Neuroprotective	Alkaloids and Flavinoids	Lima <i>et al.</i> , 2025

Challenges and Future Directions

Despite significant advancements, challenges such as pathway complexity, metabolite toxicity, and regulatory constraints persist. Future research must improve pathway predictability, expand microbial host capabilities, and develop better computational tools for designing optimized biosynthetic pathways. Integration of AI-based modeling, omics technologies, and sustainable bioprocess engineering will accelerate the progress in plant metabolite engineering of pharmaceuticals.

Conclusion

Synthetic biology has revolutionized plant metabolite engineering, offering precise, scalable, and sustainable solutions for pharmaceutical production. By integrating pathway reconstruction, metabolic flux analysis, and engineering tools, researchers can enhance the biosynthesis of vital medicinal compounds. With continued advancements, synthetic biology has tremendous potential to drive next-generation pharmaceutical innovations and address global healthcare challenges.

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Carbon Farming: A New Income Stream for Farmers

Article ID: 71027

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Abstract

Carbon farming is a new practice with both environmental and economic advantages for farmers. Through using farm methods that lock up atmospheric CO₂ in vegetation and soil carbon, farmers can earn carbon credits, which can be sold on voluntary and compliance-based carbon markets. This paper discusses the principles, techniques, economic opportunities, and policy implications of carbon farming as a sustainable source of income for farmers while being a potential climate mitigation strategy.

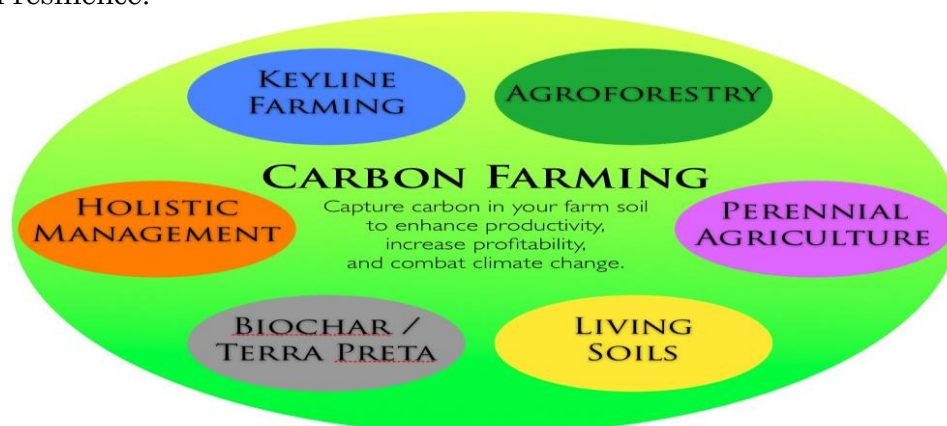
Introduction

The farming sector is both a cause and an effect of climate change. Conventional farming methods tend to emit greenhouse gases (GHGs) like CO₂, methane (CH₄), and nitrous oxide (N₂O). In response, carbon farming—a collection of land management practices that sequester CO₂ from the atmosphere and store it in soil and biomass—has been proposed as a win-win solution. Not only does it reduce climate change, but it also generates carbon credits that farmers can sell on carbon markets, a new source of income.

With countries pledging net-zero emissions, carbon farming aligns agriculture with environmental sustainability objectives while boosting rural incomes. Prices and incentives, infrastructure, and awareness, and this method can be used to turn agricultural landscapes into carbon sinks.

What is Carbon Farming?

Carbon farming refers to a climate-smart agriculture strategy that comprises a series of practices devoted to building the pool of carbon in soil and plants and hence lowering greenhouse gas (GHG) emissions. Besides enhancing agricultural productivity, the practices help promote environmental sustainability and provide opportunities for new farmers' income. The major carbon farming practices are agroforestry and tree planting, cover crops, crop rotation, reduced or no-till agriculture, application of biochar, better pasture management, organic composting, mulching, and rehabilitation of degraded land and wetlands. All these increase soil organic carbon, soil structure, and fertility and enhance water retention, which promote long-term agricultural resilience.



Techniques of Carbon Farming

Source: Drishti IAS

Carbon Sequestration Mechanism: Carbon sequestration, which is the central tenet of carbon farming, involves the process by which plants take in carbon dioxide (CO₂) from the atmosphere through photosynthesis and deposit it in their stems, leaves, and roots. Plant residues or organic amendments applied to the soil decompose and are transformed into stable organic matter, which fixes carbon in the soil. Soils with high organic carbon content not only avoid climate change but also increase crop yields, lower erosion levels, and increase the nutrient cycle, and thus carbon farming is an economic and ecological value-added option for contemporary agriculture.

Carbon Credits and Market Opportunities

One metric tonne of CO₂ (or equivalent) sequestered or avoided is a carbon credit. Farmers can obtain credits by adopting certified carbon farming practices and subsequently market these credits in:

Voluntary Carbon Markets (VCMs): Applied by companies to offset emissions on a voluntary basis.

Compliance Markets: Required by governments under carbon trading regimes.

Verification and Certification: Farmers need to deal with carbon aggregators or certifiers who quantify and verify the amount of carbon stored. Verified Carbon Standard (VCS), Gold Standard, and national bodies such as India's Bureau of Energy Efficiency (BEE) have roles in certification.

Income Potential: Depending on the area and approach, a farmer may make \$10 to \$50 per carbon credit. For instance, enhancing pasture on 100 hectares could earn 300–500 carbon credits every year. With growing corporate attention to sustainability, demand for carbon credits is likely to grow, making carbon farming a long-term prospect.

Global and Indian Perspectives

International Context: Countries like Australia and the United States have integrated carbon farming into national climate strategies. The Australian Emissions Reduction Fund (ERF) pays farmers for verified carbon sequestration, and California's Cap-and-Trade Program allows carbon offset projects from agriculture.

India's Carbon Farming Potential: India, with more than 140 million hectares of agricultural land, has huge potential for carbon farming. Techniques such as zero-tillage in wheat, application of organic manure, and agroforestry under National Agroforestry Policy already help sequester carbon. The Indian Council of Agricultural Research (ICAR) and Ministry of Environment are investigating pilot carbon farming programs in the states of Madhya Pradesh and Maharashtra.

Challenges in India:

- a. Limited awareness and technical capability
- b. Monitoring and verification expense is high
- c. Stratified landholding systems
- d. Lack of strong carbon market link

Carbon farming can be scaled through government support, capacity development, and digital monitoring technologies (e.g., satellite images, remote sensing).

Co-Benefits of Carbon Farming

Carbon farming also delivers a broad range of co-benefits aside from carbon sequestration. Although its fundamental purpose is the mitigation of atmospheric CO₂, the implementation of carbon farming leads to a range of co-benefits improving farm sustainability and ecosystem well-being overall.

1. Increased soil fertility and productivity: Practices such as composting, cover cropping, and biochar increase the content of organic matter and nutrients in the soil, contributing to healthier crops and yields.

2. Lower production costs: By encouraging the use of organic fertilizers and minimizing reliance on synthetic chemicals, carbon farming reduces production costs, making farming economically viable in the long term.

3. Better water retention and drought tolerance: Soils with high organic carbon content have improved structure and water retention capacity, supporting crops against dry spells and minimizing irrigation requirements.

4. Higher biodiversity: Methods like agroforestry and reduced tillage produce varied habitats for advantageous organisms, aiding pollinators, microbes, and biological pest control.

5. Lower land degradation and erosion: Mulch and cover crop ground cover defend soil from water and wind erosion, conserving land quality.

Generally, carbon farming promotes essential aims such as sustainable development, climate resilience, and food security, rendering it a comprehensive solution for both farmers and the environment.

Policy Support and the Way Forward

In order to facilitate large-scale adoption, the following is proposed:

1. Establish national carbon registries and markets
2. Subsidies and incentives for adopting sustainable practices
3. Include carbon farming in climate-smart agriculture missions
4. Foster public-private partnerships in carbon verification and trading
5. Digital platforms to monitor, report, and verify carbon sequestration

Capacity-building programs by Krishi Vigyan Kendras (KVKs) and agricultural universities can provide training to farmers in carbon farming.

Conclusion

Carbon farming is a paradigm change in agriculture—converting farmers into climate heroes from polluters. Through the implementation of climate-smart agriculture, farmers not only support international climate objectives but also gain access to new sources of income via carbon credits. With growing attention, policy support, and market growth, carbon farming could become a cornerstone of profitable and sustainable agriculture in the 21st century.

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Advances in Raceway Aquaculture System

Article ID: 71028

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Abstract

Raceway systems, also known as flow-through systems, are engineered aquaculture structures designed for high-density fish culture through continuous water flow, typically sourced from springs, streams, or deep wells. A modern evolution of this system is the In-Pond Raceway System (IPRS), which integrates raceway technology within pond environments to enhance productivity, water efficiency, and waste management. IPRS confines fish to raceway cells within ponds and utilizes mechanical aeration, baffle walls, and quiescent zones for optimized water circulation and solid waste removal. With stocking densities reaching 80–100 fish/m³, IPRS supports species such as Indian Major Carps, trout, and catfish. The system relies on nutritionally balanced floating feeds and offers precise disease treatment methods. IPRS presents advantages including increased yields, reduced manpower, ease of harvest, and minimal water exchange. However, challenges such as high initial costs, disease susceptibility, and environmental sensitivity limit its widespread adoption. Fixed and floating variants of raceways offer structural flexibility depending on pond conditions. Overall, raceway and IPRS technologies represent significant advancements in sustainable and intensive aquaculture practices.

Introduction

A raceway, also known as a flow-through system, is an artificial channel used in aquaculture to culture aquatic organisms. Raceway are designed to provide a flow-through system to enable rearing of much denser population of fishes. Raceways are obviously smaller in size than ponds and occupy much less space. The main sources of water are springs, streams, deep wells or reservoirs.

Type of Raceway

1. Series Raceway System
2. Parallel Raceway System

Series Raceway System: A **series raceway system** in aquaculture refers to a configuration where multiple raceways are connected in sequence, allowing water to flow from one to the next. This design is commonly employed in intensive aquaculture operations to maximize space utilization and manage water flow efficiently.

Parallel Raceway System: A **parallel raceway system** in aquaculture is designed with multiple raceways arranged side by side, each receiving a direct supply of water from the source. This configuration ensures that each raceway maintains consistent water quality, as there is no shared water flow between them.

In-Pond Raceway systems: An **In-Pond Raceway System (IPRS)** is an innovative aquaculture technology that integrates the benefits of traditional pond farming with the efficiency of raceway systems. In-Pond Raceway systems (IPRS) are confining fish in small portion of the pond with the production capacity of a flowing water system. In-Pond Raceway systems (IPRS) are an aquaculture production approach initiated at Auburn University in the early 1990's. (Yoo *et al.*, 1995). The In-Pond Raceway System (IPRS) is a fish culture technology developed to increase production efficiency and yield. (Arana *et al.*, 2018).

Type of In-Pond Raceway System

They generally fall into two main types:

- a. Floating Raceway Systems
- b. Fixed Raceway Systems.

Floating Raceway Systems: These systems involve raceways that float on the pond's surface. They are typically constructed using lightweight materials such as high-density polyethylene (HDPE) or other corrosion-resistant materials.

Fixed Raceway Systems: Fixed raceways are permanently installed within the pond, often constructed using concrete or other durable materials. They are designed to remain stationary and are integrated into the pond's infrastructure.

Design, Construction and Operation of IPRS

In-Pond Raceway System (IPRS) technology in newly constructed ponds:

1. Average depth of pond - 2.0-3.0 meters.
2. For the pond, levees should be flat or have width to height slopes of 1.5:1 to reduce erosion.
3. Pond levees with steeper slopes should incorporate some means of stabilizing soil.
4. Ponds should be rectangular in shape ideally with a long side to short side ratio of approximately.
5. Avoid building deep areas within the pond (>3.5m) which comprise more than 2-5% of pond floor area.
6. Minimum pond volume: 30,000 m³.
7. The volume of standard production raceway cells (production zone) is 220 m³.

IPRS uses a continual flowing water approach adapted to pond culture.



Pond reconstruction Slab construction with rebar posts Construction nearing completion



Fatima *et al.*, 2021

Overview of the USSEC Standard IPRS Farm Labeled with Key Components

1. Confinement Gates
2. Feed Storage
3. Mechanical Auto-Feeder
4. Mechanical Solids Waste Removal
5. Open pond Area
6. Production Zone
7. Quiescent Zone
8. Solids Waste Removal
9. Supplementary Aeration
10. Working Walkway
11. White Water unit (Open pond)
12. White Water units (Raceway head)
13. Baffle.



Arana *et al.*, 2018

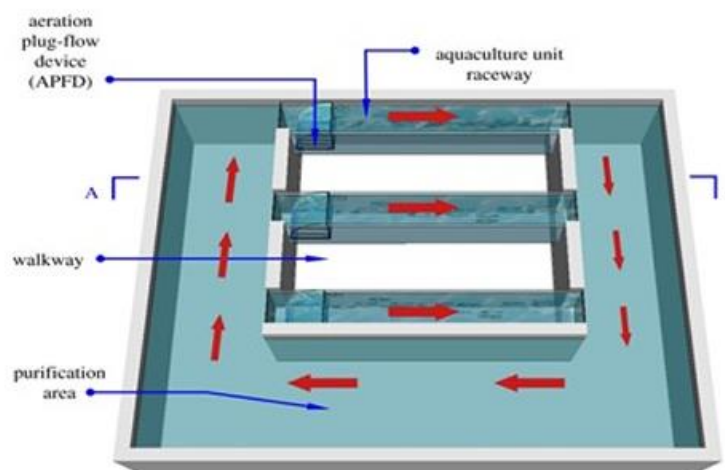


Diagram of an IPRS with aeration plug-flow device for control over water flow and quality
(Source: Li *et al.* 2019)

White Water Unit

The aerating and water mixing unit plays a crucial role in maintaining optimal water quality and circulation in aquaculture systems, such as raceways and open ponds. This unit utilizes a combination of aerators, motors, and air lifting pumps to ensure efficient oxygenation and water movement.

Quiescent Zone

It is also known as sludge collection unit or waste collection unit. The last 3 to 6 meters in length of raceway or IPRS cell is used as the waste collection point at the extreme downstream portion of the raceway where fish are harvested, and solid waste is collected and removed.

Baffle Wall

A **baffle wall** is constructed from soil or fabric and placed along the centerline (longitudinal axis) of the pond. Its main purpose is to **redirect the flow of water**, forcing it to travel a longer path around the pond before returning to the IPRS system head.

Species Cultured and Stocking in IPRS Cells

Freshwater Species: Commonly cultured freshwater species in raceways include Indian Major Carps (IMC), trout, and catfish. These species thrive in systems with continuous water flow.

Stocking Density in IPRS Cells: Intensive Pond Raceway System (IPRS) cells can be stocked at densities of 80 to 100 fish per cubic meter.

Example Stocking in a Pond: A pond of 1 hectare area equipped with 2 IPRS cells, each having a volume of 440 m³, can be stocked with approximately 35,000 to 45,000 advanced fingerlings in the raceways.

Feeds and Feeding

Although sinking feeds, such as medicated feed, are allowed when needed, a floating feed is ideal for the raceway. Raceway culture is dependent on full, high-quality diets due to its high density and absence of natural foods. For fish raised in IPRS raceways, feed must include all of their nutritional needs, including protein, fat, energy, vitamins, minerals, and more. IPRS fish must be fed balanced, nutritionally sufficient diets.

Disease Treatments

Disease treatments in raceways are usually done by dripping the therapeutant into the incoming water, maintaining a specific concentration for about one hour. This ensures continuous exposure as water flows through the raceway. Alternatively, some systems stop water flow and treat the raceway like a tank, mixing the therapeutant directly for precise dosing. This method uses less chemical and allows better control.

Advantages of IPRS

1. Higher stocking densities
2. Improved water quality
3. Reduced manpower
4. Ease of feeding
5. Ease of grading
6. Ease of harvest
7. Precise disease treatments
8. Collection of fish wastes
9. Low use of water due to zero exchange of water.

Limitations of IPRS

1. High water requirement
2. Need for consistent water flow
3. Vulnerability to environmental fluctuations
4. The IPRS has problems related to disease, reaction time, and predators.
5. Diseases, particularly bacterial diseases, are common in all high density systems, especially race ways.

6. Initial cost for IPRS setup is very high, which limits the adaptation of technology.
7. Bacterial diseases, particularly Enteric Septicemia of Catfish (ESC) and Columnaris, have been problematic with the IPRS catfish research at Auburn University.

Conclusion

Raceway and In-Pond Raceway Systems (IPRS) offer innovative solutions for intensive aquaculture by combining efficient water use, high production capacity, and improved environmental management. Despite their technical and financial challenges, these systems hold strong potential for meeting the growing demand for sustainable fish production, especially in areas with limited land and water resources.

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Recirculatory Aquaculture Systems (RAS)

Article ID: 71029

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Abstract

The Recirculating Aquaculture System (RAS) is an advanced, sustainable fish farming technology that enables intensive aquaculture with minimal water and land use. By continuously filtering and recycling water, RAS maintains optimal water quality and supports the cultivation of various freshwater and marine species in controlled environments. The system employs mechanical, biological, and chemical filtration units, along with disinfection technologies, to manage waste and pathogens effectively. Key species suitable for RAS include Tilapia, Rainbow Trout, and Pangasius. RAS allows precise regulation of environmental parameters, ensuring improved fish growth, biosecurity, and year-round production. Despite its advantages—such as water conservation, reduced environmental impact, and space efficiency—RAS faces challenges including high initial costs, energy demand, and technical complexity. Nonetheless, RAS represents a crucial innovation in sustainable aquaculture, meeting rising seafood demand while protecting natural ecosystems.

Introduction

The Recirculation Aquaculture System (RAS) is a technology that recycles and reuses water after filtering and removing metabolites and suspended matter (Murray et al., 2014). It is used to cultivate a variety of fish species at high density using the least amount of water and land (Murray et al., 2014). Fish are usually raised in indoor tanks in a "controlled" environment (Helfrich et al., 1991).



Recirculatory Aquaculture System

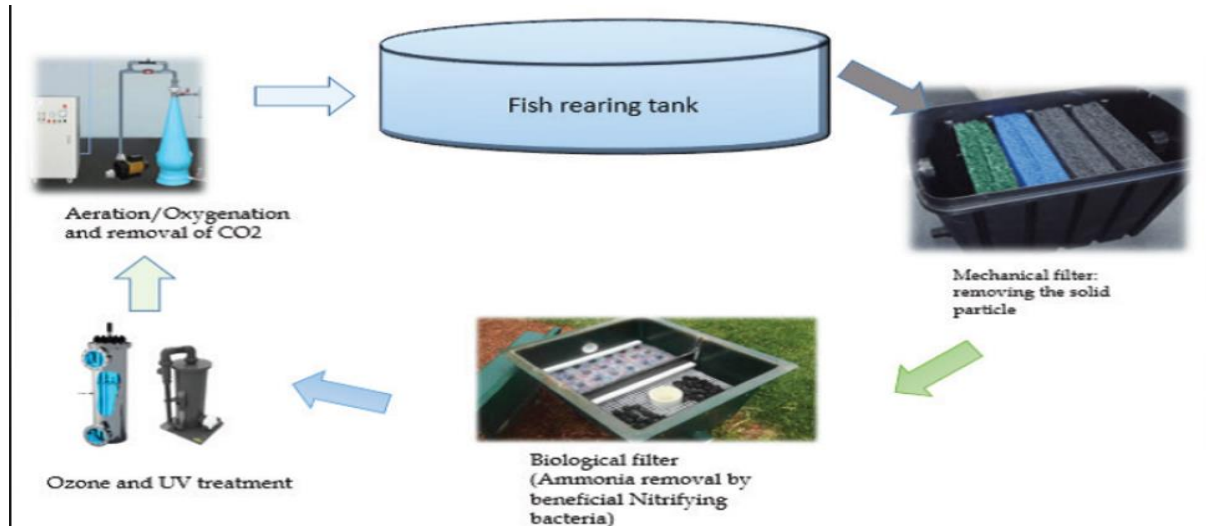
(source: <https://seafoodnetworkbd.com/facts-of-recirculating-aquaculture-system>)

Components of RAS

1. Insulated shed/ Building
2. Store cum office for feed and accessories
3. Pump house
4. Grow out tanks: Circular cement tanks/ FRP tanks
5. Overhead tanks
6. Mechanical filters
7. Pumps and motors
8. Aeration system (air/ oxygen)

9. Power generator
10. Biofilters, UV units
11. Electrification
12. Automatic feeder (required)
13. Laboratory
14. Water supply system.

How RAS Work?



<https://agriculture.vikaspedia.in/viewcontent/agriculture/fisheries/fishproduction/culture-fisheries/types-of-aquaculture/recirculatory-aquaculture-system-ras?lgn=en>

Types of Filter Use in Recirculatory Aquaculture System

In a Recirculating Aquaculture System (RAS), several types of filters are used to maintain water quality by removing waste, toxins, and pathogens.

Types of Filters in RAS:

Mechanical Filters- Remove suspended solids such as fish feces, uneaten feed, and other particulate matter from the water. Examples include drum filters and sand filters, which are often the first step in the filtration process.

Biological Filters- Host beneficial bacteria that convert toxic ammonia (from fish waste) into less harmful nitrite and then nitrate. This is crucial for maintaining water quality and preventing ammonia toxicity.

Chemical Filters- Remove dissolved organic compounds, odors, and sometimes specific toxins or medications. Activated carbon is a common chemical filter medium, though not always present in every RAS setup.

Disinfection Units- Used to control pathogens and reduce disease risk. Common methods include UV sterilization and ozone treatment.

Species Suitable for RAS

Baramundi/ Asian Seabass/Bhetki (*Lates calcarifer*)
 Cobia (*Rachycentron canadum*)
 Silver/Indian Pompano (*Trichinotus Blochii/ Trichinotus mookalee*)
 Tilapia (*Oreochromis niloticus*)
 Pearl spot/Karimeen (*Etroplus suratensis*)
 Pangasius (*Pangasianodon hypophthalmus*)
 Rainbow Trout (*Oncorhynchus mykiss*), especially in Hilly/cold water Region

Water Quality Parameter in RAS

Water parameter	Optimum range
Dissolved oxygen	4-6ppm

PH	7-8
Alkalinity	120-150 ppm
Ammonia	<0.05ppm
Nitrite	<0.5ppm
Nitrate	<5ppm
Temperature	26-30°C

Need for RAS

The need for a Recirculatory Aquaculture System (RAS) arises from the growing demand for sustainable, efficient, and controlled fish farming.

Water conservation- RAS uses much less water compared to traditional aquaculture system because water is continuously recycled (Pilone et al., 2021).

Environmental sustainability- It reduces the environmental impact of aquaculture such as water pollution because waste is filtered out and toxin are treated (Helfrich et al., 1991).

Space efficiency- RAS system can be used in urban setting or location where land for traditional open-water aquaculture is limited (Helfrich et al., 1991).

Environmental Protection- Minimizes discharge of waste and nutrients into natural water bodies. Reduces the risk of **environmental degradation**, such as eutrophication.

Biosecurity and Disease Control- Closed-loop system limits exposure to external pathogens. Easier to monitor and control diseases, reducing the need for antibiotics.

Year-Round Production- Environmental parameters (temperature, oxygen, light) can be controlled. Allows continuous and consistent fish production regardless of season.

Better Growth Rates and Quality- Optimal conditions improve fish health, growth performance, and product quality. Less stress for fish leads to better survival and feed conversion.

Advantages of a Recirculatory Aquaculture System (RAS)

1. Water Efficiency- RAS recycles up to 99% of water, drastically reducing water usage compared to traditional systems.

2. Environmental Sustainability- Minimal water discharge means less pollution and reduced impact on surrounding ecosystems.

3. Year-Round Production- Fully controlled environment allows consistent fish production regardless of climate or season.

4. Higher Stocking Densities- Fish can be raised in higher concentrations due to controlled water quality and oxygenation.

5. Better Biosecurity- Limited exposure to external contaminants or pathogens. Reduces disease outbreaks and use of antibiotics.

6. Location Flexibility- Can be built close to markets, reducing transport costs and fish stress. Suitable for urban, arid, or landlocked areas.

7. Improved Product Quality- Cleaner water and less stress lead to better tasting, healthier fish.

8. Waste Management- Solid waste can be captured and treated or used as fertilizer, making the system more sustainable.

9. Species Versatility- Supports a wide range of freshwater and marine species, including high-value or sensitive ones.

Limitations of a Recirculatory Aquaculture System (RAS)

1. High Initial Cost- Setting up a RAS requires significant investment in tanks, filtration, sensors, plumbing, and automation systems.

2. Complex System Management- Requires skilled operators to monitor and manage water quality, biofilters, and fish health. Small mistakes (e.g. pump failure or poor water chemistry) can have rapid, serious consequences.

3. High Energy Consumption- Constant water circulation, aeration, heating/cooling, and lighting consume a lot of electricity. Operating costs can be substantial without energy-efficient systems or renewable sources.

4. Technical Failures- Pumps, filters, or sensors can fail, putting fish stock at risk. System downtime or failure can lead to mass fish mortality if not addressed immediately.

5. Disease Outbreak Risk- Although external biosecurity is strong, diseases introduced internally (e.g., from broodstock) can spread quickly in high-density systems.

6. Limited Market in Some Regions- High-value species are usually needed to make RAS financially viable. In some areas, consumers may prefer wild-caught or traditionally farmed fish.

Conclusion

Recirculatory Aquaculture Systems (RAS) represent a modern and sustainable approach to fish farming, offering efficient water use, environmental protection, and the ability to produce high-quality fish in controlled conditions. While the system demands high initial investment and technical expertise, its benefits such as year-round production, biosecurity, and suitability for urban or resource-limited areas make it an increasingly viable option for the future of aquaculture. With growing global demand for seafood and pressure on natural water resources, RAS plays a critical role in promoting responsible and scalable aquaculture.

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Open Crop Residue Burning: Cause, Impact, and Mitigation

Article ID: 71030

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Introduction

India, with 17% of the global population, faces the challenge of sustaining its large population on a limited geographical area and resources, requiring the implementation of intensive agriculture. A significant shift occurred in the agricultural systems of Punjab, Haryana, and western Uttar Pradesh during the green revolution. Traditional crops like as maize, pearl millet, pulses, and oilseeds were replaced by rice-wheat cropping systems. (Janaiah & Debdutt, 2017) state that the Rice Wheat Cropping System (RWS) is extensively used in India, particularly in the Indo-Gangetic Plains (IGP), where around 90% of the area is dedicated to this system. The implementation of the rice-wheat cropping system resulted in a reduction in crop diversity, leading to an increased incidence of diseases and insect infestations (Lohan et al., 2018a). As to the Ministry of New and Renewable Energy (2009) and IARI (2012) (*Crop Residues Management with Conservation Agriculture: Potential, Constraints and Policy Needs*, 2012), monoculture and intensive farming practices produce a significant amount of agricultural residue, estimated to be over 500 million tonnes (MT). Cereals, including rice, wheat, maize, and millets, make up around 70% of this total.

In the period of the 1990s, when agricultural mechanisation was becoming increasingly popular, governments also implemented restrictions on the practice of stubble burning. Despite its limits, this phenomenon is mostly observed in the Indian rice-wheat area, encompassing Uttar Pradesh, Punjab, and Haryana. Uttar Pradesh is the top producer of agricultural residue in the country, with an output of 59.97 million metric tons (MT). Punjab follows with 50.75 MT, Maharashtra with 46.45 MT, and Haryana with 27.83 MT. Punjab is the state with the highest amount of residue burning, totalling 19.65 million metric tons. Uttar Pradesh comes in second place with 11.92 million metric tons. Due to the limited time frame between harvesting and planting the subsequent crop, farmers incinerate these remnants de the field between the months of October and November.

The incineration of rice straw is a prevalent activity in the northwestern regions of India, which presents a significant hazard to the well-being and safety of the general people. This practice leads to substantial nutrient depletion and severe deterioration of air quality. Open-field fire possesses some disadvantages, notwithstanding the farmers' belief in its land-enhancing properties. The pollutants generated during the combustion process has garnered significant attention in recent years. The burning of crop residue is a significant contributor to both land and air pollution at local, regional, and global levels. The combustion of straw produces thermal energy that permeates the soil, resulting in the evaporation of moisture, the demise of advantageous microorganisms, and an adverse effect on the soil. Incinerating agricultural waste leads to a multitude of environmental problems. The act of burning crop residue has several adverse effects, such as the emission of greenhouse gases (GHGs), heightened levels of particulate matter (PM) and smog, reduction in biodiversity within agricultural fields, degradation of soil fertility, and a detrimental influence on human welfare. The papers mostly address the significant agricultural, environmental, and human health impacts resulting from the burning of crop residue.

Major Causes

1. Labour shortage.
2. Short time duration for preparation and cleaning of field.
3. A lack of suitable agricultural equipment for harvesting reasons.
4. Lack of information about crop residue management.
5. Low-cost insect and weed control in the field.

Impact of Open Crop Residue Burning

1. Depletion of air quality standard: Unregulated combustion results in the emission of CO, CO₂, NO_x, SO₂, and other substances into the environment, hence causing air pollution. Research has shown that the combustion of one ton of rice straw releases 3 kg of particulate matter, 60 kg of carbon monoxide, 1460 kg of carbon dioxide, 199 kilogram of ash, and 2 kg of sulfur dioxide. The burning of crop wastes was predicted to provide 0.10 Tg of SO₂, 0.96 Tg of NO_x, 379 Tg of CO₂, 23 Tg of CO, and 0.68 Tg of CH₄ annually, resulting in an increase in greenhouse gas levels (Lohan et al., 2018b). An estimation was made of the greenhouse gas (GHG) emissions resulting from the combustion of cereals, particularly rice and wheat straw, in Punjab during May and October 2005. The study indicated that the emissions from wheat crop residues in Punjab are comparatively lower than those from paddy fields. According to (Gadde et al., 2009), the estimated range for PM 2.5 mass concentration during paddy residue burning is between 60 and 390 mg m⁻³.

2. Harmful effects a human and animal: The practice of increasing stubble burning leads to the release of dangerous air pollutants, which can have serious effects on human health such as chronic heart disease and lung cancer, as well as asthma and coughing. These effects are particularly pronounced in children, the elderly, and pregnant women. In addition to the more serious risks of leukaemia and blood bone marrow illness, exposure to benzene can also cause dizziness, sleepiness, headache, nausea, aplastic anemia, pancytopenia, and myelodysplastic syndrome cytopenia (Chandra & Sinha, 2016). Fire causes the death of beneficial microorganisms such as bacteria and earthworms. Snakes, frogs, earthworms, and lizards perish within the burrows. The combustion of all verdant flora around the field results in a reduction in the avian population inhabiting the area. Sparrows, eagles, and vultures are facing extinction as a consequence of this phenomenon. This has the potential to result in the depletion of biodiversity.

3. Deteriorating the soil health quality: The combustion of straw resulted in an increase in soil temperature ranging from 33.8 to 42.2 °C at a depth of 10 meters (Gupta et al., 2004). Approximately 23 to 73 percent of nitrogen is lost, resulting in an abrupt drop in the populations of fungi and bacteria in the soil. The soil's structural stability is seeing a notable decline when the organic carbon content decreases as a result of stubble burning. The combustion of straw elevates the soil temperature, leading to a disruption in the carbon-nitrogen equilibrium within the soil system.

4. Loss of nutrients: The practice of burning leftovers has hindered the ability to effectively manage and maintain a proper balance of nutrients. The carbon, nitrogen, and sulphur contained in straw are completely combusted and released into the environment, resulting in their loss. The straw experiences a total absence of C, 80% reduction in N, 25% reduction in P, 50% reduction in S, and 20% reduction in K, as stated by (Rani Sharma et al., 2010). According to estimates, burning one ton of paddy straw results in a loss of around 79.38 kg ha⁻¹ of nitrogen, 183.71 kg ha⁻¹ of phosphorus, and 108.86 kg ha⁻¹ of potassium (Singh et al., 2013).

Mitigation Techniques

1. Adaptation of Resource conservation technologies (RCTs): Randomized controlled trials (RCTs) offer a more reliable prospect for effectively managing paddy wastes to enhance soil health, increase production, mitigate pollution, and promote sustainable agriculture. An sophisticated technique called zero-till seed-cum-fertilizer drill/seed planters (such as the happy seeder and spatial zero seed cum fertiliser drill) has been created for directly sowing the next crop in the remaining stubble of the previous crop. According to (Somasundaram et al., 2017), the combination of no-tillage (NT), stubble retention (SR), and nitrogen (N) fertilizer application (90 N, 90 kg N ha⁻¹) might enhance soil aggregation. In a study conducted by Sun et al. in 2007, it was shown that soil organic matter levels rose by 15.8% - 18.1%, 6.6% - 10.6%, and 1.3% - 1.9% in the 0-10 cm, 10-20 cm, and 20-40 cm layers, respectively, when stubble was retained compared to when straw was removed. This study was conducted in the Wushan soils of China over a period of 15 years. According to (Huang et al., 2012) Huan, after eight years of cultivation, the yield of wheat was found to be 21% (0.344 t ha⁻¹), which was higher in the no till with stubble cover method compared to conventional tillage. The data clearly shows that soil aggregation was improved under the no tillage method, which might have a beneficial impact on the storage of carbon in the soil.

2. Mulching effect: The presence of residue on the soil surface can regulate soil temperature by reducing it in the summer and raising the lowest soil temperature in winter. Therefore, it reduces the amount of

moisture lost via evaporation during the summer months and keeps the soil at an ideal temperature for crop development, promoting microbial activity. It mitigates soil erosion caused by surface runoff and lowers soil compaction, which directly hampers root development and impairs crop establishment. Organic mulches enhance the process of soil desalinization and aid in the breakdown of pesticides and other pollutants, hence reducing their negative impact on soil fertility. Mulches can also inhibit seed germination of several weed species and limit light exposure to weeds, hence inducing stress in existing weeds and promoting their growth.

3. Improving soil health biodiversity: The absorption of agricultural waste directly into the soil has several beneficial effects on soil health characteristics, including pH, organic carbon content, infiltration rate, and water holding capacity. It enhances the hydraulic conductivity, cation exchange capacity (CEC), and decreases the bulk density of soil by enhancing soil structure and aggregate stability. Additionally, it mitigates the development of surface crust, lowers water evaporation from the uppermost soil layers, and inhibits the loss of nutrients through leaching. Additionally, it augments the microbial biomass, their population, and stimulates the functions of enzymes such as dehydrogenase and alkaline phosphatases, therefore facilitating the process of nutrient mineralization and mobilization. According to a paper by (Lohan et al., 2018a), using 6 grams of Nitrogen and 0.8 grams of phosphorous per kilogram of paddy straw might result in a reduction of 15-20% in the overall consumption of fertilizers.

4. Increasing nutrient availability: The alterations in soil total nitrogen caused by stubble are frequently correlated with variations in soil organic carbon levels, since soil organic matter can impact the retention and provision of nutrients. Both the practice of retaining stubble and avoiding tillage can lead to a large rise in the content of total nitrogen in the top 0-5 cm of the soil surface. There was no notable rise in the overall concentration of phosphorus (P) in the lower layer (10-30cm) of the soil. This lack of increase can be attributed to the immobilization of fertilizer P and the presence of surface stubble cover. However, an upward trend in the concentration of total phosphorus was seen in the topsoil layer of fields where field pea and wheat were rotated. The content of available potassium (K) was considerably higher in the top 5 cm layer of soil in the stubble retention treatments throughout the wheat and field pea rotation sequence. Hence, the utilization of both rice or wheat straw and inorganic fertilizer can enhance the productivity of rice and wheat in rice-wheat systems under Indian circumstances.

5. Off farm use of residue after harvest: The residue that has been gathered can also be utilized for reasons such as animal food and home fuel. Rice residue, due to its high silica concentration, is mostly utilized for fodder purposes instead of wheat straw. Straw baler machines offer an efficient and financially viable alternative for ecologically responsible straw management. Paddy straw may be utilized for cultivating many mushroom species, including *Agaricus bisporus*, *Volvariella volvacea*, and *Pleurotus* spp. According to Ojha and Tiwari (2019), one kilogram of paddy straw produces 300 grams, 120-150 grams, and 600 grams of these mushrooms, respectively. The biothermal power plant utilizes rice straw as a source of electricity generation, which is somewhat unexpected. A 10 MW power station, fueled by paddy straw, has been established in Jalkheri village, Fatehgarh Sahib. Paddy straw may be utilized in the manufacturing of paper and pulp. The Punjab state government has received a recommendation to utilize paddy straw as bedding material for crossbred cows in the winter season. The utilization of paddy straw bedding enhances the animals' well-being by promoting optimal udder and leg health, thus leading to improved milk production in terms of both quality and quantity.

Conclusion

The practice of stubble burning in India intensifies the levels of greenhouse gases and other harmful substances such as benzene and toluene. This poses an elevated danger to farmers and communities residing in close proximity to the fields. The use of agricultural waste is crucial not only for promoting sustainable agriculture but also for maintaining the balance of the entire human community. The utilization of agricultural leftovers as amendments serves to enhance soil fertility and preserve ecological equilibrium. Blaming just the farmers may not be the solution to these issues; it is imperative to identify sustainable technical alternatives. In this context, the objectives include promoting technologies to maximize the use of agricultural waste, training various stakeholders such as farmers and extension workers through different programs, conducting field demonstrations, and formulating and implementing policies to control agricultural waste through appropriate laws and regulations.

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Mapping Plant Health: How GIS and QGIS are Transforming Plant Disease Assessment in Agriculture

Article ID: 71031

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Introduction

With mounting challenges of climate change, emerging pathogens, and the demands of sustainable agriculture, plant disease management has never been important. Conventional disease monitoring methods, including field observations and manual surveys, tend to be inadequate in terms of generating timely and accurate information. Plant diseases have spatial and temporal characteristics that necessitate innovative approaches. Step forward Geographic Information System (GIS) and programs such as Quantum GIS (QGIS), which are transforming the way we track, analyze, and fight plant diseases, thereby presenting new possibilities for precision agriculture.

Understanding GIS and QGIS

What is GIS? Geographic Information Systems (GIS) are advanced technologies meant to capture, store, analyze, and present spatial data. GIS entails handling different types of geographic data, including maps, satellite imagery, and sensor readings, which are analyzed to identify patterns and make predictions. GIS in agriculture aids in comprehending how diseases, pests, and environmental conditions affect crop health, allowing precision in disease management. GIS operates by stacking data. For instance, a disease map may superimpose multiple layers of data, including soil health, humidity, temperature, and disease outbreaks, to visualize the most vulnerable areas.

What is QGIS? QGIS (Quantum GIS) is free and easy-to-use open-source GIS software used broadly across numerous applications, such as agriculture and plant pathology. Using QGIS, users can do spatial data analysis, model data sets with lots of complexity, and create maps—all without paying the hefty prices of proprietary products like ArcGIS. QGIS can be programmed with plugins for specific requirements, such as modelling disease or monitoring crop health by satellite imagery.

QGIS handles vector (points, lines, and polygons) and raster (gridded data, e.g., satellite data) data types. QGIS may be coupled with GPS, drones, and other data collection devices, and thus it is a valuable tool for managing plant diseases.

How GIS Works in Agriculture?

In agriculture, GIS combines various data sources into detailed maps and models to guide decision-making. These data sources can encompass satellite imagery, weather information, soil content, and crop health ratings.

Key Components of GIS in Agriculture

- 1. Data Collection:** It may be acquired from remote sensing, drones, weather stations, and field surveying. They give real-time or near real-time information regarding agricultural landscapes.
- 2. Data Analysis:** GIS assists in detection trends, e.g., regions where disease in plants would most likely strike, by interpreting data layers to detect correlations among environmental variables (e.g., rainfall, temperature) and diseases.
- 3. Decision Support:** GIS delivers information for pest control, disease management, and best crop planting timing. It assists in resource management, including deciding where pesticides must be applied, which saves costs and minimizes environmental damage.

GIS in Plant Pathology: Assessing and Managing Diseases

1. Disease Mapping: GIS enables plant pathologists to generate maps indicating where certain diseases have been present and how they move over time. Maps can be created, for instance, to indicate the intensity of a disease outbreak in an area. This enables them to determine where intervention is most desperately required.

2. Risk Assessment and Disease Forecasting: GIS facilitates the combination of climate data, plant pathology data, and soil health data to determine high-risk areas for disease outbreaks. Through environmental factor analysis, including temperature, humidity, and rainfall, GIS can forecast possible disease outbreaks and recommend preventive actions to reduce risks.

3. Real-Time Monitoring and Precision Interventions: One of GIS's greatest benefits is that it can offer near-real-time or real-time data. Through satellite imagery, aerial photography with the help of drones, and sensor networks on the ground, GIS allows for continual monitoring of the health of the plants. Plant disease outbreaks are immediately reported, enabling farmers to take prompt measures, like fungicide application or changing crop handling practices.

4. Mapping Disease Hotspots and Interventions: GIS can be used to identify hotspots of disease intensity and monitoring the distribution of plant disease over time. It enables the effective optimization of resources like water, fertilizers, and pesticides to avoid wastage and get the best out of interventions.

QGIS: A Tool for Precision Agriculture

QGIS is also a go-to tool among scholars and agriculturalists for managing crop health owing to its convenience, versatility, and powerful analytics capabilities. Below are some main attributes that qualify QGIS for efficient use in disease management for crops:

Open-Source: QGIS is openly sourced and free to utilize, making it a great option for resource-limited settings such as small-scale farms or research facilities.

Integration with Remote Sensing: QGIS supports processing data from satellite, drone, and other sensor data, which is important for tracking vast agricultural lands.

User-Friendly Interface: Although it is very capable, QGIS has a fairly gentle learning curve, making it easy for individuals with little GIS experience to use.

The Future: Integrating GIS with Advanced Technologies

The future of GIS in agriculture is its integration with new technologies, including drones, artificial intelligence (AI), and big data analytics. These technologies have the potential to improve GIS capabilities by providing real-time monitoring and predictive analytics.

For instance, the integration of GIS with machine learning-based disease prediction models enables more precise anticipation of where and when plant disease outbreaks are expected to occur most, enabling farmers to initiate pre-emptive measures far before the outbreak, reducing reactive control of diseases enormously and improving yield.

Conclusion

GIS and QGIS are robust tools that have transformed how plant diseases are evaluated and controlled. Through spatial data, GIS allows plant pathologists to pinpoint disease hotspots, evaluate risk, and streamline interventions, all leading to healthier crops and more environmentally friendly farming practices. As technology advances further, the marriage of GIS with AI and remote sensing will better enable us to forecast and control plant diseases, guaranteeing food security and environmental sustainability.

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A Case Study on Multicollinearity in Agricultural Data: Causes, Consequences, and Detection

Article ID: 71032

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Abstract

This article examines the detection and management of multicollinearity in a multiple linear regression model using a vegetable production dataset. The dataset, consisting of 15 predictor variables, explores how multicollinearity can affect model reliability and interpretation. To delve deeper into the analysis, various diagnostic methods, such as correlation matrix analysis, eigen system analysis, and VIF values were used to check for multicollinearity and understand how strongly the predictors were related. The study focuses on addressing multicollinearity to ensure robust and accurate regression results, using R software for implementation.

Introduction

The main aim of multiple linear regression is to understand how a set of independent variables (regressors) influences a dependent variable. One of the key assumptions of regression analysis is that the covariance between independent variables, $Cov(X_i, X_j)$ is zero, where $i \neq j$ implying that the regressors should ideally not be highly correlated, thereby allowing clear interpretation of each regressor's individual effect. However, such independence among predictors is seldom observed in real-world datasets.

When two or more regressors are strongly correlated, the individual effect of each regressor gets masked, posing a challenge in interpretation. This problem is known as **multicollinearity**. As a consequence, it can distort regression results by inflating standard errors, masking the true effects of predictors, and reducing the reliability of hypothesis tests, ultimately weakening the model's interpretability and credibility. This article helps understand multicollinearity from both a theoretical perspective and a practical standpoint using a real-world dataset. It covers the common causes of multicollinearity, its consequences, detection methods, impact on model accuracy and interpretability, and practical strategies for addressing it.

Causes and Effects of Multicollinearity

Multicollinearity arises when predictors are highly correlated, often due to overlapping information, derived variables (e.g., polynomials or interactions), or poor variable encoding. It may also stem from sampling or data structure issues. This inflates variances of coefficient estimates, making them unstable and sensitive to small changes. For example, in an MLR model with centered and scaled variables, $Var(\hat{\beta}_1) = Var(\hat{\beta}_2) = \frac{\sigma^2}{1-r_{12}^2}$. As $|r_{12}| \rightarrow 1$, variances explode, leading to unreliable estimates. Even if R^2 is high, individual predictors may appear insignificant due to inflated standard errors, complicating interpretation and inference.

Problems Due to MC

1. Large Variances and Covariances: Strong multicollinearity between regressors results in large variances and covariances of regression coefficients.

2. Unstable Estimates: Multicollinearity causes LSE $\hat{\beta}$ to vary greatly from true β . Expected squared distance: $E(L^2) = \sigma^2 \sum_i \frac{1}{1-R_i^2}$. when MC exist $\frac{1}{1-R_i^2}$ will be large for at least one i .

$\frac{1}{1-R_i^2}$ goes to infinity as R_i^2 goes to 1.

3. Wrong Signs: Coefficients may have unexpected (even opposite) signs.

4. F-test vs t-test Conflict: Model looks significant overall (F-test), but individual variables may not be (t-test).

5. Model Instability: Different model selection methods give different models due to high intercorrelation.

Techniques for Detecting Multicollinearity

1. Correlation Matrix: It inspects off-diagonal elements r_{ij} of the $\mathbf{X'X}$ matrix. If $|r_{ij}| > 0.9$, it suggests strong pairwise multicollinearity. However, this method cannot detect multicollinearity involving more than two variables.

2. Eigen System Analysis: Small eigenvalues of $\mathbf{X'X}$ indicate near-linear dependencies among regressors. The **condition number of $\mathbf{X'X}$** , defined as $K = \frac{\lambda_{max}}{\lambda_{min}}$ gauges severity: If $K < 100$: No issue; $100 \leq K \leq 1000$: Moderate to strong; $K > 1000$: Severe multicollinearity. Eigenvectors reveal which variables are involved.

3. Variance Inflation Factor (VIF): It measures multicollinearity in a regression model, which is defined as, $VIF = \frac{1}{1-R_i^2}$, where R_i^2 is from regressing the i^{th} predictor on others. In general, $VIF \geq 5$: Possible multicollinearity; $VIF \geq 10$: Serious issue. VIF quantifies inflation, while eigenanalysis better reveals structure.

Dealing with Multicollinearity

1. Collect additional data: Collecting more data can help break up collinearity by providing more independent variations between predictors.

2. Remove regressors: Identify and remove regressors that are linearly dependent (e.g., $x_1 = 2x_2$). While this can reduce multicollinearity, removing a variable may decrease the model's predictive power if it contains valuable information.

3. Collapse variables: Combine linearly dependent variables into a single composite variable. This retains the essential information while reducing multicollinearity, without losing valuable data.

Results and Discussions

To study the presence of multicollinearity among the predictor variables in a multiple linear regression framework, we considered a vegetable dataset where production (Y: quintal per hectare) is the response variable (Y). The dataset includes 15 independent variables (X_1 - X_{15}) covering morphological, biomass indicators, soil nutrient values, and biochemical characteristics.

Detecting Multicollinearity

1. Using the correlation matrix ($\mathbf{X'X}$ matrix): To identify relevant predictors for the response variable Y, a correlation analysis was first conducted. Among all variables, only five variables i.e. X_6 , X_{11} , X_{13} , X_{14} , and X_{15} showed a correlation coefficient greater than 0.54 with Y. These were therefore selected for further analysis. Fig. 1 shows strong correlations among several variables, especially X_{13} with X_{14} (0.84) and X_{15} (0.80), indicating potential chances of multicollinearity. However, the existence of multicollinearity may further be ensured by VIF and eigen system analysis of the dataset. Similarly, X_6 is also closely related to X_{11} (0.70) and X_{13} (0.76), while weaker links appear between X_{11} and X_{15} (0.20).

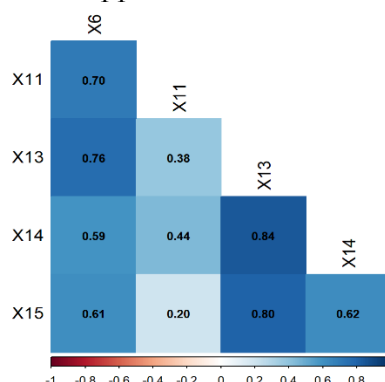


Fig. 1: Correlation Matrix of Independent Variables

2. Eigen system analysis: Eigen decomposition of the correlation matrix yielded a maximum eigenvalue of 3.4223 and a minimum of 0.0648, resulting in a condition number of **52.7414**, which suggests moderate multicollinearity, but within acceptable limits for model interpretation.

3. VIF analysis: The VIF values support the presence of multicollinearity observed in Fig. 1. X_{13} has the highest VIF (9.18), indicating a strong linear relationship with other variables, particularly X_{14} and X_{15} . X_6 also shows moderate multicollinearity with a VIF of 5.28. In contrast, X_{11} (2.85), X_{14} (4.38), and X_{15} (2.97) remain within acceptable limits. These findings suggest that X_{13} , and to a lesser extent X_6 , may need to be addressed to reduce redundancy in the model.

Conclusion

The analysis of multicollinearity in the vegetable production dataset highlights its potential impact on the stability and interpretability of regression models. While moderate multicollinearity was observed among certain predictors, particularly X_{13} , X_{14} , and X_{15} , it did not reach critical levels that would invalidate the model. The use of correlation matrix, eigen system analysis, and VIF values provided valuable insights into the relationships between the predictors, suggesting that addressing redundancy in specific variables could improve model reliability. Overall, the findings emphasize the significance of diagnosing and managing multicollinearity to enhance the accuracy and robustness of regression analyses.

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Role of Herbal Additive in Aquaculture

Article ID: 71033

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Abstract

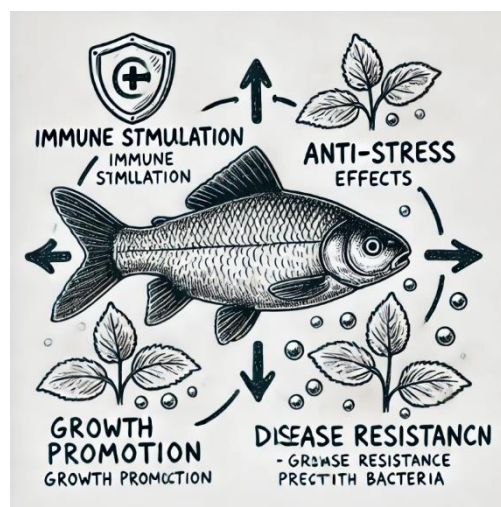
Herbal additives, derived from medicinal plants, are increasingly used in aquaculture as natural alternatives to synthetic chemicals and antibiotics. These plant-based compounds enhance fish health, growth, immunity, and stress resistance through their antiviral, antibacterial, antifungal, antiparasitic, and antioxidant properties. Common herbal additives include garlic, ginger, onion, tulsi, neem, aloe vera, turmeric, and moringa, each offering unique bioactive compounds that contribute to improved performance and disease resistance in cultured species. The use of plant components—mainly leaves, roots, and extracts—not only improves growth rates and immune responses but also supports sustainable and eco-friendly aquaculture practices. Despite their many benefits, challenges such as variability in effectiveness, lack of standardization, and higher costs can hinder widespread adoption. Nonetheless, herbal additives remain a promising tool for promoting health, productivity, and environmental sustainability in modern fish farming.

Introduction

Herbal additives, derived from plant-based compounds, are incorporated into fish feed to improve fish health, growth, and immune function. These additives exhibit antiviral, antifungal, antiparasitic, and antimicrobial properties, making them effective natural alternatives to antibiotics and chemical agents in aquaculture. Their use enhances digestive efficiency, stimulates appetite, and promotes faster growth rates in fish. Moreover, herbal supplements contribute to disease resistance by stimulating immune responses and directly inhibiting pathogens, thereby supporting sustainable and safer fish farming practices without harmful environmental impacts. (Barad, R. R *et al.*,2024).

Medicinal Plants Used as Herbal Additives

Medicinal plants are abundant sources of bioactive compounds, including tannins, alkaloids, terpenoids, saponins, and phenolics. When incorporated as feed additives in aquaculture, these plants have been shown to enhance immune stimulation, anti- stress, growth promote, and increase disease resistance in fish. (Hodar *et al.*,2021).



Common Herbal Plants Used in Aquaculture

Garlic (*Allium sativum*)- garlic (*Allium sativum*) is one of the most widely studied herbal additives in aquaculture due to its potent bioactive compound, like allicin. Dietary incorporation of garlic has been shown to improve specific growth rate and increase protein levels. (Hodar *et al.*,2021).

Ginger (*Zingiber officinale*)- Ginger (*Zingiber officinale*) is a flowering plant whose rhizome (underground stem) is widely used as a spice and in traditional medicine. it contains zingiberene as its main compound, along with zingerone, shogaols, and gingerols. Adding ginger to diets has been shown to improve growth, boost the immune system, and provide anti-parasitic, antibacterial, antiviral, and antifungal effects in aquaculture. (Caruana *et al.*, 2012)

Onion (*Allium cepa*)- Onion (*Allium cepa*) is a widely cultivated vegetable belonging to the *Allium* genus, known for its culinary and medicinal applications. Rich in bioactive compounds such as thiosulfinates, phenolic acids, and flavonoids, onion exhibits a range of biological activities, including antimicrobial and antioxidant effects. In aquaculture, the dietary inclusion of onion has been associated with improved growth performance, enhanced immune response, and better overall health in fish. (Hodar *et al.*, 2021)

Tulsi (*Ocimum sanctum*)- Tulsi, also known as holy basil (*Ocimum sanctum*), is a medicinal herb widely used in traditional Ayurvedic medicine. In aquaculture, Tulsi has gained attention for its potential as a natural feed additive. Supplementation with Tulsi has been reported to enhance growth performance, strengthen immune responses, and improve resistance to diseases in fish. (Hodar *et al.*, 2021).

Neem (*Azadirachta indica*)- Neem - known as Indian herbal doctor. it is a fast-growing, evergreen tree native to the Indian subcontinent. Its leaves, bark, and fruit extracts are commonly used in aquaculture due to their rich content of bioactive compounds that offer various health benefits. These extracts have been shown to enhance fish growth, boost immunity, and provide protection against bacterial, viral, and parasitic infections, contributing to improved health and sustainability in aquaculture systems. (Hodar *et al.*, 2021).

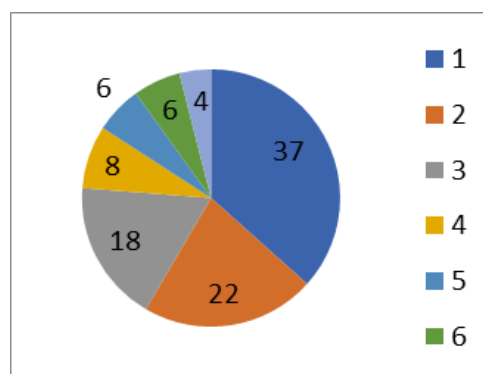
AloeVera(*Aloebarbadensis*)- Aloe vera is known for its anti-inflammatory, antimicrobial, and wound-healing properties. In aquaculture, aloe vera extracts are used to improve fish health by enhancing the immune response and promoting faster healing of injuries or lesions caused by handling or disease.

Turmeric (*Curcuma longa*)- Turmeric contains curcumin, which has powerful antioxidant, anti-inflammatory, and antimicrobial properties. In aquaculture, turmeric supplementation has been found to improve growth rates, boost immunity, and reduce oxidative stress, contributing to better overall health in fish and shrimp.

Moringa (*Moringa oleifera*)- Moringa is a highly nutritious plant that contains essential amino acids, vitamins, and minerals, along with bioactive compounds like flavonoids and phenolic acids. Moringa has been shown to improve growth rates, enhance immune function, and provide protection against infections, making it a valuable supplement in aquaculture diets.

Plants Components Used as Herbal Additive in Aquaculture

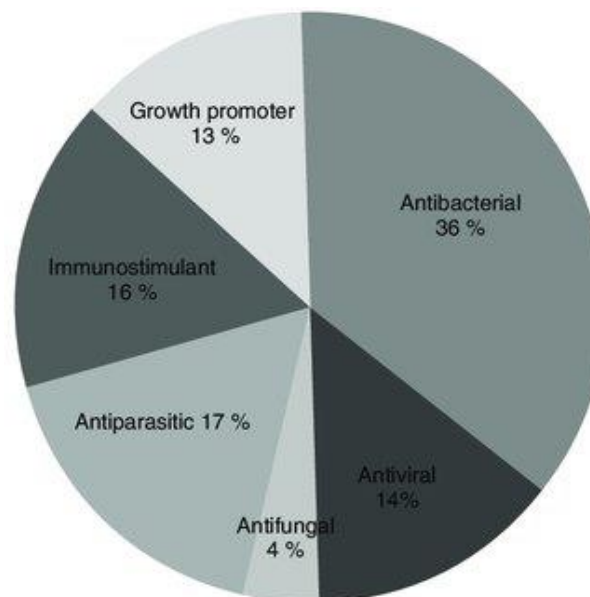
According to various studies usage of different components of plants as herbal additive in aquaculture is:



1. 37% plant leaves
2. 22% whole plant (powder, oil or extract)
3. 18% roots
4. 8% seeds
5. 6% barks
6. 6% fruits ,4% flowers.

Importance of Medicinal Plants in Aquaculture

Growth Enhancement: Herbal additives can support better growth rates and improved feed efficiency. For instance, *Garlic* (*Allium sativum*) has been shown to increase growth rates and protein content in fish. (Shalaby *et al.*, 2006).



Reverted *et al.*, 2017

Immune System Stimulation: Many herbal additives help boost the immune system, making fish more resistant to infections. *Neem* (*Azadirachta indica*) is particularly known for its ability to enhance immune responses and protect against bacterial and parasitic diseases. Dietary inclusion of *Ocimum sanctum* has been shown to enhance lysozyme activity, increase levels of immunoglobulin, serum protein, and globulin, and improve hematological parameters such as red and white blood cell counts and hemoglobin content in *Labeo rohita*. (Das *et al.*, 2015).

Medicinal plants act as Anti-bacterial agents: Medicinal plants have gained significant attention as natural antibacterial agents in aquaculture due to their effectiveness in controlling bacterial infections without the harmful side effects often associated with synthetic antibiotics. Ethanolic extracts derived from medicinal plant roots have been shown to effectively suppress the growth of both Gram-positive and Gram-negative bacteria. Methanolic extracts of *Solanum trilobatum*, *Andrographis paniculata*, and *Psoralea corylifolia*, when used to enrich *Artemia*, have been found to reduce *Vibrio* bacterial load in *Penaeus monodon* post-larvae. (Citarasu *et al.*, 2003).

Medicinal plants act as antiviral agents: The most significant viral pathogens responsible for high mortality in fish aquaculture include infectious pancreatic necrosis virus (IPNV) and infectious hematopoietic necrosis virus (IHNV) (Sivasankar *et al.*, 2015). Bioactive compounds derived from medicinal plants have been shown to inhibit viral transcription, thereby limiting viral replication within host cells and enhancing the host's innate immune response (Syahidah *et al.*, 2015). Additionally, immersion treatment with a herbal solution (AquaHerb) at a concentration of 20 mg/l has demonstrated effectiveness in providing resistance against iridovirus infection in Tiger grouper (Novriadi and Haw, 2015).

Medicinal plants act as Anti-parasitic agents: Medicinal plants have been increasingly recognized for their effectiveness as natural anti-parasitic agents in aquaculture. Major parasitic diseases posing serious threats to fish populations include *Ichthyophonus* and *Nanophyetus salmincola*. Herbal plants such as *Galla chinensis* and *Carica papaya* have demonstrated both therapeutic and preventive effects against white spot disease (Zhang *et al.*, 2013). Additionally, *Garlic* (*Allium sativum*) has shown potential as an effective alternative treatment against *Trichodina* infections (Martins *et al.*, 2002).

Medicinal plants act as Anti-stress agents: Stress, whether physical or chemical, can provoke bodily responses that may eventually result in disease. Medicinal plants are known to boost physical stamina, cognitive performance, and overall resistance in fish. For instance, Flavescent sophora and *Andrographis paniculata* have demonstrated anti-stress properties in Common carp (Wu *et al.*, 2007). Additionally, Hsieh

et al. (2008) found that Rutin enhanced hematological, biochemical, and immune responses in white-leg shrimp exposed to stress caused by *Vibrio alginolyticus*.

Sustainability of Herbal Additives

Environmental Benefits of Herbal Additives: Herbal additives offer significant environmental advantages in aquaculture. Unlike synthetic chemicals, plant-based substances are biodegradable and pose minimal risk to aquatic ecosystems. Their use helps reduce the reliance on conventional chemical treatments, thereby lowering the environmental footprint of fish and shrimp farming operations.

Reducing Chemical Usage: Plant-based substances help minimize the dependence on synthetic chemical additives in aquaculture. By utilizing natural herbs and plant-derived compounds, the need for conventional chemicals such as antibiotics, pesticides, and preservatives is significantly reduced. This not only promotes more sustainable and eco-friendly farming practices but also supports the health and well-being of aquatic organisms by avoiding the harmful effects often associated with chemical treatments.

Organic Certification: Herbal additives play a crucial role in helping aquaculture systems meet organic certification standards. These natural ingredients align with organic farming principles, which emphasize the use of environmentally friendly practices and the avoidance of synthetic chemicals.

Challenges

Effectiveness Variability: The effectiveness of herbal additives can vary depending on several factors, including the species being cultivated, environmental conditions, and the form in which the additives are applied. Different fish or shrimp species may respond differently to herbal treatments due to variations in metabolism, immune systems, and nutritional needs. Additionally, environmental factors such as water temperature, salinity, and pH levels can influence the bioavailability and efficacy of plant-based compounds.

Lack of Standardization: The use of herbal supplements in aquaculture faces challenges due to limited research and the absence of regulatory standards. This lack of standardization makes it difficult to ensure consistent quality, optimal dosage, and effective application, leading to variability in results. More research and clear guidelines are needed to improve their reliability in aquaculture.

Cost: Some herbal additives can be costly, particularly for large-scale aquaculture operations. The higher price of these natural supplements may limit their widespread adoption, especially for producers with limited budgets or those operating on a large scale.

Advantages of Herbal Additive

Improved Fish Health and Disease Resistance: Herbal additives boost fish health by enhancing immunity and disease resistance. They provide natural antimicrobial and immune-boosting properties, reducing the need for antibiotics and promoting overall well-being in aquaculture systems.

Enhanced Growth and Feed Efficiency: Herbal additives can improve growth rates and feed efficiency in fish. They help optimize digestion, nutrient absorption, and metabolism, leading to better feed conversion and faster growth.

Improved Water Quality: Herbal additives can help improve water quality by reducing harmful substances like ammonia and nitrites. They support the health of aquatic ecosystems, promoting a cleaner and more stable environment for fish.

Safe for the Aquatic Ecosystem: Herbal additives are generally non-toxic and environmentally friendly, making them safe for the aquatic ecosystem. Unlike synthetic chemicals, they do not harm water quality or disrupt the balance of aquatic life.

Disadvantages of Herbal Additive

Inconsistent Efficacy: The effectiveness of herbal additives can vary depending on factors like species, environmental conditions, and dosage, leading to inconsistent results in aquaculture systems.

Lack of Standardization and Quality Control: There is a lack of standardized guidelines and quality control measures for herbal additives, leading to variability in their potency and effectiveness across different products and applications.

Conclusion

Herbal additives offer a natural, effective, and environmentally friendly approach to enhancing fish health, growth, and disease resistance in aquaculture. While challenges like variability in efficacy and lack of standardization remain, their benefits in promoting sustainable and antibiotic-free fish farming make them a valuable tool for the future of aquaculture.

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Storage Entomology: Insect Pests in Stored Products

Article ID: 71034

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Abstract

Insect pests pose a significant threat to global food security and quality by causing substantial losses during storage. These pests, including moths, beetles, and weevils, thrive in environments conducive to their growth, such as high humidity, inadequate storage methods, and ineffective pest management. The Khapra beetle (*Trogoderma granarium*), Lesser grain borer (*Rhyzopertha dominica*), and Rice weevil (*Sitophilus oryzae*) are particularly damaging insects that infest stored cereals and pulses. Species and environmental variables influence pest behavior and damage, with Lepidoptera pests causing most damage as larvae and Coleoptera pests causing damage at both larval and adult stages. Secondary pests target mechanically or already infected seeds, while primary pests like *Sitophilus* species attack intact seeds. In addition to consuming stored goods, these pests also disperse dangerous bacteria and fungi, lowering food quality and contaminating products, making them unfit for human consumption.

Introduction

Stored insect pests, including insects, bacteria, fungi, and rodents, damage stored crops, with insects alone causing 10–50% of grain losses. These pests invade during storage or are carried from fields, thriving in inadequate storage conditions. Pulses, rich in protein (20–30%), are particularly vulnerable to prolonged storage and insect damage, which also introduces pathogens. Both Coleoptera (adults and larvae) and Lepidoptera (larvae) harm crops, while primary pests like *Sitophilus oryzae* attack intact seeds, and secondary pests target already damaged grains. Post-harvest insect infestations account for 24% of global food losses, with developing nations facing over 20% losses compared to 9% in developed countries. Effective management requires understanding pest life cycles, storage conditions (temperature, moisture), and vulnerabilities.

Storage Insect Pest

Khapra Beetle – *Trogoderma granarium*: These insects are found in India and several European nations, and they are of significant quarantine relevance globally. These insects typically breed during the active days of April through October. The infestation is particularly bad from July to October, when it's warmer. The ravenous feeders are grubs. The primary function of adults is reproduction. The harmful stage is grubs, which scratch the germ portion of the grain until they consume the entire grain.

Pulse Beetle – *Callosobruchus chinensis*: The host's range is all entire beans, grams, and pulses. The pulse beetle's distinguishing characteristic is Only the adult and eggs are visible. Male antennae are pectinate, while female antennae are serrated. The entire body is covered by Elytra. There are teeth in the hind femur spine. Adults are tiny, dark brown, and chocolate in color. The only damaging things are grub. Before harvest, the infestation may begin in the pods and spread to the storage area, where it could cause large losses. Grubs create a cavity by consuming the grain kernel. Adults emerge with openings for escape.

Rice Weevil- *Sitophilus oryzae*: The world's most devastating insect pest of raw cereal grains is the rice weevil, which can lead to up to 100% losses in stored maize in India and other nations. The significance of *S. oryzae* in India's stored maize is evident. The adult weevil was seen to be reddish brown, with four reddish or yellowish dots on its elytra. Its head protruded into a projection that resembled a snout, and at the end of this projection were two powerful jaws.

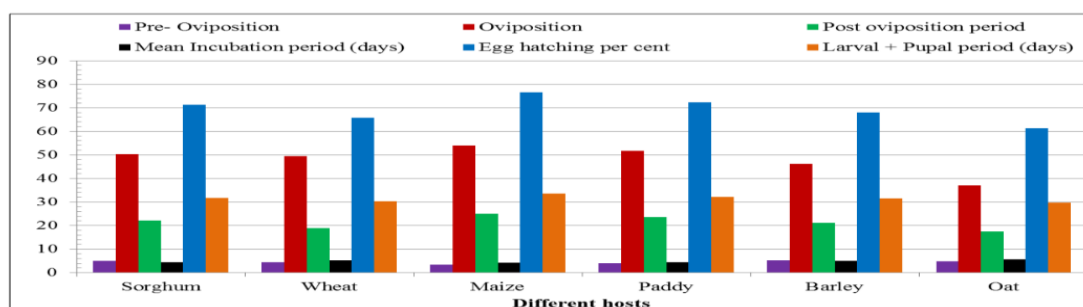


Fig-Effect on different host on biological parameter of rice weevil, *Sitophilus oryzae* (Ajay Manjhu, 2022)

Red Flour Beetle (RFB)-*Tribolium castaneum*: The head may be seen from above. Adult beetles are powerful flyers and extremely busy. At the termina segments, antennae suddenly grew larger . Eyes near one another, bent thoracic side Three-year-old female with approximately 1000 eggs. Eggs that are sticky and placed on food, cracks, or sacks.

Lesser Grain Borer- *Rhyzopertha dominica*: The lesser grain borer (*Rhyzopertha dominica*), a thermophilic pest, thrives in warm climates (optimal: 30±2°C, 75±5% humidity) and rapidly completes its life cycle at higher temperatures. Native to South America, it has spread globally via trade, now infesting grain silos, mills, and ships, particularly in India, Australia, the U.S. Gulf states, and southern Canada. This pest causes significant damage to stored grains, emphasizing the need for integrated, non-chemical approaches to curb infestations.

Cigarette Beetle - *Lasioderma serricorne*: It is a worldwide pest that also consumes seeds and dehydrated plant matter. The beetle is spherical and has a light brown color. The hunched nature is a result of the head and prothorax bending down. Grubs have a light brown head and a yellowish color. The material it feeds on is where eggs are placed. The pup is in a silky cocoon with food fragments on top. Adults and grubs alike punched holes in tobacco goods, such as chewing tobacco and cigarettes.

Saw-Toothed Grain Beetle - *Oryzaephilus surinamensis*: The host range includes dry fruits, oil seeds, rice, wheat, maize, and cereal goods. Grain Odor and surface roughness are caused by adults and grub. Grain that contains more cracked, docked, and foreign debris is heavily infested, which causes the grain to heat up. During their usual lifespan of six to ten months, females lay 43-285 eggs, which are then placed on feeding masses. The ideal temperature range for egg development is 27–29.

Grain Moth Or Angoumois Grain Moth- *Sitotroga cerealella*: Only whole cereals are attacked by larvae, which are the harmful stage. It hibernates as a larva during the winter. Larvae are responsible for damage. The color of eggs is crimson. The larvae have created a very tiny opening. Once inside, the larvae entrance is sealed off by silken web, making it hard to notice. Adults are innocuous, but larvae injure cereals. Grain is decomposed. It targets stores as well as fields.

Potato Tuber Moth- *Pthorimaea operculella*: The larva has a brown head and is pale apodous. Adults and grubs ate the tubers. Both in the field and in storage, damage happens. Larvae either bore into delicate shoots and developing tubers or mine into leaves. The tuber is rotting and smells bad. The potato tuber moth is a significant pest of potatoes, particularly in retail establishments where using biological agents instead of chemical pesticides is more environmentally friendly

Rice Moth- *Corcyra cephalonica*: The moth has a light buff brown hue. The wings are 25 mm wide and have dark veins on the forewings. Compared to other grain moths, it is larger. The lifespan of an adult is one week. Damage is solely Caterpillar's fault. It Favors feed and partially damaged grains Converted grain to webbed mass.

Indian Meal Moth- *Plodia interpunctella*: An extremely prevalent insect in homes, the Indian meal moth mostly consumes food items that have been preserved. Indeed, it has been dubbed the most significant pest of stored goods that are frequently discovered in grocery shops and households in the United States. The larvae feed on a variety of foods, including grains, nuts, dried fruit, dog food, and spices.

Conclusion

Stored insect pests (e.g., rice weevils, Khapra beetles) damage grains through feeding and contamination, causing 9–20% global losses. Effective management combines biological controls, optimized storage (temperature/humidity), and selective pesticides. Integrated strategies tailored to pest lifecycles reduce economic impacts and safeguard food security, especially in vulnerable regions.

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From Algorithms to Animals: Integrating AI into India's Livestock Sector for Inclusive Growth

Article ID: 71035

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India is the world's largest milk producer, a leading producer of eggs, and home to a rapidly growing meat industry. The country's livestock sector, which sustains millions of smallholder farmers, is foundational to its rural economy. However, despite its immense contribution, this sector faces persistent challenges related to animal health, productivity, market inefficiencies, and inadequate access to veterinary services. In recent years, Artificial Intelligence (AI) has emerged as a potential game-changer, offering the possibility to address some of these deep-rooted issues. AI-driven technologies such as precision livestock farming (PLF), disease detection apps, and AI-powered breeding programs promise improved productivity, animal health, and market efficiency.

However, despite the transformative potential of AI, the integration of these technologies into India's rural livestock farming ecosystem remains limited. A significant gap exists between the cutting-edge AI innovations designed for large-scale commercial farms and the smallholder farmers who form the backbone of India's livestock sector. This paper explores the challenges and opportunities for deploying AI solutions in India's livestock farming sector, focusing on the rural poor, and emphasizes the need for inclusive design and community-based interventions.

Challenges in Implementing AI for Smallholder Farmers

Digital Divide and Technological Access: A primary barrier to the widespread adoption of AI in smallholder livestock farming is the digital divide. Rural India, which houses the majority of smallholder farmers, has limited access to digital infrastructure. According to the 2021 report by the Ministry of Electronics and Information Technology (MeitY), nearly 60% of rural households do not own a smartphone, and internet connectivity remains patchy, especially in remote areas. This lack of access to basic digital tools undermines the ability of smallholders to adopt AI-based solutions effectively. While AI technologies can make substantial contributions to improving livestock management, their use is contingent on reliable internet access and digital literacy, both of which remain limited among rural farmers.

Economic Barriers: AI-based technologies, including genomic selection for breeding, wearable health monitoring devices, and sensor-based feeding systems, are costly. While large-scale commercial farms can afford to implement these technologies, smallholder farmers often lack the financial resources or access to credit to invest in these systems. A study by the International Food Policy Research Institute (IFPRI) notes that smallholders typically face financial barriers to adopting high-tech solutions, particularly when the technologies are priced for large-scale commercial operations. Without subsidies, financing options, or community-based models, these technologies will remain inaccessible to the vast majority of farmers.

Cultural and Contextual Adaptation: Another challenge lies in the lack of localization in AI tools. Many AI-based solutions are designed for urban or large-scale commercial farms and are often built in English, which is a barrier for smallholders who may not be proficient in the language. Furthermore, cultural and regional differences play a crucial role in the adoption of these technologies. A solution that works in one context may not be suitable for another due to varying livestock management practices, climate conditions, and market dynamics. Technologies that are not adapted to the local environment, language, and practices fail to gain traction among rural farmers.

Opportunities for AI to Enhance Livestock Farming in India

AI-Driven Disease Prediction and Health Monitoring: One of the most promising applications of AI in livestock farming is in disease prediction and health management. AI systems that can monitor animal

behavior, detect early signs of illness, and provide diagnostic predictions offer an invaluable tool for farmers, particularly in remote areas where veterinary services are sparse. For example, AI-powered mobile applications, such as FarmersFone and SmartVet, can allow farmers to send images or videos of sick animals for remote diagnosis. In Telangana, pilot projects have already demonstrated success in AI-based disease monitoring for poultry and dairy cattle, showing significant reductions in animal mortality and increased productivity.

Market Intelligence and Price Prediction: AI can also help smallholder farmers make more informed decisions about when to sell their produce and at what price. Market volatility often leads to exploitation by middlemen, with farmers receiving a fraction of the fair market price. AI-based platforms that aggregate real-time market data can offer price forecasting and help farmers connect directly with buyers, reducing dependency on intermediaries.

AI-Powered Breeding and Genetic Selection: AI-based breeding programs can help optimize livestock productivity by selecting the best animals for breeding. This technology can help increase milk yields, meat quality, and disease resistance. While genomic selection and precision breeding tools have traditionally been accessible only to large-scale operations, AI solutions are beginning to be developed that can serve smallholder farmers through cooperative models. Through cooperative networks, smallholder farmers can share the costs of such advanced technologies and benefit from their use.

Designing AI for Inclusivity: To bridge the gap between cutting-edge AI technologies and smallholder farmers, several key interventions are necessary:

Inclusive Design and Local Adaptation: AI tools must be designed with the local context in mind. This includes using regional languages, voice-based interfaces, and intuitive design that does not require advanced technical literacy. Furthermore, AI applications must be tailored to local livestock management practices, climatic conditions, and market realities. Technologies developed for global markets may fail to meet the needs of smallholders if they do not consider the realities of rural India.

Community-Based Models for Shared Access: Rather than focusing on individual ownership, AI technologies should be deployed through community-based models. For example, farmer cooperatives, women's self-help groups, and village-level service centers can act as hubs for shared access to AI tools. These models reduce the financial burden on individual farmers and encourage shared learning and resource pooling.

Capacity Building and Extension Services: Farmers, especially women and young people, need digital literacy training and education in AI applications. Extension services should be revamped to integrate AI tools into their outreach, providing farmers with the support and knowledge they need to use new technologies effectively.

Public-Private Partnerships: Collaborations between government agencies, private tech companies, and non-governmental organizations (NGOs) are essential to creating sustainable AI solutions for smallholder farmers. The government's role in subsidizing technologies, supporting infrastructure development, and incentivizing AI-based innovation will be key to scaling AI adoption.

Conclusion

AI holds tremendous potential to transform India's livestock sector, but its benefits must be extended to the poorest and most marginalized farmers. By adapting AI tools to local conditions, making them accessible and affordable, and supporting community-based delivery models, India can ensure that these technologies serve the needs of smallholder livestock farmers. The promise of AI is not just about increasing productivity; it is about improving the livelihoods of millions of rural families who rely on livestock for their survival.

The success of AI in livestock farming, particularly in marginalized areas like Telangana, can serve as a model for other regions of India. However, a concerted effort from policymakers, the private sector, and rural communities will be necessary to realize this vision. Only then will India's livestock farmers truly benefit from the transformative potential of AI, moving from the fringes of technological advancement to the center of agricultural innovation.

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Documentation and Preservation of Indigenous Technical Knowledge (ITK) for Better Knowledge Management in Agriculture

Article ID: 71036

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Introduction

Agriculture in India has a rich legacy of Indigenous Technical Knowledge (ITK) that has evolved through generations of experiential learning, environmental observation, and cultural practices. Long before the advent of modern scientific approaches, rural communities developed their own techniques for crop cultivation, soil conservation, pest management, irrigation, and post-harvest storage. These knowledge systems are low-cost, eco-friendly, and locally adapted, making them especially relevant in today's context of climate change and the quest for sustainable farming. However, rapid modernization, urbanization, and the declining interest of youth in traditional occupations have endangered these time-tested knowledge systems. The oral mode of transmission, combined with the lack of proper documentation, has further accelerated their erosion. Therefore, identifying, documenting, preserving, and disseminating ITKs is crucial for agricultural innovation and knowledge management (Warren, 1991; Gupta, 1996).

Understanding ITK

Indigenous Technical Knowledge (ITK) refers to the local knowledge developed by rural communities through generations of interaction with their natural surroundings. This knowledge is not limited to agriculture but extends to health care, animal husbandry, water conservation, and ecological management. In the agricultural domain, ITKs include practices such as mixed cropping, seed treatment with cow urine, organic manure use, and pest repellents prepared from local herbs. Unlike formal scientific knowledge, ITK is largely oral, experience-based, and highly specific to local agro-ecological contexts. It reflects a close relationship between the people, their environment, and their belief systems (Rajasekaran et al., 1991).

Salient Features of ITK

ITK is unique because it is location-specific and deeply embedded in the socio-cultural fabric of rural communities. It is adaptive in nature, shaped by long-term experimentation and environmental feedback. Most importantly, it is accessible and affordable, relying on local resources rather than external inputs. Although often overlooked by mainstream science, ITKs have demonstrated resilience, sustainability, and innovation across centuries (Somasundaram, 2007).

Because these practices are community-owned, their credibility lies in their repeated use and success. However, their credibility in formal systems can only be enhanced through proper documentation, validation, and policy recognition.



Fig.01 Salient features of ITKs

Techniques for Identifying ITKs

The process of identifying ITKs involves active community engagement. Participatory Rural Appraisal (PRA) methods have proven effective in this regard. Through mapping, seasonal calendars, and historical timelines, local communities are encouraged to share traditional practices that may not be immediately visible.

Key informant interviews with village elders and traditional practitioners yield in-depth insights. Focus Group Discussions (FGDs) allow community validation of the shared knowledge. Transect walks with farmers through their fields reveal practices in action. Ethnographic studies, which involve long-term immersion in a community, can uncover the cultural logic behind certain practices (Chambers, 1994; Pretty et al., 1995).

Approaches to Documentation and Preservation

Once identified, ITKs must be carefully documented. Written records in local languages, field diaries, case studies, and classification of practices under themes such as soil fertility, pest control, and seed storage form the foundation of systematic documentation (Gupta, 2002). In addition, community knowledge registers maintained at the village level help formalize ownership and prevent knowledge erosion.

Audio-visual methods such as video documentation and oral history recording help preserve the context, expressions, and demonstration aspects of practices. These are especially useful in capturing complex or performative ITKs that are hard to convey in text alone.

Digitization has brought transformative potential to ITK preservation. Traditional knowledge databases, digital libraries, and web portals such as the Traditional Knowledge Digital Library (TKDL) and platforms run by the National Innovation Foundation (NIF) serve as national repositories for ITKs. With proper indexing and metadata, these resources make ITKs globally searchable and usable (Sreekumar & Parvathi, 2010).

Preservation efforts must also focus on legal protection through intellectual property rights and benefit-sharing mechanisms. The Biological Diversity Act, 2002, and the Convention on Biological Diversity (CBD) recognize the need to safeguard the rights of indigenous knowledge holders and ensure their participation in decision-making (MoEF, 2002).

Another vital preservation approach is reviving ITKs through practice. Agricultural extension programs, farmer field schools, and organic farming policies can integrate proven ITKs, thus keeping them alive and dynamic.

Digital Documentation and Knowledge Management

Knowledge Management refers to the **systematic process of creating, capturing, sharing, and utilizing knowledge** to improve organizational or systemic effectiveness (Davenport & Prusak, 1998). In agriculture, it involves gathering scientific and traditional knowledge, validating it, organizing it efficiently, and ensuring its timely dissemination to farmers, extension workers, agribusinesses, and policymakers. Knowledge in agriculture is both **explicit** (scientific research papers, manuals, policies) and **tacit** (experiential knowledge, indigenous practices). Effective KM integrates both forms, enabling innovation and adaptability in farming systems (Nonaka & Takeuchi, 1995).

Digital tools and platforms have revolutionized the way ITKs are managed. With cloud storage, mobile applications, AI-enabled advisory systems, and blockchain technologies, ITKs can now be documented, validated, and disseminated more effectively than ever before.

Digital repositories not only offer longevity but also facilitate cross-regional and even global knowledge sharing. Mobile-based advisory systems can deliver ITK-based solutions to farmers in real-time, offering location-specific advice on pest management, crop selection, or natural remedies (Dey & Choudhury, 2020). AI models can integrate ITKs with weather forecasts, soil health data, and other scientific inputs to develop decision-support systems for climate-resilient farming.

Importantly, digital documentation enables traceability and attribution. Blockchain technology is being explored to track the origin of ITKs, ensuring fair recognition and benefit-sharing with knowledge holders (Tripathi et al., 2021).

Conclusion

The preservation and promotion of Indigenous Technical Knowledge in agriculture are crucial for building a resilient, inclusive, and sustainable food system. ITKs are not relics of the past but dynamic assets that complement modern scientific knowledge. With proper identification, ethical documentation, community participation, and the use of digital tools, ITKs can be mainstreamed into agricultural education, extension, and policy.

Efforts to manage knowledge effectively must bridge the gap between traditional and modern, oral and digital, local and global. By valuing and protecting indigenous knowledge, we not only honor our cultural heritage but also empower communities to shape their agricultural future.

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Medicinal And Nutritional Values of Goat Milk

Article ID: 71037

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Keywords

Goat Milk, Nutrition Value, Health Benefits, Fatty acid, Amino acid.

Abstract

Goats are a vital part of the livestock business because they can withstand difficult conditions, making them ideal for marginal and landless farmers. Goats play a major role in the rural economy and health by providing a large amount of milk and milk products. Regarding the production of milk from various species worldwide, goats come in third. More calcium, magnesium, and phosphorus are found in goat milk than in cow or human milk. It has been established that the medium chain triglycerides (MCT) and proteins found in greater amounts in goat milk are special lipids and proteins with special health advantages. Adult humans with ulcers and gastrointestinal disorders may benefit from the soft curd of goat milk. Goat milk is used to boost immunity and is crucial for preventing cancer, allergies, microbes, and cardiovascular disease.

For infants, the elderly, and those recovering from illness, goat milk is advised. Goat milk and its products are said to be very well-liked by consumers. Goats have continued to be overlooked in research and development despite this. To get the greatest benefits, goats must now be completely utilized, especially for their meat, milk, and medicinally valuable milk products.

Introduction

The goat is one of the most versatile domestic animals in adaptation to arid and humid, tropical and cold, desert and mountain conditions, providing people with many important products, such as meat, milk, cashmere, mohair, skins, leather, draught and pack power, and manure for crops and gardens. Goat is called “Cow of the poor people. Jamunapari, barbari, beetal, gohiwadi, malbari, mehsana, sirohi, kutchi, etc., are the main breeds used for milk production.

The growing interest in goat milk is not only focused on the sustenance of the poor and rural people with small land holdings and to educate them of the value and acceptability of goat milk, but also as an important “super” dairy food product with special medical, nutritional, biological, and immunological characteristics.

Table 1: Physical Properties of goat and cow milk:

Properties	Goat	Cow
Specific Gravity (Density)	1.029-1.039	1.023-1.039
Viscosity (cP)	2.12	2.0
Surface Tension (dyne /cm)	52.0	42.3-52.1
Conductivity (Ω -1/cm)	0.0043-0.0139	0.0040-0.0055
Refractive index	1.450±0.39	1.451±0.35
Freezing point (°C)	0.540-0.573	0.530-0.570
Acidity (LA% %)	0.14-0.23	0.15-0.18
pH	6.50-6.80	6.65-6.71

Composition

Caprine milk, on average, contains 12.2% total solids, consisting of 3.8% fat, 3.5% protein, 4.1% lactose, and 0.8% ash (Table 1), indicating that it has more fat, protein, and ash, and less lactose than cow milk. Goat milk contains slightly less total casein, but higher non-protein nitrogen than its cow counterpart.

Table 2. Basic composition of goat milk and cow milk (mean values per 100 g):

Constituents	Goat Milk	Cow Milk
Fat	3.8	3.6
Protein	3.5	3.3
Lactose	4.1	4.6
Ash	0.8	0.7
Total solids	12.2	12.3

Lipids

One of the significant differences between goat and cow milk is found in the physicochemical structure and composition of milk fats. The average size of goat milk fat globules is about 3.5 micrometers (μm) as compared to 4.5 μm for cow milk fat. Average diameters of fat globules for goat, cow, buffalo, and sheep milks were reported to be 3.49, 4.55, 5.92, and 3.30 μm , respectively. Smaller fat globules make a better dispersion and more homogeneous mixture of fat in goat milk, which would provide lipases with a greater surface area of fat for enhanced digestive action. That's why goat milk is considered "self-homogenized" milk. In respect to free lipids, goat milk has higher values than those of cow milk.

The smaller physical size of goat milk fat globules appears to be associated with the poor creaming ability of goat milk. Goat milk contains 97–99% of free lipids and 1–3% bound lipids of total milk fat. The comparison of fatty acid composition of total lipids showed that goat milk fat has significantly higher levels of short and medium-chain-length fatty acids (MCT) (C4:0-C14:0) than cow and human milks (Table 2). Goat milk has almost twice as high amounts of caproic (C6:0), caprylic (C8:0), and capric (C10:0) acids as cow milk, which are highly correlated to "goaty" flavour. Goat milk has a unique characteristic in the lauric: capric fatty acid (12:10) ratio, where it has a significantly lower ratio than cow milk (0.46 versus 1.16). The FFA fraction in goat milk has been related to "goaty" flavor intensity in the milk. Free fatty acid (FFA) content of goat milk is 3.11 $\mu\text{eq/ml}$ compared with cow milk (3.0 $\mu\text{eq/ml}$) and buffalo milk (3.4 $\mu\text{eq/ml}$). Lipolysis in goat milk increases during storage at room temperature for 4 and 12 h. Goat milk has a higher sensitivity to spontaneous lipolysis than cow milk due to the difference in lipase distribution.

Carbohydrates

The major carbohydrate of goat milk is lactose, which is about 0.2–0.5% less than that of cow milk. Other carbohydrates found in goat milk are oligosaccharides, glycopeptides, glycoproteins, and nucleotides in small amounts. Goat milk is significantly richer in lactose-derived oligosaccharides compared to cow milk. Milk oligosaccharides are thought to be beneficial to human nutrition because of their prebiotic and anti-infective properties.

Proteins

There are five principal proteins in goat milk: β -lactoglobulin (β -Lg), α -lactalbumin (α -La), κ -casein (κ -CN), β -casein (β -CN), and as2 -casein (as2 -CN) (Table 3). Electrophoretic mobility under standard conditions shows that β -casein is the major component of the casein fraction in goat milk, whereas as1 -casein is the major casein in cow milk. The total casein content of goat milk is slightly lower than that of cow milk. The percentages of as1 - and as2 -caseins in goat milk are markedly different from those in cow milk, where goat milk has much lower as1 and higher as2 than cow milk. However, goat milk showed considerable variations in its as1 -casein content, ranging from 2.7 g/l to only 0.12 g/l. β -Casein is the most abundant protein in goat and human milks, while as1 is the major protein in cow milk. Levels of as -casein are minimal in human milk.

Enzymes

The distribution of enzymes in goat milk is quite different from that in cow milk. Alkaline phosphatase content in goat milk ranged from 11 to 13 mg/l, and the inactivation of this enzyme was reportedly at around 45°C by some authors, implying that the alkaline phosphatase test may not be effective for the pasteurization of goat milk. Acid phosphatases (AP) have also been determined in goat and cow milks, where the activity levels of the enzyme in goat and cow milks were 0.136 and 0.076 units/g protein, respectively. Xanthine oxidase activity of goat milk is less than 10% of that of cow milk. Xanthine oxidase

has been associated with the control of various redox reactions in the cell and plays an important role in Fe absorption, facilitating the oxidation and combination of Fe with transferrin, and coupling antibacterial effect via the lactoperoxidase system. Goat milk contains less lipase than cow milk. Lipase is a lipoprotein with technical applications due to its involvement in spontaneous and induced lipolysis. In contrast to that in cow milk, lipase activity in goat milk is significantly correlated with spontaneous lipolysis, possibly because of its specific lipolytic system. Lipases play a major role in flavour development in milk and dairy products during milk processing and storage. Goat milk exhibited significantly lower lipoprotein lipase activity in fresh milk cooled to 4°C than cow counterparts.

Minerals & Vitamins

Goat milk has higher calcium, phosphorus, potassium, magnesium, and chlorine, and lower sodium and sulphur contents than cow milk.

Goat milk has higher amounts of vitamin A than cow milk. Caprine milk is whiter than bovine milk because goats convert all β -carotene into vitamin A in the milk. Goat milk, however, has a significant drawback in deficiencies of folic acid and vitamin B12 as compared to cow milk. Cow milk has 5 times more folate and vitamin B12 than goat milk, where folate is necessary for the synthesis of haemoglobin. Vitamin B12 deficiency has been reportedly implicated in “goat milk anemia,” which is a megaloblastic anemia in infants. However, the major cause of the anemia is attributable to the folate deficiency in goat milk. Both goat and cow milks are equally deficient in pyridoxine (B6), vitamin C, and vitamin D, where these vitamins must be supplemented from other food sources.

Table 3. The percent composition of different protein fractions in goat and cow milks is summarized below:

Proteins	Goat	Cow
Proteins (%)	3.5	3.3
Total casein (g/100ml)	2.11	2.70
α s1 (% of total casein)	5.6	38.0
α s2 (% of total casein)	19.2	12.0
β (% of total casein)	54.8	36.0
κ (% of total casein)	20.4	14.0
Whey protein (%) (albumin and globulin)	0.6	0.6
Non-protein N (%)	0.4	0.2
Lactoferrin (μ g/ml)	20-200	20-200
Transferrin (μ g/ml)	20-200	20-200
Prolactin (μ g/ml)	44	50
Folate-binding protein (μ g/ml)	12	8
Immunoglobulin		
IgA (milk: μ g/ml)	30-80	140
IgA (colostrum: mg/ml)	0.9-2.4	3.9
IgM (milk: μ g/ml)	10-40	50
IgM (colostrum: mg/ml)	1.6-5.2	4.2
IgG (milk: μ g/ml)	100-400	590
IgG (colostrum: mg/ml)	50-60	47.6
Lysozyme (μ g/100 ml)	25	10-35
Ribonuclease (μ g/100 ml)	425	1000-2000
Xanthine oxidase (μ l O ₂ /h/ml)	19-113	120

Table 4. Amino acid composition of goat and cow milk (mg/100g):

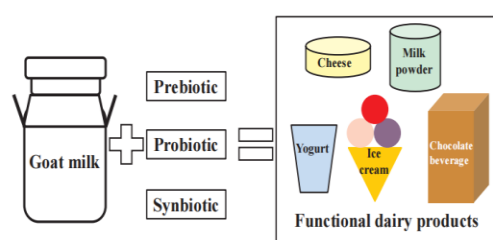
Amino acid	Goat	Cow
Tryptophan	44	46
Threonine	163	148
Isoleucine	207	198
Leucine	314	321
Lysine	290	260

Methionine	80	82
Cystine	46	30
Phenylalanine	155	158
Tyrosine	179	158
Valine	240	220
Arginine	119	119
Histidine	89	89
Alanine	118	113
Aspartic acid	210	249
Glutamic acid	626	687
Glycine	50	69
Proline	368	318
Serine	181	178

Table 5: Fatty Acid Composition of Goat and Cow Milk:

Fatty acid (g/100g)	Total lipid (g/100 g fat)	
	Goat milk	Cow milk
Butyric acid C4:0	2.6	3.3
Caproic acid C6:0	2.9	1.6
Caprylic acid C8:0	2.7	1.3
Capric Acid C10:0	8.4	3.0
Lauric acid C12:0	3.3	3.1
Myristic acid C14:0	10.3	9.5
Palmitic acid C16:0	24.6	26.5
Stearic C18:0	12.5	14.6
Oleic C18:1	28.5	29.8
Linoleic C18:2	2.2	2.5

Source: Goat Milk: Composition & Processing Technology; National Dairy Development Board 2018



500 ml of goat milk or the equivalent amount of cheese or yoghurt can provide up to 94% of the recommended dietary allowance (RDA) of essential amino acids, 83% of calcium, and 78% of riboflavin needs, while also being a dietary source of other minerals and vitamins.

Fig.1: Products From Goat Milk & Nutritional Value

Source: Journal of Functional Foods; Silvani Verruck *et al.*, 2019

Conclusion

The main objective of this article is to achieve several goals. Firstly, it aims to provide a thorough overview of the nutritional and functional properties of goat milk proteins, including the different types of protein coprecipitates and the methods used for their preparation. Secondly, it aims to investigate the factors that influence the interaction between milk proteins and minerals and quantify these interactions. Thirdly, the nutrient profiling and medicinal properties of goat milk proteins will be investigated to assess their potential health benefits. Finally, it aims to identify areas where further research is needed to improve our

understanding of the potential benefits of the consumption of goat milk proteins and derived products for human health and nutrition.

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Goat Milk: A Versatile Dairy Alternative with Unique Health Benefits and Functional Properties

Article ID: 71038

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Keywords

Goat Milk, Nutrition Value, Health Benefits, functional properties, Fatty acid, Amino acid.

Abstract

Goat milk is the third most produced milk in the world, after cow and buffalo milk. It stands out for having a distinct nutritional profile enhanced with bioactive ingredients that provide a host of medicinal advantages. Improved digestibility and nutrient absorption are facilitated by its unique protein, which includes low α s1-casein and higher β -casein, and fat composition, which includes smaller fat globules and higher concentrations of medium-chain triglycerides, taurine, polyamines, oligosaccharides, bioactive peptides, essential minerals, and vitamins. According to research studies, goat milk's aforementioned special qualities work together to enhance digestive, cardiovascular, and brain health by imparting hypoallergenic, antioxidant, antipathogenic, immune-modulating, anti-inflammatory, and anti-proliferative properties. Goat milk and its constituents are used for many physiological and health-promoting purposes due to these qualities. Additionally, a variety of specialist products have been made possible by the bioactive components of goat milk, which are presently being studied for their potential therapeutic benefits. This paper highlights goat milk's growing significance in consumer health and wellness by examining its remarkable composition, physiological function, and medicinal potential.

Introduction

The United Nations' Food and Agriculture Organization (FAO) statistics show that goat milk is the world's third most produced variety of milk, behind cow and buffalo milk. The importance of goats in human nutrition has probably been recognized since the early stages of domestication. Goat milk proteins have different ratios of caseins and whey proteins than cow's milk, resulting in different functional properties. Thus, goat milk proteins show promise for use in a variety of food products, especially for those who are sensitive to cow milk. The fact that goat products have been classified as functional food due to their nutritive and dietetic value and thus health-promoting benefits calls for the development of goat husbandry and breeding as well as for increasing the production of goat milk and meat. Goat milk is a valuable food product and excellent raw material from which products of high nutritive value and exquisite taste are made.

Flavour of Goat Milk

An important feature of goat milk is the well-known goat flavour (discussed in Sec Lipids), often reported as "goaty," which is not accepted by some consumers. The sensory profile and off-flavors, in particular, of raw milk are associated with the following factors, which must be controlled:

1. Breed and other genetic factors.
2. Physiological factors (stage of lactation, udder health).
3. Feeding systems (pasture or indoor feeding, preservation method of feed, botanical composition of pasture, and type of diet) can affect the oxidative stability of milk and consequently the development of off-flavors.
4. Environmental conditions, because volatile compounds may be transferred into milk.
5. Induced or spontaneous lipolysis in raw milk, which is the hydrolytic rancidity of raw milk, is the hydrolysis of triacylglycerides catalyzed mainly by indigenous lipoprotein lipase (LPL). Lipolysis, expressed

by a high level of free fatty acids (FFA), can be induced by particular treatments (pumping, agitation, mixing with air, foaming, milking systems, temperature changes), which disrupt the integrity of the milk fat globule membrane. On the other hand, spontaneous lipolysis occurs in some individuals' milk cooled soon after milking.

6. Microbial quality of raw milk, especially the counts of psychrotrophs that dominate raw milk kept at low temperatures for >2 days; off-flavors result often from the activity of their proteolytic and lipolytic enzymes.

7. Similarly, high SCC is often correlated with enhanced proteolytic activity induced by plasmin or other proteinases.

Off-flavors in goat milk can be avoided by controlling the above-mentioned factors. Especially FFA must be low, since goat flavor is attributed to an excessive FFA content, in particular medium- and short-chain ones. Capric, caproic, and caprylic acids make up 20 to 25% of all FFA in goat milk, giving it thus “goaty” and rancid taste to goat milk. **Chilliard *et al.*, (2003)** ascribe the development of goat flavor to the release of branched medium-chain fatty acids and the development of rancidity to excessive release of butyric acid. They report that the goat flavor in cold, stored fresh milk appearing at low lipolysis levels comes from C6:0 to C9:0 FFA and more specifically from volatile branched-chain C9 and C10 as 4-methyl and 4-ethyl-C8, which are 0.3–0.4 g per kg of fat in goat milk. Goat milk fat composition and its lipolytic system are the responsible factors. The latter is practically the activity of lipoprotein lipase (LPL), which is lower compared to that in cow's milk. However, spontaneous lipolysis is correlated well with LPL activity in goat milk, apparently because a large proportion of it is bound to cream, in contrast to LPL of bovine milk bound to casein micelles. The membrane is more fragile in goat milk fat than in cow milk fat and easily broken during improper handling, insufficient cooling, and repeated rewarming, when enzymes are liberated and cause lipolysis, releasing FFA.

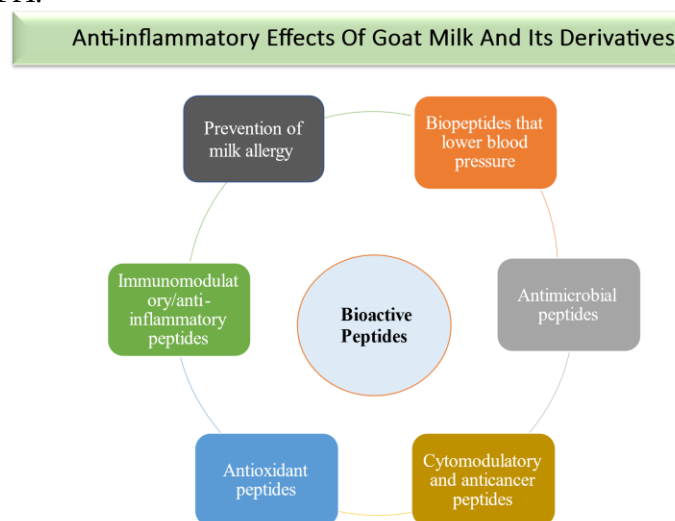


Fig. 1: Anti-Inflammatory Effects of Goat Milk and Its Derivatives

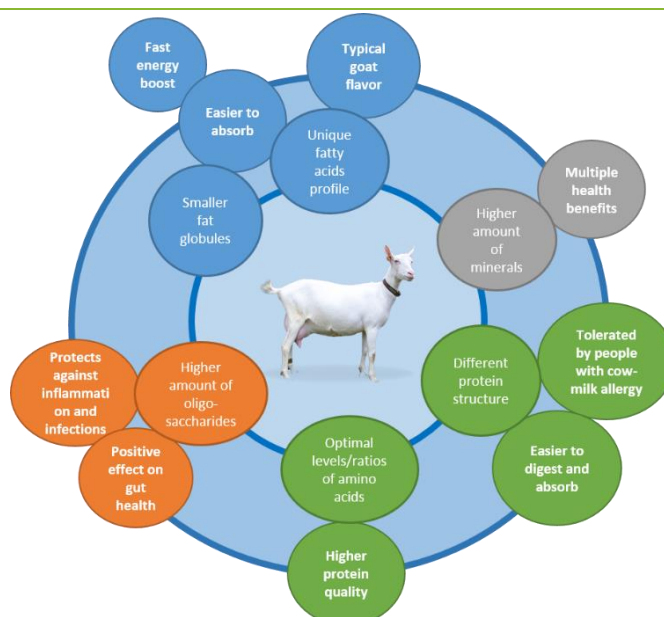


Fig.2: Health Benefits of Goat Milk

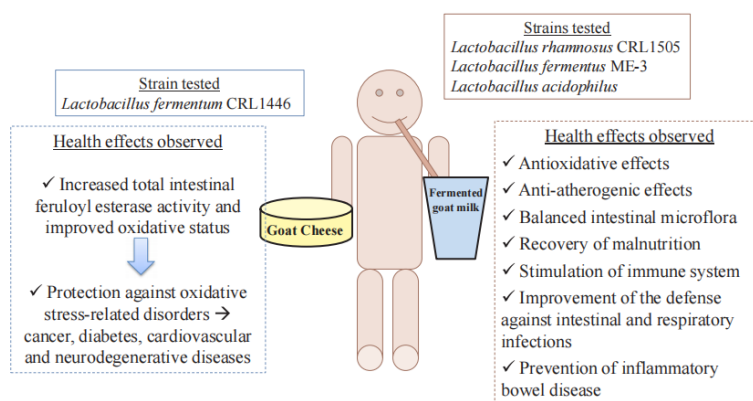


Fig.3: Health Benefits of Goat Milk cheese and fermented goat milk products

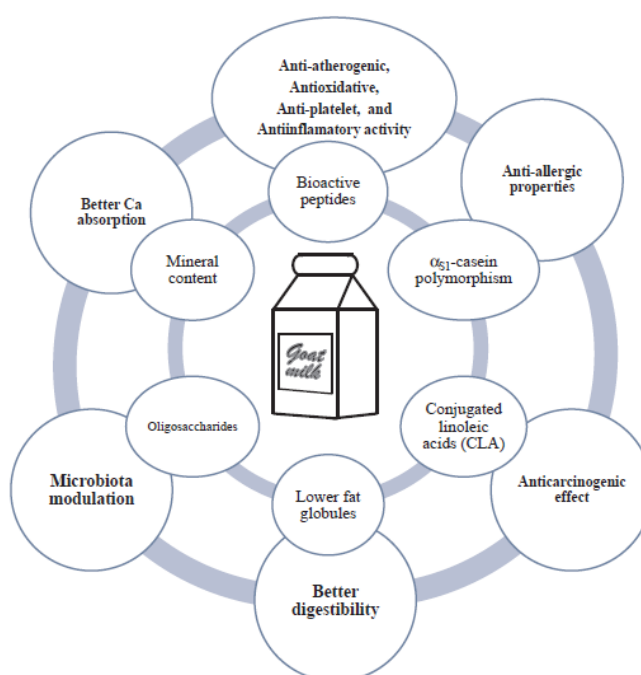


Fig.4: Summary of the main agents of the beneficial effects of goat milk.

Packed with High Nutrient Content

Goat's milk is rich in nutrients such as calcium, potassium, Vitamin A, and copper, to name a few. It is also known to have a slightly higher protein content as compared to cow's milk. Along with this, the protein profile of goat's milk is higher when compared to cow's milk. However, it is low in Vitamin B₁₂ and folate.

Beneficial for Kids with Cow's Milk Allergy

Did you know that around 3% of children suffer from cow milk allergies all over the world. It is a serious condition that can lead to various symptoms, right from diarrhea, vomiting, and stomachache to shortness of breath and anaphylaxis.

If this is the case with your child, then replacing it with Goat's milk can be a healthier option. This is because goat's milk has higher protein content as compared to cow's milk, and it has smaller fat particles, which helps in the easy digestion of the fats. Goat's milk also has lactose in it; however, the concentration is slightly lower than cow's milk.

Can Help Build Strong Bones

Milk contains two essential proteins, namely whey and casein. While whey is known to aid in muscle growth, casein aids in increasing calcium absorption by the small intestine[3]. Due to its higher content of casein, goat's milk is known to play an important role in building strong bones and maintaining bone mineral density, which is essential for a child's growth and development.

Easy on the Stomach

Goat's milk contains smaller fat particles, which can easily pass through the intestine and are easier to digest, hence light on the stomach. According to a study, the fat particles of goat's milk are almost 1/3rd the size of those present in cow milk. Moreover, goat's milk forms a soft and loose curd in the stomach, which eases the digestion process.

Acts as an Energy Booster

Growing kids need high-energy foods to keep up with their active lives. And a simple and healthy way to rejuvenate their energy level is to drink a cup of goat's milk. It acts as a great source of energy due to the presence of medium-chain fatty acids. As per research, medium fatty chains are the best to boost your metabolic activity, not just in kids but also in adults.

Shelf Life

Goats' milk of excellent flavor, bacteriological quality, and storage stability could be produced by pasteurizing fresh milk no more than 1 or 2 days old. Holding the chilled raw milk for several days before pasteurization, a common home and commercial practice, decreased the flavor quality both initially and during storage at 4 to 5°C. Pasteurization of raw goats' milk either at 63°C for 30 min or 72°C for 15 s within 1 d of milking ensures a better tasting product both initially and during storage at 4-5°C for 6 weeks than if the raw milk is aged for several days at 4-5°C before being pasteurized.

Conclusion

The main objective of this article is to achieve several goals. Goat milk is an excellent source of nutrients, and its by-products are considered a delicacy in many countries. As such, these products have gained market size due to the greater knowledge of goat's milk chemical composition, which is rich in high biological value proteins, essential fatty acids, high mineral bioavailability, and vitamin content. Nonetheless, the functional benefits of this food matrix remain unexplored by the dairy industry and consumers as a whole.

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Revolutionizing the Food Industry with Blockchain: Enhancing Transparency, Traceability, and Trust

Article ID: 71039

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Abstract

Blockchain technology has emerged as a transformative tool for various industries, including the food sector. The decentralized and immutable nature of blockchain ensures transparency, traceability, and efficiency in food supply chains. This research article explores the applications of blockchain technology in the food industry, its benefits, challenges, and future prospects. Additionally, the paper highlights real-world case studies and suggests potential areas for further research.

Introduction

The food industry is a vital sector that directly impacts global health and economies. However, it is plagued by several challenges, such as food safety concerns, fraudulent activities, inefficiencies in supply chains, and inadequate traceability mechanisms. The rising number of foodborne disease outbreaks and counterfeit food products has heightened consumer and regulatory concerns. To address these challenges, blockchain technology has emerged as a viable solution. By leveraging its decentralized and tamper-proof ledger system, blockchain provides a secure framework for recording transactions, tracking food products throughout their lifecycle, and ensuring supply chain transparency. This study explores how blockchain is transforming the food industry and bolstering consumer trust.

Blockchain Technology Overview

Blockchain is a form of distributed ledger technology (DLT) designed to record transactions securely and transparently. It consists of a chain of interconnected blocks containing transactional data that is encrypted and immutable. Key characteristics of blockchain technology include:

- 1. Decentralization:** Eliminates reliance on a central governing entity, reducing the risk of data manipulation.
- 2. Immutability:** Ensures that once data is recorded, it remains unalterable, thereby mitigating fraud and errors.
- 3. Transparency:** Enables all network participants to verify transactions, enhancing trust and accountability.
- 4. Smart Contracts:** Facilitates automated agreements, ensuring compliance and minimizing the role of intermediaries.

Applications in the Food Industry

Food Traceability: Blockchain technology allows real-time tracking of food products throughout the supply chain. This capability aids in identifying contamination sources swiftly and minimizing foodborne illness outbreaks. A notable example is Walmart's collaboration with IBM's Food Trust, where blockchain is used to monitor leafy greens and other perishable goods, significantly reducing the time needed to trace contamination sources.

Food Safety and Quality Assurance: By ensuring product authenticity, blockchain helps prevent counterfeiting and food fraud. The technology validates claims such as organic, non-GMO, and halal certifications, preventing false labeling. Consumers can also scan QR codes to verify product history and sourcing details.

Supply Chain Efficiency: Blockchain optimizes logistics and streamlines food supply chains by eliminating cumbersome paperwork and improving coordination among stakeholders, including farmers, manufacturers, distributors, and retailers. It also minimizes food wastage by enhancing inventory management and refining food transportation logistics.

Fair Trade and Ethical Sourcing: The integration of blockchain technology in fair trade initiatives ensures that farmers and laborers receive equitable compensation. It provides traceability for ethically sourced products, such as fair-trade coffee and cocoa, thereby fostering greater transparency in global trade practices.

Consumer Trust and Engagement: Blockchain enhances consumer confidence by enabling them to verify product authenticity, origin, and compliance with food safety regulations via QR codes. This level of transparency fosters brand loyalty and meets the growing demand for informed purchasing decisions.

Real-Life Implementations Underscore Blockchain's Transformative Impact

1. Walmart and IBM Food Trust: Walmart uses blockchain to trace the origin of leafy greens and other perishables. In one case, it reduced the time to track the source of mangoes from 7 days to just 2.2 seconds—an achievement that drastically improves food safety responses.

2. Nestlé's Use of OpenSC Platform: Nestlé partnered with OpenSC to track milk sourced from farms in New Zealand and palm oil in the Americas. This initiative helps ensure ethical sourcing and environmental sustainability.

3. Carrefour (France): Carrefour uses blockchain to trace poultry, eggs, cheese, milk, and other products. Consumers can scan QR codes on packaging to access real-time data on the product's origin, farming methods, and logistics.

4. Tea Board of India: In collaboration with blockchain firms, the Tea Board implemented blockchain technology to track the authenticity of Darjeeling tea exports, ensuring geographic indication (GI) compliance and preventing counterfeiting.

5. Bumble Bee Foods: The seafood company uses blockchain to track yellowfin tuna from the ocean to the plate. Consumers can verify information on where, when, and how the fish was caught by scanning a QR code.

These examples demonstrate how blockchain can restore trust, ensure quality, and enhance traceability across global food systems. As consumer demand for authenticity, safety, and sustainability continues to rise, blockchain is poised to play a central role in building a more transparent and reliable food ecosystem.

Challenges and Limitations

While blockchain presents significant advantages in the food industry, its implementation is accompanied by several challenges:

1. High Implementation Costs: The initial investment required for blockchain infrastructure, training, and technology adoption is substantial.

2. Scalability Concerns: Large-scale adoption demands significant computational resources and robust data management capabilities.

3. Integration with Legacy Systems: Many food businesses still rely on conventional supply chain management systems, making blockchain integration a complex process.

4. Regulatory and Compliance Issues: The absence of standardized global regulations poses hurdles in blockchain adoption across different regions.

Future Prospects

The adoption of blockchain in the food industry is poised for substantial growth, driven by technological advancements and evolving regulatory frameworks. Potential future developments include:

1. Integration with IoT: The combination of blockchain and smart sensors can enhance food monitoring by ensuring proper storage and transportation conditions.

2. AI-Powered Analytics: Artificial intelligence can leverage blockchain data to generate predictive insights, aiding in more efficient decision-making in supply chain operations.

3. Regulatory Harmonization: Governments may work toward establishing unified blockchain standards to streamline compliance with global food safety regulations.

Conclusion

Blockchain technology is redefining the food industry by fostering greater transparency, strengthening food safety measures, and improving supply chain efficiency. Despite the existing challenges, ongoing technological advancements and industry collaborations can help overcome these barriers. As consumer demand for food authenticity and sustainability continues to rise, blockchain will play an increasingly vital role in ensuring a reliable and transparent global food system.

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Terraforming Through Agriculture for a Long-Term Vision

Article ID: 71040

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Abstract

Terraforming- the process of turning an inhospitable environment into one that can sustain human life- has been a dream of scientists and science fiction writers for a long time. Although the idea usually evokes a vision of high technology fixes on Mars, this article discusses a more realistic approach: using agriculture as a main tool for terraforming. Based on recent breakthroughs in agronomy, biotechnology, and ecological engineering, here is a vision of long-term prospect in which sustainable agriculture becomes the basis for converting barren or degraded lands of the Earth and, perhaps, other planets into ecosystems.

Introduction

While humanity is confronted with unprecedented environmental challenges—climate change, desertification, and soil erosion—the need for restoring Earth's ecosystems is becoming more apparent. Meanwhile, settling other planets in the distant future is making rapid strides. In either scenario, agriculture becomes a leading force in terraforming. It is not merely a matter of producing food, but of reshaping landscapes, recycling nutrients, and regulating atmospheric conditions.

Terraforming, classically described within planetary science, refers to changing a planet's atmosphere, temperature, surface contours, and ecology to Earth-like. Complete planetary terraforming is theoretical, but localized and managed terraforming by agriculture is already underway on Earth and provides a template for extrapolation.

The Position of Agriculture in Environmental Altered States

1. Regeneration of Soils and Carbon Sequestration: Viable soil is the basis of any terraformed system. Regenerative agriculture practices including cover cropping, composting, and minimal tillage can refurbish degraded soil. Not only do these measures restore soil fertility but also carbon sequestration from the atmosphere, which can help stabilize climate. Technologies like biochar, mycorrhizal inoculation of fungi, and synthetic biology are utilized to hasten soil renewal.



Source: Parametrics Architecture

2. Water Management and Microclimate Creation: Agriculture has the potential to alter hydrological cycles. In dryland areas, rainwater harvesting, drip irrigation, and permaculture earthworks can restore fertility and moisture. Agroforestry systems also assist in creating microclimates by raising humidity, lowering surface temperatures, and bringing rainfall.

3. Photosynthesis and Atmospheric Balancing: By photosynthesis, plants absorb CO₂ and emit oxygen—two of the major ingredients of atmospheric engineering. Reforestation and increasing green cover on Earth can restore atmospheric balance. Genetically modified crops on extraterrestrial landscapes can perhaps do the same in the future by existing in marginal environments and gradually altering the atmosphere.

Terraforming Earth: A Precedent for Space

Africa's Great Green Wall project, meant to stop desertification throughout the Sahel region, is among the most ambitious terraforming agricultural projects on the planet. China's Loess Plateau restoration project also converted untillied land into arable land via integrated land management and sustainable agriculture.

These terrestrial projects demonstrate that it is possible to transform ecological wastelands into productive and habitable zones through long-term agricultural planning. The knowledge gained here will be invaluable when approaching terraforming on other planets.



Source: Istock

Terraforming Mars: A Future Through Agriculture

1. The Martian Challenge: Mars presents a hostile environment: extreme cold, low atmospheric pressure, high radiation, and no liquid water. Yet, it has resources—CO₂, sunlight, and regolith—that can be harnessed. Terraforming Mars would require creating green zones or “bio-domes” where agriculture can thrive under controlled conditions.

2. Closed-loop Agricultural Systems: Systems like hydroponics, aquaponics, and aeroponics provide soilless ways of producing food within closed systems. Vertical farming has the potential to optimize space usage, while photosynthesis based on LEDs can provide growth in low-light environments. These systems are already being explored for use in space missions.

3. Synthetic Biology and GMOs: To initiate biological cycles on Mars, synthetic biology may be employed to design plants that thrive in Martian environments—low gravity, high CO₂, and low water. These crops could fix nitrogen, photosynthesize under low light intensities, and even generate oxygen as a byproduct.

Challenges and Ethical Considerations

Terraforming any landmass—on our planet or elsewhere—has to be a responsible process. There are ethical concerns about planetary protection, ecological disturbance, and the dangers of importing Earth life onto extraterrestrial ecosystems. Likewise, on Earth, ill-conceived agricultural expansion has created biodiversity loss and water shortages in the past.

Thus, agro-terraforming needs to emphasize sustainability, inclusivity, and ecological integrity. Participatory land management, indigenous knowledge integration, and long-term monitoring are essential for success.

Policy, Research, and the Way Forward

Governments and research institutions need to invest in:

1. Climate-resilient crop breeding
2. Desert agriculture and saline farming
3. Monitoring soil health using AI and sensors
4. Space agriculture research programs (e.g., NASA VEGGIE, ESA MELiSSA)
5. Eco-restoration incentives for marginal lands.

Interdisciplinary collaborations among space agencies, agronomists, biotechnologists, and ecologists will be crucial in establishing a knowledge base for terraforming in the future. Universities need to integrate terraforming and space agriculture into agronomy and environmental science education.

Conclusion

Agriculture is more than a means of sustenance—it is a force for global transformation. Whether rejuvenating Earth's degraded environments or paving the way for Martian colonies, the ability of plants and soil to transform environments is staggering. Looking toward the stars, let us not lose sight of what we can learn from our own earth: terraforming starts with a seed.

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Push-Pull Strategy: A Game-Changer in Integrated Pest Management

Article ID: 71041

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Summary

Integrated Pest Management (IPM) represents a paradigm shift in pest control, advocating for an ecologically balanced, economically feasible, and socially acceptable approach. Within this framework, the *push-pull strategy* has emerged as a transformative innovation, employing behavior-modifying stimuli to manage agricultural pests in a sustainable manner. This review provides a comprehensive overview of the principles, ecological mechanisms, practical applications, benefits, constraints, and future prospects of the push-pull strategy, emphasizing its pivotal role in promoting resilient and climate-smart agricultural systems.

Introduction

Agricultural productivity worldwide is severely compromised by pest infestations, which lead to significant crop losses, food insecurity, and economic instability for farmers. Conventional methods of pest control—predominantly based on synthetic chemical pesticides—have yielded short-term benefits but at considerable ecological and human health costs. Issues such as pesticide resistance, pest resurgence, environmental pollution, and the decimation of non-target organisms underscore the urgent need for alternative, sustainable pest management practices. Integrated Pest Management (IPM) offers a holistic and multi-tiered approach to address these challenges by integrating biological, cultural, mechanical, and chemical tools in a coordinated manner. Within the IPM framework, the *push-pull strategy*—an innovative ecological tactic—has demonstrated remarkable efficacy in regulating pest populations while enhancing agroecological sustainability. By manipulating pest behavior through strategic deployment of repellent (“push”) and attractive (“pull”) stimuli, this method exploits the pest’s innate responses to create a hostile environment for infestation and reproduction. Its successful implementation in both subsistence and commercial farming systems, particularly in Africa and Asia, illustrates its scalability and adaptability.

Principles of the Push-Pull Strategy

The push-pull strategy operates on a behavioral ecology foundation, utilizing semiochemicals and plant interactions to simultaneously repel pests from the target crop and lure them toward trap crops or designated control zones.

1. Push Component: This involves deploying repellent plants or substances around or within the crop field to dissuade pests from colonizing or laying eggs. These may include leguminous plants like *Desmodium*, or plant-based essential oils and synthetic analogs that mimic alarm or deterrence signals.

2. Pull Component: Simultaneously, attractant crops or traps are planted around the field perimeter to lure pests away from the main crop. These “pull” elements—such as *Pennisetum purpureum* (Napier grass)—may act as decoy hosts, absorbing the pest pressure and serving as sites for mechanical or biological control interventions.

This dual-action mechanism creates a protective zone around the crop, reducing pest colonization and improving crop health with minimal reliance on chemical inputs.

Mechanisms Underpinning the Push-Pull Strategy

A wide array of ecological and biochemical interactions contribute to the success of the push-pull strategy. These mechanisms are grounded in a deep understanding of pest ecology, plant secondary metabolism, and trophic interactions.

1. Semiochemical Communication: The use of plant volatiles such as allelochemicals and pheromones plays a central role in manipulating insect behavior. For instance, *Desmodium* emits volatile organic compounds that repel stem borers while simultaneously suppressing *Striga* spp., a noxious parasitic weed (Hassanali et al., 2008).

2. Trap Cropping: Plants used as pull components serve as preferential hosts for pests, drawing them away from the crop of interest. These trap crops can also attract natural enemies or be treated with bio-insecticides to eliminate the pests.

3. Spatial Diversification (Intercropping): Alternating rows of push and pull plants within or around the main crop field help in redistributing pest pressure and complicating host location, thus reducing infestation rates (Barzman et al., 2015).

Enhancement of Natural Enemies: Many push-pull systems are designed to support populations of parasitoids and predators by providing habitat or floral resources, thereby amplifying natural biological control (Khan et al., 2014).

Real-World Applications in Agriculture

The push-pull strategy has demonstrated practical success across diverse cropping systems, particularly in resource-constrained and ecologically sensitive regions.

Cereal Systems (e.g., Maize and Sorghum): In Eastern Africa, a notable example is the *Desmodium-Napier* grass system, which has proven effective against stem borers (*Busseola fusca*, *Chilo partellus*) and *Striga hermonthica*. This model, promoted by the International Centre of Insect Physiology and Ecology (icipe), has significantly improved yields and soil fertility (Cook et al., 2007).

1. Vegetable Cultivation: Intercropping tomatoes with marigold (*Tagetes spp.*) or basil (*Ocimum spp.*) helps repel aphids, thrips, and whiteflies, enhancing pollinator activity and overall crop performance.

2. Fruit Orchards: Use of sex pheromone traps as pull devices combined with repellent companion planting (e.g., garlic, onion) has successfully reduced codling moth populations in apple orchards and fruit fly infestations in mango plantations.

3. Rice Farming Systems: In Asian rice paddies, push-pull has been adapted using plants like *Chrysopogon zizanioides* (vetiver grass) and neem-based repellents to manage brown planthoppers and rice stem borers.

4. Organic and Low-Input Farming: The strategy aligns seamlessly with organic agriculture principles, offering a non-chemical means of pest suppression while fostering ecosystem services such as pollination and nutrient cycling.

Advantages of the Push-Pull Strategy

The widespread adoption of push-pull technology offers multifaceted benefits that reinforce its value as a sustainable pest management solution:

1. Environmental Sustainability: Significant reduction in pesticide use protects water bodies, soil microbiota, and non-target beneficial insects, including pollinators and parasitoids.

2. Pest Resistance Management: By relying on behavioral and ecological controls rather than chemical toxicity, the strategy mitigates the risk of resistance development.

3. Agrobiodiversity Enhancement: Inclusion of diverse plant species contributes to habitat complexity, ecological stability, and resilience against climate variability.

4. Economic Benefits: Lower input costs, improved yields, and the additional utility of intercrops (e.g., fodder from Napier grass, nitrogen fixation by *Desmodium*) improve farmer profitability.

5. Multipurpose Utility: Besides pest management, the system provides soil cover, prevents erosion, suppresses weeds, and offers animal fodder—creating an integrated agroecological benefit.

Challenges and Constraints

Despite its success, several limitations hinder the universal application of the push-pull strategy:

- 1. Agroecological Specificity:** Effectiveness is contingent on local pest complexes, climate, soil types, and crop phenology, requiring customized designs.
- 2. Farmer Knowledge and Training:** Lack of awareness and technical capacity among smallholders can limit adoption. Establishing and maintaining push-pull systems demand initial labor and learning.
- 3. Environmental Variability:** Climatic fluctuations may alter the production of plant volatiles, affect pest migration patterns, and influence trap crop efficacy.
- 4. Scalability Issues:** Adapting push-pull methods to large-scale monoculture operations or mechanized farms presents design and management challenges.

Future Perspectives and Research Priorities

To unlock the full potential of the push-pull strategy, interdisciplinary and participatory approaches are essential:

- 1. Genomic and Biotechnological Advancements:** Genetic engineering of crops to express semiochemicals or resist pests can optimize the strategy. For instance, transgenic lines producing insect-repelling volatiles could substitute for push plants.
- 2. Climate-Smart Crop Varieties:** Developing repellent and trap crops with tolerance to heat, drought, or salinity will enhance resilience and consistency under climate stress.
- 3. Digital Integration:** Precision agriculture tools, including remote sensing, drones, and decision support systems, can monitor pest dynamics and optimize spatial configurations of push-pull systems.
- 4. Extension and Capacity Building:** Strengthening farmer field schools, knowledge-sharing platforms, and women-led outreach initiatives will support broader uptake.
- 5. Policy and Institutional Support:** Governments and development agencies must incorporate push-pull into national IPM strategies, offer financial incentives, and invest in participatory research and development (R&D).

Conclusion

The push-pull strategy exemplifies a cutting-edge, ecologically grounded innovation in Integrated Pest Management. By exploiting behavioral ecology and enhancing biodiversity, it provides an effective and environmentally safe alternative to chemical-intensive pest control. While challenges related to site specificity, awareness, and scalability remain, advances in agroecological research, biotechnology, and digital agriculture—coupled with strong policy support—can facilitate its mainstream adoption. As agriculture strives toward sustainability, food security, and resilience in the face of climate change, the push-pull strategy holds immense promise in shaping the future of pest management.

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White Fly as Vectors: Uncovering Their Role in Plant Disease Transmission

Article ID: 71042

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Summary

Whiteflies (Aleyrodidae) are among the most destructive agricultural pests due to their dual role as direct plant feeders and as highly efficient vectors of plant viruses. Chief among these is *Bemisia tabaci*, a complex of cryptic species responsible for the transmission of several devastating viruses, particularly geminiviruses, criniviruses, and torradoviruses. These viruses significantly impair crop productivity across a broad range of economically important species such as tomato, cotton, cassava, and beans. This review outlines the mechanisms by which whiteflies transmit plant viruses, highlights the major virus groups associated with whiteflies, and discusses the complex challenges in managing whitefly-transmitted diseases. Emerging integrated pest management strategies and innovative molecular approaches offer promising avenues for sustainable control.

Introduction

Whiteflies, belonging to the family *Aleyrodidae*, are diminutive sap-sucking insects that represent a substantial threat to global agriculture. Their significance arises not just from direct feeding damage but more critically from their capacity to act as vectors for plant pathogens, particularly viruses. Among the most damaging are geminiviruses, which alone are responsible for severe economic losses in a wide array of crops, including tomato, cassava, cotton, and legumes (Gilbertson et al., 2015). This review delves into the biological mechanisms underpinning virus transmission by whiteflies, the specific viral groups they disseminate, and the evolving challenges in curbing their impact on agriculture.



Whiteflies as Efficient Virus Vectors

Among the diverse species of whiteflies, *Bemisia tabaci*—notably the Middle East–Asia Minor 1 (MEAM1) and Mediterranean (MED) biotypes—has emerged as a particularly competent vector. This species complex transmits plant viruses predominantly in a *persistent, circulative* manner. In this mode, the virus is acquired during phloem feeding, traverses the gut barrier, circulates through the insect hemolymph, and ultimately accumulates in the salivary glands, from where it is introduced into new host plants during subsequent feeding events (Navas-Castillo et al., 2011). This sophisticated mechanism enhances the efficiency and longevity of transmission.

Major Virus Families Transmitted by Whiteflies

1. Geminiviruses (Family: Geminiviridae): Comprising single-stranded DNA viruses, geminiviruses such as *Tomato yellow leaf curl virus* (TYLCV) are persistently transmitted and can cause devastating crop failures.

2. Criniviruses (Family: Closteroviridae): These are RNA viruses transmitted in a semi-persistent manner, meaning they do not circulate or replicate within the vector. Examples include *Tomato chlorosis virus*, which leads to chlorosis and yield decline.

3. Torradoviruses (Family: Secoviridae): Although relatively recent in emergence, viruses like *Tomato torrado virus* are also vectored by whiteflies and are increasingly becoming a concern due to their destructive potential.

Mechanisms of Virus Transmission

Whiteflies utilize two primary virus transmission strategies:

- 1. Persistent-Circulative Transmission:** Characteristic of geminiviruses, this involves the internalization of the virus within the whitefly body. The virus crosses the midgut epithelium, circulates through the hemocoel, and is deposited in the salivary glands.
- 2. Semi-Persistent Transmission:** Viruses such as criniviruses are retained in the insect's foregut or stylet without systemic movement within the insect. They are typically retained for a shorter duration but can still be effectively transmitted.

The *B. tabaci* species complex is genetically diverse, comprising multiple cryptic species or biotypes with varying capacities to transmit specific viruses (De Barro et al., 2011). This diversity complicates both virus-vector interaction studies and control strategies.

Challenges in Management

Efforts to mitigate whitefly-transmitted diseases face several hurdles:

- 1. Insecticide Resistance:** The extensive and often indiscriminate use of chemical insecticides has led to the rapid evolution of resistance in many whitefly populations.
- 2. Rapid Viral Evolution:** High mutation and recombination rates in plant viruses make it difficult to develop long-lasting resistant crop varieties.
- 3. Global Trade and Mobility:** International movement of plant materials facilitates the dissemination of both whiteflies and the viruses they carry, making containment difficult.

Future Directions and Integrated Management Strategies

Sustainable management of whitefly-transmitted viruses necessitates the implementation of *integrated pest management (IPM)* approaches that combine various control tactics:

- 1. Biological Control:** Utilization of natural enemies such as parasitoid wasps (*Encarsia formosa*) and predatory insects shows promise in suppressing whitefly populations.
- 2. Resistant Varieties:** Breeding crop cultivars with resistance to whiteflies or their associated viruses is a long-term solution but requires continuous updates due to viral evolution.
- 3. Molecular Approaches:** Advanced tools like *RNA interference (RNAi)* are being explored to disrupt key genes involved in whitefly development or virus transmission.
- 4. Cultural Practices and Quarantine Measures:** Improved sanitation, crop rotation, and stringent control of plant movement can help minimize virus introduction and spread.

Conclusion

Whiteflies, particularly *Bemisia tabaci*, represent one of the most important insect vectors in agricultural systems due to their ability to efficiently transmit a broad spectrum of plant viruses. Their biology, adaptability, and interactions with a diverse viral community make them formidable adversaries in plant protection. Addressing the complex dynamics of whitefly-virus-host interactions through integrated, sustainable, and innovative approaches is essential for securing global crop productivity and food security.

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Rice Blast Disease: A Growing Concern for Food Security

Article ID: 71043

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Summary

Rice is a staple food for more than 3.5 billion people, serving as a primary source of nutrition and livelihood for millions worldwide. However, rice production faces severe challenges from diseases, with rice blast being the most destructive. Caused by the fungal pathogen *Magnaporthe oryzae*, this disease leads to substantial yield losses, economic strain on farmers, and long-term risks to food security. Effective management strategies are urgently needed to mitigate its impact.

Introduction

Rice (*Oryza sativa*) is one of the most culturally and economically significant crops, with a history spanning over 7,000 years. It thrives in diverse environments—from flooded paddies to upland fields—and supports millions of small-scale farmers, laborers, and traders. Beyond its nutritional value, rice holds cultural and religious importance, symbolizing prosperity and sustenance in many societies.

Despite its resilience, rice production is threatened by pests, diseases, climate change, water scarcity, and soil degradation. Among these, rice blast disease stands out as a major global concern, capable of destroying up to 30-50% of crop yields under favorable conditions. The fungus spreads through:

Airborne spores (primary mode of transmission):

1. Contaminated seeds
2. Infected plant debris
3. Irrigation of water

Addressing this disease is critical for ensuring stable rice production and global food security.

Symptoms of Rice Blast Disease

Symptoms vary depending on growth stage, environmental conditions, and rice variety.

1. Seedling Stage:

- a. Lesions on leaves and stems
- b. Yellowing or browning of leaves
- c. Wilting and death of seedlings.

2. Vegetative Stage:

- a. Spindle-shaped lesions with gray centers and dark brown edges
- b. Leaf blighting (large necrotic patches)
- c. Premature defoliation.

3. Reproductive Stage (Most Damaging)

- a. Panicle blast (infection of flowering structures)
- b. Blackened or discolored grains
- c. Empty or shriveled grains (reduced yield)
- d. Premature drying and breakage of panicles
- e. Severe infections can lead to complete crop loss, making early detection and management essential.

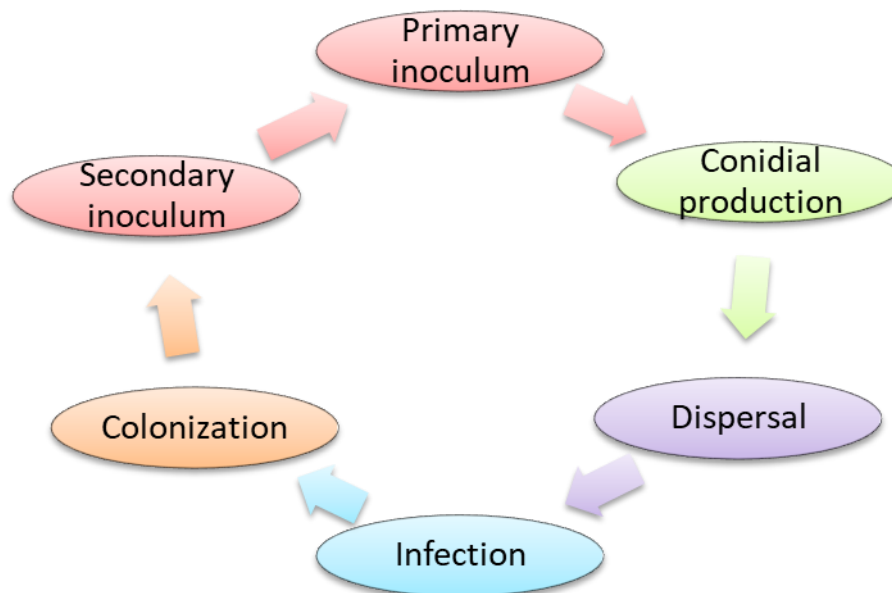
Epidemiology and Disease Cycle

Causal Agent:

Fungus: *Magnaporthe oryzae* (Anamorph: *Pyricularia oryzae*)

Transmission & Disease Cycle:

- Primary Inoculum: Survives in infected seeds, plant debris, or soil.
- Spore Production: Fungus produces conidia (spores) under humid conditions.
- Dispersal: Spores spread via wind, rain, or irrigation water.
- Infection: Spores enter through stomata or wounds, colonizing tissues.
- Secondary Spread: New spores form on lesions, repeating the cycle.



Key Epidemiological Factors

Factor	Influence on Disease
Temperature	20-30°C (optimal for infection)
Humidity	>80% RH favors spore germination
Rainfall	Prolonged leaf wetness promotes spread
Wind	Disperses spores over long distances
Crop Density	High density increases humidity & spread
Farming Practices	Excessive nitrogen, poor water management, and monocropping worsen outbreaks

Risk Factors in Blast Disease

1. Warm, humid climates (tropical & subtropical regions)
2. Overuse of nitrogen fertilizers (promotes lush, susceptible growth)
3. Continuous rice cropping (builds up fungal inoculum)
4. Use of susceptible varieties (lack of genetic resistance)
5. Poor field sanitation (infected residues left in fields)

Management Strategies

An integrated approach is crucial for sustainable control.

1. Cultural Practices:

- a. Crop rotation with non-host crops (e.g., legumes)
- b. Field sanitation (burn or bury infected residues)
- c. Balanced fertilization (avoid excess nitrogen)
- d. Proper water management (avoid prolonged leaf wetness)

2. Resistant Varieties:

- a. Plant blast-resistant cultivars (e.g., IR64, Swarna Sub1)
- b. Monitor for resistance breakdown (pathogen evolves rapidly)

3. Chemical Control:

- a. Fungicides (e.g., Tricyclazole, Azoxystrobin) at critical growth stages
- b. Rotate fungicides to prevent resistance

4. Biological Control:

- a. Antagonistic microbes (e.g., Trichoderma, Pseudomonas)
- b. Biofungicides for seed treatment

5. Forecasting & Early Warning:

- a. Weather-based prediction models
- b. Farmer alert systems for high-risk periods

6. Breeding & Genetic Resistance:

- a. Gene pyramiding (stacking multiple resistance genes)
- b. CRISPR & marker-assisted selection for durable resistance.

Conclusion

Rice blast disease poses a severe threat to global food security, with the potential to devastate yields and livelihoods. Combating this disease requires integrated management, including resistant varieties, proper agronomic practices, and timely fungicide use. Research, farmer education, and policy support are essential to safeguard rice production for future generations. By adopting sustainable and science-backed strategies, we can reduce blast disease impact and ensure stable rice supplies for the world's growing population.

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Mites as Vectors: Uncovering Their Role in Plant Disease Transmission

Article ID: 71044

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Summary

Mites, particularly those belonging to the subclass *Acari*, have emerged as critical vectors in the transmission of various plant pathogens, contributing significantly to global agricultural losses. This comprehensive review explores the biology and ecological behavior of plant-pathogenic mites, emphasizing their feeding morphology, host specificity, population dynamics, dispersal mechanisms, and their association with viral, bacterial, and fungal diseases. By elucidating these aspects, the review aims to support the development of sustainable, science-based pest management strategies. Furthermore, it highlights future research directions, including the application of molecular tools like RNA interference and the enhancement of integrated pest management (IPM) frameworks to effectively combat mite-borne plant diseases.

Introduction

Mites, microscopic arthropods classified under the subclass *Acari*, play a pivotal role in plant health due to their capacity to act as vectors for a wide range of plant pathogens, including viruses, bacteria, and fungi. Despite their diminutive size, their impact on global agriculture is substantial, often resulting in severe economic losses due to compromised crop yields and quality. The complex interactions between mites and their host plants, coupled with their ability to facilitate pathogen transmission, make them a significant concern in plant protection science. This review delves into the multifaceted biology of plant-pathogenic mites, focusing on their morphological adaptations for feeding, host-mite specificity, population dynamics across seasons, dispersal strategies, and a curated overview of major mite-transmitted crop diseases. A thorough understanding of these factors is critical for designing effective and sustainable pest and disease management protocols.



Feeding Organ and Morphology

Mites possess highly specialized feeding structures known as *chelicerae*, which range in length from approximately 15 to 40 micrometers. These needle-like mouthparts are adept at piercing plant epidermal tissues to access and extract cellular contents, resulting in direct mechanical injury and physiological disruption to the host. More importantly, this feeding activity serves as an efficient pathway for introducing pathogens into plant tissues. Different mite families exhibit variable feeding behaviors that influence their vector competence. For instance, eriophyid mites (*Eriophyidae*) are known for their refined piercing-sucking technique, while spider mites (*Tetranychidae*) possess stylet-like chelicerae adapted for mesophyll

extraction. Such variations not only determine the extent of plant damage but also affect the efficiency with which these mites transmit pathogens.

Host-Mite Relationships

The host specificity of mites varies significantly across different taxonomic families, influencing the epidemiology and geographical spread of the diseases they vector:

1. Eriophyid mites (*Eriophyidae*) display high host specificity, typically infesting only one or a few closely related plant species. This narrow host range often results in a strong co-evolutionary relationship between the mite and its plant host.
2. In contrast, members of the Tetranychidae, Tenuipalpidae, and Tarsonemidae families tend to exhibit a broader host range, feeding on a diverse array of plant species across different botanical families.

The degree of host selectivity plays a crucial role in determining the potential spread of mite-transmitted diseases. Generalist mite species may facilitate cross-crop disease transmission, whereas specialist mites often intensify the disease burden on specific crops.

Seasonal Occurrence

The population dynamics of phytophagous mites are profoundly influenced by seasonal and climatic variables:

1. Tropical and subtropical climates, characterized by consistently high temperatures and moderate humidity, provide optimal conditions for rapid mite reproduction and population buildup.
2. Conversely, rainy and winter seasons tend to suppress mite populations due to increased humidity, cooler temperatures, and limited availability of favorable host plants.

Understanding these seasonal fluctuations is essential for forecasting potential outbreaks and implementing timely interventions. For instance, pre-emptive control strategies can be aligned with anticipated population surges during hot and dry months, particularly in arid and semi-arid agricultural zones.

Dispersal Mechanisms

Mites utilize a combination of active and passive dispersal mechanisms to colonize new habitats and spread plant pathogens across broad geographic areas:

1. **Active dispersal** typically involves slow crawling over short distances within or between adjacent plants.
2. **Passive dispersal** mechanisms are more diverse and include:
 - a. **Ballooning** – the release of silk threads that catch the wind, allowing mites (especially eriophyids) to be transported over long distances.
 - b. **Phoresy** – the practice of hitchhiking on insects, birds, mammals, or even human clothing and farm machinery. This mode of transport enhances long-range dissemination and contributes to inter-farm spread of infestations.

These dispersal strategies significantly complicate management efforts, necessitating integrated approaches that target both mite populations and their potential vectors.

Mite-Transmitted Plant Diseases

Mites are known vectors of several economically important plant diseases, caused by viruses, bacteria, and fungi. A summary of these diseases and their respective vectors is presented below:

Viral Diseases:

Disease Name	Crop Affected	Vector Mite Species
Wheat streak mosaic virus	Wheat	<i>Aceria tulipae</i>
Wheat curl virus	Wheat	<i>Aceria tosichella</i>
Peach mosaic virus	Peach	<i>Eriophyes insidiosus</i>
Cherry mottle leaf virus	Cherry	<i>Eriophyes inaequalis</i>
Coffee ring spot virus	Coffee	<i>Brevipalpus phoenicis</i>

Black currant reversion virus	Black currant	<i>Eriophyes ribis</i>
Fig mosaic virus	Fig	<i>Aceria ficus</i>
Citrus leprosy virus	Citrus	<i>Brevipalpus californicus</i>

Bacterial Diseases:

Disease Name	Crop Affected	Vector Mite Species
Walnut blight	Walnut	<i>Eriophyes tristriatus</i>

Fungal Diseases:

Disease Name	Crop Affected	Vector Mite Species
Apple rust mite symptoms	Apple	<i>Phyllocoptes</i> spp.
Dutch elm disease	Elm	Oribatid & Tyroglyphid mites
Aspergillus flavus (Aflatoxin)	Groundnut	<i>Sancassania</i> sp.

Future Perspectives

To advance sustainable solutions against mite-transmitted plant diseases, the following areas of research and innovation merit focused attention:

- 1. Molecular characterization of mite-pathogen-plant interactions**, especially the mechanisms underlying pathogen acquisition and transmission.
- 2. Development of RNA interference (RNAi)-based technologies** aimed at silencing critical mite genes to curb their population growth and vector potential.
- 3. Strengthening Integrated Pest Management (IPM) frameworks**, incorporating biocontrol agents, resistant cultivars, and precision monitoring tools for proactive control.

Conclusion

Although minute in size, mites have outsized importance in plant health management due to their role in disease transmission. Their specialized feeding adaptations, varying degrees of host specificity, and efficient dispersal mechanisms make them potent agents in the spread of viral, bacterial, and fungal plant diseases. Seasonal variations and environmental conditions further compound the complexity of managing mite populations. Therefore, the integration of cultural, chemical, and biological control strategies is essential. Moreover, cultivating disease-resistant plant varieties and improving early detection methods can substantially mitigate the impact of these pests on agriculture.

Disease Detectives: Using Remote Sensing and GIS to Monitor Crop Health

Article ID: 71045

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Summary

Crop diseases pose a persistent threat to global food security by causing considerable yield losses and economic damage. Traditional methods of disease detection are often reactive, labor-intensive, and limited in spatial coverage. In contrast, Remote Sensing (RS) and Geographic Information Systems (GIS) have emerged as revolutionary tools that enable proactive, precise, and large-scale crop disease monitoring. This review critically explores the principles, methodologies, applications, and limitations of RS and GIS technologies in the context of plant disease detection and management. Supported by case studies from around the globe, it underscores the transformative potential of these technologies in reshaping modern agricultural practices and promoting sustainable crop production systems.

Introduction

Crop diseases account for a significant proportion of global agricultural losses, contributing to diminished food availability, economic instability, and heightened vulnerability among farming communities. In many developing nations, the problem is compounded by limited access to advanced diagnostics, skilled manpower, and timely interventions. Traditional approaches to disease detection, such as manual field surveys and laboratory testing, are inherently constrained by their spatial and temporal inefficiencies. Recent advancements in geospatial technologies—particularly Remote Sensing (RS) and Geographic Information Systems (GIS)—have revolutionized the surveillance of crop health. Remote sensing involves acquiring data about the Earth's surface without physical contact, utilizing satellite-based sensors, aerial imagery, or unmanned aerial vehicles (UAVs) to monitor vegetation characteristics over time. GIS, on the other hand, is a framework for gathering, managing, and analyzing spatial and geographical data, enabling sophisticated mapping and decision-making capabilities. The integration of RS and GIS empowers stakeholders—scientists, policymakers, and farmers alike—to detect disease outbreaks early, assess their spatial spread, evaluate risk levels, and implement targeted interventions. This synergy fosters data-driven agriculture, offering a scalable and sustainable alternative to traditional plant protection methods.

Remote Sensing Technologies in Crop Disease Detection

Remote sensing facilitates the non-destructive detection of plant stress by analyzing variations in spectral reflectance. Plant diseases often manifest through physiological changes—such as chlorophyll breakdown or altered transpiration—that can be captured across specific wavelengths of the electromagnetic spectrum (Mulla, 2013).

1. Spectral Indices for Disease Identification:

a. Normalized Difference Vegetation Index (NDVI): A widely used index that reflects the photosynthetic activity of plants. A decrease in NDVI values often signals stress due to disease or drought (Zhang & Kovacs, 2012).

b. Green NDVI (GNDVI) and Red Edge NDVI (RENDVI): These refined indices are more sensitive to early changes in chlorophyll content, offering improved detection of disease and nutrient deficiencies.

2. Advanced Sensing Modalities:

a. Multispectral and Hyperspectral Imaging: These technologies allow for detailed characterization of plant physiological status by capturing data across multiple or hundreds of

spectral bands. Hyperspectral sensors can identify disease-specific "spectral fingerprints," distinguishing between biotic and abiotic stresses (Calderón et al., 2013).

b. Thermal Infrared Imaging: Captures canopy temperature variations that may indicate transpiration changes associated with infection.

c. Synthetic Aperture Radar (SAR): Uses microwave signals to enable all-weather and day-night imaging, suitable for regions with persistent cloud cover.

Applications of Remote Sensing in Disease Management

1. Early Detection of Diseases: Timely identification of spectral anomalies linked to pathogens enables swift containment measures (Mulla, 2013).

2. Severity Assessment: Quantitative measures of disease intensity support precision treatment applications, such as site-specific pesticide use.

3. Environmental Monitoring: RS platforms can assess climatic variables like humidity, rainfall, and temperature, which are pivotal in predicting disease outbreaks.

4. Crop Stress Diagnosis: RS aids in differentiating between disease stress and other stressors such as drought, pest attacks, or nutrient deficiencies.

Role of GIS in Disease Mapping and Analysis

GIS is instrumental in translating remotely sensed data into actionable insights. It allows for the visualization, analysis, and interpretation of disease patterns across space and time.

Key Applications of GIS Include:

1. Disease Hotspot Identification: Mapping areas with high disease incidence to prioritize surveillance and intervention.

2. Risk Modeling: Integrating climatic, soil, and crop data to assess and predict vulnerability.

3. Temporal Analysis: Monitoring disease progression over time for trend analysis.

4. Data Layer Integration: Combining multiple datasets—vegetation indices, soil maps, climate data—for comprehensive decision-making.

Remote Sensing Platforms for Disease Surveillance

1. Satellite-Based Platforms: Such as Landsat, Sentinel-2, and MODIS offer extensive spatial coverage and temporal resolution, suitable for regional and national-level monitoring.

2. UAVs (Drones): Deliver ultra-high-resolution imagery ideal for field-level assessments and real-time monitoring (Tsouros et al., 2019).

3. Manned Aircraft: Serve as an intermediate platform, offering balance between coverage and resolution for large-scale precision agriculture.

Methodological Approaches in RS and GIS-Based Disease Monitoring

1. Multispectral and Hyperspectral Image Processing: For early detection and classification of disease types.

2. Thermal Mapping: Identifying stress zones through heat signatures.

3. SAR Data Integration: Enhancing cloud-penetrative monitoring capacity.

4. Machine Learning and AI Techniques: For automated classification and predictive modeling (Tsouros et al., 2019).

5. Dynamic GIS Layers: For real-time risk evaluation and decision support.

Synergistic Use of RS and GIS

The convergence of RS and GIS technologies fosters a holistic disease surveillance system capable of:

1. Predictive Modeling: Forecasting disease emergence based on climatic trends and crop phenology.

2. Dynamic Risk Assessment: Continuously updating risk zones for adaptive management.

3. Decision Support Systems (DSS): Facilitating data-driven recommendations for policy and field action.

4. Early Warning Systems: Integrating satellite and ground data with meteorological forecasts to issue timely alerts (Zhang & Kovacs, 2012).

Global Case Studies

1. Wheat Rust in East Africa: Integration of NDVI from satellite data and GIS tools helped forecast disease outbreaks, enabling preventive fungicide deployment.

2. Rice Blast in Southeast Asia: UAVs coupled with GIS were used to delineate infection zones, significantly reducing manual survey time.

3. Citrus Greening in the U.S.: Thermal imagery combined with spatial mapping allowed for focused monitoring and eradication efforts.

4. Potato Late Blight in Europe: Hyperspectral imaging and GIS analytics guided precision fungicide application, lowering costs and environmental impact.

Benefits and Opportunities

1. Proactive Disease Management: Early detection allows for timely intervention, reducing crop losses.

2. Large-Area Monitoring: Enables regional and national scale surveillance, unattainable through conventional means.

3. Precision Agriculture: Facilitates targeted chemical application, reducing input costs and environmental load.

4. Data-Driven Policy Making: Empowers governments and institutions with reliable information for contingency planning.

Challenges and Limitations

1. Resolution Limitations: Satellite data may lack the resolution needed for smallholder field detection.

2. High Costs: Acquisition and analysis of high-resolution imagery can be economically prohibitive.

3. Environmental Interference: Cloud cover and atmospheric conditions may affect optical sensor data.

4. Data Processing Requirements: High computational power and expertise are necessary for handling large datasets.

Future Directions

1. Artificial Intelligence and Machine Learning Integration: Enhancing classification accuracy and automating disease detection.

2. IoT-Enabled Networks: Real-time ground sensor data can be integrated with RS for improved validation.

3. High-Resolution Satellite Missions: Upcoming satellites will offer more frequent and finer-scale data acquisition.

4. Crowdsourced and Participatory GIS: Inclusion of farmer-generated data for ground-truthing and community-based surveillance.

Conclusion

The convergence of remote sensing and GIS technologies has ushered in a new era of precision and proactive plant disease management. While limitations remain, especially in terms of cost and data resolution, ongoing technological innovations—particularly in AI, sensor networks, and spatial analytics—are poised to overcome these challenges. By enabling early detection, spatial risk modeling, and data-driven interventions, RS and GIS significantly contribute to sustainable agricultural intensification and global food security.

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Harvesting Opportunities: Agro Eco-Tourism as a Path to Sustainable Rural Entrepreneurship

Article ID: 71046

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Summary

Agro-tourism, a fusion of agriculture and tourism, is emerging as a powerful tool for sustainable rural development. With India's agrarian roots and growing tourism sector, agro-tourism provides a unique opportunity to boost farmer incomes, preserve cultural heritage, and offer immersive experiences to urban visitors. This review explores India's current agricultural and tourism scenarios, highlights agro-tourism models and benefits, discusses policy support, and evaluates the challenges and future prospects of the sector.

Introduction

Tourism is one of the fastest-growing economic sectors globally, contributing 10.4% to the world's GDP and supporting 1 in 10 jobs (WTTC, 2022). India, with its vast geographic diversity, rich biodiversity, and a tapestry of cultural traditions, holds immense untapped potential to position itself as a leading agro-tourism destination. The tourism sector in India contributes 9.3% to the GDP and employs 8.1% of the total workforce (Vishwanath et al., 2022), showcasing its socio-economic significance.

At the same time, agriculture remains the backbone of the Indian economy, supporting nearly 70% of the rural population. Despite technological advancements and self-sufficiency in food production, the sector's GDP share has dwindled—from 57% in 1950 to approximately 18% today. This decline is primarily due to erratic climatic conditions, diminishing land holdings, rising input costs, and the lure of urban employment. Agro-tourism emerges as a synergistic solution, combining agriculture with hospitality, recreation, and education to forge new income streams and rejuvenate rural livelihoods.

The Current Agricultural Scenario

India's agricultural success is visible in its consistent food grain production, now surpassing 350 million tonnes annually. This achievement marks a milestone in ensuring national food security. However, structural and systemic issues continue to plague the sector:

- 1. Fragmented Landholdings:** A staggering 86% of Indian farmers are small and marginal, owning less than 2 hectares. This limits their capacity to invest in innovative practices or diversify income.
- 2. Monsoon Dependence:** Agriculture remains heavily reliant on rainfall, making it vulnerable to erratic weather patterns, droughts, and floods.
- 3. Profitability Challenges:** Increased input costs, fluctuating market prices, and limited market access reduce profitability and discourage youth from engaging in farming.

Agro-tourism can act as a supplementary income generator, allowing farmers to capitalize on their existing resources—land, knowledge, culture, and lifestyle—while also reducing dependence on crop yields alone.

Tourism in India: A Growing Sector

India's tourism industry has demonstrated robust growth in both domestic and international arrivals, contributing significantly to foreign exchange earnings. Although the COVID-19 pandemic temporarily disrupted travel trends, the recovery has been swift, driven by a growing preference for nature-centric, sustainable, and immersive travel experiences.

The post-pandemic traveler seeks authenticity—rural escapades, organic cuisine, farm life, and cultural immersion—making agro-tourism not just viable but highly appealing. This shift marks a pivotal moment to strategically develop and promote rural tourism ventures across the country.

Why Agro-Tourism?

Urban Disconnect from Rural Life: Urbanization has widened the gap between city dwellers and rural realities:

- Over one-third of urban Indians have no familial connection to rural areas, while nearly half have never experienced village life firsthand.
- Children grow up unfamiliar with farming, wildlife, and indigenous practices, resulting in a generational disconnect from nature.

Agro-tourism bridges this gap by providing experiential learning opportunities and fostering environmental awareness among visitors, especially youth.

Economic Benefits for Farmers: Agro-tourism ventures create alternate revenue streams through:

- Farm stays and eco-lodges:** Accommodating tourists in rustic, comfortable setups on farms.
- Workshops and demonstrations:** Hands-on participation in sowing, harvesting, composting, and cooking traditional meals.
- Sale of farm produce:** Direct marketing of fruits, vegetables, dairy, and homemade items like jams and pickles.

Moreover, these ventures generate local employment in hospitality, guiding, culinary services, and handicrafts—especially empowering rural women and youth.

Environmental & Cultural Preservation: Agro-tourism encourages sustainable practices and cultural pride:

- Promotes organic farming, soil conservation, rainwater harvesting, and eco-friendly technologies like solar energy and biogas.
- Helps revive traditional arts, folk music, dances, crafts, and culinary heritage, making culture a revenue-generating asset.

Agro-Tourism: Concept and Models

Definition & Principles: Agro-tourism involves visiting operational farms to participate in or observe farming activities, experience rural life, and connect with nature. It is based on three core principles:

- Something to See:** Livestock farms, crops in different stages, heritage tools, and local architecture.
- Something to Do:** Visitors engage in hands-on activities like feeding animals, harvesting, preparing meals, or learning traditional crafts.
- Something to Buy:** Tourists purchase fresh produce, seeds, traditional food items, handmade goods, or eco-products, adding to farmer income.

Global & Indian Market Trends

The global agro-tourism market, valued at USD 42.46 billion in 2019, is expected to reach nearly USD 63 billion by 2027, growing at a CAGR of 13.4%. In India, agro-tourism is growing rapidly at 20% annually. States like Maharashtra and Karnataka have pioneered agro-tourism models, offering templates for replication nationwide.

Successful Indian Models

Agro-Tourism Center	State	Key Attractions
Baramati Agro-Tourism	Maharashtra	Farm stays, bullock cart rides, grape harvesting
Akshayakalpa Farms	Karnataka	Organic dairy tours, biogas demonstrations
Dewalokam Homestay	Kerala	Spice plantation tours, bamboo rafting
Yatra Organic Farms	Assam	Tea tourism, tribal cuisine experiences

These examples illustrate the diversity of agro-tourism experiences across India's ecological and cultural zones.

Policy Support & Institutional Framework

Several states and institutions have begun promoting agro-tourism through targeted policies and financial assistance:

- 1. Maharashtra Agro-Tourism Policy (2020):** Introduced direct financial incentives and infrastructure support for farmers.
- 2. Karnataka Tourism Policy (2020–2026):** Encourages establishment of farm stays with specified land area and basic amenities.
- 3. NABARD and KVGB:** Offer subsidized loans, technical guidance, and startup support to farmers initiating agro-tourism businesses.

Such institutional support is critical to formalize agro-tourism and encourage participation at grassroots levels.

Challenges & Solutions

Challenge	Solution
Small landholdings	Cluster farming and farmer cooperatives
Lack of hospitality skills	Capacity-building and training by tourism boards
Inadequate infrastructure	Public-private partnerships (PPP) for roads, utilities
Low awareness	Digital campaigns, social media, travel agency tie-ups

Addressing these challenges systematically can unlock agro-tourism's potential on a national scale.

Future Prospects & Conclusion

Agro-tourism in India holds transformative potential. With digital innovations like virtual farm tours, agricultural games, and AI-powered rural navigation tools, the sector can cater to tech-savvy tourists. Integration of sustainable farming methods, renewable energy, and eco-tourism certification can further enhance credibility and appeal.

Looking ahead, agro-tourism can serve as a model for rural revival—preserving traditions, promoting responsible tourism, and empowering communities. The Indian tourism narrative is shifting—from sightseeing to sense-feeling, from monuments to millets, and from palaces to plantations. The true essence of India resides in its villages—and agro-tourism opens the gate.

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Sowing the Seeds of Change: Urban Agriculture for a Greener Future

Article ID: 71047

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Summary

Urban agriculture (UA) has emerged as a sustainable response to growing urbanization, food insecurity, and environmental degradation. By transforming vacant lands, rooftops, and community spaces into productive green areas, UA offers multifaceted benefits—ranging from improving urban food systems and reducing carbon footprints to fostering community engagement and enhancing biodiversity. This review explores the historical evolution, typologies, socio-economic impacts, technological advancements, and policy frameworks underpinning urban agriculture. It also addresses the challenges and proposes future directions for scaling UA as a central strategy in building greener and more resilient cities.

Introduction

As the global urban population is projected to rise from 4.4 billion in 2020 to over 6.7 billion by 2050 (UN DESA, 2018), ensuring food security and environmental sustainability in cities has become an urgent challenge. Urban agriculture (UA), defined as the cultivation, processing, and distribution of food in and around urban areas, is increasingly recognized as a transformative solution to these intertwined crises (FAO, 2020). Rooted in ancient practices yet revitalized by modern technological and socio-political contexts, UA contributes to food sovereignty, ecological sustainability, and urban resilience.

Historical Context and Evolution

Urban agriculture is not a new phenomenon. From the Hanging Gardens of Babylon to the victory gardens of World War II, growing food in urban spaces has deep historical roots. In modern contexts, cities like Havana, Detroit, and Nairobi have demonstrated how UA can support food systems during economic hardships and institutional transitions (Mougeot, 2005; Altieri et al., 1999).

Typologies and Practices of Urban Agriculture

Urban Agriculture (UA) takes on diverse forms, shaped by spatial constraints, technological advancements, and socio-economic factors. These variations allow UA to adapt to different urban environments, serving purposes ranging from food security to community engagement and sustainability. Below are some of the most common types of urban agriculture:

1. Backyard and Community Gardens: These are small-scale, decentralized farming systems that utilize private yards or shared communal plots. Backyard gardens allow individuals to grow food for personal consumption, while community gardens serve as collaborative spaces where residents collectively cultivate crops. These gardens foster local food production, environmental education, and social cohesion by bringing neighbors together around a shared purpose. They often incorporate organic practices, composting, and rainwater harvesting, promoting sustainable urban living.

2. Rooftop Farming: Rooftop farming transforms underutilized urban spaces—such as the tops of residential, commercial, or industrial buildings—into productive agricultural areas. Depending on structural capacity, these systems may employ:

a. Soil-based farming: Using raised beds or lightweight growing media to cultivate vegetables, herbs, or even fruit trees.

b. Hydroponics: A soilless method where plants grow in nutrient-rich water, reducing weight and increasing efficiency.

c. Greenhouses: Enclosed structures that extend growing seasons and protect crops from urban pollution and extreme weather.

Rooftop farms contribute to urban cooling, stormwater management, and local food accessibility while reducing the urban heat island effect.

3. Vertical Farming: A high-tech approach to UA, vertical farming involves growing crops in stacked layers or vertically inclined surfaces, often within controlled indoor environments. Pioneered by Despommier (2010), this method relies on:

- a. Artificial lighting (LEDs):** Optimized light spectra to enhance plant growth.
- b. Climate control:** Precise regulation of temperature, humidity, and CO₂ levels.
- c. Automated systems:** Robotics and AI for planting, monitoring, and harvesting.

Vertical farms maximize space efficiency, enabling year-round production with minimal land use. They are particularly valuable in densely populated cities with limited arable land.

4. Hydroponics and Aquaponics: These soil-less cultivation techniques are gaining popularity due to their high yields and efficient resource use:

- a. Hydroponics:** Plants grow in nutrient-enriched water, reducing water consumption by up to 90% compared to traditional farming (Goddek et al., 2019). This method is ideal for urban settings where soil quality is poor or space is limited.
- b. Aquaponics:** A symbiotic system combining hydroponics with aquaculture (fish farming). Fish waste provides nutrients for plants, while plants filter and clean the water for fish. This closed-loop system enhances sustainability by recycling water and minimizing waste.

Each of these UA typologies demonstrates how cities can integrate agriculture into their landscapes, addressing food security, environmental challenges, and social needs in innovative ways. The choice of method depends on factors such as available space, technological access, and community objectives, highlighting the adaptability of urban agriculture to diverse contexts.

Environmental Benefits of Urban Agriculture

1. Mitigation of Urban Heat Island (UHI): Urban green spaces, including UA installations, reduce surface and air temperatures through evapotranspiration and shading, thereby mitigating the urban heat island effect (Bowler et al., 2010).

2. Reduction of Food Miles and Emissions: By localizing food production, UA reduces the carbon footprint associated with transportation, storage, and packaging (Kulak et al., 2013).

3. Biodiversity Conservation: UA spaces support pollinators and other beneficial species, contributing to urban biodiversity (Lin et al., 2015).

Socio-Economic and Health Impacts

1. Food Security and Nutrition: Urban agriculture enhances access to fresh, nutritious, and culturally appropriate foods, especially in underserved neighborhoods (Zezza & Tasciotti, 2010).

2. Employment and Economic Development: UA generates green jobs in production, processing, and marketing, particularly among youth and marginalized groups (Armar-Klemesu, 2000).

3. Social Cohesion and Mental Health: Community gardens foster social inclusion, intergenerational exchange, and improved mental well-being through contact with nature (Hale et al., 2011).

Technological Innovations in Urban Agriculture

1. IoT and Smart Sensors: Monitor environmental parameters and automate irrigation/fertilization (Sharma et al., 2021).

2. LED Grow Lights: Optimize plant growth in indoor vertical farms.

3. GIS and Remote Sensing: Identify suitable sites and monitor productivity.

Policy and Institutional Frameworks

Effective UA promotion requires supportive policies including land-use planning, zoning regulations, subsidies, and educational programs. Cities like Toronto, Singapore, and Rosario (Argentina) have implemented progressive UA policies integrating food systems into urban planning (Dubbeling et al., 2010).

Challenges and Barriers

Despite its potential, UA faces several challenges:

- 1. Land Access and Tenure Insecurity:** Limited and expensive urban land restricts long-term investments.
- 2. Contamination Risks:** Heavy metals in urban soils necessitate monitoring and soil remediation (Defoe et al., 2014).
- 3. Policy Gaps and Bureaucratic Hurdles:** Inconsistent regulatory frameworks limit scalability.

Future Directions

To mainstream UA, the following strategies are crucial:

- 1. Integrated Urban Planning:** Embedding UA into city master plans and sustainability agendas.
- 2. Research and Innovation:** Developing region-specific low-cost technologies.
- 3. Community Engagement:** Strengthening participatory governance and urban-rural linkages.

Conclusion

Urban agriculture represents a promising pathway to build greener, healthier, and more equitable cities. By reimagining urban landscapes as productive ecosystems, UA not only addresses food insecurity and climate change but also reweaves the social fabric of cities. Collaborative efforts between policymakers, researchers, and communities are essential to scale its impact and sow the seeds of a sustainable urban future.

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Biofertilizers: A Natural Solution for Improving Soil Fertility

Article ID: 71048

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Summary

Soil fertility is fundamental to sustainable agricultural productivity, but the overreliance on chemical fertilizers has led to severe ecological consequences, including soil degradation, reduced microbial diversity, and water contamination. Biofertilizers, which consist of living microorganisms that enhance nutrient availability through natural processes such as nitrogen fixation, phosphate solubilization, and production of growth-promoting substances, offer an eco-friendly alternative. This review presents an in-depth overview of the types, mechanisms, benefits, and constraints of biofertilizers, with emphasis on their role in enhancing soil fertility and crop productivity. Recent advances in microbial biotechnology, formulation technologies, and policy frameworks are also discussed.

Introduction

Modern agricultural intensification has heavily relied on synthetic fertilizers to meet the food demands of a growing population. While effective in boosting yields, indiscriminate use of chemical fertilizers has led to soil acidification, nutrient imbalance, and environmental pollution (Tilman et al., 2002). Biofertilizers offer a sustainable and environmentally benign alternative. These are preparations containing live or latent microbial strains that colonize the rhizosphere and facilitate nutrient acquisition through biological processes (Vessey, 2003). Their application not only improves soil fertility but also promotes long-term soil health.

Classification and Types of Biofertilizers

Biofertilizers play a crucial role in sustainable agriculture by enhancing soil fertility and promoting plant growth through the action of beneficial microorganisms. These biofertilizers can be categorized based on the specific nutrients they mobilize and the functional groups of microbes involved. Below is an expanded elaboration on each category:

1. Nitrogen-Fixing Biofertilizers: Nitrogen is a vital nutrient for plant growth, and nitrogen-fixing biofertilizers help convert atmospheric nitrogen (N_2) into plant-available forms like ammonium (NH_4^+). These biofertilizers can be classified into two main types:

- a. Symbiotic Nitrogen Fixers:** These microorganisms form mutualistic associations with specific plants.
- b. Rhizobium:** Establishes root nodules in leguminous plants (e.g., soybeans, peas, lentils), where it fixes nitrogen in exchange for carbon from the host.
- c. Frankia:** Forms symbiotic relationships with actinorhizal plants (e.g., alder, casuarina), fixing nitrogen in root nodules similar to Rhizobium.
- d. Non-symbiotic (Free-living) Nitrogen Fixers:** These microbes fix nitrogen independently in the soil without forming direct plant associations.
- e. Azotobacter:** A free-living aerobic bacterium that enhances nitrogen availability in the rhizosphere while also producing growth-promoting substances.
- f. Azospirillum:** Colonizes the root surfaces of cereals (e.g., wheat, maize) and grasses, improving nitrogen uptake and root development.
- g. Clostridium:** An anaerobic bacterium that contributes to nitrogen fixation in waterlogged or low-oxygen soils.

These microbes utilize the nitrogenase enzyme to break the strong triple bond of N_2 , converting it into ammonia (NH_3), which is further transformed into ammonium (NH_4^+) for plant absorption.

2. Phosphate-Solubilizing Microorganisms (PSMs): Phosphorus (P) is often present in soils in insoluble forms, making it inaccessible to plants. PSMs solubilize fixed phosphorus through biochemical processes:

Mechanism of Action: Secretion of organic acids (e.g., gluconic, citric, oxalic acids) chelates cations (Ca^{2+} , Fe^{3+} , Al^{3+}) bound to phosphate, releasing soluble orthophosphates (H_2PO_4^-). Production of phosphatase enzymes that mineralize organic phosphorus into plant-available forms.

Key Microorganisms:

- a. *Pseudomonas* spp.:** Highly efficient in solubilizing inorganic phosphates and suppressing soil-borne pathogens.
- b. *Bacillus* spp.:** Enhances phosphorus availability while promoting plant growth through additional mechanisms like siderophore production.
- c. *Aspergillus* and *Penicillium* (Fungi):** Acid-producing fungi that effectively solubilize rock phosphate in acidic and neutral soils.

3. Potassium and Zinc Solubilizers: Potassium (K) and zinc (Zn) are essential micronutrients often locked in mineral forms (e.g., feldspar, mica, zinc oxide). Certain microbes release these nutrients through solubilization:

Potassium-Solubilizing Microbes (KSMs):

- a. *Bacillus mucilaginosus*:** Produces organic acids and polysaccharides to break down potassium-bearing minerals like illite and orthoclase.
- b. *Frateriia aurantia*:** A highly efficient potassium mobilizer, particularly beneficial for crops like bananas and potatoes.

Zinc-Solubilizing Microbes: *Bacillus subtilis*, *Pseudomonas* spp.: Secrete organic acids that dissolve zinc oxides and carbonates, improving Zn uptake in crops like rice and wheat. These microbes enhance soil fertility by converting fixed K and Zn into plant-absorbable ions (K^+ and Zn^{2+}), preventing deficiencies that limit crop yield.

4. Mycorrhizal Fungi: Arbuscular mycorrhizal fungi (AMF), such as *Glomus* and *Gigaspora* species, form symbiotic relationships with ~80% of terrestrial plants.

Functions:

- a. Phosphorus Uptake:** Extends hyphal networks beyond root zones, accessing distant phosphorus pools.
- b. Water Retention:** Improves drought resistance by enhancing soil aggregation and water-holding capacity.
- c. Stress Resistance:** Protects plants from heavy metal toxicity and salinity stress.
- d. Disease Suppression:** Competes with pathogenic fungi, reducing root infections.

The plant supplies carbohydrates to the fungus in exchange for nutrients, making this a highly efficient mutualistic system.

5. Plant Growth-Promoting Rhizobacteria (PGPR): PGPR are beneficial bacteria that colonize the rhizosphere and directly or indirectly stimulate plant growth through multiple mechanisms:

Direct Mechanisms:

- a. Phytohormone Production:** Synthesis of auxins (IAA), cytokinins, and gibberellins that enhance root branching and shoot growth.
- b. Nitrogen Fixation:** Some PGPR (e.g., *Azospirillum*) fix nitrogen non-symbiotically.
- c. Nutrient Solubilization:** PSMs and KSMs often exhibit PGPR traits.

Indirect Mechanisms:

- a. Biocontrol:** Antibiotic production (e.g., 2,4-diacetylphloroglucinol by *Pseudomonas*) suppresses pathogens.
- b. Induced Systemic Resistance (ISR):** Activates plant defense mechanisms against pests and diseases.
- c. Siderophore Production:** Sequesters iron, limiting its availability to pathogenic microbes.

Common PGPR Genera:

- a. *Bacillus*:** Forms spores that survive harsh conditions, making it a robust biofertilizer.

- b. *Pseudomonas*: Highly versatile, with strains that solubilize phosphorus, produce antibiotics, and induce stress tolerance.
- c. *Streptomyces*: Known for antifungal properties and promoting root development.

Mechanisms of Action

Biofertilizers enhance plant growth and soil fertility through multiple pathways:

1. **Biological Nitrogen Fixation (BNF)**: Conversion of atmospheric N_2 to NH_4^+ .
2. **Phosphate Solubilization**: Organic acid production lowers soil pH and releases bound P.
3. **Production of Plant Hormones**: Auxins, cytokinins, and gibberellins enhance root development.
4. **Siderophore Production**: Chelation of iron suppresses pathogen proliferation.
5. **Induced Systemic Resistance (ISR)**: Strengthens plant defenses against biotic stressors (Lugtenberg & Kamilova, 2009).

Benefits of Biofertilizers

1. **Sustainable Soil Fertility**: Improves nutrient cycling and organic matter dynamics.
2. **Reduced Chemical Input**: Decreases dependence on synthetic fertilizers.
3. **Improved Crop Yield and Quality**: Enhances nutrient uptake and plant health.
4. **Environmental Safety**: No risk of groundwater contamination or heavy metal accumulation.
5. **Economic Viability**: Cost-effective and accessible to smallholder farmers.

Constraints and Challenges

Despite their potential, biofertilizers face several adoption challenges:

1. **Short Shelf-life and Storage Sensitivity**: Microbial viability declines under heat and desiccation.
2. **Variable Field Performance**: Influenced by soil pH, moisture, and native microbial competition.
3. **Poor Awareness and Extension Support**: Limited farmer knowledge on use and benefits.
4. **Lack of Quality Control**: Variability in product quality and microbial counts in commercial formulations (Rai, 2006).

Technological Advances

Recent innovations have improved biofertilizer efficacy:

1. **Carrier-Based and Liquid Formulations**: Enhance shelf-life and field viability.
2. **Consortium Inoculants**: Combine multiple functional microbes for synergistic effects.
3. **Microbial Genomics and Synthetic Biology**: Help identify elite strains and engineer stress-tolerant microbes (Bhattacharyya & Jha, 2012).

Conclusion

Biofertilizers present a powerful tool for sustainable soil fertility management and agricultural productivity enhancement. Their integration into conventional and organic farming systems can reduce ecological footprints, restore soil health, and empower farmers. Future efforts should focus on improving product quality, farmer training, and supportive policy frameworks to unlock their full potential.

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Boosting Crop Potential: The Benefits of Bio-Stimulants in Agriculture

Article ID: 71049

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Summary

In the context of sustainable agriculture and climate-resilient crop production, biostimulants have emerged as promising agents that enhance plant growth, stress tolerance, and nutrient use efficiency without directly acting as fertilizers or pesticides. These substances—comprising microbial inoculants, humic substances, protein hydrolysates, seaweed extracts, and more—function by modulating plant physiological processes. This review explores the various categories of biostimulants, their mechanisms of action, their impact on plant productivity and stress tolerance, and recent regulatory developments. Scientific evidence and global trends suggest that integrating biostimulants into crop production systems can substantially improve agricultural sustainability and resilience.

Introduction

Modern agriculture faces numerous challenges including soil degradation, nutrient inefficiency, and climate-induced stress. While conventional agrochemicals have boosted food production, they have also contributed to environmental and health concerns. In this context, plant biostimulants have gained attention as eco-friendly products that stimulate natural plant processes to enhance nutrient uptake, abiotic stress tolerance, and overall crop quality and yield (du Jardin, 2015). Unlike fertilizers or pesticides, biostimulants do not supply nutrients or control pests directly but work synergistically with soil and plant systems to improve performance.

Definition and Regulatory Landscape

Biostimulants are natural or synthetic substances that enhance plant growth, nutrient uptake, stress tolerance, and crop quality without directly providing nutrients like fertilizers. They work by stimulating biological processes in plants and soil, improving efficiency in nutrient use, water retention, and resilience against environmental stresses. Below is an expanded and detailed discussion of the major categories of biostimulants.

1. Humic and Fulvic Acids: Humic and fulvic acids are vital components of soil organic matter, playing a crucial role in improving soil structure, enhancing nutrient availability, and stimulating root growth. Derived from the decomposition of organic matter, humic substances increase soil porosity, aeration, and water retention, facilitating healthy root development. Fulvic acids, being smaller molecules, can easily penetrate plant cells, enhancing nutrient transport and promoting overall plant health (Nardi et al., 2002).

2. Seaweed Extracts: Seaweed extracts, particularly those derived from brown algae like *Ascophyllum nodosum* and *Ecklonia maxima*, are rich in polysaccharides, phytohormones, and antioxidants. These bioactive compounds stimulate seed germination, enhance photosynthesis, and promote stress resilience in plants. By applying seaweed extracts, farmers can improve crop yields, enhance plant growth, and increase resistance to environmental stresses. (Craigie, 2011).

3. Protein Hydrolysates and Amino Acids: Protein hydrolysates and amino acids are derived from the enzymatic or chemical hydrolysis of plant or animal proteins. These compounds serve as nitrogen sources and signaling molecules, enhancing nitrogen assimilation and metabolic activity in plants. By providing readily absorbable nitrogen, protein hydrolysates promote plant growth, improve yields, and reduce the need for synthetic fertilizers (Colla et al., 2015).

4. Microbial Biostimulants: Microbial biostimulants, including Plant Growth-Promoting *Rhizobacteria* (PGPR) like *Azospirillum* and *Bacillus*, and mycorrhizal fungi, play a vital role in improving nutrient availability and protecting plants against stress. These beneficial microorganisms fix nitrogen, solubilize

phosphorus, and produce phytohormones, promoting healthy plant growth and development. By harnessing the potential of microbial bio-stimulants, farmers can reduce their reliance on chemical fertilizers and promote sustainable agriculture practices (Rouphael & Colla, 2020).

5. Chitosan and Other Biopolymers: Chitosan, a biopolymer derived from chitin, possesses bio-stimulant and elicitor properties, stimulating defense responses in plants and enhancing tolerance to drought and pathogens. By activating defense pathways, chitosan promotes plant resistance to diseases and environmental stresses, reducing the need for chemical pesticides. As a natural and biodegradable compound, chitosan offers a promising solution for sustainable agriculture, promoting healthy plant growth and reducing environmental impact (El Hadrami et al., 2010).

Mechanisms of Action

Biostimulants act through a wide range of physiological and molecular mechanisms:

1. Enhancement of root growth and architecture via auxin-like activity
2. Modulation of plant hormone signaling (ABA, auxins, cytokinins)
3. Upregulation of antioxidant enzymes (SOD, CAT, POD)
4. Improvement of nutrient uptake and translocation
5. Priming of plant defense mechanisms against abiotic stress (Rouphael et al., 2018).

Benefits of Biostimulants in Agriculture

1. Enhanced Nutrient Use Efficiency (NUE): Biostimulants improve nutrient uptake efficiency, thereby reducing the need for chemical fertilizers. This is critical in regions facing nutrient depletion and high fertilizer costs (Calvo et al., 2014).

2. Improved Abiotic Stress Tolerance: They mitigate oxidative damage under drought, salinity, and temperature extremes by enhancing antioxidant responses and osmolyte accumulation (Yakhin et al., 2017).

3. Yield and Quality Improvement: Several field studies have demonstrated yield gains and quality improvements such as increased sugar content, color, or shelf-life in horticultural crops (Halpern et al., 2015).

4. Environmental and Economic Sustainability: Reduction in agrochemical usage lowers environmental risks and promotes a more sustainable, climate-resilient agricultural system.

Case Studies and Applications

1. Application of *Ascophyllum nodosum* extract in tomatoes improved fruit yield and enhanced chlorophyll content under heat stress (Shukla et al., 2019).

2. Use of protein hydrolysates in lettuce cultivation improved biomass and nitrogen efficiency even under reduced nitrogen inputs (Colla et al., 2014).

3. Inoculation with PGPRs enhanced phosphorus uptake and drought tolerance in maize (Backer et al., 2018).

Challenges and Future Prospects

Despite their benefits, biostimulants face regulatory, scientific, and market challenges:

1. Lack of standardization in formulations and efficacy data
2. Complexity of biological modes of action
3. Inconsistent performance due to environmental variability
4. Need for multi-omics and precision agriculture approaches to tailor applications

Future advancements in metabolomics, transcriptomics, and machine learning will be key to unlocking the full potential of biostimulants and integrating them into precision farming systems (Rouphael & Colla, 2020).

Conclusion

Biostimulants are emerging as powerful tools to sustainably boost crop performance, nutrient efficiency, and resilience to abiotic stresses. Their adoption is aligned with the goals of eco-intensification and climate-smart agriculture. As regulatory frameworks mature and research expands, biostimulants are expected to become a mainstream component of sustainable crop production strategies globally.

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Blockchain in Agriculture: Enhancing Transparency, Security, and Efficiency

Article ID: 71050

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Summary

The agricultural sector, a vital component of the global economy, faces persistent challenges such as fragmented supply chains, limited transparency, and operational inefficiencies. These issues hinder productivity, reduce profitability for farmers, and erode trust among stakeholders, including producers, distributors, retailers, and consumers. Traditional agricultural systems often rely on centralized databases, paper-based records, and manual verification processes, which are prone to errors, fraud, and delays. Blockchain technology, with its decentralized, immutable, and transparent ledger system, presents a groundbreaking solution to these challenges. By enabling secure and tamper-proof record-keeping, blockchain can revolutionize agricultural operations, ensuring greater accountability and efficiency across the value chain. This review explores the diverse applications of blockchain in agriculture, emphasizing its role in enhancing transparency, security, and operational efficiency. Key areas of focus include supply chain traceability, smart contracts for fair trade, land ownership verification, crop and weather insurance, sustainable resource management, and agri-finance accessibility. Additionally, the paper examines real-world case studies, identifies barriers to adoption, and outlines future research directions to maximize blockchain's potential in agriculture.

Introduction

Agriculture remains a fundamental driver of economic growth, food security, and rural livelihoods worldwide. However, the sector struggles with inefficiencies such as disjointed supply chains, lack of real-time data sharing, and weak enforcement of fair trade practices. These problems lead to food safety concerns, financial losses for farmers, and difficulties in verifying product authenticity. Blockchain technology, originally developed for cryptocurrencies like Bitcoin, has evolved into a versatile tool for enhancing trust and efficiency in various industries. In agriculture, blockchain's decentralized architecture, cryptographic security, and smart contract functionality can address systemic inefficiencies by enabling real-time tracking, automated transactions, and fraud-resistant record-keeping (Lv et al., 2023).

Blockchain Fundamentals in Agriculture

Blockchain operates as a distributed ledger where transactions are recorded across multiple nodes, ensuring data integrity and transparency. Key features that make blockchain suitable for agriculture include:

- 1. Decentralization:** Eliminates reliance on a single authority, reducing risks of manipulation.
- 2. Immutability:** Once recorded, data cannot be altered, preventing fraud in supply chains and financial transactions.
- 3. Transparency:** All authorized stakeholders can access verified data, fostering trust.
- 4. Smart Contracts:** Self-executing agreements that automate processes like payments upon fulfillment of predefined conditions (Srivastava et al., 2023).

Applications of Blockchain in Agriculture

1. Supply Chain Transparency and Traceability Blockchain enables end-to-end traceability of agricultural products, ensuring food safety and quality. By recording every transaction from farm to fork, stakeholders can verify the origin and handling of products. For instance, IBM Food Trust has been utilized to trace food products, enhancing transparency and consumer trust (Francisco & Swanson, 2018).

2. Smart Contracts for Fair Trade: Smart contracts automate transactions based on predefined conditions, ensuring timely payments and reducing disputes. They can be used to enforce fair trade practices, where farmers receive payments upon meeting certain quality or delivery standards (Doshi et al., 2024).

3. Land Ownership and Records: Blockchain can secure land records by providing an immutable and transparent ledger of ownership. This reduces disputes and fraud, especially in regions where land titles are contested or poorly documented (Awan et al., 2023).

4. Weather and Crop Insurance: Blockchain facilitates the development of parametric insurance products, where payouts are automatically triggered based on predefined weather conditions or crop yields. This ensures timely compensation for farmers affected by adverse conditions (Awan et al., 2023).

5. Sustainable Resource Management: By integrating blockchain with IoT devices, farmers can monitor resource usage such as water and fertilizers. This data can be recorded on the blockchain, promoting sustainable practices and enabling stakeholders to track environmental impact (Tan & Zhang, 2021).

6. Agri-finance and Credit Access: Blockchain can provide farmers with a transparent credit history, facilitating access to loans and financial services. By recording transactions and production data, financial institutions can assess creditworthiness more accurately (Akella et al., 2023).

Case Studies

1. IBM Food Trust enhances traceability in food supply chains (Lv et al., 2023).
2. OpenSC by WWF tracks ethically sourced products, starting with seafood (Wired, 2019).
3. Sourcing's Impact and Assurance Program links cotton farmers directly with brands (Vogue Business, 2024).

Challenges and Limitations

Challenges include scalability, digital infrastructure, standardization, and privacy concerns (Srivastava et al., 2023).

Future Prospects and Research Needs

Future research should focus on developing scalable solutions, improving accessibility, establishing standards, and ensuring data privacy (Lv et al., 2023).

Conclusion

Blockchain technology offers transformative potential for the agricultural sector by enhancing transparency, security, and efficiency. Its applications span supply chain management, financial services, and sustainable farming. While challenges exist, ongoing research and technological advancements are paving the way for more resilient and equitable agricultural systems.

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Kewda Source of Liquid Gold

Article ID: 71051

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Abstract

The *Pandanus fascicularis* (Kewda), native to India and Southeast Asia, is a plant of immense economic and cultural significance, primarily due to its fragrant male flowers used in the production of Kewda attar, water and oil. Cultivated mostly in the Ganjam district of Odisha, this plant thrives in coastal, humid conditions and offers a range of culinary, medicinal, and traditional uses. Its labor-intensive hydro-distillation process yields highly valued essential oils and floral waters that contribute to both domestic and international fragrance markets.

Introduction

The Indian Ayurvedic plant (kewda) *Pandanus* sps. belongs to the family Pandanaceae, with chromosome number $2n = 60$ (1 species of *Pandanus*, *P. spiralis* has $2n = 120$). Native to South Asia and India, consists of 600 species distributed mainly in subtropical and tropical regions. The pandanus derives from 'Pandan', a Malayan word means 'conspicuous'. About 600-650 species are widely distributed in moist areas of world, kewda is most widespread species recorded from Mauritius Islands in West to Polynesian island in East. The greatest number of species are found in Madagascar and Malaysia. In India there are around 30 to 40 species of which *Pandanus fascicularis* Lam., is most common one known as Kewda or Kiya, widely distributed over coastal districts of Orissa, Andhra Pradesh, Tamil Nadu and in parts of Uttar Pradesh. The plant is characterized by its long, narrow, spiny saw edged leaves that spiral around the stem, resembling a screw hence the name "**Screw pine**". The commercially cultivated pandanus is *P. fascicularis* due to production of Kewda perfume from its male spadices, exploited mainly in Ganjam district of Odisha, accounting of about 90% of India and 50% of world production.

Distribution

Naturally pandanus distributed in high water marking areas at the edge of the sea and near coastal forests in Southeast Asia, including the Philippines and Indonesia, extending Eastward through Papua New Guinea and Northern Australia and throughout the pacific ocean beaches, where it can withstand drought salty spray and strong wind.

Botanical Description

Kewda is a palm-like evergreen tree, grows upto 20 metres height, have an upright trunk that is smooth with many horizontal spreading branches with annular leaf scars, supported by prop root system. At the end of each branch, spiral cluster of long, linear leaves with a pectinate (comblake) edge tapering to a long point at the apex.

Leaves: are long, narrow can be up to 2 metres long and 3 to 11 centimetres broad, parallel veined palm like leaves with spiny margins and midribs that are produced in tufts at the branch tips in three or four, the old leaf scars spiral around the branches and trunk, like a screw that give the common name screw pine to these plants.

Flowers: It is dioecious, with the female and male reproducing structures occurring on different plants. Flowers are simple, petalless, usually densely clustered and either male or female, sexes being produced on different plants. Individual plants are either male producing microspores or female producing megaspores. The male tree flowers are grouped in 3 and gathered in large clusters 2–3 cm surrounded by narrow white bracts known as racemes, are small with 8–12 stamens inserted pseudo-umbellately. The

female tree produces flowers which has 3–8 celled ovary crowned by a sessile stigma give rise to round fruits that are also bract-surrounded resemble pineapples, typically flower 1 to 3 times per year while male trees will flower every 2 months. This plant being unisexual allows it to cross-fertilize with other screwpines.

Pollinators: Small insects, such as bees and wind are usually the pollinators. It takes 1 to 2 years from pollination to produce fruit on female trees.

Fruits: are called as drupes, heavy ball-shaped or cone like aggregates produced by the coalescence of the developing ovaries of many adjacent flowers. Each drupe has 2-9 seeds. Hollow spaces inside the fruits enable them to float, thus aiding in distribution. The fruit-heads are very variable, but usually stand out by being up to 20 cm wide and containing 100-200 drupes.

Nut: Each drupe containing as many cells as there are divisions on the apex of the drupe.

Uses of Pandanus

Culinary use: Most well-known use of pandanus is in cooking. The leaves, particularly from the species *Pandanus amaryllifolius* are prized for their unique aroma and flavor. The scent of pandan is often described as a blend of vanilla, almond and freshly cut grass, which makes it a staple in Southeast Asian cuisine.

- a. Pandan leaves used to flavor rice dishes, especially in countries like Thailand, Indonesia, and Malaysia. Pandan-infused rice, known as "**nasi pandan**," a popular dish that combines the fragrant leaves with coconut milk and jasmine rice.
- b. The extract from pandan leaves is used as food coloring and flavoring agent in cakes and pastries to savory curries, and also a common ingredient in beverages like **pandan tea**.

Medicinal use: The plant is known for its **anti-inflammatory**, **antioxidant**, and **analgesic** properties, which make it useful for treating a variety of ailments. The leaves contain beneficial compounds that may help reduce inflammation and promote overall health. Pandanus tea is sometimes used to alleviate indigestion and improve digestion.

Cultural and traditional use: Pandanus has deep roots in the cultures of the Pacific Islands and Southeast Asia, where it is not only a food source but also a key material in traditional crafts and rituals.

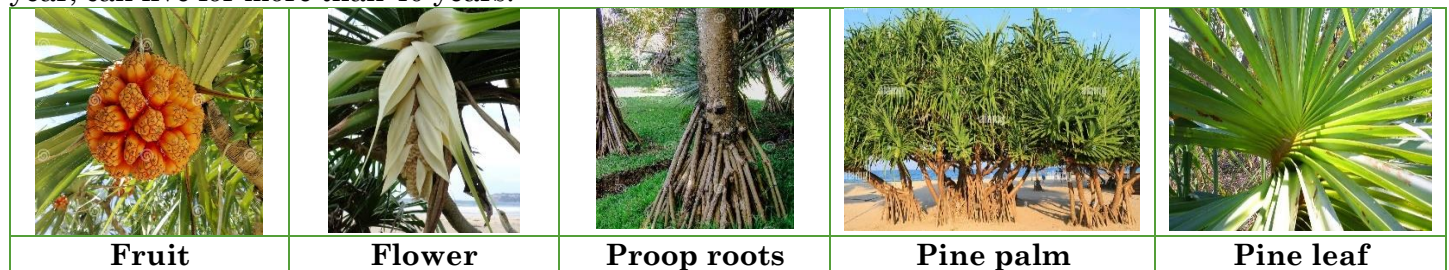
- a. Trunks and branches may be burnt for fuel wood or used to make compost
- b. The leaves are used to make mats, baskets, hats, fans, pillows, canoe sails (formerly), toys and other plaited wares
- c. In India and Burma, the male flowers are valued for their fragrance and some kewda products.
- d. It is estimated that there are about 30–40 thousand trees in Ganjam district and nearly to a million spadices are annually used for the production of kewda attar (otto content is 0.03% on weight of spadices), kewda water, and kewda oil, most demanded in Arab countries. The perfumes are prepared through hydro distillation method.
- e. Kewda perfume blends with all fancy perfumes, used to scent clothes, flavouring beetles, tobacco, bouquets, lotions, cosmetic soaps, hair oil and agarbattis.
- f. Kewda water used in flavouring sweets, syrups and softdrinks, popular in North India
- g. The fragrant male flowers are used to scent coconut oil, perfume tapa cloth and make garlands
- h. Fruits are berries or drupes, usually multiple prop or aerial roots are used in fabrication of house walls and as supports, mats, basket handles, paintbrushes, skipping ropes and sails for boats.
- i. In Southeast Asian countries, pandanus leaves woven into items used during weddings symbolizing purity and good fortune.

Propagation: The plant can be propagated by off sets or division of the ground suckers and leaf bearing terminal cuttings. For raising scented types, a fertile, well-drained-soil is preferable. It grows in full sun to partial shade but prefers at least 6 hours of direct sunlight. Seed collected from ripe fruits sown during spring, usually takes three months for germination. (Bailey, 1950). Spacing followed is 8-10m. paired row of planting with a spacing of 4m between plants and rows of a paired-row and 6m between two paired rows. As an intercrop wild melons are highly recommended.

Art of Distillation

The process of creating Kewda attar is as precious as the product itself. Flowers are mixed with water @60litres/1,000 flowers in big copper still and directly heated in a furnace. The vapours produced are condensed and collected in a copper vessel connected through bamboo condenser. Attars are manufactured by absorbing flower distillates either over sandalwood oil or liquid paraffin. several grades of attar are prepared based on number of flowers used per kg of sandalwood oil. About distillation of 1,000 flowers yields 18 litres of kewda water and grade is known as 'Khazara', cost about 150-450/litre. 1lac flowers require for 1kg oil, cost of 2,50,000. The high cost of Kewda attar stems from its labor-intensive production, limited availability and the sheer number of flowers required.

Harvest and yield: The tree begins to flower 3 to 4 years after planting. The flowering period is rainy season (July–October). Highly prized by Indian perfumer a fully mature tree bears 30–40 spadices in a year, can live for more than 40 years.



Conclusion

Kewda, often termed "liquid gold", holds significant commercial and therapeutic value. Its unique aromatic properties, extensive traditional applications and limited but highly specialized production make it a prized commodity in perfumery and cultural rituals. Sustainable cultivation and scientific distillation methods can further enhance its global market potential while preserving its ecological and cultural heritage.

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Synergy Between Environment Sustainability and Crop Growth Efficiency

Article ID: 71052

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Abstract

The synergy between environmental sustainability and crop growth efficiency is crucial for ensuring global food security while mitigating environmental degradation. Modern agricultural systems face challenges such as soil degradation, water scarcity, biodiversity loss, and climate change. Addressing these challenges requires a holistic approach that balances high crop yields with ecological conservation. Sustainable agricultural practices, including soil conservation, water-efficient irrigation, integrated pest management (IPM), agroforestry, and precision farming, provide a pathway to achieving this balance. Soil health is a cornerstone of sustainable agriculture. Practices like crop rotation, reduced tillage, and organic fertilization enhance soil structure, retain moisture, and increase nutrient availability, leading to improved plant growth and yield. Similarly, efficient water management techniques—such as drip irrigation, rainwater harvesting, and mulching—optimize water use while reducing wastage and preserving freshwater resources. These practices ensure that crops receive adequate hydration without contributing to groundwater depletion or soil salinization. Integrated Pest Management (IPM) fosters a natural balance between pests and their predators, reducing reliance on chemical pesticides that harm beneficial organisms and ecosystems. Likewise, agroforestry and biodiversity-enhancing strategies create resilient farming systems by improving microclimates, enriching soil fertility, and promoting pollination. These methods not only enhance crop productivity but also contribute to carbon sequestration and climate change mitigation. Advancements in smart farming and precision agriculture—such as the use of AI-driven analytics, data-driven decision-making—allow farmers to optimize inputs like fertilizers and water. These innovations minimize environmental impact while maximizing efficiency, ensuring sustainable food production. Moreover, the development of climate-resilient crops through breeding and biotechnology enhances agricultural adaptation to changing environmental conditions.

Introduction

Environmental sustainability: It's the rates of renewable resource crop, pollution creation, and non renewablere source reduction that can be continued indefinitely (Daly, 1990; Morelli, 2011) and is the most vital for the survival of living organisms (Díaz et al., 2006). mortal conditioning like industrialization, deforestation, and overexploitation of natural coffers by exploding population, depriving agrarian practices, and much further have led the terrain to the point of collapse driving world nations to arms to help farther deterioration of the terrain and restore its stability (Hopwood et al., 2005; Tilman and Clark, 2014). Numerous approaches like waste recycling and effluent treatment systems have been tried to palliate the situation but only met with little or no success. Agriculture, in the morning, was aneco-friendly exertion, but with the arrival of the green revolution, chemical diseases and fungicides dominated and increased its negative footmark on the terrain (Horrigan et al., 2002).

Crop growth efficiency: Crop growth rate depends upon its radiation- use effectiveness, which is the quantum of interdicted photosynthetic active radiation and the effectiveness of the crop to convert interdicted photosynthetic active radiation to aboveground biomass (Cirilo et al., 2009).

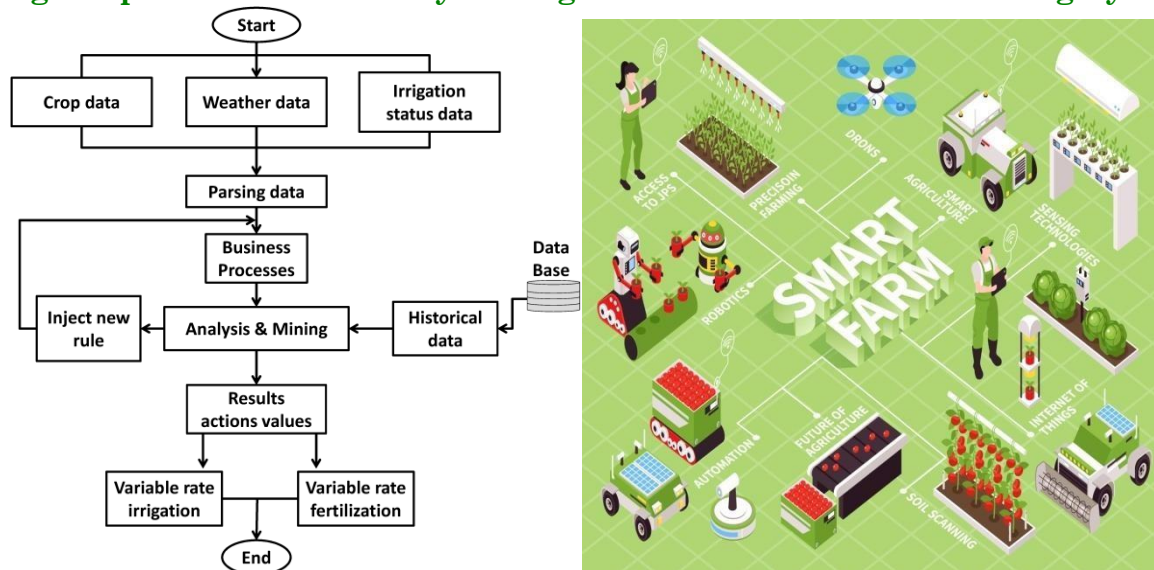
Principles of Environmental Sustainability

Environmental sustainability is a conservation conception which is the meeting of services and coffers of present and unborn generations without affecting the health of the ecosystems that give them. The principles for Strategy of Environmental Sustainability are given below as:

1. Biodiversity conservation this is the preservation of biodiversity and energy coffers.

2. Social needs the vacuity of introductory requirements, products, and services for present and unborn generations. Support original employment, fair trade and environmental attributes of raw material.
3. Renewable coffers within the capacity of rejuvenescence.
4. Exercise, recovering support the exercise, recovering practices to reduce waste, emigrations, and cost and ameliorate product effectiveness.
5. Limitations of nonrenewable coffers and waste generation the mortal profitable system should be within the carrying capacity, the emigrations should be within the assimilative capacity of the ecosystem, prioritize low- impact transportation, and effective opinions with consideration of environmental quality (Morelli, 2011).

Enhancing Crop Growth Efficiency through IoT Enabled Smart Farming System



Smart Farming system

Synergy Between Environmental Sustainability and Crop Growth Efficiency

1. Mutual Benefits:

a. How Environmental Sustainability Enhances Crop Growth Efficiency: Soil Health Improvement: Conservation agriculture, including no-till farming and cover cropping, helps maintain soil structure, increase organic matter, and improve nutrient retention. Studies show that conservation tillage improves soil moisture by 20 -30% and enhances microbial activity, leading to better plant growth (Journal of Soil and Water Conservation, 2020). Climate Change Mitigation: Adopting sustainable practices reduces greenhouse gas emissions, contributing to a stable climate conducive to consistent crop production. For example, integrating bioenergy production with agriculture in India offers a sustainable solution to energy scarcity while promoting environmental sustainability. (Kumar, 2024)

b. Crop Growth Efficiency Contributing to Environmental Sustainability: Resource Optimization Effective use of inputs like diseases and water minimizes environmental impurity and conserves coffers. Inventions in toxin product, similar as green ammonia, aim to reduce emigrations associated with traditional toxin use. (Mehta, 2024). Lower Emigrations Effective crop product systems can reduce the carbon footmark associated with agrarian conditioning. Enforcing sustainable practices aligns with India's commitment to achieving net- zero emigrations by 2070, integrating environmental sustainability with profitable growth. (Bawa, 2024).

2. Strategies for Achieving Synergy:

a. Conservation Agriculture:

i. **Principles:** Minimal soil disturbance, Soil cover, and crop diversification

ii. **Benefits:** Enhances soil organic matter, improves water retention, and increases resilience to climate variability.

iii. Implementation: Adopting no-till farming, using cover crops, and practicing diverse crop rotations. (Sharma *et al.* 2023)

b. Precision Agriculture:

i. Principles: Utilizing technology to monitor and manage field variability in crops. Benefits: Optimizes input use, increases yields, and reduces environmental impact.

ii. Implementation: Employing GPS mapping, soil sensors, and data analytics to guide farming decisions. (Maurya *et al.* 2024)

c. Organic Farming:

i. Principles: Avoiding synthetic inputs, enhancing soil fertility naturally, and promoting ecological balance.

ii. Benefits: Improves soil health, supports biodiversity, and meets consumer demand for organic products.

iii. Implementation: Using compost, green manures, crop rotations, and biological pest control methods. (Organic farming, 2025).

Case Studies

1. Conservation Agriculture in Eastern India: A long-term study conducted in eastern India assessed six cropping systems under conservation agriculture (CA) practices. The findings indicated that CA-based systems enhanced soil health, reduced input costs, and improved crop yields compared to traditional methods. This approach not only promoted environmental sustainability by minimizing soil disturbance and chemical usage but also increased productivity and profitability for farmers. (Dutta *et al.* 2023)

2. Sustainable Agriculture Practices and Systems (SAPSs): The Council on Energy, Environment, and Water (CEEW) conducted a comprehensive study on Sustainable Agriculture Practices and Systems (SAPSs) in India. The research identified 16 SAPSs, including natural farming, agroforestry, and the System of Rice Intensification (SRI), highlighting their positive impacts on farm incomes, environmental health, and social outcomes. For instance, natural farming practices have been adopted by around 800,000 farmers, leading to reduced input costs and enhanced soil fertility. (Gupta *et al.* 2021)

3. Soil Sensors for Precision Agriculture: In Maharashtra, the implementation of soil moisture sensors enabled precision irrigation, resulting in a 40% reduction in water usage and an 18% increase in crop yields. Similarly, in Punjab, soil nutrient sensors facilitated precise fertilization, decreasing fertilizer use by 30% and boosting wheat yields by 15%. These technologies exemplify how precision agriculture can enhance resource efficiency and crop productivity while promoting environmental sustainability. (Hondetechco.com, 2025)

Conclusion

Achieving a harmonious balance between environmental sustainability and crop growth efficiency is essential for the future of agriculture in India. Implementing sustainable farming practices has been shown to enhance productivity while preserving natural resources. For instance, studies have demonstrated that agricultural diversification practices, such as intercropping and organic farming, increase financial profitability, biodiversity, and ecosystem services over time. Additionally, optimizing agrivoltaics systems, which combine crop production with solar energy generation, has been shown to improve land-use efficiency and contribute to sustainability goals.

These findings underscore the potential of sustainable agricultural practices to simultaneously achieve environmental conservation and crop productivity. By adopting such methods, India can work towards a more resilient and sustainable agricultural sector.

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Soil-Plant Dynamics: A Key to Maximize Crop Productivity

Article ID: 71053

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Abstract

Soil-plant dynamics play a critical role in determining crop productivity and sustainability in agricultural ecosystems. This paper explores the complex interactions between soil properties, plant physiology, and environmental factors that influence nutrient uptake, root development, and yield optimization. By understanding and managing these interactions, farmers and agronomists can improve soil health, optimize fertilization strategies, and enhance crop output. This research highlights the significance of integrated soil-plant management with reference to recent studies, including the impact of soil texture, organic matter, microbial activity, and precision agriculture techniques.

Introduction

Soil and plant systems are inherently interdependent. The productivity of crops hinges on the soil's ability to supply essential nutrients, retain moisture, and support root growth. Globally, an estimated 33% of soils are moderately to highly degraded due to erosion, nutrient depletion, acidification, and pollution (Montanarella et al., 2016). As the demand for food continues to rise, improving the efficiency of soil-plant interactions is critical for sustainable agriculture.

Soil Properties and their Role in Plant Growth

Soil texture, structure, pH, organic matter content, and microbial population significantly influence plant health and productivity.

Table 1: Key Soil Properties and Their Influence on Crop Growth:

Soil Property	Ideal Range/Condition	Influence on Plants
Soil Texture	Loamy (balanced sand, silt, clay)	Good drainage and aeration
Soil pH	6.0 – 7.5	Optimal nutrient availability
Organic Matter	>3% organic carbon	Enhances nutrient cycling and water holding
Microbial Activity	High microbial biomass	Improved nutrient uptake and disease control

1. Soil Texture and Structure: Sandy soils have low water-holding capacity, while clay soils may impede root growth due to compaction. Loamy soils, a balance of sand, silt, and clay, are ideal for most crops due to good aeration and drainage (Brady & Weil, 2016).

2. Soil pH: Nutrient availability is pH-dependent. For example, phosphorus is most available in soils with pH 6.0–7.5 (Fageria & Baligar, 2008).

3. Organic Matter: Soils with >3% organic carbon support higher microbial activity and better nutrient cycling. Research indicates that a 1% increase in organic matter can increase water retention by approximately 25,000 gallons per acre (Hudson, 1994).

4. Microbial Activity: Beneficial microbes like mycorrhizal fungi enhance nutrient uptake (especially phosphorus) and protect plants from pathogens (Smith & Read, 2008).

Plant Physiology and Nutrient Uptake

Plants absorb nutrients primarily through their root systems, and this process is highly influenced by soil conditions. Root architecture, influenced by genetic and environmental factors, determines the efficiency of water and nutrient uptake.

Table 2: Nutrient Uptake Efficiency of Selected Crops:

Crop	Nutrient Use Efficiency (NUE)	Typical Root-to-Shoot Ratio
Wheat	33–40%	0.15–0.20
Maize	30–35%	0.17–0.20
Rice	25–30%	0.12–0.18

1. Root-to-Shoot Ratio: Crops like maize and wheat have root-to-shoot ratios of 0.15–0.20 under optimal conditions, which decreases under drought or nutrient-deficient conditions (Lynch, 2007).

2. Nutrient Use Efficiency (NUE): Modern wheat varieties have an NUE of about 33– 40%, meaning 60–67% of applied nutrients are lost to the environment. Enhancing NUE through better soil management can reduce input costs and environmental impact (Tilman et al., 2002).

Soil-Plant Interactions and Crop Productivity

Effective soil-plant interactions ensure nutrient availability aligns with crop demand. Practices that enhance these interactions include:

- 1. Cover Cropping:** Improves soil structure and organic matter (Snapp et al., 2005).
- 2. Crop Rotation:** Breaks pest cycles and optimizes nutrient use (Karlen et al., 1994).
- 3. Precision Agriculture:** Uses technologies like GPS and sensors to apply inputs site- specifically. Studies show yield increases of 10–15% with precision fertilization (Gebbers & Adamchuk, 2010).

Case Study: Rice-Wheat System in India

The Indo-Gangetic Plains, supporting the rice-wheat cropping system, face soil degradation and declining productivity. Adoption of conservation agriculture practices, including zero tillage and residue retention, has improved yields by 5–10% and increased soil organic carbon by 0.2–0.3% over five years (Jat et al., 2014).

Table 3: Impact of Conservation Practices on Rice-Wheat System:

Practice	Yield Improvement	SOC Increase	Water Use Efficiency
Zero Tillage	5–10%	0.2–0.3%	20–30%
Crop Residue Retention	8–12%	0.3–0.4%	25–35%

Conclusion

Understanding and optimizing soil-plant dynamics is essential for enhancing crop productivity. Integration of soil health management, advanced breeding for root traits, and precision farming can lead to more sustainable and productive agricultural systems. Further research is needed to tailor practices to specific soil and crop conditions.

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Nutritional and Sustainable: Plant-Based Beverages

Article ID: 71054

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Summary

Plant-based beverages are drinks derived from plant sources and are increasingly popular as alternatives to dairy milk. These beverages are made by extracting liquid from plant materials such as cereals, legumes, nuts, seeds, or fruits. They are often consumed for their nutritional benefits, suitability for lactose-intolerant or vegan individuals, and lower environmental impact compared to dairy production. These beverages typically contain water as the main ingredient, along with plant solids, sometimes fortified with vitamins and minerals (like calcium and B12) to match the nutritional profile of cow's milk. Many are also flavored or sweetened to enhance taste.

Introduction

Plant-based milk are water soluble extracts of plant sources. These alternatives have gained significant popularity as substitutes for traditional dairy milk. Derived from a variety of plant sources such as soy, almonds, oats, rice, and coconut, these non-dairy beverages cater to a wide range of dietary needs and preferences.

Driving Force for their Demand

Social media and the internet have greatly enhanced consumers' awareness of nutrition and health. Customers are becoming more conscious of the different environmental and health issues related to meals derived from animals. Customers are becoming more conscious of the different environmental and health issues related to meals derived from animals. Foods generated from animals are frequently linked to several public health dangers and issues, such as the use of antibiotics, which increases the chance of antibiotic-resistant bacteria spreading and endangering human health by increasing morbidity, mortality, and medical expenses (Mehndiratta & Bhalla, 2014). During growth and production, hormones are frequently given to animals, livestock, and poultry, which may have long-term deleterious effects on human health (Malekinejad & Rezabakhsh, 2015). Production of milk through the use of animals puts far more strain on the environment than other kinds of food production. Demand for plant-based foods and drinks has increased as a result of customers' inspiration to make environmentally friendly decisions due to sustainability and environmental consciousness (Sharma *et al.*, 2024).

Health Benefits

Plant-based beverages not only cater to the needs of consumers suffering from lactose intolerance and looking for some alternative to conventional milk but have proven beneficial for people suffering from cow milk allergy, hypercholesterolemia, having calorie concerns and looking for lifestyle changes like switching to vegan diets (Sethi, Tyagi, & Anurag, 2016). recent studies have well established vital role of these plant-based beverages in improving or management of immune system, have potential antimicrobial effects, helps in reducing risk of cardiovascular and gastro-intestinal diseases with improved physiological functions, decreased risk of low bone mass and very high levels of antioxidants with free radical scavenging properties (Paul *et al.*, 2020). Plant-based alternatives to dairy products can vary in their nutritional content depending on the ingredients used to make them. However, many plant-based alternatives are fortified with vitamins and minerals to make up for any potential deficiencies. These products are typically made from nuts, seeds, or grains, such as soy, almond, and oat. Plant-based milk can offer a variety of nutritional benefits, including reduced saturated fat, cholesterol, and lactose (Fructuoso *et al.*, 2021).

Common Types of Plant-Based Milks

1. Soy Milk: Produced by soaking and grinding soybeans, soy milk is notable for its high protein content and presence of isoflavones, which may offer health benefits. It is considered a superfood containing the highest amount of protein among cereals and legumes. Soymilk has emerged as a great substitute for traditional milk for consumers willing to switch to plant-based milk (Liu, K., 2004). is the most popular plant-based milk used around the world which was first launched in Hong Kong in 1940 (Makinen *et al.*, 2016).

2. Almond Milk: Almonds are considered as one of the “brain-foods” as they ensure a healthy brain by promoting mental alertness, concentration, recall skills, memory and helps to get good sleep. Made from ground almonds and water, almond milk is low in calories and rich in vitamin E. However, it has a lower protein content compared to cow's milk.

3. Oat Milk: Derived from whole oats, oat milk contains beta-glucans, a type of soluble fiber known for its cholesterol-lowering effects ((Sethi, Tyagi, & Anurag, 2016).

4. Rice Milk: Produced from milled rice and water, rice milk is naturally sweet and hypoallergenic but has a high carbohydrate content and low protein levels. Its broad acceptance as a hypoallergenic cereal has contributed to its popularity in the milk analog market (Michelet *et al.*, 2017).

5. Coconut Milk: Extracted from grated coconut meat, coconut milk is rich in medium-chain triglycerides (MCTs) but low in protein. Milk obtained from coconut is used world-wide for confectionaries, bakeries, biscuits, ice-creams, etc.

6. Pea Milk: Made from yellow peas, pea milk offers a protein content comparable to cow's milk. It has a nutritional significance as they are rich in protein, minerals and essential fatty acids such as linoleic and oleic acids, valuable components in human nutrition (Abou-Dobara *et al.* 2016).

7. Hemp milk: Hemp seeds are considered to be as one of the richest sources of poly-unsaturated-fatty acids such as a-linolenic acid and linoleic acid. It is oil in water emulsion and another delight significantly growing in milk analogy category (Wang *et al.*, 2018).

Conclusion

One of the food segments with the quickest rate of growth in the more recent food product development category is the nutraceutical and functional food industry. The beverage sector has recently turned its attention to improving the nutritional value and functional enrichment of food. Because of their high nutritional content, legumes, grains, and oilseeds are the main ingredients used to make several milk substitutes. Plant-based beverages are a diverse and rapidly growing sector in the food industry, meeting consumer demand for sustainable, health-conscious, and ethical choices. Each type of plant-based drink offers distinct nutritional and sensory profiles, making them suitable for a variety of dietary needs and culinary applications.

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Regenerative Agriculture: Building Healthy Soils for Future Generations

Article ID: 71055

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Abstract

Regenerative agriculture is a disruptive strategy for responding to the ecological, economic, and social disasters plaguing current farming systems. It is unlike standard systems of high-input use based on monoculture production that can cause devastating negative effects. Instead, it prioritizes building soils, diversity, water cycling, and ecosystem services, forming regenerative and resilient agro-ecosystems. Built from agroecological paradigms, traditional knowledge, and science, it seeks to replenish soils lost and stem the climate change using carbon capture. This article discusses the philosophy, practices, advantages, disadvantages, and increasing momentum of regenerative agriculture in India. The potential of this system to transform food production while promoting environmental sustainability and farmer livelihoods is critically analyzed, and the necessity for collective policy, education, and research support is emphasized.

Introduction

Agriculture has been the cornerstone of human society for centuries, but industrial farming methods have brought severe environmental issues, such as soil erosion, loss of biodiversity, water shortage, and enhanced greenhouse gas emissions. To counter this, regenerative agriculture has come forward as a comprehensive approach that transcends sustainability to rejuvenate and revitalize the well-being of our soils, ecosystems, and communities. This practice has great potential for developing resilient food systems and ensuring a healthy planet for generations to come.

What is Regenerative Agriculture?

Regenerative agriculture is an ecological and moral farm practice aimed at restoring and rebuilding the native health of the soil and local ecosystem. In essence, it is a farm practice based on agroecology, indigenous knowledge, and scientific knowledge, intended not just to maintain the productivity of agriculture, but enhance the long-term health of the land and communities.

A Break with Traditional Methods

Unlike traditional agriculture, which is based on synthetic fertilizers, monoculture cropping, deep tillage, and chemical pest control, regenerative agriculture focuses on working together with natural systems. Conventional farming tends to deplete the land, lower biodiversity, contaminate water bodies, and exacerbate climate change through carbon emissions. Regenerative agriculture, however, gives life back to the soil with the goal of reversing environmental degradation while making food production sustainable and resilient.

Core Goals of Regenerative Agriculture

Rebuilding Soil Health: Through organic matter buildup, promoting microbial diversity, and reducing soil disturbance, regenerative methods restore degraded soils to fertile, porous, and biologically active states.

Carbon Sequestration: Plants naturally draw carbon dioxide from the air through photosynthesis. Regenerative systems increase the soil's capacity to sequester this carbon in the long term, transforming farmland into a powerful weapon in the battle against climate change.

Increased Biodiversity: Regenerative farms tend to have a diverse range of crops, native vegetation, beneficial insects, and animals, thus promoting a self-sustaining environment that is resistant to pests and climate shocks.

Optimization of Water Cycle: Healthy soils function like sponges, soaking up water and holding it in the most efficient way. Cover cropping, no-till farming, and mulching prevent runoff of water, minimize irrigation requirements, and recharge groundwater.

Economic and Social Well-being: Aside from environmental advantage, regenerative agriculture also aims for local communities, equitable labor, and profitable farming, presenting a socially accountable agricultural development model.

Practices Included in Regenerative Agriculture

No-Till or Minimum Tillage: Limiting mechanical disruption of soil in order to preserve its structure and microbiology.

Cover Cropping: Planting crops such as legumes or grasses during off-season periods in order to cover the land and naturally fix nitrogen.

Diverse Crop Rotations: Crop rotation to disrupt pest cycles, increase nutrient cycling, and promote soil health.

Agroforestry and Perennial Crops: Incorporating trees and perennial crops into cropland to enhance soil structure, create shade, and promote biodiversity.

Managed Grazing: Grazing livestock in managed rotations, which promotes grass growth and spreads nutrients evenly through manure.

Composting and Mulching: Utilizing organic matter to build up soil and naturally suppress weeds.

A Regenerative Mindset

Regenerative agriculture is not a list of practices it is a philosophy that treasures the soil as a living system, the farm as a continuum, and the farmer as a custodian of nature. It promotes ongoing learning, adaptive management, and long-term planning, informed by the principle of leaving the land in better condition than we inherited it.

Key Principles of Regenerative Agriculture

Minimizing soil disturbance is one of the core principles of regenerative agriculture. By reducing or eliminating tillage, farmers preserve the natural structure of the soil, prevent soil erosion, which is a frequent result of mechanical disturbance, and protect beneficial microbial life.

Another fundamental concept is having cover on the soil year-round. This is obtained by planting cover crops or the preservation of crop residues following harvesting. Having soil cover protects not only the soil from erosion but also retains moisture in the soil, prevents weed growth, and aids in building organic matter.

Crop rotation and diversification are key practices in regenerative agriculture. Crop rotation breaks the life cycles of pests and diseases, minimizes the likelihood of soil nutrient loss, and favors a greater number of soil microorganisms, which increase soil fertility and health.

Another significant practice is integrating livestock into agricultural systems. Livestock recycle nutrients, promote plant regrowth, and sequester carbon in the soil through well-managed grazing.

One of the primary objectives of regenerative agriculture is the development of organic matter in the soil. This is achieved by applying compost, green manures, and crop residues, which provide nutrients to soil organisms, enhance fertility, and increase the water-holding capacity of the soil.

Finally, minimizing the use of synthetic chemicals, like synthetic pesticides and fertilizers, is very important. Regenerative agriculture supports biological control and natural alternatives that conserve beneficial organisms and build healthy soils for the long term.

Advantages of Regenerative Agriculture

Among the biggest advantages of regenerative agriculture is soil improvement. Microbially rich, organically bound soils have more structure, water better, and foster vigorous, healthy plant life.

The second most important advantage is climate change mitigation. Increased organic matter and improved soil carbon sequestration are achieved by regenerative approaches, which minimize the levels of greenhouse gases in the atmosphere and contribute to planetary climate solutions.

Regenerative farming also results in more biodiversity on farms. Regenerative approaches are made possible by varied cropping systems and wildlife-friendly methods, enhancing both above- and belowground biodiversity, and creating more robust ecosystems.

The method enhances water holding capacity in soils. Healthy soils retain and absorb more water, which is especially useful during drought or excessive rainfall, to mitigate runoff and soil erosion.

Economically, regenerative farming increases economic sustainability. Although it can be associated with short-term difficulties, in the long run, it lowers input costs, increases yields, and promotes farmers' financial autonomy.

Finally, regenerative agriculture promotes food security and nutrition. Healthier soils yield crops with greater nutrient density, which improves human health and ensures stable food supplies for increasing populations.

Challenges in Adoption

Even with its many advantages, the large-scale adoption of regenerative agriculture is not without challenges. One of the biggest challenges is the absence of awareness and adequate training among farmers about regenerative methods and their long-term benefits.

There is also a lack of financial incentives and enabling policies. Farmers are typically subject to economic limitations and risk aversion, particularly when switching from traditional to regenerative approaches.

Short-term productivity issues might also deter adoption, since regenerative systems may take time to realize their full benefits.

Finally, the lack of research for specific regions, demonstration models, and extension services restricts the scalability of regenerative practices in varied agro-ecological zones.

It will be essential to overcome these challenges with joint efforts from farmers, agricultural scientists, civil society organizations, policy-makers, and consumers to develop an enabling environment that can flourish regenerative agriculture.

Regenerative Agriculture in India: A Growing Movement

India is witnessing a significant shift towards regenerative agriculture, particularly in the face of extensive land degradation, soil erosion, and productivity decline. Knowing the need, some Indian states have encouraged alternative farming systems that are compatible with regenerative principles.

Programs like Bharatiya Prakritik Krishi Paddhati (BPKP) and Zero Budget Natural Farming (ZBNF) have become popular. These approaches focus on the utilization of local, natural inputs and prioritize soil health, biodiversity, and farmer freedom.

Farmers following these approaches have seen dramatic reductions in input expenses, enhanced soil fertility, and increased resistance of crops to climate-related stresses such as drought and pest attacks.

Those such as Andhra Pradesh and Himachal Pradesh have since set the pace by implementing large-scale programs to promote regenerative and natural farming practices, hoping to assist millions of smallholder farmers in the transition.

Conclusion

Regenerative agriculture is not just a sustainable farming practice it is a revolutionary philosophy that puts harmony with nature first. Through the restoration of soil health, increased biodiversity, and decreased dependence on synthetic inputs, regenerative agriculture presents a compelling solution to the environmental and economic crises confronting global agriculture.

As the globe contends with climate change, food insecurity, and land degradation, regenerative agriculture offers a promising way forward. Committing to and scaling regenerative approaches now is crucial to creating healthy soils, thriving communities, and a secure food future for generations.

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Women Empowerment through Fruit Processing and Marketing in Rural India

Article ID: 71056

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Abstract

Rural women in India have a central position in agriculture and household management, but they are usually marginalized regarding economic autonomy and decision-making opportunities. Fruit processing and marketing provide a promising way to empower rural women by strengthening their income-generating abilities, enhancing livelihoods, and stimulating socio-economic growth. This article examines the prospects of fruit processing and marketing as a means for women's empowerment, the setbacks encountered, and the policy intervention needed to expand such interventions successfully.

Introduction

Empowering women is not merely an issue of gender equality it is a key strategy for integrated rural development. In India, where over two-thirds of the population continues to live in rural India, women play an important role in agricultural production, animal husbandry, and home food security. In spite of their contributions, rural women are systematically deprived of access to education, land ownership, credit facilities, technology, and market linkages. This restricts their opportunities for converting labor into economic autonomy and status.

Agriculture in India has undergone changes, and so has that of women. From planting and harvesting to post-harvest management, women contribute along the value chain. But the sector of post-harvest processing and value addition, especially in horticulture and fruits, is still underexploited by rural women as a source of livelihood. Fruit processing involves drying, preserving, jam making, pickling, squashing, and juice making all of which fit well with the traditional knowledge and household skills many women already have. Formalizing and upgrading these skills by way of training and access to the market can turn rural women into micro-entrepreneurs.

India is a fruit production leader worldwide, cultivating numerous tropical and subtropical fruits like mango, banana, guava, citrus, papaya, and litchi. Nevertheless, fruit post-harvest losses are exceedingly high, amounting to 25–30%, because of poor infrastructure and absence of preservation methods. Supporting rural women through fruit processing projects not only curbs wastage but also increases value addition to raw produce, extends shelf life, and generates new sources of income.

In addition, as women are economically empowered, they will invest more in their households particularly children's education, nutrition, and health hence exerting a positive intergenerational influence. Empowerment through income-generating activities such as fruit processing and marketing translates into more decision-making autonomy, self-esteem, and civic engagement, and changes women from passive recipients of aid to active development agents.

Here, fruit marketing and processing offer a strategic intervention to address both rural unemployment and post-harvest losses, along with advancing gender equality. This article explores the scope, advantages, challenges, and institutional support systems needed to promote women-owned fruit processing enterprises in rural India.

Range of Fruit Processing in Rural India

India is the world's second-largest fruit producer, growing a vast range of horticultural crops such as mango, banana, guava, citrus, papaya, and litchi. Most of these fruits are grown in rural regions, but the post-harvest loss is alarmingly high at 25–30% every year. The main reason is the lack of proper cold storage, transportation, and processing facilities.

Small-scale fruit processing provides a viable means of reducing these losses. Rural women can be involved in the production of value-added products like jams, jellies, squashes, pickles, and dried fruits. These products not only have a longer shelf life but also fetch better prices in the market. Such activities enable women to utilize local resources, minimize reliance on middlemen, and develop sustainable micro-enterprises that generate both household income and local economies.

Women's Role in Fruit Processing

Rural women already have inherited skills in food preservation that they apply to domestic household practice. The skills can be upgraded with formal training programs to enable them to create high-quality, standardized fruit products for commercial markets. This upgrading of household skills to entrepreneurship is an essential step towards economic empowerment.

Self-Help Groups (SHGs) led by women have become a model of success in rural India. SHGs have set up and operated small-scale processing units, which are usually backed by NGOs, government schemes, and local institutions. Through group efforts, SHG members achieve enhanced bargaining power, access to resources, and the confidence to run enterprises.

Fruit processing businesses also provide jobs both direct and indirect. Women are employed, not just in processing but also in packaging, grading, sorting, and marketing. This has a ripple effect in stemming rural-to-urban migration as well as improving community development by fostering local livelihood opportunities.

Marketing Opportunities and Strategies

Local markets are crucial for the sale of processed fruit products. Weekly village haats, seasonal fairs, and cooperative shops provide platforms where women can sell their products directly to customers without involving middlemen. This allows for higher profit margins and establishment of direct customer relations.

The increasing availability of digital platforms offers new possibilities. With expanding access to smartphones and digital literacy programs, women entrepreneurs can market and sell their products online using e-commerce websites, social media, and mobile apps. This shift to digital markets greatly expands their customer base beyond the village or district level.

Packaging and branding are crucial to promote the visual attractiveness and image quality of processed fruit products. Aesthetically pleasing, clean packaging and distinctive brand identities assist products in distinguishing themselves in the market and attracting premium prices. Branding and marketing training can assist rural women entrepreneurs in making their products more competitive.

Success Stories

A number of success stories from India underscore the life-changing power of fruit processing for rural women. A traditional example is the Lijjat Papad model, in which a women's cooperative developed into a large-scale business with national and international reputation, even though not fruit products, it illustrates the success of women enterprises.

In Maharashtra, SHGs under different rural development schemes have been able to process mangoes into pulp, pickles, and squashes. Some of these are now being exported to Gulf nations, demonstrating how rural women can access global markets.

In the North-Eastern states of Meghalaya and Nagaland, women-owned businesses have become popular for their pineapple and orange-based products. These products, which are usually produced using traditional techniques, have been sold under local branding, becoming popular at regional and national exhibitions.

Challenges Faced

Although there are possibilities, a number of drawbacks inhibit rural women from engaging in fruit processing and marketing. Lack of credit and financial institution access discourages most women from establishing or expanding their enterprises. In many instances, women have no collateral or are subjected to procedural hurdles in obtaining credit from cooperatives or banks.

They lack formal training in food processing methods, quality requirements, packaging, business planning, and modern technology, which constrains them to compete in wider markets. Training facilities are lacking in rural areas or are unaffordable to women for social and logistical reasons.

Infrastructure is also still a major stumbling block. Most villages have no access to basic processing facilities, cold storage space, clean working areas, and packaging facilities. Without the infrastructure, it is hard to ensure product safety and quality.

Market linkages are also poor. Women do find it hard to reach wholesalers, retailers, and institutional buyers. They also lack proper knowledge about branding, prices, and consumer tastes.

Gender- and culture-based restrictions also curb mobility and engagement. Women in most regions are discouraged from going out alone or entering public transactions, thereby lessening their capability to run businesses independently.

Government and Institutional Support

The Indian Government, via the National Rural Livelihood Mission (NRLM), is actively involved in the establishment and capacity development of SHGs. NRLM extends financial and technical support to enable women to manage their businesses successfully.

The Ministry of Food Processing Industries (MoFPI) has different schemes under the PM-FME (Pradhan Mantri Formalization of Micro Food Processing Enterprises) for offering subsidy and loans for micro food processing units, with a large number of them headed by women.

Krishi Vigyan Kendras (KVKs), agricultural universities, and NGOs organize routine training programs on food processing, hygiene, packaging, and entrepreneurship development. The institutions are playing a key role in handholding and mentoring rural women entrepreneurs.

Farmer Producer Organizations (FPOs) are also being promoted to enroll more women members and leaders and facilitate their active involvement in agribusiness and value chains.

Recommendations for Policy and Practice

There is a pressing need for focused training and capacity development. There should be regular workshops at the block or village level on food safety, quality, product diversification, and business skills.

Financial inclusion needs to be encouraged by facilitating easier access to microcredit, government subsidies, and bank loans. Streamlining procedures and offering financial literacy will enable more women to access formal finance.

Market connections should be consolidated through tie-ups with organized retail chains, cooperatives, and online marketplaces. Exposure to market trends and possibilities can be facilitated through attending trade fairs and exhibitions.

Creation of gender-sensitive infrastructure like women-friendly workspaces, child-care facilities, and secure transportation will enhance the role of women in processing activity.

Lastly, there must be monitoring, mentoring, and follow-up assistance by extension services, NGOs, and local government agencies. Long-term mentoring guarantees sustainability and women entrepreneurs' resilience.

Conclusion

Fruit processing and marketing are great tools for improving the socio-economic status of rural Indian women. These activities give employment with a sense of meaning, minimize post-harvest losses, and enhance women's self-reliance. With the right skills, infrastructure, and access to markets, women can become bold and efficient agripreneurs. Their empowerment has a multiplying effect on family, society,

and the larger economy. In investing in women through fruit processing, India approaches inclusive, gender-equitable, and sustainable rural development.

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Regenerative Agriculture: Building Healthy Soils for Future Generations

Article ID: 71057

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Abstract

Regenerative agriculture is a disruptive strategy for responding to the ecological, economic, and social disasters plaguing current farming systems. It is unlike standard systems of high-input use based on monoculture production that can cause devastating negative effects. Instead, it prioritizes building soils, diversity, water cycling, and ecosystem services, forming regenerative and resilient agro-ecosystems. Built from agroecological paradigms, traditional knowledge, and science, it seeks to replenish soils lost and stem the climate change using carbon capture. This article discusses the philosophy, practices, advantages, disadvantages, and increasing momentum of regenerative agriculture in India. The potential of this system to transform food production while promoting environmental sustainability and farmer livelihoods is critically analyzed, and the necessity for collective policy, education, and research support is emphasized.

Introduction

Agriculture has been the cornerstone of human society for centuries, but industrial farming methods have brought severe environmental issues, such as soil erosion, loss of biodiversity, water shortage, and enhanced greenhouse gas emissions. To counter this, regenerative agriculture has come forward as a comprehensive approach that transcends sustainability to rejuvenate and revitalize the well-being of our soils, ecosystems, and communities. This practice has great potential for developing resilient food systems and ensuring a healthy planet for generations to come.

What is Regenerative Agriculture?

Regenerative agriculture is an ecological and moral farm practice aimed at restoring and rebuilding the native health of the soil and local ecosystem. In essence, it is a farm practice based on agroecology, indigenous knowledge, and scientific knowledge, intended not just to maintain the productivity of agriculture, but enhance the long-term health of the land and communities.

A Break with Traditional Methods

Unlike traditional agriculture, which is based on synthetic fertilizers, monoculture cropping, deep tillage, and chemical pest control, regenerative agriculture focuses on working together with natural systems. Conventional farming tends to deplete the land, lower biodiversity, contaminate water bodies, and exacerbate climate change through carbon emissions. Regenerative agriculture, however, gives life back to the soil with the goal of reversing environmental degradation while making food production sustainable and resilient.

Core Goals of Regenerative Agriculture

Rebuilding Soil Health: Through organic matter buildup, promoting microbial diversity, and reducing soil disturbance, regenerative methods restore degraded soils to fertile, porous, and biologically active states.

Carbon Sequestration: Plants naturally draw carbon dioxide from the air through photosynthesis. Regenerative systems increase the soil's capacity to sequester this carbon in the long term, transforming farmland into a powerful weapon in the battle against climate change.

Increased Biodiversity: Regenerative farms tend to have a diverse range of crops, native vegetation, beneficial insects, and animals, thus promoting a self-sustaining environment that is resistant to pests and climate shocks.

Optimization of Water Cycle: Healthy soils function like sponges, soaking up water and holding it in the most efficient way. Cover cropping, no-till farming, and mulching prevent runoff of water, minimize irrigation requirements, and recharge groundwater.

Economic and Social Well-being: Aside from environmental advantage, regenerative agriculture also aims for local communities, equitable labor, and profitable farming, presenting a socially accountable agricultural development model.

Practices Included in Regenerative Agriculture

No-Till or Minimum Tillage: Limiting mechanical disruption of soil in order to preserve its structure and microbiology.

Cover Cropping: Planting crops such as legumes or grasses during off-season periods in order to cover the land and naturally fix nitrogen.

Diverse Crop Rotations: Crop rotation to disrupt pest cycles, increase nutrient cycling, and promote soil health.

Agroforestry and Perennial Crops: Incorporating trees and perennial crops into cropland to enhance soil structure, create shade, and promote biodiversity.

Managed Grazing: Grazing livestock in managed rotations, which promotes grass growth and spreads nutrients evenly through manure.

Composting and Mulching: Utilizing organic matter to build up soil and naturally suppress weeds.

A Regenerative Mindset

Regenerative agriculture is not a list of practices it is a philosophy that treasures the soil as a living system, the farm as a continuum, and the farmer as a custodian of nature. It promotes ongoing learning, adaptive management, and long-term planning, informed by the principle of leaving the land in better condition than we inherited it.

Key Principles of Regenerative Agriculture

Minimizing soil disturbance is one of the core principles of regenerative agriculture. By reducing or eliminating tillage, farmers preserve the natural structure of the soil, prevent soil erosion, which is a frequent result of mechanical disturbance, and protect beneficial microbial life.

Another fundamental concept is having cover on the soil year-round. This is obtained by planting cover crops or the preservation of crop residues following harvesting. Having soil cover protects not only the soil from erosion but also retains moisture in the soil, prevents weed growth, and aids in building organic matter.

Crop rotation and diversification are key practices in regenerative agriculture. Crop rotation breaks the life cycles of pests and diseases, minimizes the likelihood of soil nutrient loss, and favors a greater number of soil microorganisms, which increase soil fertility and health.

Another significant practice is integrating livestock into agricultural systems. Livestock recycle nutrients, promote plant regrowth, and sequester carbon in the soil through well-managed grazing.

One of the primary objectives of regenerative agriculture is the development of organic matter in the soil. This is achieved by applying compost, green manures, and crop residues, which provide nutrients to soil organisms, enhance fertility, and increase the water-holding capacity of the soil.

Finally, minimizing the use of synthetic chemicals, like synthetic pesticides and fertilizers, is very important. Regenerative agriculture supports biological control and natural alternatives that conserve beneficial organisms and build healthy soils for the long term.

Advantages of Regenerative Agriculture

Among the biggest advantages of regenerative agriculture is soil improvement. Microbially rich, organically bound soils have more structure, water better, and foster vigorous, healthy plant life.

The second most important advantage is climate change mitigation. Increased organic matter and improved soil carbon sequestration are achieved by regenerative approaches, which minimize the levels of greenhouse gases in the atmosphere and contribute to planetary climate solutions.

Regenerative farming also results in more biodiversity on farms. Regenerative approaches are made possible by varied cropping systems and wildlife-friendly methods, enhancing both above- and belowground biodiversity, and creating more robust ecosystems.

The method enhances water holding capacity in soils. Healthy soils retain and absorb more water, which is especially useful during drought or excessive rainfall, to mitigate runoff and soil erosion.

Economically, regenerative farming increases economic sustainability. Although it can be associated with short-term difficulties, in the long run, it lowers input costs, increases yields, and promotes farmers' financial autonomy.

Finally, regenerative agriculture promotes food security and nutrition. Healthier soils yield crops with greater nutrient density, which improves human health and ensures stable food supplies for increasing populations.

Challenges in Adoption

Even with its many advantages, the large-scale adoption of regenerative agriculture is not without challenges. One of the biggest challenges is the absence of awareness and adequate training among farmers about regenerative methods and their long-term benefits.

There is also a lack of financial incentives and enabling policies. Farmers are typically subject to economic limitations and risk aversion, particularly when switching from traditional to regenerative approaches.

Short-term productivity issues might also deter adoption, since regenerative systems may take time to realize their full benefits.

Finally, the lack of research for specific regions, demonstration models, and extension services restricts the scalability of regenerative practices in varied agro-ecological zones.

It will be essential to overcome these challenges with joint efforts from farmers, agricultural scientists, civil society organizations, policy-makers, and consumers to develop an enabling environment that can flourish regenerative agriculture.

Regenerative Agriculture in India: A Growing Movement

India is witnessing a significant shift towards regenerative agriculture, particularly in the face of extensive land degradation, soil erosion, and productivity decline. Knowing the need, some Indian states have encouraged alternative farming systems that are compatible with regenerative principles.

Programs like Bharatiya Prakritik Krishi Paddhati (BPKP) and Zero Budget Natural Farming (ZBNF) have become popular. These approaches focus on the utilization of local, natural inputs and prioritize soil health, biodiversity, and farmer freedom.

Farmers following these approaches have seen dramatic reductions in input expenses, enhanced soil fertility, and increased resistance of crops to climate-related stresses such as drought and pest attacks.

Those such as Andhra Pradesh and Himachal Pradesh have since set the pace by implementing large-scale programs to promote regenerative and natural farming practices, hoping to assist millions of smallholder farmers in the transition.

Conclusion

Regenerative agriculture is not just a sustainable farming practice it is a revolutionary philosophy that puts harmony with nature first. Through the restoration of soil health, increased biodiversity, and decreased dependence on synthetic inputs, regenerative agriculture presents a compelling solution to the environmental and economic crises confronting global agriculture.

As the globe contends with climate change, food insecurity, and land degradation, regenerative agriculture offers a promising way forward. Committing to and scaling regenerative approaches now is crucial to creating healthy soils, thriving communities, and a secure food future for generations.

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Evaluation of Herbicide Efficacy in Non-Crop Situations

Article ID: 71058

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Abstract

Non-crop plots like roadsides, railways, industrial areas, irrigation ditches, and airports frequently encounter heavy infestations of weeds. Weeds tend to hamper visibility, interfere with infrastructure upkeep, lead to fire risks, and act as reservoirs for pests and diseases that infect crops. Herbicides provide a reliable technique to manage vegetation in these non-crop settings. This paper discusses the classes of herbicides applied, their effectiveness, application techniques, and environmental aspects in non-crop conditions.

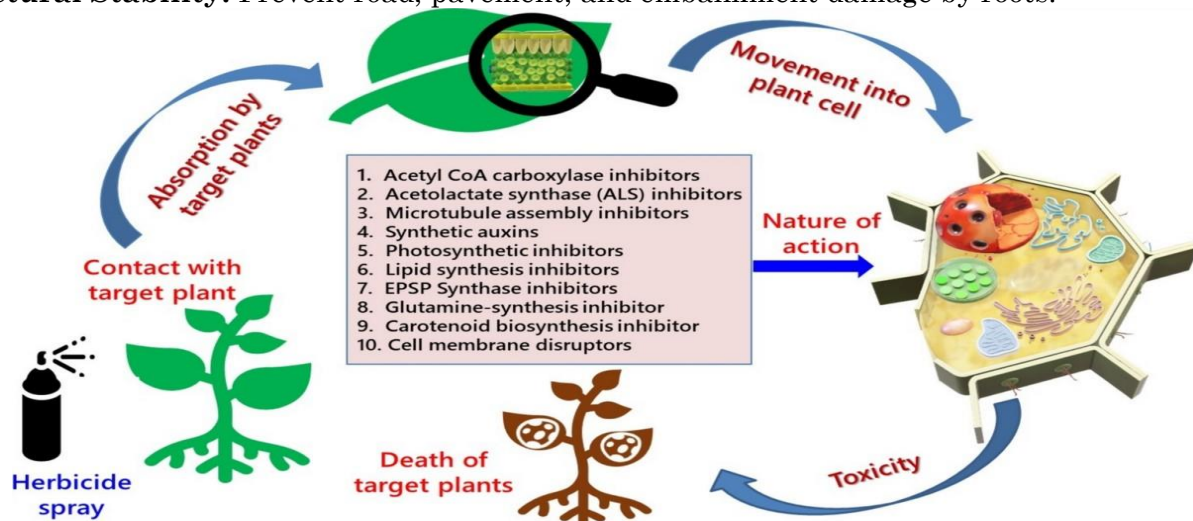
Introduction

Weeds in non-crop situations are usually not considered in weed management, but they are serious ecological and operational problems. Non-crop situations refer to land that is not cultivated for crops but needs vegetation control, e.g., railway embankments, roadside verges, power line corridors, airports, military areas, and industrial peripheries. Uncontrolled vegetation in these places can decrease traffic sign visibility, provide shelter for pests and pathogens, enhance the risk of fire, or destroy infrastructure.

Although mechanical as well as hand weeding remains in practice, herbicides continue to be the most efficient, cost-effective, and labor-reducing control measure for weeds in such circumstances. Assessing herbicide efficiency in non-agricultural environments calls for knowledge on the nature of target vegetation, selectivity, spectrum of weed control, residue activity, impact on the environment, and protection measures.

Herbicide Use Targets in Non-Agricultural Locations

- 1. Vegetation Control:** Suppress obstruction of access routes, electrical lines, as well as movement of water within canals.
- 2. Fire Prevention:** Minimize fire risk by removing dry and combustible vegetation.
- 3. Aesthetic Maintenance:** Enhance the landscape appearance of public and private areas.
- 4. Pest and Disease Control:** Prevent the infestation of insects, rodents, and diseases from untended regions to cropped land.
- 5. Structural Stability:** Prevent road, pavement, and embankment damage by roots.



Source:link.Springer.com

Types of Herbicides Used in Non-Crop Areas

Herbicides in non-crop settings are generally non-selective and long-residual to ensure prolonged control. Some commonly used herbicides include:

Herbicide	Mode of Action	Key Features
Glyphosate	Non-selective, systemic	Controls a wide range of annual and perennial weeds; rainfast; no soil residual.
Glufosinate-ammonium	Contact, non-selective	Fast-acting, effective on foliage; minimal soil activity.
Diuron	Photosynthesis inhibitor	Residual control; suitable for bare ground maintenance.
Imazapyr	Systemic, residual	Controls broad-spectrum weeds including woody species.
Bromacil	Soil-applied, residual	Provides long-term control; used on railways and rights-of-way.
Sodium chlorate	Non-selective desiccant	Highly effective but environmentally persistent.
2,4-D	Selective, systemic	Controls broadleaf weeds; often used in combination.

Application Methods in Non-Crop Environments

- 1. Spot Treatment:** On-spot application on particular patches of weeds, reducing the use of herbicides.
- 2. Broadcast Spraying:** Application over large surfaces; often employed for roadside or rail corridor applications.
- 3. Wick Application:** Herbicide is wiped on the weeds directly; effective where there is sensitive vegetation in the vicinity.
- 4. Aerial Spraying:** Sprayed from helicopters or drones in large or inaccessible areas such as forest corridors or power lines.
- 5. Cut-Stump and Basal Bark Application:** For woody vegetation; herbicide is sprayed onto recently cut stumps or bark.

Herbicide Efficacy Factors

Herbicide effectiveness in non-crop environments is influenced by several variables:

- 1. Weed Species:** Annuals, perennials, grasses, sedges, and woody plants react differently.
- 2. Growth Stage:** Younger weeds are easier to control chemically.
- 3. Climate and Weather:** Temperature, precipitation, and wind affect herbicide uptake and persistence.
- 4. Soil Type:** Influences leaching, binding, and residual activity.
- 5. Application Rate and Method:** Under-dosing can lead to regrowth, whereas over-application can enhance environmental risk.

Environmental and Safety Considerations

Although herbicides are convenient, misapplication can result in soil and water resource contamination and impact non-target organisms.

- 1. Runoff and Leaching:** Herbicides such as bromacil and imazapyr can pollute water bodies if used close to drainage points.
- 2. Volatilization and Drift:** Particularly under hot, windy weather conditions, resulting in off-target injury.
- 3. Resistance Development:** Excessive dependence on a single mode of action encourages herbicide-resistant weed populations.
- 4. Human and Animal Safety:** Proper PPE, application training, and adherence to label instructions are essential.

Integrated Weed Management (IWM) in Non-Crop Areas

To improve sustainability and minimize dependence on herbicides alone, integrated methods are favored:

1. **Mechanical Control:** Mowing, trimming, or digging out weeds.
2. **Biological Control:** Utilization of natural enemies such as insects (e.g., *Zygogramma bicolorata* for Parthenium).
3. **Preventive Measures:** Mulching or using ground covers in certain spots to suppress weeds.
4. **Rotational Herbicide Use:** Avoiding resistance development and enhancing long-term management.

Recent Progress in Non-Crop Weed Management

1. **Use of Drones:** To apply herbicides with precision in remote areas.
2. **Smart Sprayers with AI:** To target weeds alone, minimizing use of chemicals.
3. **Bioherbicides:** Microbial or plant-based natural formulations (e.g., Phytotoxins of *Alternaria* spp.).
4. **Herbicide-Soil Interaction Modelling:** Forecasts movement and persistence for improved planning.
5. **GIS-Based Weed Mapping:** Facilitates targeted interventions.

Case Studies of Herbicide Use in India

1. **Railways:** Glyphosate and diuron mixtures are extensively used along tracks for long-term control.
2. **Irrigation Canals:** Imazapyr is effective in aquatic and terrestrial vegetation control.
3. **Roadside Management:** Tank mixtures of glyphosate + 2,4-D offer broad-spectrum control with low regrowth.
4. **Public Parks and Industrial Areas:** Application of glufosinate in ornamental grounds provides quick weed destruction with no residue toxicity.

Conclusion

Herbicide use in non-crop environments is an important aspect of non-crop vegetation management for safety, beautification, and infrastructure protection. Although chemical weed control is still effective, it must be managed judiciously, taking into consideration environmental, health, and resistance factors. Combining chemical approaches with mechanical and biological methods promotes sustainable weed management. Periodic re-evaluation of herbicide performance, safety guidelines, and new technology will provide improved decision-making on non-crop weed management.

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The Science of Ripening in Vegetables: Ethylene Role and Changes During Ripening

Article ID: 71059

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Introduction

Ripening in fruits & vegetables is a genetically programmed, irreversible process involving physiological, biochemical, and organoleptic changes that mark the transition from maturity to senescence. Ripeness, typically indicating readiness for harvest, is associated with ethylene production, respiration rate changes, and transformation in texture, colour, and flavour. Fruits are classified as climacteric or non-climacteric based on their ethylene response and respiration patterns. Ethylene, synthesized via methionine through ACC, regulates ripening by interacting with other hormones. System 1 (basal production) and System 2 (autocatalytic synthesis in climacteric fruits) describe ethylene regulation. Vegetables typically lack a climacteric ripening stage and undergo varied physiological aging. Ethylene inhibitors and biochemical markers influence postharvest management.

Climacteric fruits: These are harvested at full maturity, can be ripened off the parent plant. These produce much larger quantities of ethylene in association with their ripening, and exposure to ethylene treatment will result in faster and more uniform ripening. The respiration rate is minimum at maturity and remains rather constant, even after the harvest. Fruit softening, colour changes, development of taste and flavour and a number of other parameters of ripening process are associated with the climacteric cycle.

Non-climacteric fruits: These are not capable of continuing their ripening process, once they are detached from the parent plant. Also, these fruits produce a very small quantity of endogenous ethylene, and do not respond to external ethylene treatment. Non-climacteric fruits show comparatively low profile and a gradual decline in their respiration pattern and ethylene production, throughout the ripening process. This division is not fully conclusive and both types may also be found.

Ethylene and Ripening

Ethylene is a fruit ripening hormone which in minute amounts can trigger many events of cell metabolism including initiation of ripening and senescence. Treatment of unripe climacteric fruits with low concentrations of ethylene induces the climacteric rise in respiration and the onset of ripening and also stimulates the fruit tissue to produce its own ethylene and promotes in some changes associated with ripening such as loss of green colour from the skin. In the non-climacteric fruits ethylene production does not rise with ripening.

Ethylene does not play an important role in the maturation of most vegetables. Generally the gas is produced in small amounts throughout the life of the vegetable and there is no upsurge in production as it matures. In vegetables there are no abrupt breaks in the respiratory pattern. However, metabolic changes are noticed on treatment of vegetables with ethylene. i.e. the respiration rate of potatoes rises in the presence of small amounts of ethylene while carrots produce a bitter tasting compound isocoumarin.

Ethylene Biosynthesis

Ethylene is synthesized from methionine in three steps:

1. Conversion of methionine to S-adenosyl-L-methionine (SAM) which is catalyzed by the enzyme SAM synthetase
2. Formation of 1-aminocyclopropane-1-carboxylic acid (ACC) from SAM via ACC synthase (ACS) activity

3. The conversion of ACC to ethylene, which is catalysed by ACC oxidase (ACO).

At the onset of fruit ripening, expression of multiple ACC synthase genes are activated, resulting in increased production of ACC.

Mode of Action

It has been proposed that two systems exist for the regulation of ethylene biosynthesis.

System 1: It is common to both climacteric and non-climacteric fruit and is responsible for both basal ethylene production and the ethylene produced when tissue is wounded. This system functions during normal growth and development and during stress responses. It corresponds to low ethylene production in the pre-climacteric period of climacteric fruit. This system is auto-inhibitory such that exogenous ethylene inhibits synthesis and inhibitors of ethylene action can stimulate ethylene production. However, external application of ethylene during ripening to non-climacteric fruit may hasten the process in some cases.

System 2: This system operates during floral senescence and fruit ripening. It refers to an auto-stimulated massive ethylene production, called 'autocatalytic synthesis' and is specific to climacteric fruit. The inhibitor of ethylene action inhibits ethylene production. Apart from stimulating the ripening of climacteric and some non-climacteric fruits ethylene is also causes synthesis of anthocyanins, degradation of chlorophyll (degreening), germination of seeds, formation of adventitious roots, abscission and senescence, flower initiation, and respiratory and phenyl propanoid metabolism.

Ethylene Inhibitors

Chemicals that inhibit the synthesis of ethylene or its action are known as ethylene inhibitors.

1. Ethylene synthesis inhibitors: These compounds block the synthesis of ACC from SAM. e.g. aminoethoxyvinyl glycine, methoxyvinyl glycine, aminoacetic acid etc.

2. Ethylene action blockers: These directly inhibit the action of ethylene e.g. silver thiosulphate, carbon dioxide, nickel, cobalt, methylcyclopropane, norbornadiene etc.

Table-1 Classification of Vegetables according to ethylene production rates at 20°C:

Class	Rate (µl/kg/h)	Examples
Very low	<0.1	Artichoke, asparagus, cauliflower, leafy vegetables, potato
Low	0.1-1.0	Cucumber, eggplant, okra, olive, pepper, tamarillo
Moderate	1.0-10.0	Tomato, pumpkin, melons
High	10.0-100.0	None (Most high ethylene producers are fruits)
Very high	>100.0	None (Vegetables typically do not fall in this category)

Changes During Ripening

Fruit ripening involves many complex biochemical changes, including seed maturation, change in colour, abscission from the parent plant, texture softening, production of flavour volatiles, wax development on skin, tissue permeability and change in carbohydrate composition, organic acids and proteins.

Colour Changes

Color is often the major criteria used by consumers to determine whether the fruit is ripe or unripe. As fruit matures and ripen, green colour decline and develops yellow, red or other colours due to the presence of accessory pigments, which are characteristic of the various cultivars.

Flavour Changes

Flavour of a fruit depends upon synthesis of various flavour compounds which are unique to each fruit. These flavour compounds are present in very low amount and includes alcohols, aldehydes, esters and other chemical groups. In both climacteric and non-climacteric fruits, the most important aroma volatiles that increase during ripening are the **esters**.

Human taste sensations and experiences play an important role in characterizing volatile compounds in vegetables, similar to fruits. A vocabulary has been developed to describe their sensory nature. The terms used relate a particular flavor sensation to that of a widely available standard and have led to descriptors such as:

1. **‘Earthy’** – found in root vegetables like beets, carrots, and potatoes
2. **‘Grassy’** – common in spinach, lettuce, and green beans
3. **‘Herbaceous’** – present in celery, parsley, and asparagus
4. **‘Peppery’** – associated with radishes, arugula, and watercress
5. **‘Nutty’** – noticeable in broccoli, cauliflower, and Brussels sprouts.

Carbohydrates And Organic Acid Changes

Ripening induces the breakdown of carbohydrate polymers by various carbohydrases, leading to the conversion of starch to sugars. This has the dual effect of altering the taste and texture of the produce. The increase in sugar makes vegetables taste sweeter and, therefore, more acceptable to consumers. However, there are exceptions. In tomatoes and bell peppers, acidity decreases during ripening, while in rhubarb and certain varieties of sorrel, acid content may increase.

Texture Changes

Fruit texture is influenced by various factors like structural integrity of the primary cell wall and the middle lamella, accumulation of storage polysaccharides, and the turgor pressure generated within cells by osmosis. Change in turgor pressure, and degradation of cell wall polysaccharides and starch determine the extent of fruit softening. Cell wall polysaccharides that undergo modifications during ripening are pectin, cellulose, and hemicelluloses. Starch is almost completely hydrolyzed to free sugars, thus contributing to loosening of the cell structure and textural softening during ripening.

Firmness in vegetables is also related to the turgor properties of their tissues or organs. During postharvest storage and aging, there is a decline in turgor, which contributes to textural changes. This is probably due partly to an accumulation of osmotic solutes in the cell wall space and partly to water loss from the vegetable. In leafy vegetables like lettuce and spinach, wilting and softening are mainly associated with changes in turgor pressure. Similarly, in root vegetables such as carrots and radishes, loss of turgor leads to a limp texture. In crisp vegetables like bell peppers and cucumbers, water loss significantly impacts their firmness.

According to softening behaviour, fruits are divided in to two groups. These are:

1. Very Soft Vegetables: These vegetables become significantly softer after ripening or cooking and have a melting or mushy texture.

Examples: Tomato, eggplant, zucchini, cucumber, pumpkin, and okra.

2. Moderately Soft Vegetables: These vegetables retain more firmness and have a crisp or fracturable texture even after ripening or slight cooking.

Examples: Carrot, radish, bell pepper, cabbage, cauliflower, and green beans.

Change in Protein

During the climacteric phase of many fruits and vegetables there is a decrease in free amino acids which often reflects an increase in protein synthesis. During senescence, the level of free amino acids increases reflecting a breakdown of enzymes and decreased metabolic activity.

Change in Cellulose and Hemicellulose

There is often little change in the cellulose structure in fruits during ripening and the activity of enzymes does not correlate with softening changes that occurs. Ripening also involves degradation of hemicellulose. There is a decline in characteristic monomers of hemicelluloses viz. glucose, xylose, and mannose during ripening of fruits but that does not have a very drastic influence on the texture of the product.

Changes in Lipid

Little is known about changes in the lipid fraction. There are speculations about shifts in composition and quantity of phospholipid fraction during ripening.

Summary of Changes Occurring During Ripening of Fleshy Fruit

Physiological Changes	Textural and Biochemical Changes
Seed Maturation	Softening of Texture

Colour Changes	Change in Carbohydrate Composition
Abscission	Change in Organic Acid
Change in Respiration Rate	Protein Changes
Change in Rate of Ethylene Production	Production of Flavour Volatiles
Change in Tissue Permeability	Development of Wax on Skin

Table-2 Adapted from Pratt, H. K. The role of ethylene in fruit ripening. Facteurs et regulation de la maturation des fruits. Anatole. France. Centre National de la Recherche Scientifique: 1975:153-160.

Conclusion

Ripening, itself considered to be readiness for harvest, brings about many specialized changes in the fruit that makes it aesthetically appealing. These changes are essentially genetically controlled and much less can be done to alter them at the eye level. Ethylene plays an important role in governing the ripening cycle. The study of changes related to ripening helps in differentiation between desirable and undesirable changes occurring due to ripening. Biotechnological alterations can help in manipulation of the ripening process for the benefit of human kind. Control of ripening process can render the produce to be more aesthetically sound for longer duration and delaying the senescence and undesirable changes.

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Insight on Major Fungal Diseases of Some Medicinal Plants

Article ID: 71060

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Summary

Medicinal plants play an integral role in traditional healthcare systems and the modern pharmaceutical industry. They are a valuable source of bioactive compounds with therapeutic properties. However, the productivity and quality of these plants are significantly hindered by fungal pathogens, which cause a wide range of diseases that affect plant vigor, reduce biomass, and lower the concentration of secondary metabolites. This comprehensive review presents an in-depth analysis of major fungal diseases affecting key medicinal plants grown in India and globally. It covers the causal organisms, symptoms, mode of dissemination, epidemiological factors, and integrated disease management practices. The article emphasizes the need for sustainable and eco-friendly control measures, including the use of biocontrol agents and cultural practices.

Introduction

Medicinal plants are essential for the development of natural remedies and modern pharmacological formulations. India, being a biodiversity-rich country, cultivates a variety of medicinal plants such as Ashwagandha, Tulsi, Neem, Giloy, Brahmi, and others, which are known for their immense therapeutic potential. However, these plants are vulnerable to various fungal pathogens, which significantly reduce their quality and yield. Fungal diseases can lead to leaf spots, blights, wilts, rots, and cankers, adversely impacting the commercial value and medicinal efficacy of plant parts such as leaves, roots, and stems. Understanding the disease cycle, pathogen biology, and environmental conditions favoring disease development is crucial for designing effective management strategies. Integrated Disease Management (IDM) approaches, involving cultural, biological, and chemical controls, are necessary to sustainably manage fungal diseases in medicinal crops.

Major Fungal Diseases of Medicinal Plants

1. Leaf Spot and Stem Blight of Ashwagandha (*Withania somnifera*)

- Causal Organisms:** *Alternaria alternata*, *Alternaria tenuissima*
- Symptoms:** Initial symptoms appear as small, circular to irregular necrotic lesions on older leaves. As the disease progresses, the spots enlarge with concentric rings and may coalesce, leading to blighting. Stems may exhibit dark lesions and necrosis.
- Mode of Spread:** Airborne conidia disseminated by wind and splashing rainwater.
- Epidemiology:** High relative humidity (>80%) and temperatures between 25–30°C favor disease development.
- Management:** Use of certified disease-free seeds, seed treatment with *Trichoderma harzianum*, timely removal of infected plant parts, and foliar sprays of Mancozeb (0.2%) at 15-day intervals.

2. Cercospora Leaf Spot of Tulsi (*Ocimum sanctum*)

- Causal Organism:** *Cercospora ocimi*
- Symptoms:** Brown to dark brown, irregular lesions with chlorotic halos on both leaf surfaces. Severe infections result in leaf curling and premature defoliation.
- Mode of Spread:** Dissemination through wind-borne conidia and rain splash.
- Epidemiology:** Warm and humid conditions (25–28°C) promote rapid disease spread, especially in dense canopy.
- Management:** Sanitation of infected leaves, use of resistant cultivars, application of carbendazim (0.1%), and intercropping with non-host species.

3. Powdery Mildew of Neem (*Azadirachta indica*)

- a. **Causal Organism:** *Oidium azadirachtae*
- b. **Symptoms:** White, powdery fungal growth on the surface of young leaves, tender stems, and flower buds. Leads to leaf curling, yellowing, and reduced photosynthesis.
- c. **Mode of Spread:** Wind-borne conidia.
- d. **Epidemiology:** Dry weather with high day temperatures and cool nights encourages disease development.
- e. **Management:** Spraying of sulfur-based fungicides (0.2%), neem oil emulsions, pruning of infected shoots, and maintaining aeration in plantation.

4. Leaf Spot of Giloy (*Tinospora cordifolia*)

- a. **Causal Organism:** *Phyllosticta tinosporae*
- b. **Symptoms:** Light brown to dark brown lesions with defined margins, often accompanied by chlorosis. Severe infections result in leaf drop.
- c. **Mode of Spread:** Rain splash and wind-mediated dispersal of conidia.
- d. **Epidemiology:** Disease incidence is highest during the monsoon and late rainy season when humidity exceeds 85%.
- e. **Management:** Application of neem-based biopesticides, removal of infected leaves, and crop rotation with non-host plants.

5. Root Rot of Brahmi (*Bacopa monnieri*)

- a. **Causal Organisms:** *Fusarium solani*, *Pythium spp.*
- b. **Symptoms:** Wilting, yellowing of leaves, rotting of roots, and eventual plant collapse. Root cortex turns brown and mushy.
- c. **Mode of Spread:** Soil-borne spores transmitted through irrigation water and contaminated tools.
- d. **Epidemiology:** Excessive soil moisture, poor drainage, and high temperatures favor pathogen proliferation.
- e. **Management:** Soil solarization, raised bed cultivation, incorporation of neem cake, and use of bioagents like *Trichoderma viride*.

6. Crown and Root Rot of Shatavari (*Asparagus racemosus*)

- a. **Causal Organism:** *Fusarium oxysporum*
- b. **Symptoms:** Chlorosis of foliage, stunted growth, browning and rotting of crown and roots, leading to plant death.
- c. **Mode of Spread:** Through infected planting material and contaminated soil.
- d. **Epidemiology:** Waterlogged conditions and high soil temperatures promote pathogen activity.
- e. **Management:** Use of disease-free seedlings, crop rotation, biological soil amendments, and application of neem cake.

7. Leaf Spot of Arjuna (*Terminalia arjuna*)

- a. **Causal Organism:** *Phyllosticta terminaliae*
- b. **Symptoms:** Circular to oval brown lesions on leaves with possible marginal necrosis. Premature leaf fall may occur under severe infections.
- c. **Mode of Spread:** Splashing rain and wind dissemination.
- d. **Epidemiology:** Cool, humid weather and dense canopy favor disease.
- e. **Management:** Pruning for aeration, application of copper oxychloride (0.3%), and removal of infected debris.

8. Leaf Blight of Haritaki (*Terminalia chebula*)

- a. **Causal Organism:** *Alternaria alternata*
- b. **Symptoms:** Large necrotic blotches on leaves that dry and fall prematurely. Seedling mortality can occur in nurseries.
- c. **Mode of Spread:** Windborne spores and infected plant debris.
- d. **Epidemiology:** Moisture-rich environments and temperatures between 25–30°C accelerate disease spread.
- e. **Management:** Field sanitation, fungicidal sprays with Mancozeb, and use of resistant varieties.

9. Leaf Spot and Blight of Kalmegh (*Andrographis paniculata*)

- a. **Causal Organism:** *Cercospora andrograhi*
- b. **Symptoms:** Angular greyish necrotic spots on leaves, often merging to form blighted areas.
- c. **Mode of Spread:** Rain-splashed spores and tools.
- d. **Epidemiology:** Prolonged rainfall and humidity >80% favor infection.
- e. **Management:** Seed treatment with *Trichoderma harzianum*, foliar sprays with carbendazim (0.1%) + mancozeb (0.2%) mixture.

10. Root Rot of Mulethi (*Glycyrrhiza glabra*):

- a. **Disease:** Root Rot
- b. **Causal Organism:** *Macrophomina phaseolina*
- c. **Symptoms:** Progressive yellowing and wilting, root decay with formation of microsclerotia in root tissues.
- d. **Mode of Spread:** Soil-borne microsclerotia and contaminated irrigation.
- e. **Epidemiology:** Dry periods followed by sudden rainfall are conducive to disease outbreak.
- f. **Management:** Deep summer ploughing, addition of compost and bioagents (*Pseudomonas fluorescens*), and proper irrigation scheduling.

11. Stem Canker of Guggul (*Commiphora wightii*):

- a. **Causal Organisms:** *Fusarium spp.*, *Alternaria spp.*
- b. **Symptoms:** Development of sunken, cracked cankers on stems; gum exudation; reduced vigor.
- c. **Mode of Spread:** Through pruning wounds and airborne spores.
- d. **Epidemiology:** High humidity, injuries, and poor sanitation increase disease incidence.
- e. **Management:** Application of Bordeaux paste on wounds, proper pruning techniques, and use of systemic fungicides.

12. Leaf Spot of Chitrak (*Plumbago zeylanica*):

- a. **Causal Organism:** *Cercospora plumbaginicola*
- b. **Symptoms:** Tiny black spots on leaves expanding to necrotic areas, which may result in blight under humid conditions.
- c. **Mode of Spread:** Spores spread by wind and water splash.
- d. **Epidemiology:** High humidity and warm weather (27–30°C) favor pathogen activity.
- e. **Management:** Use of neem oil spray, biological agents like *Trichoderma asperellum*, and maintaining optimal spacing for air circulation.

Integrated Disease Management (IDM) Strategies

To sustainably manage fungal diseases, a combination of approaches is essential:

1. Cultural Practices:

- a. **Crop Rotation:** Disrupts pathogen life cycles.
- b. **Sanitation:** Removal of infected plant debris reduces inoculum.
- c. **Proper Spacing:** Enhances air circulation, reducing humidity.

2. Biological Control:

- a. **Biocontrol Agents:** *Trichoderma spp.*, *Pseudomonas fluorescens*, and neem-based formulations suppress pathogens.
- b. **Biofungicides:** Garlic extract, *Bacillus subtilis*, and compost teas enhance resistance.

3. Chemical Control (Minimal & Targeted Use)

- a. **Fungicides:** Mancozeb, carbendazim, and copper-based sprays for severe outbreaks.
- b. **Seed Treatment:** Fungicide-coated seeds prevent early infections.

4. **Host Resistance & Breeding:** Development of disease-resistant cultivars through traditional breeding and biotechnological approaches.

Conclusion

Fungal diseases represent a critical barrier to the sustainable cultivation of medicinal plants. They not only reduce yield but also compromise the phytochemical quality of medicinal raw materials. Timely identification, understanding of epidemiological patterns, and implementation of integrated disease management strategies especially those emphasizing eco-friendly approaches are essential. Continued

research on host resistance, biocontrol agents, and disease forecasting models is necessary to mitigate losses and ensure sustainable medicinal plant production.

Insight on Bacterial Diseases of Medicinal Plants

Article ID: 71061

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Summary

Medicinal plants, widely revered for their therapeutic properties, serve as a cornerstone in traditional and modern healthcare systems. Their demand has surged globally due to increasing reliance on herbal remedies and natural pharmaceuticals. However, bacterial diseases pose a significant threat to the health and productivity of medicinal plants, leading to substantial yield losses, deterioration of phytochemical quality, and reduced efficacy of plant-derived medicinal compounds. This comprehensive review presents an extensive analysis of major bacterial diseases affecting medicinal plants, covering key aspects such as symptoms, causal organisms, dissemination pathways, environmental conditions conducive to disease development, and management strategies. Emphasis is placed on sustainable practices, including cultural controls, biological interventions, and the need for resistant varieties to ensure the long-term health and productivity of medicinal plant resources.

Introduction

Medicinal plants hold immense significance in healthcare systems due to their bioactive compounds, which are used for therapeutic, preventive, and curative purposes. India, with its rich biodiversity and Ayurvedic heritage, is one of the leading cultivators and exporters of medicinal plants. However, these valuable botanical resources are increasingly vulnerable to bacterial pathogens, which can cause various foliar, vascular, and root diseases. Bacterial diseases often go unnoticed in their early stages but can rapidly escalate under favorable environmental conditions, leading to severe economic and ecological consequences.

Unlike fungal pathogens, bacterial pathogens often exhibit rapid colonization and systemic spread, complicating diagnosis and control. Some common bacterial diseases of medicinal plants include leaf blights, wilts, cankers, galls, and soft rots. The causal organisms typically belong to genera such as *Xanthomonas*, *Pseudomonas*, *Erwinia*, *Ralstonia*, and *Agrobacterium*. These pathogens spread primarily through contaminated tools, infected planting material, rain splash, insects, and irrigation water.

Effective disease management requires a thorough understanding of pathogen biology, host-pathogen interactions, environmental influences, and implementation of integrated disease management strategies. The increasing prevalence of bacterial diseases in medicinal plant cultivation underscores the urgency of adopting holistic, eco-friendly approaches that combine good agricultural practices with modern plant protection technologies.

Major Bacterial Diseases of Medicinal Plants

1. Bacterial Leaf Spot of Ashwagandha (*Withania somnifera*):

Causal Organism: *Xanthomonas campestris* pv. *withaniae*

Symptoms: Water-soaked spots on the leaf surface that enlarge into necrotic lesions with yellow halos. In severe cases, the entire leaf blade becomes blighted. Defoliation and dieback are common in advanced stages.

Dissemination: Splashing rain, insect vectors, and contaminated equipment.

Favorable Conditions: High humidity and moderate temperatures (25–30°C).

Management: Removal of infected debris, sterilization of pruning tools, crop rotation, and use of resistant cultivars.

2. Bacterial Wilt and Leaf Blight of Tulsi (*Ocimum sanctum*):

Disease: Causal Organism: *Ralstonia solanacearum*, *Pseudomonas syringae*

Symptoms: Sudden wilting of young plants, brown streaks on vascular tissues, marginal blight on leaves, and stunting. Root decay is evident upon uprooting.

Dissemination: Soil-borne, water-borne, and through infected plant material.

Favorable Conditions: Warm, moist soils with poor drainage.

Management: Use of raised beds, organic amendments, hot water treatment of seeds, and soil solarization.

3. Bacterial Leaf Spot and Twig Blight of Neem (*Azadirachta indica*):

Causal Organism: *Xanthomonas axonopodis*

Symptoms: Irregular necrotic lesions on leaves with chlorotic margins; twig dieback and leaf drop may follow. Affected twigs show black streaks.

Dissemination: Rain splash, pruning injuries, and insect activities.

Favorable Conditions: Humid climate with intermittent rainfall.

Management: Pruning of infected twigs, application of copper-based bactericides, and maintenance of plantation hygiene.

4. Bacterial Blight of Giloy (*Tinospora cordifolia*):

Causal Organism: *Xanthomonas campestris* pv. *campestris*

Symptoms: Water-soaked lesions that turn dark brown and become papery. Infection may spread to stems and petioles. Severe attacks cause wilting.

Dissemination: Through rain splash and mechanical transmission.

Favorable Conditions: Prolonged leaf wetness and high humidity.

Management: Timely removal of infected foliage, ensuring proper drainage, and use of protective sprays during monsoon.

5. Soft Rot and Leaf Blight of Brahmi (*Bacopa monnieri*):

Causal Organism: *Erwinia carotovora*

Symptoms: Aqueous, soft rotting of leaves and stems emitting foul odor. Collapsing tissues under wet conditions.

Dissemination: Contaminated water and handling tools.

Favorable Conditions: Saturated soils and poor air circulation.

Management: Avoiding overhead irrigation, improving soil drainage, and applying bioformulations with antagonistic bacteria.

6. Bacterial Spear Rot of Shatavari (*Asparagus racemosus*):

Causal Organism: *Pseudomonas fluorescens*

Symptoms: Spear tips show soft decay, wilting, and black discoloration. Affected tissues collapse in humid conditions.

Dissemination: Through infected soil and irrigation systems.

Favorable Conditions: High soil moisture and dense plant canopy.

Management: Soil aeration, mulching, raised bed planting, and application of bio-agents.

7. Bacterial Leaf Blight of Arjuna (*Terminalia arjuna*):

Causal Organism: *Xanthomonas* spp.

Symptoms: Angular, water-soaked lesions confined by leaf veins; drying of leaf tips and margins; premature defoliation.

Dissemination: Infected plant parts, pruning tools, and rain splash.

Favorable Conditions: Frequent rainfall and crowded plantations.

Management: Pruning for ventilation, foliar application of bactericides, and sanitation.

8. Crown Gall of Haritaki (*Terminalia chebula*):

Causal Organism: *Agrobacterium tumefaciens*

Symptoms: Formation of rough, tumor-like galls at the crown and roots; stunted growth and yellowing of leaves.

Dissemination: Through infected nursery stock and mechanical injury.

Favorable Conditions: Warm, moist soil conditions and poor sanitation.

Management: Use of gall-free planting material, disinfection of tools, and biocontrol agents such as *Agrobacterium radiobacter*.

9. Bacterial Leaf Streak of Kalmegh (*Andrographis paniculata*):

Causal Organism: *Xanthomonas oryzae* pv. *oryzicola* (suspected cross-host pathogen)

Symptoms: Narrow, translucent streaks on leaves with eventual necrosis and blighting. Leaf tips dry up.

Dissemination: Splashing water, contaminated tools.

Favorable Conditions: Monsoon season and continuous rain.

Management: Field hygiene, seed treatment with bactericides, crop rotation with non-hosts.

10. Bacterial Root Rot of Mulethi (*Glycyrrhiza glabra*):

Causal Organism: *Ralstonia solanacearum*

Symptoms: Progressive wilting, discoloration of vascular bundles, browning of roots, and sudden plant collapse.

Dissemination: Infected irrigation water, soil, and tools.

Favorable Conditions: High soil temperatures and moisture.

Management: Solarization, crop rotation, use of biofertilizers, and resistant lines.

11. Bacterial Stem Blight of Guggul (*Commiphora wightii*):

Causal Organism: *Pseudomonas syringae* pv. *tabaci*

Symptoms: Dark, sunken lesions on stems, leaf yellowing, defoliation, and exudation of bacterial ooze. Stems may crack under severe infection.

Dissemination: Pruning wounds, insect bites, and water splash.

Favorable Conditions: High humidity and temperature fluctuations.

Management: Use of pruning sealants, sterilization of tools, and timely application of copper bactericides.

12. Bacterial Spot of Chitrak (*Plumbago zeylanica*):

Causal Organism: *Xanthomonas campestris* pv. *plumbaginicola*

Symptoms: Small water-soaked lesions turning necrotic; lesions often have angular boundaries and may cause leaf deformation.

Dissemination: Wind-blown rain, insects, and mechanical injury.

Favorable Conditions: High rainfall and dense planting.

Management: Balanced spacing, sanitation, foliar application of copper-based sprays.

Conclusion

Bacterial diseases are an under-recognized but serious constraint to the productivity and sustainability of medicinal plant cultivation. These diseases compromise both yield and the therapeutic quality of plant-derived products. The unpredictable and often aggressive nature of bacterial pathogens necessitates a proactive and integrated approach to disease management. Early detection, proper sanitation, resistant varieties, and the use of biocontrol agents can significantly mitigate disease incidence. Future research should focus on developing rapid diagnostic tools, identifying resistant genotypes, and enhancing the role of plant microbiomes in disease suppression to promote resilient medicinal plant production systems.

Insight on Viral Diseases of Medicinal Plants

Article ID: 71062

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Insight into Viral Diseases of Medicinal Plants

Summary: Viral diseases of medicinal plants, although less frequently reported than fungal or bacterial diseases, can still pose significant threats to the productivity and quality of medicinal plant crops. Viruses infect a wide range of plant species, causing various symptoms that impact plant health, growth, and the concentration of bioactive compounds. Understanding the viral pathogens affecting medicinal plants, their transmission mechanisms, symptoms, epidemiology, and management practices is crucial for ensuring sustainable cultivation and conservation of these valuable resources.

Impact of Viral Diseases on Medicinal Plants

Viral infections can lead to symptoms such as leaf mottling, chlorosis, necrosis, mosaic patterns, stunted growth, and deformation of plant tissues. These symptoms not only affect the aesthetic quality of the plants but can also reduce the synthesis of secondary metabolites, which are critical for the therapeutic properties of medicinal plants. In some cases, viral diseases can cause significant yield losses, rendering crops unfit for commercial use or medicinal purposes.

Common Viral Diseases in Medicinal Plants

Here are some key viral diseases that affect popular medicinal plants, focusing on their symptoms, causal organisms, and management:

1. Cucumber Mosaic Virus (CMV) of *Andrographis paniculata* (Kalmegh):

a. Affected Plants: Affects a wide range of crops, including medicinal plants like *Andrographis paniculata*. **Symptoms:** CMV causes yellowing, mosaic patterns on leaves, stunted growth, and flower distortion. In some cases, infected plants may experience reduced yields and poor seed set.

b. Transmission: The virus is primarily transmitted by aphids in a non-persistent manner. It can also spread mechanically through contaminated tools or hands.

c. Management: Control measures include vector management (aphid control), use of virus-free seeds, removal of infected plants, and the application of resistant cultivars.

2. Tobacco Mosaic Virus (TMV) of *Ocimum sanctum* (Tulsi):

a. Affected Plants: Is particularly susceptible to TMV.

b. Symptoms: TMV causes mottling and yellowing of leaves, and sometimes, leaf curling and deformation. Infected plants often exhibit stunted growth, reduced leaf area, and poor flowering.

c. Transmission: TMV spreads primarily through mechanical means, such as contaminated tools, equipment, and handling of infected plants. It can also be spread by infected seeds.

d. Management: Use of resistant varieties, maintaining clean cultivation practices, and disinfecting tools and hands after handling plants are effective control measures.

3. Potato Virus Y (PVY) in *Mentha* spp. (Mint):

a. Affected Plants: PVY infects a wide range of solanaceous and aromatic plants, including *Mentha* species (peppermint, spearmint), which are widely used in essential oil production.

b. Symptoms: PVY causes mosaic patterns, leaf curling, vein necrosis, and stunted growth. In severe cases, it reduces essential oil yield and quality.

c. Transmission: Primarily spread by aphids (*Myzus persicae*) in a non-persistent manner. Mechanical transmission through contaminated tools is also possible.

d. Management: Use of virus-free planting material, aphid control (insecticides or reflective mulches), and removal of infected plants.

4. Alfalfa Mosaic Virus (AMV) in Ashwagandha (*Withania somnifera*):

- a. **Affected Plants:** AMV has been reported in *Withania somnifera* (Ashwagandha), an important medicinal herb in Ayurveda.
- b. **Symptoms:** Yellow mosaic patterns, leaf distortion, and reduced root biomass, which is the primary medicinal part of the plant.
- c. **Transmission:** Spread by aphids (*Aphis craccivora*) and through mechanical inoculation.
- d. **Management:** Controlling aphid populations, using resistant cultivars, and ensuring field sanitation.

5. Chilli Leaf Curl Virus (ChiLCV) in *Aloe vera*:

- a. **Affected Plants:** Although primarily affecting chili peppers, ChiLCV has been detected in *Aloe vera*, causing significant damage.
- b. **Symptoms:** Severe leaf curling, yellowing, stunted growth, and reduced gel production.
- c. **Transmission:** Transmitted by whiteflies (*Bemisia tabaci*).
- d. **Management:** Whitefly control (neem oil, insecticidal soaps), removal of infected plants, and use of virus-free suckers.

6. Tobacco Rattle Virus (TRV) in Ginseng (*Panax ginseng*):

- a. **Affected Plants:** TRV affects *Panax ginseng*, leading to significant economic losses in ginseng cultivation.
- b. **Symptoms:** Necrotic rings, stunted root growth, and reduced ginsenoside content.
- c. **Transmission:** Spread by nematodes (*Paratrichodorus* spp.) and through infected soil.
- d. **Management:** Soil fumigation, nematode control, and use of certified disease-free roots.

7. Rice Yellow Mottle Virus (RYMV):

- a. **Affected Plants:** While primarily affecting rice, RYMV can infect certain tropical medicinal plants, especially those grown in close proximity to rice fields.
- b. **Symptoms:** RYMV induces chlorosis, yellowing, and mottle patterns on leaves, stunted growth, and sometimes necrosis.
- c. **Transmission:** The virus is transmitted by insects, particularly planthoppers.
- d. **Management:** Vector management through insecticide application, maintaining hygiene, and using resistant cultivars can help manage RYMV.

Transmission Mechanisms of Viral Diseases

Viral diseases in medicinal plants primarily spread through:

- 1. **Insect Vectors:** Aphids, whiteflies, and plant hoppers are among the most common vectors for plant viruses. These insects feed on the sap of infected plants and transfer the virus to healthy plants.
- 2. **Mechanical Transmission:** Viruses can be spread through contaminated tools, workers' hands, or through contact between infected and healthy plants.
- 3. **Seed Transmission:** Some viruses, such as TMV, can be transmitted through infected a seed, which highlights the importance of using virus-free planting material.
- 4. **Soilborne Transmission:** Certain viruses can be transmitted via soil, particularly if infected plant debris is left in the field or used as compost.

Epidemiology of Viral Diseases in Medicinal Plants

Viral diseases are influenced by several factors:

- 1. **Climate:** Warm temperatures and high humidity favor the spread of many plant viruses, especially those transmitted by insect vectors.
- 2. **Vector Population:** The presence and abundance of insect vectors significantly influence viral disease outbreaks. Areas with dense insect populations often experience higher rates of viral transmission.
- 3. **Plant Susceptibility:** Different medicinal plant species exhibit varying levels of susceptibility to viral infections. Factors such as genetic resistance, plant health, and growing conditions play crucial roles in disease resistance.

4. Agricultural Practices: Poor agricultural practices, such as improper spacing, inadequate crop rotation, and the use of contaminated tools, can facilitate viral disease spread.

Management of Viral Diseases in Medicinal Plants

Viral disease management in medicinal plants is more challenging compared to bacterial or fungal diseases due to the lack of effective chemical treatments. However, several management practices can be employed to minimize the impact of viral infections:

1. Resistant Varieties: Planting resistant or tolerant cultivars is one of the most effective strategies for managing viral diseases.

2. Vector Control: Managing insect vectors through the use of insecticides, biological control agents (e.g., parasitoids), or reflective mulches can significantly reduce the spread of viral diseases.

3. Hygiene and Sanitation: Keeping fields clean, disinfecting tools, and removing infected plants can help prevent the spread of viruses.

4. Biological Control: The use of natural enemies of vector insects, such as ladybugs or parasitoid wasps, can reduce the population of insect vectors and thereby limit viral transmission.

5. Crop Rotation: Rotating crops to non-host plants can reduce the build-up of viral pathogens in the soil and limit the spread of viruses.

6. Use of Virus-Free Seedlings: Ensuring the use of certified disease-free planting materials can prevent the introduction of viral diseases into the cultivation area.

Conclusion

While viral diseases of medicinal plants are not as commonly reported as fungal or bacterial diseases, they still pose significant threats to crop productivity and quality. Understanding the transmission mechanisms, symptoms, and epidemiological factors that favor viral disease spread is essential for effective management. Sustainable agricultural practices, including the use of resistant varieties, vector management, and maintaining plant hygiene, are critical for mitigating the impact of viral infections. Given the economic and medicinal value of these plants, ongoing research into viral disease management is essential for the future of medicinal plant cultivation.

Incubating Rural Agripreneurs through RKVY-RAFTAAR

Article ID: 71063

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Abstract

The Rashtriya Krishi Vikas Yojana – Remunerative Approaches for Agriculture and Allied Sector Rejuvenation (RKVY-RAFTAAR) is the Government of India's flagship programme with an objective of enhancing entrepreneurship and innovation in agriculture. The paper examines how the scheme builds rural agripreneurship by providing incubation support, funding, and skill development. Particular focus is placed on its structure, implementation, outcomes, and scalability potential of sustainable agribusiness models in India.

Introduction

Agriculture in India accounts for over 50% of the country's workforce, but its share in GDP is still quite low owing to issues such as fragmented farms, poor infrastructure, and poor access to technology. The youth in rural areas, though with creative ideas, are often hindered by financial and institutional constraints to initiate agri-business firms. Understanding this lacuna, the Ministry of Agriculture and Farmers Welfare initiated RKVY-RAFTAAR in 2018 to enhance agri-innovation and entrepreneurship through the provision of a strong support system in the form of incubation centers.

The initiative plans to bring about a transformation in the rural economy by providing young entrepreneurs with the necessary tools, knowledge, and capital to create scalable and sustainable agricultural businesses.

Overview of RKVY-RAFTAAR

1. Objectives:

- To make farming a profitable economic venture.
- To promote agri-entrepreneurship and rural employment.
- To facilitate innovation in agriculture and allied sectors.
- To foster startups through agribusiness incubation centres.

2. Key Components:

- Agripreneurship Orientation Program (AOP): For aspiring entrepreneurs with innovative ideas. A stipend of ₹10,000/month is given during the 2-month training.
- Startup Agri-Business Incubation: Shortlisted startups are given up to ₹25 lakh as financial support in the form of a grant-in-aid to commercialize their innovations.
- Formation of R-ABIs (RKVY-RAFTAAR Agribusiness Incubators): They are incubation facilities that are established within State Agricultural Universities (SAUs), ICAR institutions, and other approved institutes.

3. Funding Mechanism: It is a centrally sponsored scheme based on a sharing ratio of 60:40 between the Centre and States (while in the case of NE and Hilly States, the sharing ratio would be 90:10).

The Role of R-ABIs in Incubation

RKVY-RAFTAAR functions through a chain of RKVY Agribusiness Incubators (R-ABIs) that form the core of the scheme. These centers offer mentoring, infrastructure, networking, and finance to rural agripreneurs and startups.

Major Services Provided by R-ABIs:

- Development and validation of business plans
- Technical guidance by domain experts

- c. Access to laboratories, equipment, and pilot testing facilities
- d. Intellectual Property Rights (IPR) assistance
- e. Legal and compliance advice
- f. Market linkages and investor connect.

Examples of successful R-ABIs are those at Punjab Agricultural University, TNAU (Coimbatore), and IARI (New Delhi), which have facilitated the launch of dozens of agritech and food processing startups.

Impact on Rural Agripreneurship

1. Empowering Youth and Women: The program has seen growing participation from rural youth and women entrepreneurs, enabling them to develop scalable businesses in areas such as:

- a. Smart farming and precision agriculture
- b. Organic and natural food processing
- c. Supply chain and cold storage innovation
- d. Production of farm machinery and equipment
- e. Online marketplaces and e-commerce for farmers.

2. Job Creation: Every startup generally generates direct and indirect jobs in rural regions, thereby curbing migration to urban areas.

3. Sustainability and Innovation: Startups being funded under RKVY-RAFTAAR are more concentrated on climate-smart agriculture, minimizing input prices, and increasing the efficiency of resource utilization—helping attain sustainable development goals (SDGs).

Success Case Studies

Case 1: Agrowave (Incubated at IARI): Agrowave is a B2B supply chain technology startup incubated at IARI, New Delhi. It runs a mobile pickup station model that allows farmers to sell produce directly from the farm gate, cutting out intermediaries. Through real-time data and logistics optimization, Agrowave reduces post-harvest losses and delivers produce to markets faster and fresher. The platform equips farmers with improved price realization, reduces transport costs, and facilitates a more efficient and transparent agricultural value chain. Agrowave has become a replicable model for rural agripreneurship and digital agriculture in India.

Case 2: Krishi Janani (Tamil Nadu): Krishi Janani is a Tamil Nadu-based women-led agripreneurship firm that specializes in the production of environmentally friendly organic farm inputs like bio-fertilizers and bio-pesticides. The organization also empowers rural women with training on organic farming practices and sustainable agriculture knowledge, while providing livelihood opportunities. Krishi Janani helps towards women empowerment and sustainable rural development by upholding environmentally friendly practices.

Case 3: BhoomiAgri Ventures (Maharashtra): BhoomiAgri Ventures is a Maharashtra-based innovative startup that deals in hydroponics and cutting-edge vertical farming techniques. The startup focuses on the modernization of agriculture through the development of soil-less cultivation methods that are viable for peri-urban and urban farming. BhoomiAgri has empowered more than 500 rural youth through protected cultivation training, enabling them to adopt climate-resilient and resource-conserving farming techniques. It is the leader in driving sustainable agritech and rural jobs.

Challenges and the Way Forward

1. Challenges:

- a. Insufficient awareness of rural masses about the program.
- b. Inadequate private investment in rural agritech startups.
- c. Post-incubation support and market linkage needed stronger.

2. Recommendations:

- a. Widespread outreach programs in local languages.
- b. Partnership with NGOs, SHGs, and FPOs.
- c. Incentives for corporates and banks to invest in incubated startups.
- d. Making digital tools more robust for monitoring and mentoring.

Conclusion

RKVY-RAFTAAR is becoming a game-changer in the rural innovation ecosystem of India. By connecting innovation with implementation, the scheme has not only encouraged entrepreneurship but has also encouraged rural communities to pursue their economic aspirations. With continued policy support and collaboration between stakeholders, RKVY-RAFTAAR can also unleash an agrarian renaissance, providing food security, jobs, and inclusive growth to India.

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Smart Logistics and Cold Chain Management in Perishables

Article ID: 71064

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Abstract

Effective logistics and cold chain management are essential to preserve the quality, safety, and marketability of perishable farm products like fruits, vegetables, dairy, meat, and flowers. With advancements in technology, conventional logistics systems are giving way to intelligent logistics solutions that use real-time tracking, data analytics, automation, and IoT-based monitoring. This article discusses the role of intelligent logistics in handling perishables, the advantages of integrated cold chain systems, main challenges, and the future prospects for a digitally-driven supply chain in the agri-food industry.

Introduction

Perishable agricultural products are extremely sensitive to handling practices, humidity, and temperature during storage and transportation. In developing nations such as India, a considerable percentage of post-harvest losses, ranging between 20–40% for perishables, can be directly linked to inefficient logistics and poor cold chain infrastructure. With increasing consumer demand for fresh, safe, and traceable food, the agri-logistics industry needs to be modernized.

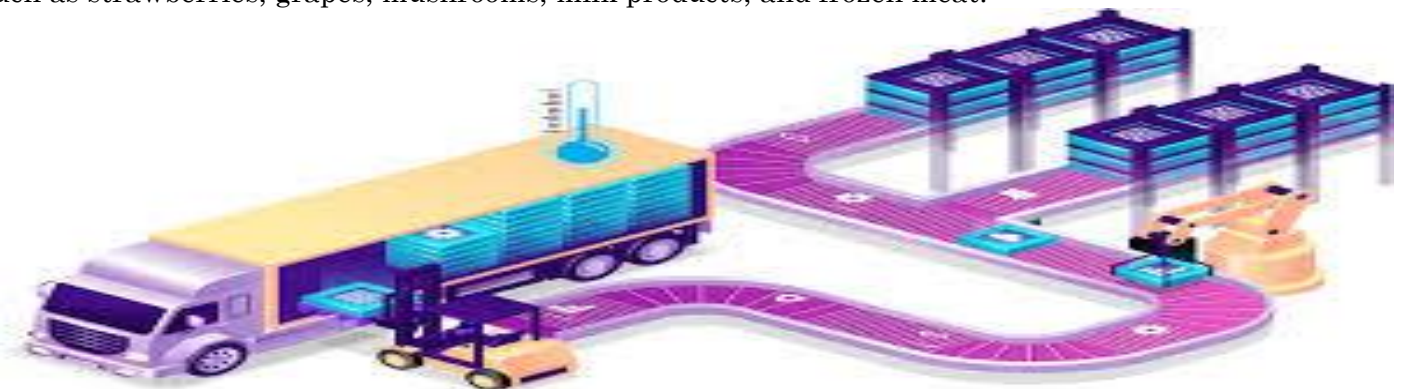
Smart logistics and cold chain systems leverage emerging technologies to enhance visibility, efficiency, and reliability across the supply chain. By minimizing wastage, preserving quality, and expanding market access, these innovations benefit farmers, processors, retailers, and consumers alike.

Understanding Cold Chain and its Importance

A cold chain is a temperature-controlled supply chain that maintains optimal environmental conditions for perishables from the point of harvest to consumption. It typically includes:

- a. Pre-cooling on the farm
- b. Cold storage at the point of collection and processing
- c. Refrigerated transportation (truck, containers)
- d. Cold display and home delivery retail systems.

Cold chain management effectively prolongs shelf life, minimizes microbial contamination, enhances price realization, and facilitates access to far-off markets. It is particularly crucial for high-value commodities such as strawberries, grapes, mushrooms, milk products, and frozen meat.



Source: Hyperthings

Smart Logistics: The Digital Evolution

Smart logistics is the use of digital technologies and tools in planning, execution, and tracking of supply chain operations. For perishables, these involve:

- 1. IoT-Based Monitoring:** Temperature, humidity, and gas level sensors placed inside cold rooms and transport vehicles continuously track temperature, humidity, and gas levels. Thresholds breached trigger alerts to prevent spoilage.
- 2. GPS and Fleet Management:** GPS-capable cars make it possible to track shipments in real time. Route planning software reduces fuel and transit costs.
- 3. Blockchain and Traceability:** Blockchain provides clarity and tamper-free records for every supply chain step. It does this and wins consumer trust as well as making it easier to recall contaminated product quickly.
- 4. Automation and Robotics:** Automated sorters, packaging, and palletizing units at cold stores streamline operations while lessening manual mistakes.
- 5. AI and Predictive Analytics:** Artificial intelligence assists with demand forecasting, dispatch scheduling, and warehouse space allocation based on levels and expiration dates of perishable inventory.

Benefits of Smart Cold Chain Logistics

Benefit	Description
Reduced Post-Harvest Losses	Minimizes spoilage through controlled storage and transport conditions
Enhanced Market Reach	Enables long-distance export and urban distribution of fresh produce
Improved Food Safety	Prevents microbial growth and ensures compliance with safety regulations
Higher Farmer Incomes	Better quality fetches premium prices and reduces dependence on middlemen
Environmental Efficiency	Optimized routes and efficient energy use lower the carbon footprint

Key Challenges

Although smart logistics holds much promise, there are a number of barriers to its large-scale adoption:

- 1. Infrastructure Gaps:** Basic cold storage, refrigerated transport, and assured electricity supply are missing in most rural and semi-urban regions.
- 2. High Costs:** Setup costs for IoT devices, cold storage, and reefer trucks are usually too high for smallholder farmers and FPOs.
- 3. Technical Skills:** Operators require training in operating smart devices, making sense of data, and keeping equipment. Unavailability of trained manpower is a crucial bottleneck.
- 4. Policy and Regulatory Issues:** Lack of common standards and inadequate financial incentives for investment in cold chains discourage private entry.

Government and Private Sector Initiatives

Startups and governments are coming together more to fill the gap in cold chain infrastructure:

- 1. Mission for Integrated Development of Horticulture (MIDH):** Provides financial support for cold storages and reefer vans.
- 2. Agri Infra Fund (AIF):** Provides medium- to long-term debt finance for cold chain initiatives.
- 3. Startups such as LEAF, WayCool, and Arya.ag** are using AI and IoT to provide integrated logistics services to farmers and agri-businesses.
- 4. Cooperative models and public-private partnerships (PPP)** are also gaining popularity in rural and peri-urban logistics centers.

Future Outlook and Recommendations

With increasing consumer consciousness, export markets, and food safety legislation, the smart logistics and cold chain industry has the potential for high growth.

Recommendations:

- 1. Policy Support:** Harmonize policies regarding cold chain subsidy, customs for imported technology, and energy-efficient infrastructure.
- 2. Skilling Programs:** Provide training to rural youth and FPOs for operating smart logistics equipment through Krishi Vigyan Kendras (KVKs) and ITIs.
- 3. Affordable Technologies:** Encourage low-cost solar-powered cold rooms and modular cold storage systems for small-scale operations.
- 4. Data Integration:** Support utilization of digital dashboards to track inventory, quality, and delivery schedules.
- 5. Financial Inclusion:** Support access to credit and insurance coverage for cold chain operators and logistics start-ups.

Conclusion

Intelligent logistics and cold chain management are no longer niceties but must-have elements of a profitable and resilient perishable supply chain. The integration of digital technologies in post-harvest handling systems not only lowers food losses but also adds value, trust, and transparency from farm to fork. For inclusive growth, infrastructure investment, training, and policy changes need to go hand-in-hand. A well-connected network of cold chains powered by intelligent logistics is the key to nourishing an increasing population with fresh, safe, and high-quality food.

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Stress: Navigating Environmental Stress on Cropping - Strategies for Boosting Crop Resilience

Article ID: 71065

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Abstract

Environmental stressors such as drought, salinity, extreme temperatures, and erratic rainfall patterns are increasingly threatening global agricultural productivity and food security. As these challenges intensify due to climate change and environmental degradation, there is an urgent need to develop and implement adaptive cropping strategies that enhance crop resilience. This paper examines the dynamic relationship between environmental stress and cropping systems, highlighting the importance of integrated approaches to sustain yields under adverse conditions. Key strategies discussed include the adoption of stress-tolerant crop varieties, crop diversification, intercropping, soil conservation techniques, and precision agriculture. By aligning agronomic practices with local environmental conditions, these approaches not only mitigate the impact of stress but also improve resource-use efficiency and ecosystem sustainability. The findings underscore the potential of adaptive cropping systems to serve as a cornerstone of climate-resilient agriculture, providing a pathway to more stable and sustainable food production in the face of environmental uncertainty.

Introduction

Agricultural productivity is increasingly challenged by a range of environmental stresses such as drought, salinity, heat, flooding, and extreme weather events—pressures that are intensifying with the global climate crisis. These stressors disrupt plant growth, reduce yields, and threaten food security, especially in regions dependent on climate-sensitive farming. In this context, enhancing crop resilience has become a central goal in sustainable agriculture.

Effective cropping strategies are critical tools in navigating environmental stress. These strategies include the use of stress-tolerant crop varieties, crop rotation, intercropping, conservation agriculture, and the integration of traditional knowledge with modern biotechnology. By aligning cropping practices with environmental realities, farmers can mitigate the adverse impacts of stress and maintain stable production. This approach not only ensures economic viability but also contributes to ecosystem health and climate adaptability.

This paper explores how targeted cropping strategies can be designed and implemented to bolster crop resilience, emphasizing their role in sustainable food systems under changing environmental conditions.

Understanding Environmental Stress on Crops

Environmental stress refers to adverse external factors that affect plant growth, development, and productivity. Key stressors include:

- 1. Drought Stress:** Limited water availability disrupts photosynthesis, impairs metabolic functions, and leads to yield losses (Fahad et al., 2017).
- 2. Salinity Stress:** High salt concentrations in soil hinder water absorption and cause ion toxicity (Shrivastava & Kumar, 2015).
- 3. Temperature Stress:** Both heat and cold stress damage cellular structures, proteins, and enzymes, negatively impacting crop development (Hasanuzzaman et al., 2013).
- 4. Nutrient Deficiency:** Degraded soils often lack essential nutrients, reducing crop productivity (Lal, 2015).

Strategies for Boosting Crop Resilience

- 1. Breeding Stress-Tolerant Varieties:** Developing stress-tolerant crop varieties through conventional breeding and genetic engineering is a proven approach. For example, drought-tolerant maize and salinity-resistant rice varieties have shown promise in maintaining yields under adverse conditions (Manavalan et al., 2009).
- 2. Precision Agriculture:** Technologies like remote sensing, GPS, and Internet of Things (IoT)-based systems help farmers monitor soil, weather, and crop conditions in real time. Precision agriculture optimizes resource use, enabling crops to withstand environmental stress (Zhang et al., 2020).
- 3. Soil Health Improvement:** Healthy soils are crucial for crop resilience. Practices such as cover cropping, crop rotation, and the application of organic matter improve soil structure, fertility, and water retention (Lal, 2015).
- 4. Water Management:** Efficient irrigation systems, such as drip and sprinkler irrigation, ensure water availability during droughts. Scheduling irrigation based on soil moisture and weather conditions further reduces water stress (Chai et al., 2016).
- 5. Biostimulants and Plant Growth Promoters:** Biostimulants, including microbial inoculants, seaweed extracts, and amino acids, enhance crop stress tolerance by improving nutrient uptake, root development, and stress resistance (Calvo et al., 2014).
- 6. Agroforestry and Intercropping:** Agroforestry systems, which combine crops with trees, and intercropping, which integrates multiple crops, reduce environmental stress by improving microclimates, reducing soil erosion, and optimizing resource use (Schoeneberger, 2009).
- 7. Climate-Smart Agricultural Practices:** Climate-smart practices such as adjusting planting schedules, diversifying crops, and adopting conservation agriculture help farmers adapt to climate variability and reduce the effects of environmental stress (Lipper et al., 2014).
- 8. Biotechnology and Gene Editing:** Tools like CRISPR-Cas9 allow for precise genetic modifications to enhance stress tolerance in crops. For instance, scientists have edited genes to improve drought tolerance in rice and wheat (Kim et al., 2021).

The Role of Policy and Collaboration

Government policies and collaborative efforts are vital for building resilient cropping systems. Investments in agricultural research, extension services, and farmer education ensure the adoption of sustainable practices. Financial incentives and insurance schemes also enable farmers to manage risks associated with environmental stress (Pretty et al., 2018).

Conclusion

Navigating environmental stress in cropping requires a holistic approach that integrates advanced technologies, sustainable farming practices, and supportive policies. Strengthening crop resilience is essential for ensuring global food security in the face of climate change and environmental challenges. By adopting innovative strategies, we can safeguard agriculture and support farmers in adapting to a changing world.

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Sustainable Aquaculture: Ensuring a Resilient Future for Global Seafood

Article ID: 71066

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Introduction

Aquaculture, sometimes known as aquafarming, is the controlled cultivation of aquatic animals such as fish, mollusks, crustaceans, and aquatic plants for a variety of reasons including human consumption, conservation, and commercial output.

This method acts as an aquatic analog to agriculture, attempting to supplement and improve the natural supply of seafood. The importance of aquaculture has expanded dramatically in recent decades. As global seafood demand grows, aquaculture has emerged as an important source of high-quality nutrition for people all over the world. However, the rise of aquaculture poses various obstacles. Traditional aquaculture operations can harm the environment by destroying habitat, polluting water, and overfishing wild fish stocks.

To address these challenges, we urgently need sustainable aquaculture practices that strike a balance between economic growth, environmental protection, and social responsibility. Sustainable aquaculture seeks to limit negative environmental impacts, decrease reliance on wild fish populations, and promote economic development in coastal and rural communities.

Aquaculture can supply expanding global seafood demand while also preserving aquatic environments for future generations by using sustainable practices.

The Need for Sustainable Aquaculture

As the world's population grows, with a projected 9.7 billion by 2050, so does the demand for protein-rich foods. Aquaculture, the activity of producing aquatic organisms, has emerged as an important means of meeting this growing demand. However, traditional aquaculture practices have brought a number of environmental issues that demand a change toward sustainability.

One major environmental hazard linked with traditional aquaculture is habitat degradation. The expansion of aquaculture operations frequently results in the destruction of essential ecosystems such as mangroves and wetlands, which provide vital habitat for a wide range of species. The extinction of these habitats affects not only biodiversity but also the ecological balance, resulting in long-term environmental consequences.

Disease outbreaks in aquaculture systems create extra environmental and economic challenges. High-density farming settings can accelerate the spread of diseases among cultivated species, necessitating the use of antibiotics and other chemical treatments. Overuse of these drugs can lead to the emergence of resistant infections and increased environmental contamination, hampering disease management efforts.

Overfishing to supply feed for farmed species puts further strain on wild fish populations. Many aquaculture operations rely on fishmeal and fish oil obtained from wild-caught fish, which adds to the depletion of marine resources. This technique jeopardizes the sustainability of both aquaculture and wild fisheries, emphasizing the critical need for alternative feed sources.

Principles of Sustainable Aquaculture

Sustainable aquaculture is critical for satisfying rising global seafood demand while reducing environmental impact and fostering social responsibility. The key principles include:

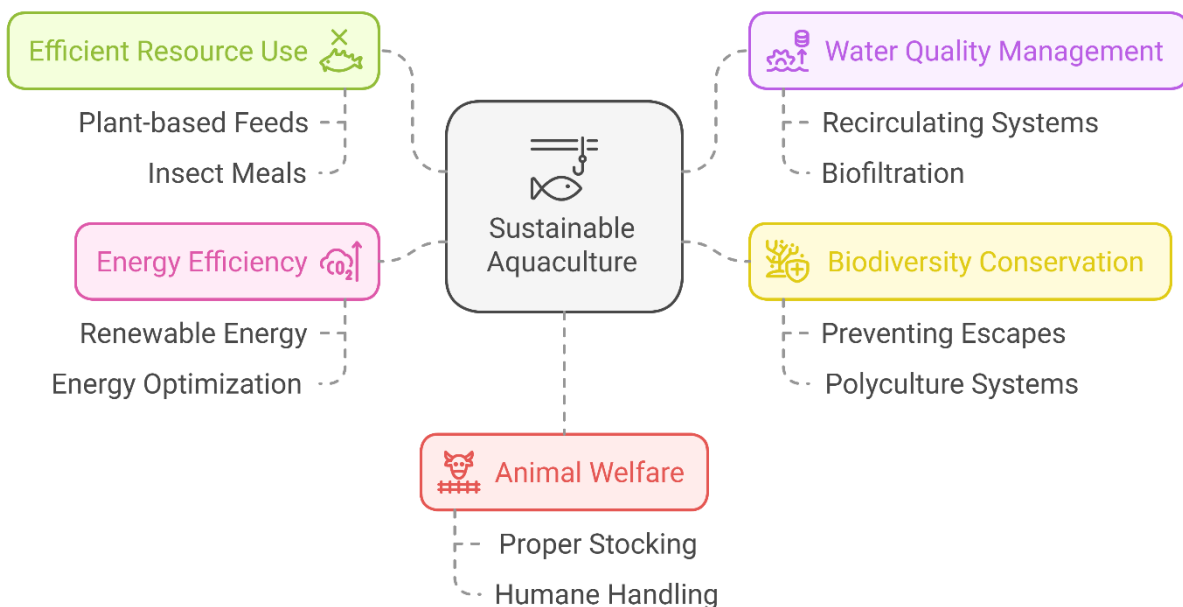
1. Efficient Resource Use: Moving away from wild fish-based feeds and toward alternate protein sources such as plant-based components, insect meals, and microbial proteins can lessen pressure on wild fish populations while also improving aquaculture sustainability.

2. Water Quality Management: Using effective waste management systems, such as recirculating aquaculture systems (RAS) and biofiltration, helps to avoid nutrient runoff and maintain water quality, hence safeguarding nearby ecosystems.

3. Biodiversity Conservation: Preventing the escape of farmed species into the wild and implementing polyculture systems, where various species are cultivated together, can maintain local biodiversity and reduce disease risks.

4. Energy Efficiency: Using renewable energy sources, such as solar or wind power, and optimizing energy use in aquaculture facilities can help to reduce greenhouse gas emissions and operational costs.

5. Animal Welfare: Ensuring ethical farming techniques, such as proper stocking densities, enough nourishment, and humane handling, benefits the health and well-being of cultivated species, resulting in increased production and product quality.



Innovations Driving Sustainable Aquaculture

The aquaculture business is undergoing substantial alterations as innovative methods and technology are adopted with the goal of improving sustainability and decreasing environmental consequences. These developments are centered on optimizing resource use, reducing environmental footprints, and boosting operating efficiencies.

Integrated Multi-Trophic Aquaculture (IMTA) is a method of cultivating diverse species from different trophic levels in a single system. This strategy permits one species' waste to act as nutrients for another, resulting in a more balanced ecosystem that lowers pollution and improves resource efficiency. For example, fish, shellfish, and seaweed can be farmed together, with fish byproducts being utilized by shellfish and seaweed, resulting in enhanced water quality and total system production.

Biofloc Technology is the development of beneficial microorganisms in aquaculture systems to transform waste products like uneaten feed and excreta into microbial biomass. This biomass can subsequently be devoured by the cultured species, thereby recycling nutrients and lowering the demand for water exchange. Biofloc systems improve biosecurity by reducing pathogen multiplication, while also contributing to sustainable production by cutting feed costs and increasing water quality.

Genetic advancements in aquaculture include selective breeding operations aiming at generating species with desired features like as quicker growth rates, disease resistance, and higher feed conversion ratios. By focusing on genetic enhancements, the industry may create strong stocks that use fewer resources and are more resistant to environmental shocks, boosting sustainability.

Digital Monitoring Systems use the Internet of Things (IoT), artificial intelligence (AI), and modern sensors to deliver real-time information on a variety of characteristics such as water quality, oxygen levels, and fish activity. These tools enable precision aquaculture, allowing farmers to make informed decisions that optimize feeding regimens, detect and reduce health risks early on, and manage resources efficiently. The incorporation of digital tools promotes proactive management, resulting in enhanced production and decreased environmental impact.

Challenges and the Way Forward

To accommodate rising demand, the aquaculture industry has made great progress in producing high-quality fish. However, significant hurdles remain, threatening its long-term viability and expansion. The main challenges are economic, technological, regulatory, and societal. To solve these obstacles and promote the expansion of sustainable aquaculture, it is critical to investigate economic and technological impediments, regulatory issues, and the need for increased cross-sector collaboration. Furthermore, increasing consumer awareness is critical for encouraging sustainable seafood practices.

Economic and Technological Barriers: Economic constraints remain one of the most major impediments to the widespread adoption of sustainable aquaculture methods. The initial investment required to deploy innovative technologies and maintain high environmental standards can be prohibitively expensive, particularly for small and medium-sized businesses. This obstacle is especially tough for developing countries with little financial resources. Addressing these economic and technological constraints necessitates significant investment in research, development, and dissemination of breakthrough technology accessible to farmers of all sizes. Subsidies, financial incentives, and advantageous lending schemes can all contribute to increase operators' access to sustainable technologies.

Regulatory Challenges: Regulatory regimes vary greatly between developed and poor countries. In rich countries, strict restrictions can stifle innovation, but in developing ones, lax regulations frequently lead to unsustainable behaviors. A unified, region-specific regulatory framework is required to strike a balance between sustainability and economic growth.

Collaboration Among Stakeholders: Collaboration among governments, researchers, and industry is vital. Governments must give policy assistance, researchers should focus on developing sustainable technology, and businesses must embrace sustainable practices. Public-private collaborations can help to close the gap and ensure the successful implementation of sustainable aquaculture solutions.

Consumer Awareness: Raising consumer awareness of the value of sustainable seafood can increase market demand for properly supplied items. Education and certification programs can help consumers make more educated decisions, pushing aquaculture operations to adopt better practices.

Conclusion

Sustainable aquaculture is critical in meeting the growing worldwide demand for seafood while protecting the environment and fostering social fairness. As the world's population grows, the demand for natural marine resources increases, making it critical to implement aquaculture practices that do not deplete or harm ecosystems. Aquaculture, by focusing on sustainability, can not only meet the increased demand for protein-rich food but also contribute to food security, especially in areas where wild fish supplies are depleted due to overfishing and climate change.

To achieve long-term success, aquaculture techniques must strike a careful balance between environmental health, economic viability, and social responsibility. Ecologically, sustainable techniques prioritize the protection of water quality, biodiversity, and natural habitats, hence lowering farming operations' environmental footprint.

To summarize, sustainable aquaculture is not only an option, but a requirement for meeting the problems of feeding a growing global population while protecting our planet's natural resources. Through innovation,

good management, and collaboration, the aquaculture industry can continue to prosper and contribute to global food security without jeopardizing ecosystem health.

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Aquaculture and Biodiversity: Balancing Production and Conservation

Article ID: 71067

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Introduction

Aquaculture, defined as the cultivation of aquatic species such as fish, crustaceans, mollusks, and aquatic plants, is one of the world's fastest-growing food production sectors, making a substantial contribution to global food security. It accounts for a significant amount of global protein intake and provides a steady source of nutritious food, helping to alleviate nutritional inadequacies and boost economic development, particularly in developing nations.

Biodiversity in aquatic ecosystems is critical for preserving ecological balance and providing a variety of ecosystem services. These ecosystems are critical repositories of the planet's biological variety, contributing greatly to overall biological productivity.

The link between aquaculture practices and biodiversity conservation is intricate and multifaceted. While aquaculture has the potential to relieve pressure on overexploited wild fisheries, it can also endanger biodiversity through habitat modification, the introduction of non-native species, and nutrient contamination. As a result, adopting sustainable aquaculture practices with low environmental effect is critical to ensuring biodiversity conservation. Strategies such as integrated multitrophic aquaculture and the utilization of native species can help to align aquaculture development with biodiversity conservation objectives.

The Role of Biodiversity in Aquaculture

Biodiversity is critical to the health of aquatic ecosystems, acting as a basis for stability, resilience, and productivity. A varied range of species ensures that biological processes such as nutrient cycling and energy flow run smoothly, which is critical for the long-term viability of aquaculture systems.

Incorporating a range of species into aquaculture systems has various advantages, including increased disease resistance and resource usage. For example, polyculture and integrated multi-trophic aquaculture (IMTA) systems use diverse species' complimentary roles to build more resilient and efficient production conditions. By farming numerous species simultaneously, these systems can prevent disease outbreaks and increase overall output, resulting in more sustainable aquaculture techniques.

Genetic diversity is also important in aquaculture because it allows organisms to adapt to changing environmental conditions and resist disease. Maintaining a diverse genetic background within cultured populations is critical for selective breeding programs that attempt to improve qualities like growth rates, feed efficiency, and stress tolerance. However, the introduction of non-native species and the escape of cultivated organisms can represent serious threats to local biodiversity, potentially displacing native species and altering ecosystem dynamics. As a result, careful management of genetic resources is critical to avoiding harmful consequences on biodiversity and ensuring the long-term viability of aquaculture operations.

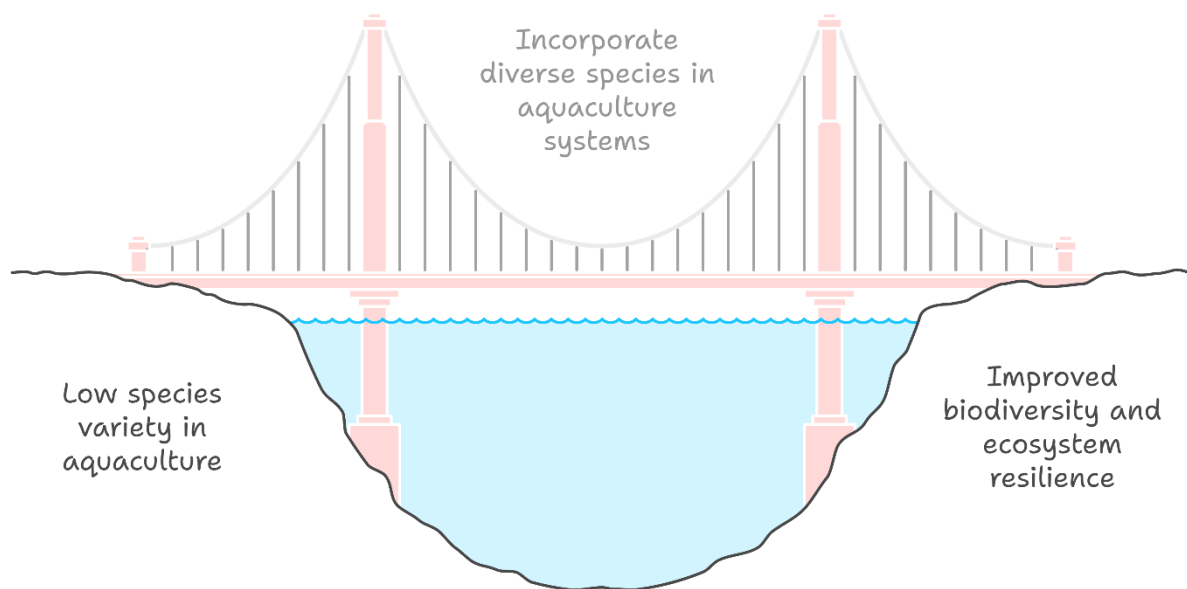
Impacts of Aquaculture on Biodiversity

Biodiversity is critical to the health of aquatic ecosystems, acting as a basis for stability, resilience, and productivity. A varied range of species ensures that biological processes such as nutrient cycling and energy flow run smoothly, which is critical for the long-term viability of aquaculture systems. High species variety in aquaculture improves ecosystem services while also contributing to the overall health and balance of the aquatic environment.

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Enhance Aquaculture Diversity for Ecosystem Health



Strategies to Enhance Biodiversity in Aquaculture

Enhancing biodiversity in aquaculture systems is a cornerstone of sustainable aquaculture development, as it ensures ecological balance, improves productivity, and reduces environmental impacts. One effective strategy is the implementation of Integrated Multi-Trophic Aquaculture (IMTA). This innovative approach involves cultivating multiple species from different trophic levels, such as fish, shellfish, and seaweed, in a single system. The waste generated by higher trophic species, such as fish, is utilized as nutrients by lower trophic species like algae and filter feeders. This symbiotic relationship reduces nutrient waste, mitigates environmental pollution, and increases overall system efficiency, making IMTA an effective solution for biodiversity-friendly aquaculture.

Another important strategy is to use sustainable feed alternatives to reduce the aquaculture industry's reliance on wild-caught fish for fishmeal and oil. Overexploitation of forage fish for feed production has serious consequences for marine biodiversity, disrupting food webs and depleting wild fish stocks. Alternatives like as plant-based proteins, insect meals, and microbial components not only reduce strain on wild fish populations, but also offer a sustainable and cost-effective aquafeed manufacturing alternative.

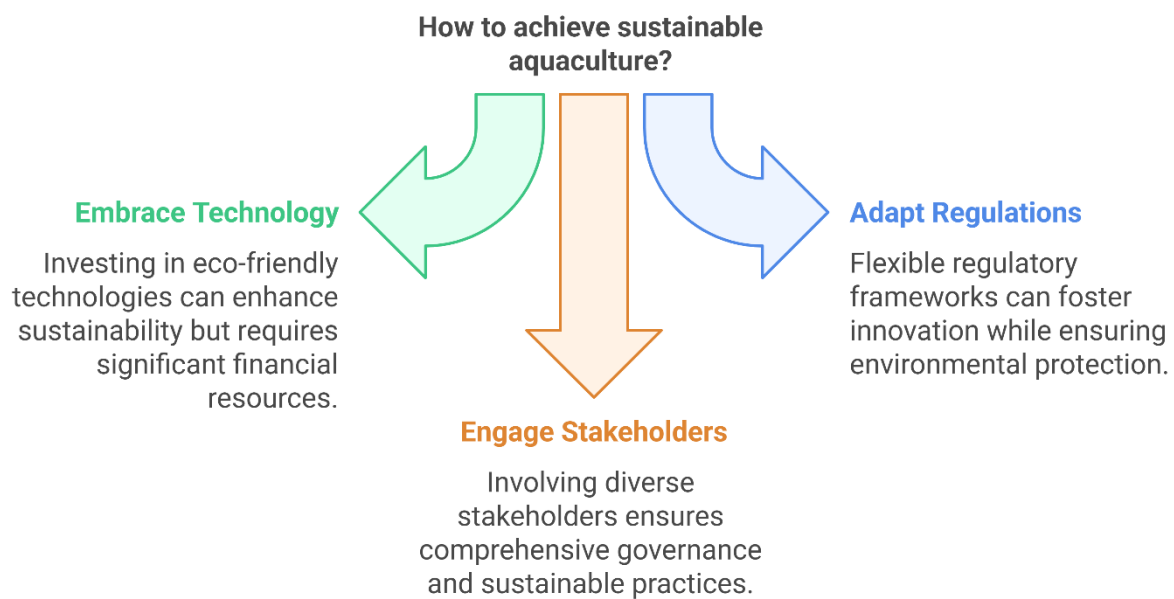
Biosecurity techniques are critical for reducing the risk of disease spread and regulating escapes in aquaculture systems. High-density farming conditions raise the likelihood of disease outbreaks, which can harm both farmed and wild populations.

Challenges and Future Directions

Balancing aquaculture productivity and biodiversity protection presents complex issues that require comprehensive techniques. Aquaculture expansion is frequently associated with habitat change, which can have a negative impact on local biodiversity. For example, converting coastal wetlands to aquaculture ponds disturbs ecosystems and reduces species diversity. Furthermore, the introduction of non-native species for agriculture entails major dangers since these species can become invasive, outcompeting native organisms and disrupting ecological balances. The escape of farmed species into the wild exacerbates these concerns, causing genetic dilution in wild populations and disease spread.

Technological, economic, and regulatory constraints also hamper the implementation of sustainable aquaculture methods. The development and application of environmentally friendly technologies frequently necessitate significant financial inputs, which can be prohibitive for small-scale enterprises. Furthermore, strict environmental restrictions, while necessary for conservation, may unintentionally stifle technological innovation and sectoral growth if not structured with flexibility and stakeholder engagement. For example, in New Zealand, regulatory challenges involving the integration of fisheries and aquaculture have created worries about meeting future food security demands, illustrating the intricate interplay between policy and practice.

The involvement of stakeholders is critical in ensuring sustainable aquaculture. To balance production and conservation aims, effective governance structures that include governments, industry entities, local communities, and environmental organizations are required.



Conclusion

Biodiversity is critical to aquaculture's sustainability, as it supports the health and resilience of aquatic ecosystems. The complicated interactions between these systems' many species contribute to nutrient cycle, disease management, and overall ecosystem stability. Recognizing the value of biodiversity is critical for creating aquaculture operations that are both productive and environmentally friendly.

To achieve this balance, it is critical to implement aquaculture techniques that promote biodiversity conservation. Implementing solutions like Integrated Multi-Trophic Aquaculture (IMTA), which uses various species in symbiotic systems, can help to restore ecological balance and reduce environmental impact. Furthermore, focusing on genetic conservation helps to minimize genetic contamination and preserves native gene pools, so ensuring the resilience of wild populations.

Habitat restoration activities can benefit adjacent ecosystems while preserving aquaculture productivity, so improving the overall health of aquatic environments. Exploring sustainable feed options can help to

alleviate overfishing concerns. Implementing comprehensive biosecurity measures is critical for preventing disease outbreaks and managing escapes, which can harm native species. Furthermore, increasing certification and regulation can stimulate the use of biodiversity-friendly aquaculture practices, ensuring that industry standards are consistent with conservation objectives.

By following these principles, the aquaculture business may help to provide food security while also protecting aquatic ecosystem diversity. This integrated approach guarantees that aquaculture development meets both human and environmental needs, promoting a sustainable future for aquatic resources.

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Biofertilizers: A Natural Path to Restoring Soil Fertility

Article ID: 71068

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Introduction

Biofertilizers are microbial-based products that enhance plant growth by carrying out key biological functions. These include generating plant growth hormones, fixing atmospheric nitrogen, and converting phosphorus into forms plants can absorb (Malusa et al., 2016). Basu et al. (2021) noted that these naturally occurring organisms help plants obtain vital nutrients that are typically difficult to access in their natural state. Biofertilizers offer a sustainable alternative to chemical fertilizers, supporting environmentally friendly agriculture by boosting soil fertility, increasing crop yields, and reducing ecological harm. These natural products contain beneficial microorganisms, such as nitrogen-fixing bacteria (rhizobium, azotobacter), phosphate-solubilizing bacteria (Bacillus, Pseudomonas), potassium-mobilizing bacteria, and mycorrhizal fungi, that enhance nutrient availability through processes like nitrogen fixation, phosphorus solubilization, potassium mobilization, and the breakdown of organic matter. Beneficial microorganisms that aid in the release of nutrients from organic matter and plant leftovers in the soil make up the majority of biofertilizers. Several microbial strains are employed as biological fertilizers to aid in this process this process, several microbial strains are employed as biological fertilizers. By supplying the host plants with necessary nutrients, these microbes help to maintain the physiological processes and healthy growth of the plants. Biofertilizers are regarded as an essential component of integrated nutrient management systems since they are produced utilizing live bacteria. They support ecologically friendly agriculture by acting as a sustainable substitute and supplement to chemical fertilizers.

Types of Biofertilizers

Biofertilizers are developed using different types of microorganisms and their interactions with crops. They can be categorized in several ways depending on their properties and functions.

Azotobacter: Among the various species of *Azotobacter*, *A. chroococcum* is the most frequently found in cultivated soils and is the only species capable of fixing nitrogen in culture media. Additionally, *Azotobacter* produces antifungal compounds that help protect plants from a range of diseases. Improving seed germination and seedling vigor contributes to stronger and more uniform crop establishment.

Azospirillum: Azospirillum bacteria fix approximately 20 to 40 kilograms of nitrogen per hectare in the rhizosphere of non-leguminous crops like cereals, millets, oilseeds, and cotton. They also stimulate the production of indole-3-acetic acid, a plant hormone that supports growth and increases tolerance to diseases and drought conditions.

Azolla: Azolla is a free-floating aquatic fern that forms a symbiotic relationship with the blue-green alga *Anabaena azollae* to fix atmospheric nitrogen. It serves as an alternative to synthetic nitrogen fertilizers or as an additional nitrogen source. Commonly used as a biofertilizer in paddy fields, Azolla can contribute approximately 40 to 60 kilograms of nitrogen per hectare in rice cultivation.

Cyanobacteria: Blue-green algae, also known as **cyanobacteria**, are a diverse group of unicellular to multicellular freshwater organisms primarily used in rice farming. They exist in both free-living and symbiotic forms but are unable to survive in acidic environments.

Rhizobium: Rhizobium is a soil-dwelling bacterium that forms a symbiotic relationship with the roots of leguminous plants, where it helps fix atmospheric nitrogen. It is considered one of the most efficient biofertilizers due to its high nitrogen-fixing capacity.

Methods of Application of Biofertilizers

Soil treatment: After mixing 200 kg of compost with 4 kg of each recommended biofertilizer, the mixture sits overnight. It is then incorporated into the soil before planting or sowing begins.

Seed treatment: Ten kilograms of seeds are well mixed with 200 grams of biofertilizer dispersed in 300–400 milliliters of water using a sticky substance like gum acacia, jaggery solution, etc. Seeds are kept on a clean sheet or cloth and allowed to dry in the sun before being used for sowing.

Seedling Root Dip: This technique is applied during transplanting. A slurry is prepared by blending 500 grams of biofertilizer culture with 50 milliliters of water. The seedling roots are then immersed in this mixture for 15–20 minutes before transplanting.

Limitations of Biofertilizers

1. Nutrient levels in compost products can vary significantly, and their application cost is often higher compared to certain chemical fertilizers.
2. The long-term and excessive use of certain substances can lead to the accumulation of salts, minerals, and heavy metals, which may adversely affect plant growth, harm soil microorganisms, degrade water quality, and pose risks to human health.
3. Large volumes are required for land application due to low contents of nutrient, in comparison with chemical fertilizers.
4. The need for seasonal biofertilizer, simultaneous crop operations, a restricted window for planting or sowing in a specific location, and other environmental constraints.
5. Constraints related to human resources and quality involve a shortage of technically skilled personnel in manufacturing departments, along with inadequate training in production procedures.

Conclusion

In sustainable agriculture, biofertilizers and integrated nutrient management serve as viable alternatives to chemical fertilizers. These eco-friendly and cost-effective inputs play a vital role in promoting organic farming, preserving ecosystems, and protecting the environment. Biofertilizers contribute significantly to enhancing soil fertility and supporting long-term agricultural sustainability.

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Digital Twin in Vegetable Farming

Article ID: 71069

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Introduction

What is vegetable: A **vegetable** is an edible part of a plant that is consumed by humans as part of a savory meal, typically cooked or raw. It includes various plant parts such as roots, stems, leaves, flowers, bulbs, seeds, and fruits.

According to the Ministry of Agriculture & Farmers Welfare (3rd Advance Estimates, 2023–24): Total Vegetable Production (India): 204.84 million metric tonnes (MMT). Total Area under Vegetable Cultivation: 11.23 million hectares.

Why there should be switch from monoculture of cereals to vegetable farming?

- a. Nutritional Security
- b. Economic benefits as most of the farmers have marginal landholdings
- c. Employment Generation
- d. Crop Diversification and Sustainability
- e. Government and Policy Support
- f. Environmental benefits of ecological balance.

In order to deal with ongoing scenario of climate change, shift in the pattern of rainfall and anthropogenic changes in the pest and diseases and call for climate resilient agriculture there is need of advancement in technologies.

This urges the introduction of digital twin in farming.

What is Digital Twin?

A Digital Twin in agriculture **is a real-time digital model** of a farm or crop system that mirrors the actual field conditions, **enabling data-driven decision-making** for better yield and resource use.

Vegetable crops are short-duration, input-sensitive, and require precise monitoring. **Digital Twin technology offers major advantages:**

1. Crop Monitoring and Prediction:

- a. Create a virtual model of a vegetable field (e.g., tomato, brinjal).
- b. Monitor growth stages, pest/disease risk, and irrigation needs.
- c. Predict yield, maturity time, and resource requirements.

2. Climate and Soil Simulation:

- a. Simulate effects of drought, rainfall, temperature fluctuations on crop performance.
- b. Adjust irrigation and fertilization plans based on digital twin predictions.

3. Resource Optimization:

- a. Determine optimal fertilizer dosage, irrigation frequency, and pesticide application based on real-time data.
- b. Reduces input cost and environmental impact.

4. Early Warning System:

- a. Digital twin can simulate disease/pest outbreak scenarios using current field conditions.
- b. Triggers alerts for preventive actions before damage occurs.

5. Precision Harvesting:

- a. Predict exact harvest time for best quality and market price.
- b. Plan labour and logistics in advance using data models.

6. Supply Chain and Traceability:

- a. Link farm-level data with post-harvest handling, storage, and transport.

b. Enables farm-to-fork traceability, important for export markets and certifications.

7. R&D and Crop Modelling:

- a. Researchers can simulate different varieties, agronomic practices, and input strategies without testing them in real fields.
- b. Saves time and cost in vegetable breeding and agronomy trials.

Conclusion

Incorporating **Digital Twin** in vegetable farming can:

1. Increase **precision and productivity**
2. Reduce **crop losses**
3. Improve **profitability**
4. Enable **predictive and smart farming**

It represents the next level of digital agriculture and is especially useful for high-value, perishable crops like vegetables.

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Sangri - A Popular Humble Bean of Desert Rajasthan in Pursuit of GI Tag

Article ID: 71070

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Sangri, also known as the *Desert Bean*, is a highly nutritious and versatile food derived from the Khejri tree (*Prosopis cineraria*), a vital plant of arid regions like Rajasthan. Celebrated for its unique earthy flavor and impressive health benefits, Sangri holds a special place in Rajasthani cuisine, particularly in traditional dishes like *Ker Sangri*, *punchkutta*, *sangri aachar*. Sangri Consumed both fresh and in processed forms, Sangri pods are typically dried and used as a vegetable, while its leaves are valued in traditional medicine. Beyond its medicinal and nutritional value, Sangri plays a crucial role in the sustainability and livelihoods of rural communities, especially in desert areas, making it a powerful example of a climate-resilient and underutilized food source that deserves wider recognition and promotion.



Pic-1-Sangri –The Dessert Bean

Table-1: Nutrient composition of sangri:

S.No	Nutrients	Fresh	Shade Dried
1	Moisture	79.3	6.7
2	Crude Protein	6.1	13.3
3	Fat	0.4	2.1
4	Crude fibre	5.1	20.1
5	Total Ash	1.2	5
6	Carbohydrate	13.7	53
7	Energy	83.6	286.9
8	Iron(mg)	0.48	1.7
9	Calcium(mg)	0.40	1.6
10	Phosphorus(mg)	0.04	0.86

Benefits of Sangri

Nutritional Value: Sangri is rich in essential minerals like potassium, magnesium, calcium, zinc, and iron, as well as protein and fiber.

Digestive Health: It has high fiber content and aids digestion and can help regulate blood sugar levels.

Immunity Boost: The combination of nutrients in Sangri can help strengthen the immune system.

Weight Management: The high fiber content promotes fullness and can help manage appetite, aiding in weight loss or maintenance.

Traditional Uses: Sangri has been traditionally used in aayurvedic medicine for various ailments, including skin diseases, diabetes, and respiratory problems.

Anthelmintic and Tonic: It is believed to act as a cooling anthelmintic and tonic, helpful in treating conditions like asthma and tremors.

Culinary Versatility: Sangri is used in pickles, curries, and chutneys, adding a unique nutty flavor and spice.

Conclusion

Sangri has high nutritional value and unique taste and flavour. It is rich in essential minerals, proteins, and dietary fiber, Sangri supports digestive health, boosts immunity, and contributes to overall well-being. In aayurveda, it is used to treat a range of conditions, including diabetes, skin disorders, and respiratory ailments, still this is underutilized and needs attention to popularize it all over the world. It can be proved worth to enhance income of rural people who are totally dependent on desert produce.

Antimycotic Innovation: Revolutionary Biomaterial Packaging Extends Postharvest Fruit Viability

Article ID: 71071

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Abstract

Contemporary agricultural enterprises encounter substantial economic deficits attributable to postharvest fungal proliferation affecting perishable commodities. This article examines emerging antimycotic packaging technologies incorporating bioactive compounds that demonstrate fungistatic properties without introducing synthetic chemical residues. Novel biodegradable polymeric matrices integrating essential oil components, chitosan derivatives, and nanoparticle inclusions represent promising alternatives to conventional preservation methodologies. Implementation potential, antimicrobial efficacy mechanisms, and sustainability considerations suggest these technologies may revolutionize global food preservation paradigms while addressing consumer preferences regarding reduced synthetic preservative utilization.

Keywords: Antifungal packaging, Bioactive compounds, Preservation, Shelf-life.

Introduction

Postharvest deterioration represents a persistent challenge throughout global agricultural supply networks, with fungal contamination constituting approximately 25-30% of productivity losses worldwide. Conventional preservation approaches typically incorporate synthetic fungicides, modified atmosphere technologies, or controlled environmental parameters. However, emerging consumer preferences regarding reduced chemical intervention combined with regulatory restrictions regarding permissible residue thresholds have necessitated exploration of alternative preservation methodologies. Biomaterial-based packaging incorporating naturally-derived antimycotic compounds presents a scientifically validated approach that simultaneously addresses preservation requirements while aligning with sustainability objectives and consumer expectations regarding minimal processing.

Fungal Deterioration Mechanisms in Harvested Fruits

Postharvest pathogenic organisms primarily exploit microscopic epidermal discontinuities resulting from mechanical trauma during harvest operations. Initial colonization frequently occurs asymptotically, followed by accelerated mycelial expansion throughout susceptible tissue. Common deterioration agents include *Penicillium species*, *Botrytis cinerea*, *Colletotrichum gloeosporioides*, and various *Aspergillus sp.*. Environmental factors including relative humidity, temperature fluctuations, and ethylene concentration significantly influence pathogenic proliferation rates. Additionally, physiological senescence processes inherent within harvested commodities progressively compromise cellular integrity, thereby facilitating microbial penetration throughout storage duration.

Bioactive Components in Antimycotic Packaging

Essential Oil Constituents: Aromatic plant extracts contain numerous terpene compounds demonstrating pronounced antimycotic activity. Thymol, carvacrol, eugenol, and cinnamaldehyde exhibit particularly robust inhibitory effects through disruption of fungal membrane integrity, enzymatic inhibition, and metabolic interference. Incorporation methodologies include microencapsulation techniques preventing volatile compound dissipation while facilitating controlled temporal release throughout storage duration.

Chitosan Derivatives: Deacetylated chitin polymers extracted from crustacean exoskeletons exhibit inherent antimicrobial properties through electrostatic interaction with negatively charged microbial membranes. Chemical modification involving quaternization processes significantly enhances antimycotic potential while improving solubility characteristics. Additionally, chitosan matrices frequently

demonstrate excellent oxygen barrier properties, thereby limiting oxidative deterioration processes while simultaneously restricting fungal respiration requirements.

Nanoparticle Integration: Metal oxide nanostructures including zinc oxide, silver, and copper variants demonstrate pronounced antimicrobial efficacy through multiple mechanisms including reactive oxygen species generation, membrane disruption, and metabolic interference. Incorporation within biodegradable matrices permits controlled release kinetics while minimizing environmental migration. Particle morphology, concentration gradients, and surface functionalization significantly influence antimycotic effectiveness. Recent innovations include photocatalytic variants activated through exposure to specific wavelengths, thereby enabling temporal control regarding preservation activation.

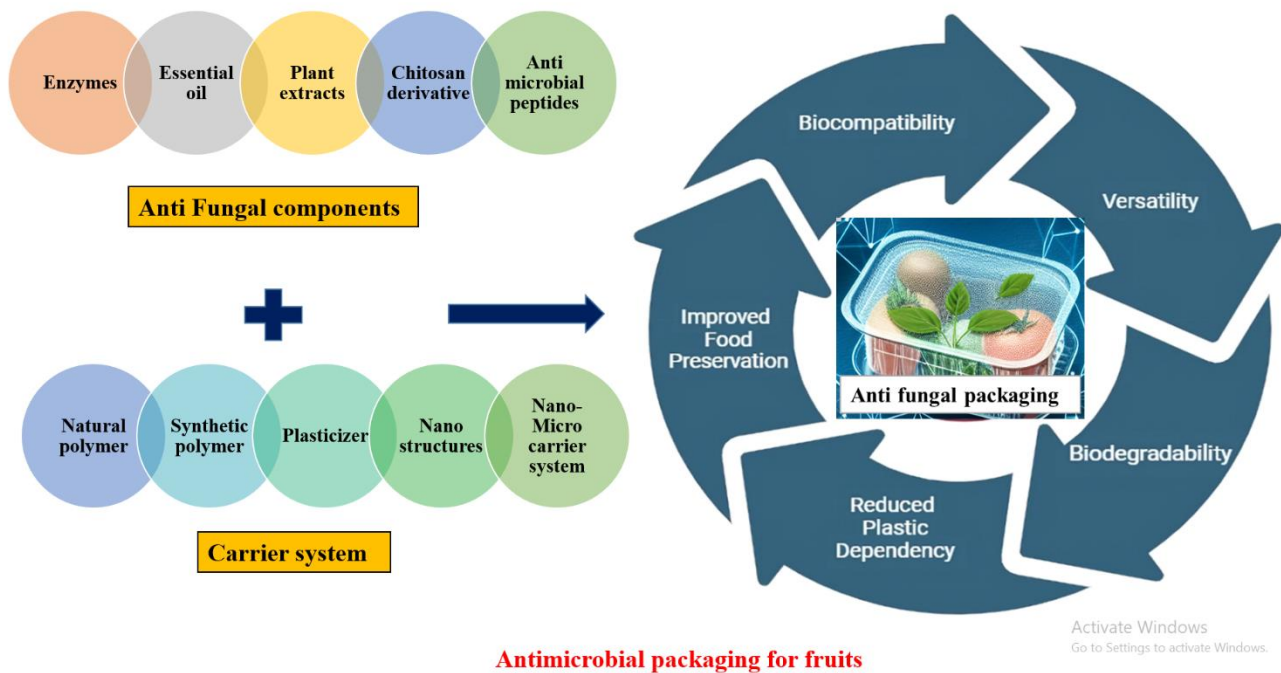


Figure.1 Antimicrobial packaging for fruits: antifungal components, carrier systems, and efficacy results

Application Methodologies for Commercial Implementation

Direct Fruit Surface Application: Edible coating formulations permit direct application through immersion, spraying, or brushing methodologies. Critical parameters affecting performance include solution viscosity, surface tension characteristics, and adhesion properties. Optimization regarding these variables ensures uniform distribution across irregular fruit morphologies, thereby preventing colonization vulnerability through discontinuous protection. Additionally, formulation compatibility with existing processing equipment facilitates integration within established commercial operations without requiring substantial infrastructure modification.

Independent Packaging Materials: Films, sachets, and structural components incorporating antimycotic compounds represent alternative deployment strategies. Controlled release mechanisms including humidity-activated systems respond dynamically to environmental conditions associated with incipient deterioration. Material formulations frequently incorporate biodegradable polymers including polylactic acid, polyhydroxyalkanoates, and cellulose derivatives. Mechanical properties including tensile strength, elongation characteristics, and puncture resistance require consideration alongside antimicrobial efficacy to ensure practical implementation feasibility.

Commercialization Challenges and Future Directions: Widespread implementation currently encounters several limitations requiring resolution. Production scalability, cost competitiveness compared with conventional methodologies, and regulatory approval pathways represent significant considerations. Additionally, sensory perception implications regarding potential organoleptic modifications necessitate comprehensive evaluation. Research priorities include optimization regarding controlled release kinetics,

enhanced stability throughout temperature fluctuations inherent within distribution networks, and formulation standardization facilitating consistent performance across diverse commodities.

Environmental Sustainability Considerations: Lifecycle assessment evaluations indicate significant advantages regarding environmental impact metrics compared with synthetic preservation approaches. Biodegradability characteristics minimize post-consumer waste accumulation while potentially contributing positively through soil amendment properties following composting processes. Additionally, reduced postharvest losses effectively improve resource utilization efficiency throughout agricultural production systems, thereby decreasing water, fertilizer, and energy inputs per consumable unit. Carbon footprint reductions associated with decreased transportation requirements for replacement commodities represent additional environmental benefits.

Conclusion

Antimycotic packaging technologies represent promising alternatives addressing contemporary challenges regarding postharvest preservation. Integration of naturally-derived bioactive compounds within biodegradable matrices aligns with evolving consumer preferences while potentially enhancing economic sustainability throughout agricultural value chains. Research progression indicates expanding application potential across diverse commodities with customization possibilities addressing specific pathogenic vulnerabilities. Continued interdisciplinary collaboration between material scientists, microbiologists, and food technologists will undoubtedly accelerate development regarding next-generation preservation systems. Implementation represents an important component within comprehensive strategies addressing global food security objectives while simultaneously reducing environmental impact associated with agricultural production systems.

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Leveraging E-NAM and Digital Mandis for Direct Marketing

Article ID: 71072

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Abstract

India's agricultural marketing system has traditionally been limited by intermediaries, transparency, and limited market access to farmers. With the emergence of digital technologies like the Electronic National Agriculture Market (e-NAM) and the creation of digital mandis, the marketing of agricultural produce in India has changed dramatically. These platforms are set to empower farmers by enabling direct marketing, assuring fair price discovery, and establishing a single national market. This article covers the structure, operation, advantages, challenges, and future directions of e-NAM and digital mandis in encouraging direct agricultural marketing.

Introduction

Indian agriculture marketing has been traditionally regulated by state-controlled APMCs (Agricultural Produce Market Committees) that are typically multi-intermediary. Not only does this reduce farmers' share of the consumer price, but their market access is also confined to local mandis. With growing digital penetration and the efforts of the Indian government to liberalize farm sector reforms, the vision of digital mandis and the e-NAM platform have been a game-changer.

The Electronic National Agriculture Market (e-NAM), which was rolled out in April 2016, is a pan-India electronic trading platform that connects APMCs from all over the country. It will establish a single national market for farm products by connecting physical mandis via a virtual platform. In conjunction with e-NAM, growth in digital mandis backed by private players and state governments is enabling farmer-to-buyer direct marketing of produce.

Objectives of e-NAM and Digital Mandis

1. To make farmers aware of a fair and transparent price discovery system.
2. To minimize the intervention of middlemen and maximize farmers' profit margins.
3. To give access to current market prices at all mandis in real time.
4. To provide for direct connections among farmers, processors, retailers, and exporters.
5. To facilitate digital payment mechanisms and book-keeping for traceability.

Features and Structure of e-NAM

Feature	Description
Unified National Market	Integration of APMCs into one electronic trading platform.
Online Trading	Buyers and sellers can participate in trade online via a transparent bidding process.
Price Discovery	Competitive bidding ensures real-time price discovery.
Quality Testing	Integration of assaying labs for grading and standardization.
Payment Integration	Digital payment gateways for direct farmer payments.
Logistics Support	Linking to warehouse and transport services for efficient delivery.

As of 2025, e-NAM has integrated over 1,000 mandis from 22 states and 3 union territories, covering more than 150 commodities including cereals, pulses, oilseeds, fruits, and vegetables.



NATIONAL AGRICULTURE MARKET

Source: Wikipedia

Digital Mandis: Private and Government-Driven Initiatives

Besides the government's e-NAM, various digital platforms and government-driven initiatives have been launched to encourage direct farmer-to-consumer or farmer-to-buyer linkages:

1. **Reliance Fresh, BigBasket, and Ninjacart:** Collaborate with FPOs for bulk procurement directly from farmers.
2. **AgriBazaar and DeHaat:** Offer an online marketplace with logistics and quality assurance services.
3. **Rythu Bazaars (Andhra Pradesh) and Uzhavar Sandhai (Tamil Nadu):** Enable direct marketing by using farmer-operated markets, some of which are online.
4. **UP e-Mandi System:** Uttar Pradesh government's project to make procurement and mandi management online.

Advantages of e-NAM and Digital Mandis

1. **Improved Price Realization:** Middlemen are removed through e-NAM, ensuring that farmers get better prices. The transparent bidding system enables market forces to decide the price and not intermediaries.
2. **Increased Market Access:** Farmers no longer have to sell their produce only in mandis within the same state. With e-NAM, they can sell it to buyers located anywhere in states, increasing their market reach.
3. **Savings on Post-Harvest Losses:** Through faster linkages with buyers and logistics providers, perishable produce can be sold and transported sooner, minimizing losses.
4. **Transparency and Confidence:** Electronic transactions introduce traceability, minimize malpractice, and increase buyer-seller confidence via quality certifications and online dispute settlements.
5. **Strengthening of Farmer Producer Organizations (FPOs):** FPOs contribute importantly to collecting produce and online trading on their members' behalf, enhancing collective bargaining.
6. **Digital Financial Inclusion:** Farmers are exposed to digital banking and online payment mechanisms, facilitating direct benefit transfers (DBTs), lending, and insurance of crops.

Challenges in Implementing e-NAM and Digital Mandis

Despite significant progress, the digital agricultural marketing ecosystem faces several hurdles:

Challenge	Details
Digital Literacy	Many small and marginal farmers lack familiarity with smartphones and online platforms.
Internet and Infrastructure Gaps	Rural areas often suffer from weak internet connectivity and power supply.
Assaying and Standardization	Lack of adequate testing labs and uniform quality standards hampers smooth trading.
Resistance from Traditional Market Players	Traders and commission agents may resist reforms that reduce their control.
Legal and Regulatory Differences	Not all states have amended their APMC Acts to fully support e-NAM.
Lack of Warehousing and Logistics Support	Storage and delivery systems are often underdeveloped, especially for perishable goods.

Case Studies

Case Study 1: Rajasthan – Convergence of e-NAM with Warehousing: Rajasthan has been leadership in converging e-NAM with the Rajasthan State Warehousing Corporation. It is now possible for farmers to store their harvest in registered godowns and subsequently sell it online through e-NAM, and thus avoid distress sales and ensure better prices.

Case Study 2: Ninjacart – Private Digital Mandi: Ninjacart, a private agritech company, links farmers with retailers directly. Farmers fix pickups of fresh produce through mobile applications, which are then transported to retailers. It gets rid of APMC mandis altogether in some regions and provides immediate payment.

Government Reforms and Policies Favoring Digital Marketing

- 1. Model APMC Act 2017:** Promotes private markets, direct marketing, and contract farming.
- 2. Farm Laws (now repealed):** Initially sought to provide free trade outside APMC mandis.
- 3. Digital India Initiative:** Enhances internet availability and digital equipment in agriculture.
- 4. Agri-Stack and Kisan Digital IDs:** Propose to enfold farmers within a national digital platform for offerings such as marketing.
- 5. PMFME Scheme:** Facilitates value addition and marketing for agri-products, particularly for FPOs.

Way Forward and Recommendations

In order to further enhance e-NAM and digital mandis, the following strategies are advised:

- 1. Capacity Building:** Educate farmers and FPOs in utilising digital platforms and market intelligence.
- 2. Infrastructure Development:** Invest in rural internet, assaying laboratories, cold storage, and transportation networks.
- 3. Incentives for Participation:** Provide incentives to FPOs and private players utilizing e-NAM for trade.
- 4. Policy Harmonization:** Inspire all states to implement model APMC reforms and integrate with e-NAM.
- 5. Inclusion of Livestock and Fisheries:** Extend the coverage of digital marketing to the entire agri-food chain.
- 6. Localized Language Interfaces:** Provide e-NAM and digital mandi apps in regional languages to ensure accessibility.

Conclusion

The e-NAM and digital mandi revolution in agricultural marketing is a critical milestone in empowering farmers and creating a new-age agri-value chain. By enabling direct marketing, making prices transparent, and offering digital services, these platforms can potentially transform the rural economy. But to realize their full potential, sustained efforts in digital literacy, infrastructure, and policy support are needed. The

future of Indian agriculture is not just about producing more but selling smarter — and e-NAM is at the center of that revolution.

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Environmental Impact Assessment of Recirculating Aquaculture Systems

Article ID: 71073

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Abstract

Recirculating Aquaculture Systems (RAS) are increasingly recognized as a sustainable alternative to conventional aquaculture because of less water use and more controlled environments. This review compiles relevant and recent research examining the environmental consequences of recirculating aquaculture systems (RAS) whereby the focus is on energy use, greenhouse gas (GHG) emissions, waste management, and use of other resources. RAS minimizes environmental concerns like habitat destruction and eutrophication, encounter challenges regarding energy use and the potential accumulation of other pollutants. The review also indicates advances in recirculating aquaculture systems (RAS) sustainability involve in utilising renewable energy, alternative waste recycling strategies, and the potential for employing biosecurity measures. Provides information for future research to include increasing energy efficiency, standardized environmental impact assessments.

Keyword: Recirculating Aquaculture Systems, greenhouse gas emissions, renewable energy, environmental impact assessment.

Introduction

The rapid expansion of aquaculture has corresponded to a growing concern about its environmental sustainability (Hall *et al.*, 2011; Martinez-Porchas and Martinez-Cordova, 2012). Aquaculture is already becoming increasingly implicated not only for habitat destruction, water pollution and eutrophication, biotic depletion, parasite and disease transmission, and increase greenhouse gas (GHG) emissions (Ahmed *et al.*, 2019, Hall *et al.*, 2011; Naylor *et al.*, 2000). Some intensive aquaculture practices have been well-known for causing antibiotic pollution, eutrophication, land occupation, and other environmental risks (Hall *et al.*, 2011).

Recirculating aquaculture systems (RASs) are intensive fish growing techniques that utilize less water and land resources. However, RASs are energy intensive systems which can result in high operational costs and depending on fossil fuels can have environmental impacts. There has been tremendous growth in RAS technology over the past two decades (Espinal and Matulic, 2019), and recently RASs have gained in popularity. They have also been developed to grow fish in areas where water scarcity, poor water quality, and adverse environmental conditions exist (Murray *et al.*, 2014). Malone (2013) reported that RASs will provide an alternative production system when environmental regulation, disease regulations, land restrictions, salinity, temperature, and water supply make more cost effective.

Environmental Benefits of Recirculating Aquaculture Systems (RASs)

Recirculating aquaculture systems (RASs) are well designed and do not have a negative impact in relation to water pollution and eutrophication. Eutrophication impacts are likely to be between 26e38% lower in RAS compared to flow-through systems (d'Orbcastel *et al.*, 2009) and about 40% lower than in net-pen systems Espinal and Matulic, 2019 (AyerandTyedmers, 2009). Recirculating aquaculture system (RAS) facilities can decrease potential environmental impacts such as eutrophication as well as reduced water consumption requirement (i.e. Verdegem *et al.* 2006; d'Orbcastel *et al.* 2009 b; Eding *et al.* 2009), also assist with waste management (i.e. reduced waste volumes) and produce higher levels of recycling (Piedrahita 2003). Waste produced by RAS is produced as a highly concentrated sludge that is relatively easy to manage, and can even be used as fertilizer for vegetable cropping (van Rijn, 2013), or at least be separated from farm effluents entering catchment ecosystems. RAS do not cause an environmental threat as far as habitat loss, due the minimal land use. Suitable sites for RAS need to meet the following, appropriate

topography and hydrology, construction capabilities, competitive land price, and access to high quality water, waste disposal, and low-cost treatment/discharge of effluent, energy supply and cost, environmental impacts avoided, production, transportation, and proximity to market (Bregnballe, 2015; Goldman, 2016; Summerfelt and Vinci, 2008; Timmons and Ebeling, 2007). Recirculating aquaculture system (RAS) can produce food sustainably, whereas having less impact on the environment (Gunning *et al.*, 2016), and the implementation of more RAS could have many positive environmental implications.

Environmental Challenges of Recirculating Aquaculture Systems (RAS)

Recirculating aquaculture systems (RAS) are inherently energy-intensive, with their substantial electricity demands driving up overall operational expenditures (Badiola *et al.*, 2018). Typical energy usages in RAS vary from 15e30 kWh/kg fish produced (Ayer and Tyedmers, 2009; Badiola *et al.*, 2017; Martins *et al.*, 2010). Total energy consumption in RAS (16 kWh/kg) is estimated to be 24e40% more than flow-through systems (10e12 kWh/kg; d'Orbcastel *et al.*, 2009). Energy is being used constantly because water is pumped through recirculated water in fish tanks along with filtration, sterilization, aeration (oxygenation), illumination, water temperature (cooling/heating), and other aquaculture processes. Energy separately, and energy cost and associated environmental impact depend on energy source and quantity used, location and the design and management of the operation. Recirculating aquaculture systems generate substantial quantities of sludge, all of which require appropriate treatment before disposal (Losordo & Timmons, 1994; van Rijn, 1996; Shnel *et al.*, 2002; Suzuki *et al.*, 2003; Timmons & Ebeling, 2010).

Greenhouse Gas (GHG) Emissions in Recirculating Aquaculture Systems (RAS)

Carbon dioxide (CO₂) emissions with other GHG (e.g., CH₄, N₂O) have been indicated to be the primary cause of climate change (IPCC, 2018). In 2014, the world's top 21 aquaculture-producing countries released a total of 6.04 million tons of CH₄ and 36,700 tons of N₂O (Yuan *et al.*, 2019). It is estimated the worldwide N₂O-N emissions from aquaculture will likely increase to 383,000 tons by 2030 (Hu *et al.*, 2012). Overall, GHG emissions from aquaculture are expected to grow from 332 million tons in 2010 to 776 million tons of CO₂eq in 2050 (Mungkung *et al.*, 2014). Notably, GHG emissions from RAS are twice the level of net-pen salmon farming (Liu *et al.*, 2016), and much higher than other aquaculture systems. Carbon dioxide emissions from RAS are essentially associated with energy use of such facilities (Badiola *et al.*, 2018; Tien *et al.*, 2019). The carbon footprint for RAS has been estimated at as high as 27kgCO₂eq/kg live weight cod in Spain (Badiola *et al.*, 2017), and 28kg CO₂ eq/kg live weight salmon in Canada (Ayer and Tyedmers, 2009). In the USA, average carbon footprint for salmon from RAS has been estimated to be 7.01 kgCO₂ eq/kg live weight salmon, which could be potentially reduced to 3.73kg CO₂eq/kg live weight salmon when using renewable sources of energy, like hydropower electricity (Liu *et al.*, 2016). In contrast, average greenhouse gas (GHG) emissions from pond aquaculture were 1.37kg CO₂eq/kg live weight of striped catfish in Vietnam, 1.58kgCO₂eq/kg live weight of Nile tilapia in Bangladesh, and 1.84kgCO₂eq/kg live weight of carps in India (Robb *et al.*, 2017). These comparisons suggest that RAS has a far greater environmental significance, regarding GHG emissions, than other forms of aquaculture.

Energy Use and Economic Implications

In conclusion, on-farm electricity consumption influences both the environmental impacts and economic costs of a RAS (Badiola *et al.* 2017), as well as the mitigation of greenhouse gas emissions from industry (Worrell *et al.* 2009). The energy consumption along with the associated costs and environmental impacts involve the source, amount of energy consumed, location of the Recirculating aquaculture system, design, and the management of the RAS. A substantial amount of sludge is formed in RAS and that sludge must be treated prior to disposal in landfill sites (Losordo and Timmons 1994; van Rijn 1996; Shnel *et al.*, 2002; Suzuki *et al.*, 2003; Timmons and Ebeling 2010). The material and energy elements of RAS have influenced these environmental impacts. In aquaculture water and energy are two important resources (d'Orbcastel *et al.*, 2009 a). Electricity generation from fossil fuels can lead to local and global environmental issues.

Mitigation Strategies and Renewable Energy

As such, the energy expended on-farm relates directly to the environmental impacts and economic costs (i.e. operation costs) of a RAS (Badiola *et al.*, 2017) mitigation of greenhouse gas emissions from industry (Worrell *et al.*, 2009). The utilization of energy, including the associated cost and environmental impacts

are influenced by the energy source and amount being used, site location, design, and management. A significant required impact of RAS, is large amounts of sludge produced which needs to be treated before being disposed of (Losordo and Timmons 1994; van Rijn 1996; Shnel *et al.*, 2002; Suzuki *et al.* 2003; Timmons and Ebeling 2010). The material and energy requirements aspects of RAS have received scrutiny for their environmental impacts. Water and energy are two of the key resources in aquaculture (d'Orbcastel *et al.*, 2009 a). Electricity generated from fossil fuels creates local and global environmental impacts.

Conclusion

While RAS are associated with sets of environmental trade-offs through energy use (O'Shea *et al.*, 2019), emissions waste, energy use and productivity should guide the system towards economically and environmentally sustainable production. When employed renewable energy is likely to reduce environmental impacts (Badiola *et al.*, 2018), but will also likely have positive benefits in reducing operational costs related to energy.

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Soil Carbon and Carbon Credits: Can Farmers Earn by Saving Soil?

Article ID: 71074

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Abstract

Soil carbon plays a pivotal role in enhancing soil health and mitigating climate change. This paper explores the potential for farmers to earn carbon credits through sustainable soil management practices that increase soil organic carbon (SOC) and promote carbon sequestration. It discusses the various forms of soil carbon—organic and inorganic—and emphasizes the importance of SOC in improving soil fertility, microbial health, and agricultural productivity. The paper outlines key climate-smart agricultural practices, including conservation tillage, cover cropping, crop residue management, agroforestry, and organic manuring, which contribute to building SOC. Furthermore, it introduces the concept of carbon credits—tradable certificates that represent the reduction or removal of CO₂ from the atmosphere—and highlights how farmers can earn these credits by implementing carbon-enhancing practices. The carbon sequestration potential and associated farm income from these practices are discussed, with estimates ranging from 0.3 to 3.0 t CO₂-eq/ha/year and potential incomes between ₹360 and ₹3,600 per hectare annually. By participating in carbon markets, farmers can earn additional income while improving the sustainability and resilience of their farming systems. The paper also presents case studies from Karnataka and Punjab, demonstrating successful models of carbon farming that generate income from carbon credits while enhancing soil health. Despite the promising opportunities, the paper identifies challenges in soil carbon trading, including the need for accurate verification, farmer awareness, and institutional support. The study concludes that with proper support and scaling, carbon farming can become a valuable income stream for farmers, contributing to both environmental and economic sustainability.

Introduction to Soil Carbon

Soil carbon is a crucial component of healthy soils and plays a major role in global climate regulation. It exists in two forms: soil organic carbon (SOC) and soil inorganic carbon (SIC). SOC is derived from plant and animal residues, root biomass, and microbial activity, and is directly linked to soil fertility and microbial health. On the other hand, SIC primarily consists of carbonates and is more stable but less influential in biological processes. SOC is the form most affected by agricultural practices and is central to discussions about improving soil health and climate-smart farming. Farmers can build SOC through organic inputs and sustainable land management, which not only benefits crop growth but also contributes to global efforts to reduce carbon emissions.

Soil as a Carbon Sink

Soils act as one of the largest reservoirs of carbon on Earth, storing more carbon than the atmosphere and vegetation combined. When managed well, agricultural soils can act as carbon sinks, absorbing atmospheric CO₂ and storing it as organic matter. This process of carbon sequestration helps mitigate climate change by removing carbon from the atmosphere and locking it into the soil for long periods. Building soil carbon also enhances the land's ability to hold water, improves nutrient availability, and boosts soil biodiversity, creating a win-win for both the environment and farming productivity. Hence, farmers play a key role in climate mitigation by improving the carbon storage capacity of their land.

Practices to Build Soil Organic Carbon

Several proven climate-smart practices can help farmers build SOC. Conservation tillage or zero tillage minimizes soil disturbance, reducing oxidation and carbon loss. Cover cropping and green manuring introduce organic biomass that feeds soil microbes and enhances fertility. Crop rotation with legumes helps

fix atmospheric nitrogen and supports diverse root systems that build organic matter. Residue retention, instead of burning, enriches the soil and protects it from erosion. Adding organic amendments like compost, farmyard manure (FYM), or biochar contributes to both immediate and long-term increases in SOC. Furthermore, agroforestry and silvopasture systems integrate perennial plants and trees into cropland, providing continuous biomass input and reducing degradation. Regular use of these practices creates healthier, carbon-rich soils over time.

Soil Health Benefits for Farmers

The benefits of building soil organic carbon go beyond environmental gains; they translate directly into agronomic and economic advantages for farmers. Higher SOC improves soil structure, making it more porous and better able to retain water—crucial in drought-prone regions. Nutrient retention improves, reducing dependency on synthetic fertilizers. Enhanced microbial diversity leads to better nutrient cycling and disease suppression. Over time, soils with high organic matter require fewer external inputs, reducing costs. The long-term result is increased productivity, better drought resilience, and higher net returns for farmers. Therefore, investing in soil carbon is also investing in sustainable yields and financial stability.

Introduction to Carbon Credits

Carbon credits are tradable certificates representing one metric tonne of CO₂ emissions reduced or removed from the atmosphere. When farmers implement practices that increase SOC, they can potentially earn these credits through verified soil carbon sequestration. These credits can then be sold in voluntary or compliance carbon markets to buyers such as companies aiming to offset their emissions. With rising interest in sustainability, carbon markets are growing rapidly, creating new revenue streams for environmentally responsible farmers. This system transforms sustainable soil management from an ethical choice to a potentially profitable one.

Farmer Participation in Carbon Markets

Participation in carbon markets involves several steps: farmers must adopt carbon-enhancing practices, record their farming activities, and measure the increase in SOC through Monitoring, Reporting, and Verification (MRV) processes. This often requires baseline soil testing and periodic sampling. Given the complexity and cost, aggregator models—where farmer groups, cooperatives, or FPOs pool efforts—are being promoted to make the process viable for smallholders. Technological tools like satellite imagery, mobile-based record keeping, and blockchain verification are making it easier to track and certify carbon gains.

NGOs and carbon market platforms are now helping farmers register and monetize their efforts. With proper support, even small-scale farmers can benefit from this new opportunity.

Income Potential from Soil Carbon

The financial gain from carbon credits depends on how much additional carbon a farmer can sequester and the prevailing carbon price. One tonne of CO₂ sequestered may earn a farmer between ₹500 to ₹2000 in voluntary markets, depending on demand and verification standards. While initial returns may seem modest—ranging from ₹800 to ₹3,000 per acre per year—the long-term gains from healthier soil, increased yield, and reduced input costs significantly boost net income.

Over time, as markets mature and verification becomes more affordable, carbon farming may become a reliable co-income source for farmers, especially when practiced at scale.

Table 1. Potential Income from Carbon Credits for Adopting Climate-Smart Agriculture Practices:

Climate-Smart Practice	Carbon Sequestration (t CO ₂ -eq/ha/yr)	Avg. Carbon Price (₹/t)	Potential Income (₹/ha/yr)
1. Conservation Tillage	0.4 – 1.2	1,200	480 – 1,440
2. Crop Residue Management	0.3 – 0.8	1,200	360 – 960
3. Agroforestry	1.5 – 3.0	1,200	1,800 – 3,600
3. Cover Cropping	0.5 – 1.0	1,200	600 – 1,200

4. Organic Manuring/ Composting	0.6 – 1.2	1,200	720 – 1,440

Note: Figures may vary by soil type, agro-climatic region, and verification standards. Based on a conservative carbon price (₹1,200 ≈ USD 15/t CO₂-eq). Voluntary carbon markets may vary.

Case Study 1: Promoting Agroforestry for Carbon Credits in Karnataka, India

In Karnataka, the Farmer-Managed Natural Regeneration (FMNR) model promoted agroforestry to regenerate degraded lands. With support from NGOs and carbon finance programs such as the VERRA Verified Carbon Standard (VCS), farmers planted indigenous and fruit-bearing trees on their farmlands. This system not only improved soil organic carbon levels but also qualified them for carbon credits.

The average carbon sequestration rate was 2.0–3.0 t CO₂-eq/ha/year. Around 500 farmers in Tumakuru and Chitradurga districts were enrolled in a carbon project managed by a development NGO. Over a five-year period, participating farmers earned ₹1,200–3,600/ha/year through carbon credits while gaining additional income from fruits, fuelwood, and fodder (Verra, 2022; ICRAF, 2021). Soil health also improved in terms of bulk density, aggregate stability, and available nitrogen.

This model demonstrates that with proper institutional support and verification mechanisms, farmers can earn carbon revenues while making their land climate-resilient (ICRAF, 2021).

Case Study 2: Conservation Agriculture in Punjab's Rice-Wheat Belt

In Punjab, where intensive rice-wheat cropping systems dominate, the Punjab Agricultural University (PAU) and CIMMYT introduced conservation agriculture (CA) practices such as zero tillage, residue retention, and crop diversification under the Climate-Smart Village Program.

Farmers adopting zero tillage with residue retention experienced carbon gains of 0.6–1.0 t CO₂-eq/ha/year (Jat et al., 2020). These gains were recognized under pilot carbon farming schemes funded by the World Bank and ICAR. While formal carbon payments were modest (₹500–800/ha/year), farmers saved on tillage costs, irrigation, and fertilizers—adding up to ₹7,000–10,000/ha annually.

Additionally, soil organic carbon increased in the top 15 cm layer, and microbial activity (especially phosphatase and dehydrogenase activity) improved—leading to enhanced soil fertility (Jat et al., 2020; FAO, 2019). The project showcased the viability of integrating carbon benefits into large-scale crop systems.

Challenges and Limitations

Despite its promise, soil carbon trading comes with challenges. Accurate soil testing and verification require technical knowledge and investment. Results vary depending on soil type, climate, and farming intensity. Moreover, carbon gains can be reversed due to changes in land use or extreme weather, making permanence a concern. Awareness is still low among farmers, and institutional support is limited. In addition, current carbon prices may not always justify the investment for individual small farmers. Hence, capacity building, aggregation, and enabling policies are needed to scale up adoption and ensure fair farmer participation.

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Nanotechnological Innovations for Sustainable Plant Disease Suppression

Article ID: 71075

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Introduction

Plant diseases continue to pose significant threats to global agriculture, reducing crop yield and quality while increasing dependency on chemical pesticides. Traditional disease control strategies often face limitations such as resistance development in pathogens, environmental pollution, and non-target effects on beneficial organisms. In this context, **nanotechnology** the manipulation of materials at the nanometer scale (1 -100 nm) has emerged as a promising, eco-friendly, and effective alternative. By integrating nanomaterials into plant protection strategies, researchers aim to improve disease detection, prevention, and treatment with precision and minimal ecological footprint.

Mechanisms of Nanotechnology in Disease Control

Nanotechnology offers multiple avenues for controlling plant diseases, primarily through:

- 1. Nano-formulations of Pesticides and Fungicides:** Conventional agrochemicals often suffer from poor solubility and high degradation rates. Nano-formulated pesticides and fungicides provide controlled and slow release of active ingredients, increasing bioavailability and reducing the frequency and dosage of application. For example, **silver nanoparticles (AgNPs)** have demonstrated broad-spectrum antimicrobial activity against plant pathogens such as *Pseudomonas syringae*, *Alternaria spp.*, and *Fusarium oxysporum*.
- 2. Nanoparticle-based Disease Diagnostics:** Early detection is key in preventing plant disease outbreaks. **Nanosensors** can detect pathogens or their biomarkers in plant tissues with high sensitivity and specificity. Gold nanoparticles, for instance, are used in colorimetric biosensors to detect DNA or protein markers of specific pathogens. This allows for real-time monitoring of plant health in the field.
- 3. Nanocarriers for Gene Delivery and Immunity Induction:** Nanoparticles can be engineered to deliver DNA, RNA, or proteins into plant cells to trigger resistance mechanisms or silence pathogenic genes. For example, **chitosan-based nanoparticles** can carry double-stranded RNA (dsRNA) for RNA interference (RNAi), targeting vital genes in pathogens and rendering them non-functional.

Examples and Case Studies

- 1. Silver Nanoparticles (AgNPs):** AgNPs exhibit potent antifungal and antibacterial properties. Studies have shown their effectiveness against various plant pathogens like *Xanthomonas campestris*, *Botrytis cinerea*, and *Colletotrichum gloeosporioides*. Their mechanism includes disruption of cell membranes, generation of reactive oxygen species (ROS), and inhibition of enzyme activity.
- 2. Zinc Oxide (ZnO) and Titanium Dioxide (TiO₂) Nanoparticles:** These metal oxide nanoparticles are used to prevent fungal spore germination and reduce pathogen survival on leaf surfaces. TiO₂ nanoparticles also exhibit photocatalytic properties, making them effective under UV or sunlight conditions for surface disinfection.
- 3. Silica Nanoparticles for Systemic Acquired Resistance (SAR):** Silica nanoparticles enhance plant defense by stimulating the production of phytoalexins and pathogenesis-related (PR) proteins. This can reduce infection severity when plants are challenged by pathogens.

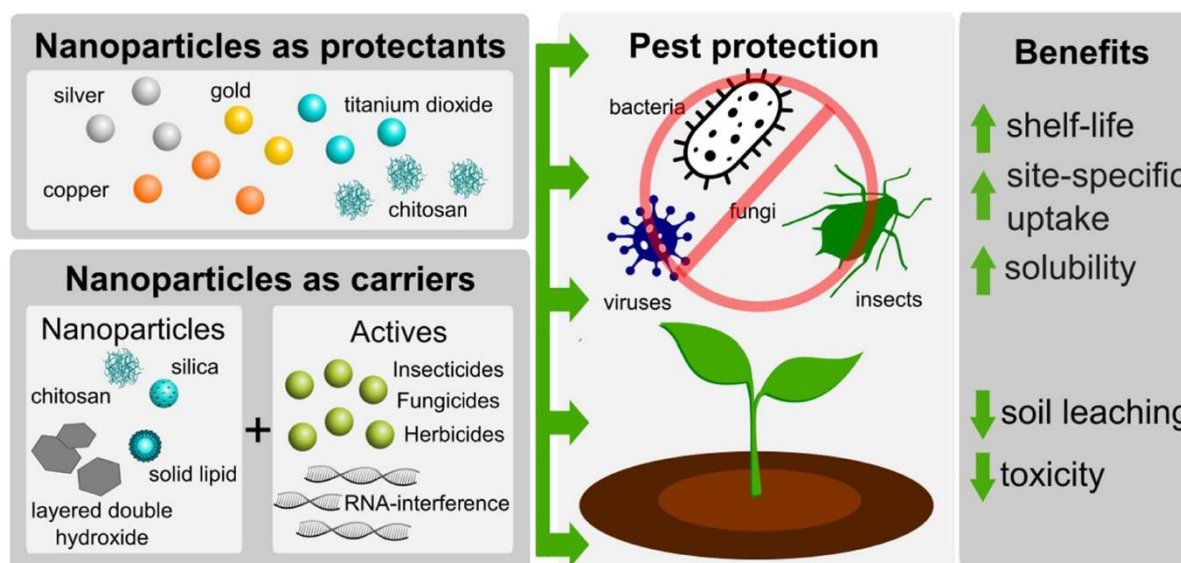


Fig. 1 Nanoparticles as Protectants and Carriers (Worrall et al., 2018)

Advantages of Nanotechnology in Plant Disease Management

- 1. Enhanced efficiency:** Nanoparticles ensure higher adherence to plant surfaces and increased absorption by target cells.
- 2. Reduced environmental impact:** Lower quantities of chemicals are required, minimizing runoff and non-target effects.
- 3. Targeted action:** Nanocarriers can deliver agrochemicals or genetic material specifically to infected tissues.
- 4. Improved shelf life and stability:** Nano-formulations are more stable under varying environmental conditions.

Challenges and Concerns

Despite its promise, nanotechnology in plant pathology comes with several challenges:

- 1. Toxicological Risks:** The long-term effects of nanoparticles on soil microbiota, non-target organisms, and human health are not fully understood.
- 2. Regulatory Uncertainty:** There is currently a lack of specific regulations and guidelines for nano-enabled agro-products.
- 3. High Cost and Scalability:** The production and application of nanoparticles on a large scale can be expensive and may not be viable for smallholder farmers.
- 4. Resistance Development:** Overuse or improper application of nanoparticle-based treatments may lead to resistance in pathogens.

Future Prospects

The integration of nanotechnology with precision agriculture, artificial intelligence, and smart sensing systems holds vast potential for sustainable disease management. Innovations such as **nano-enabled smart delivery systems**, **responsive biosensors**, and **integrated nanobiocontrols** will likely transform how plant diseases are detected and managed. Research into biodegradable, non-toxic nanoparticles from natural sources (e.g., plant extracts, biopolymers) is also gaining attention for safer applications.

Conclusion

Nanotechnology represents a cutting-edge tool in the arsenal against plant diseases. By enabling targeted delivery, enhanced efficacy, and early diagnosis, nanotech-based approaches can significantly improve plant health management while minimizing environmental harm. However, to fully harness its benefits,

further interdisciplinary research, careful risk assessment, and sound regulatory frameworks are essential. The future of sustainable agriculture may well rest on our ability to responsibly integrate these nanoscale innovations into mainstream plant disease control practices.

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Tiny Tenants: Endosymbionts - How they Power the Insect World?

Article ID: 71076

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Introduction

Insects, the most diverse group of animals on Earth, owe much of their evolutionary success to microscopic partners living within endosymbiotic bacteria. These associations, ranging from mutualistic to parasitic, play pivotal roles in insect physiology, ecology, and evolution. This chapter delves into the multifaceted world of insect endosymbionts, exploring their types, functions, evolutionary significance, and potential applications. Symbiosis is from the Greek Word, which means living together. The term symbiosis was initially coined by Heinrich Anton de Bary in 1879. Symbiont is an organism that is very closely associated with another, usually larger organism. This larger organism is called a host.

Genres of Symbionts

1. Ecto-symbiotic - when the symbiont occurs outside the body of the host.

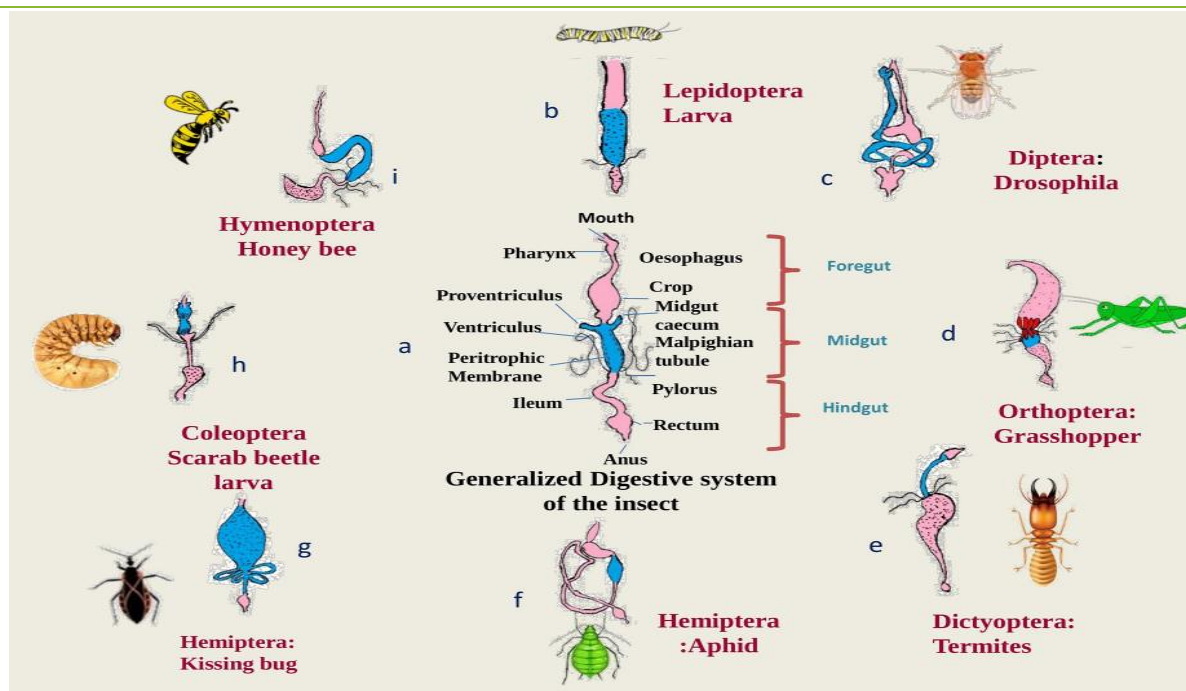
2. Endosymbiotic- When the symbiont occurs internally, either intracellularly or extracellularly. (Pal and Karmakar., 2018)

These endosymbionts are classified again into:

Primary endo-symbionts	Secondary endo-symbionts
They have an obligatory relationship with the insect host.	They have a facultative relationship with the insect host.
Essential for their host's survival and reproduction.	Not essential for their host.
Location: Restricted to bacteriocytes (modified fat cells containing symbiotic bacteria). It is an intracellular endosymbiont.	Location: In bacteriocytes, sheath cells bound bacteriocytes and haemolymph. Intra- and extracellularly distributed.
Vertical transmission only.	Vertical and horizontal transmission.
Eg: <i>Buchnera aphidicola</i> is a primary bacterial endo-symbiont in <i>Acyrtosiphon pisum</i> (Pea Aphid).	Eg: Tsetse flies, vectors of trypanosoma (protozoa), consist of a secondary bacterial endosymbiont named <i>Sodalis Glossinidius</i> .

Where do they Exist?

The cells that harbour symbiotic bacteria are called **Bacteriocytes**. A group of bacteriocytes is called a **Bacteriome**. The cells that harbour symbiotic fungi are called **Mycetocytes**. A group of mycetocytes is called **Mycetome**. The location of endosymbionts is different in different insects. Usually only one type of microorganism - **monosymbiosis** is associated with a species, but in not so rare cases, two or more different kinds of symbiotes are housed in a mycetome leading to **plurisybionism**. (Pant and Ghai, 1981).



Modifications in insect gut structure to house endosymbionts

Various modifications in the gut structure among the insect orders to accommodate gut symbionts: (A) generalized digestive system of insects with a peritrophic matrix in the midgut (dotted lines). Pink regions indicate the foregut and hindgut; blue regions indicate the midgut. Black dots represented colonies of symbionts; (B) digestive system (D.S.) of a caterpillar of moth showing the presence of symbionts in the region of midgut as well as hindgut; (C) D.S. of *Drosophila* shows the presence of symbionts in the midgut region only; (D) D.S. of Grasshopper showing the distribution of symbiont in the whole digestive system; (E) D.S. of termites showing symbionts mainly in the hindgut; (F) D.S. of aphid showing the presence of symbionts along the internal lining of hindgut; (G) D.S. of Kissing bug which shows enlarged midgut to store packets of symbionts; (H) D.S. of Scarab beetle larva which shows the presence of symbionts in the hindgut; (I) D.S. of honey bee showing the presence of symbionts in hindgut region (Rupawate *et al.*, 2023).

How do Insects Acquire Endosymbionts?

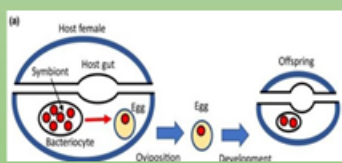
1. Vertically transmitted symbionts: The host offspring take up the symbionts from their parents (Heritable symbioses). Eg: Symbionts of **Termites and Blattids**.

Transovarial transmission

The symbionts enter the egg during early oogenesis.

Eg: *Sitophilus oryzae*

(Hosakawa and Fukatsu, 2020)



Capsule Transmission

Female *Coptosoma scutellatum* (Bug) consists of mycetome in the lower part of the midgut. The midgut of female has a special apparatus which forms capsules filled with fluid containing symbionts. These capsules are deposited among the egg mass.

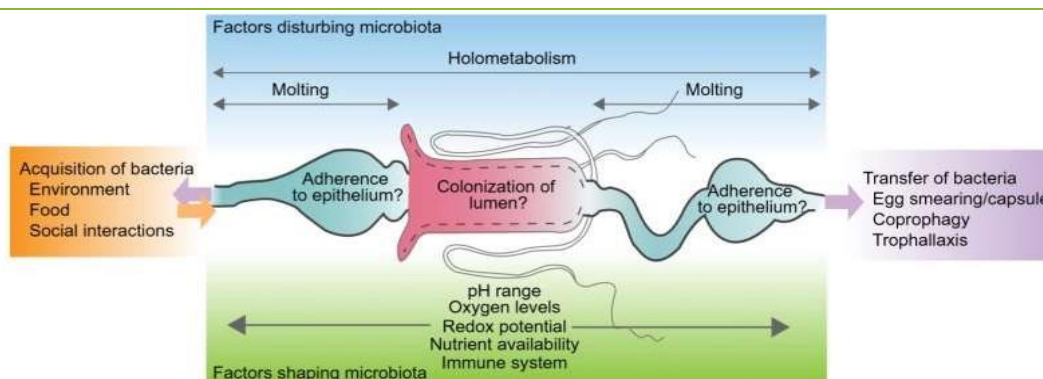
Egg surface contamination:

Females of *Lasioderma* and *Stegobium* consists of symbionts-filled transmission organs located at or near the opening of the common oviduct. As the egg is deposited, the transmission organs contract and smear the shell with a secretion containing yeast symbionts.

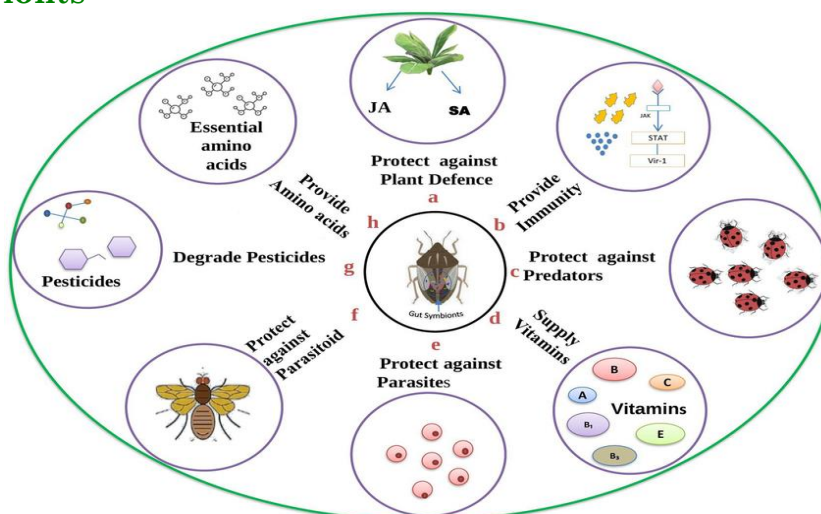
2. Horizontally transmitted symbionts: Host reproduction leads to aposymbiotic descendants, which at a certain life stage are infected with symbionts. Example: Gut microbes should be acquired throughout their lives. Micro-organisms are removed during the moulting process. Hence, acquire them through **trophallaxis**.

3. Mixed mode of transmission: Vertical transmission and occasional horizontal transmission can occur through host switching. (Bright & Bulgheresi, 2010).

4. Environmental Acquisition:



Role of Endosymbionts



Rupawate *et al.*,2023

1. Provides Nutrition to insect: Many insects subsist on nutrient-poor diets, such as plant sap or blood. To compensate, they rely on obligate endosymbionts.

Example:

- a. *Buchnera aphidicola*, residing in aphids, this bacterium synthesizes essential amino acids absent in plant sap, enabling aphids to thrive on such a limited diet.
- b. *Sulcia muelleri* (*Baumannia cicadellinicola* and *Hodgkinia cicadicola*)- amino acid synthesis
- c. *Portiera aleyrodidarum* (*Hamiltonella defensa*) - lysine synthesis (Rahman *et al.*,2022).

2. Role of symbionts in fighting plant defence systems: Studies have speculated that mutualistic symbiont associations in insects carry mediation in direct and indirect interactions between insects and their host plants via many strategies.

Insect Host	Symbiont	Plant pathway
Wheat aphid (<i>Sitobian miscanthi</i>)	<i>Hamiltonella defensa</i>	Ceases the expression of genes related to SA and JA defence pathways
<i>Leptinotarsa decemlineata</i>	Bacteria from salivary secretions	Invokes the SA-related plant defence pathway and suppresses the JA pathway
<i>Bremisia tabacii</i>	<i>Hamiltonella defensa</i>	Suppression of the JA pathway in the tomato plant
Corn root borer (<i>Diabrotica virgifera</i>)	<i>Wolbachia</i>	Suppresses plant defence
Tomato Psyllid(<i>Bactericerca cockrelli</i>)	<i>Candidatus spp.</i>	Influences the expression of defence related genes

3. Role of symbionts in immunity boosting: Defence includes the preparation of a protective matrix, which is a chitin-based peritrophic matrix and is selectively permeable to nutrients, defensins, and digestive enzymes and protects from microorganisms, etc.

Example: The gut epithelium of *Apis mellifera* harbors *Snodgrassella alvi* and *Gilliamella apicola* in the form of a dense biofilm that inhibits the entry of pathogens

4. Role of symbionts in pesticide degradation:

Insecticide	Host	Symbiont
Fenitrothion (OP) (Kikuchi <i>et al.</i> (2012))	Alydid stink bug <i>R. pedestris</i>	<i>Burkholderia</i> sp.
Indoxacarb (Oxadiazine)	Diamond back moth <i>P.xylostella</i>	<i>Bacillus cereus</i>
Acephate (OP)	Diamondback moth <i>P.xylostella</i>	<i>Bacillus cereus</i>

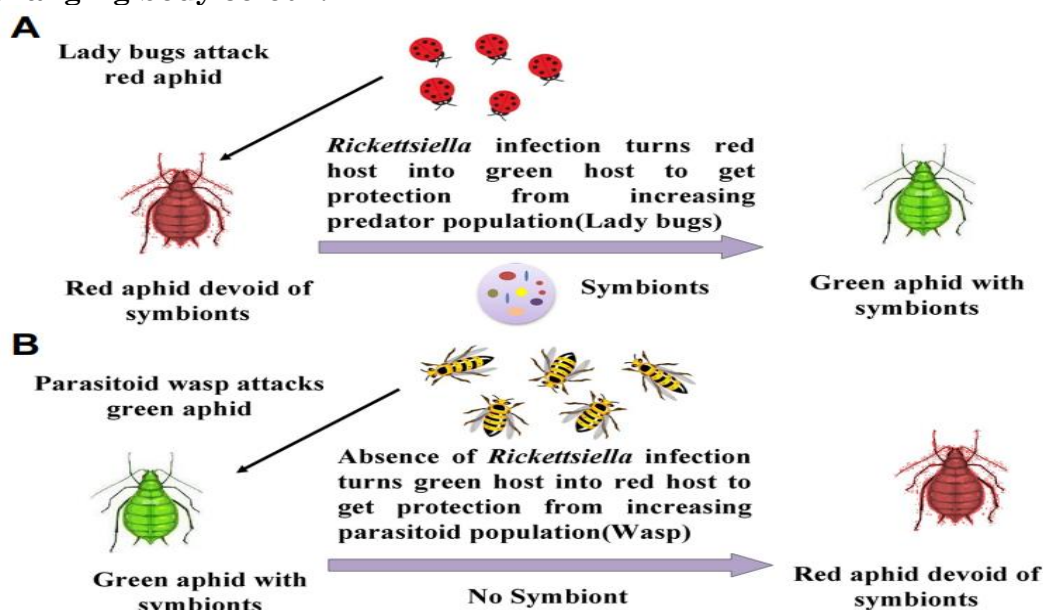
5. Protection against parasitoids: Peach-potato aphid, *Myzus persicae*, has *Hamiltonella defensa* and *Serratia symbiotica*, symbionts that aid in defending against the parasitoid wasp *Aphidius colemani*. *Hamiltonella defensa* increases the life span of aphids by interfering with oogenesis in the parasitoid wasp. These toxic effects are produced by the bacteriophage APSE of the symbiont. In another study, *Myzus persicae* was found to get protection from the parasitoid *Aphidius colemani*, due to the presence of a facultative endosymbiont, *Regiella insecticola*

6. Protection against pathogens: This is observed in a solitary hunting wasp., *Philanthus triangulum*, the European beewolf. They harbor *Streptomyces* antennal glands, produce specific antibiotics against pathogens.

7. Protection against predators:

a. Through secretions and competition: *Paederus* beetle gains protection from wolf spiders through their endosymbionts, where they produce toxin “Pederin,” which is harmful to wolf spiders.

b. By changing body colour:



Rupawate *et al.*, 2023

8. Role in integrated pest management.

Wolbachia Reproductive Manipulators: Shaping Insect Populations

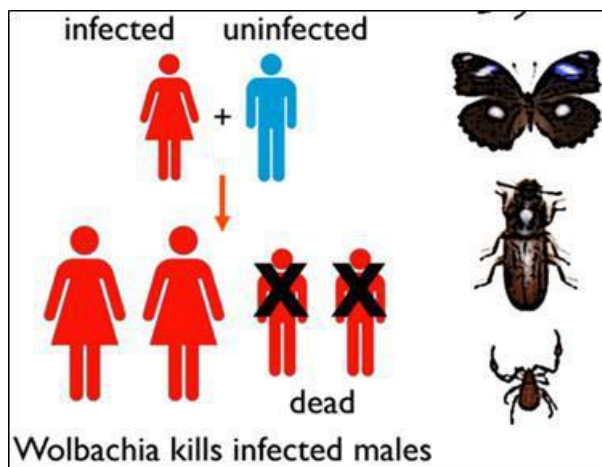
1. The most commonly found facultative endosymbiotic bacteria in insects are *Wolbachia* and *Spiroplasma*.

2. Species: *Wolbachia melophagi*, *Wolbachia persica*, *Wolbachia pipientis*

Wolbachia is a group of maternally transmitted, intracellular alpha-proteobacteria that infect a wide range of insects as well as filarial nematodes and are found in the reproductive tissues of their hosts. This was first discovered in 1924 in insects and was largely unknown until the 1990s. Studies have concluded that > 16% of neotropical insect species carry *Wolbachia* and 25 to 70 % of all insect species are estimated to be

potential hosts. These symbionts can manipulate the reproductive properties of their insect hosts by inducing.

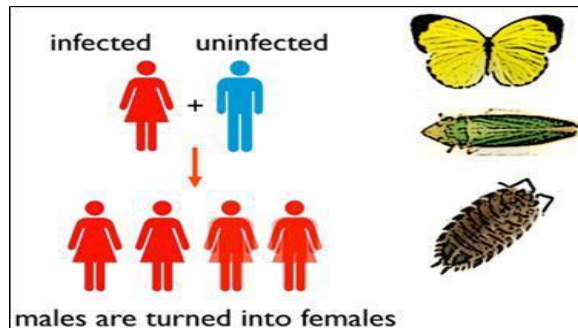
1. Male killing:



Host	Family
<i>Hypolimnna bolina</i>	Nymphalidae
<i>Eurema hecabe</i>	Pieridae
<i>Ostrinia furnacalis</i> , <i>O. scapularis</i>	Crambidae
<i>Lymantria dispar</i>	Erebidae
<i>Spodoptera exempta</i>	Noctuidae
<i>Spodoptera littoralis</i>	Noctuidae

Duploux and Hornett., 2018

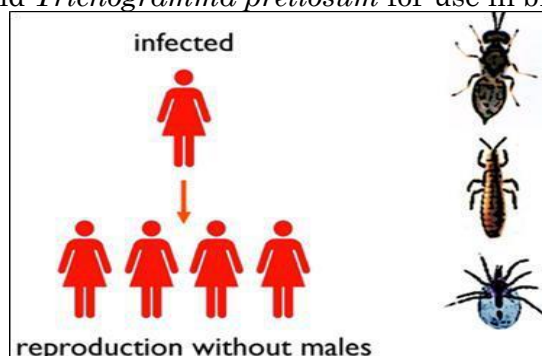
2. Feminization:



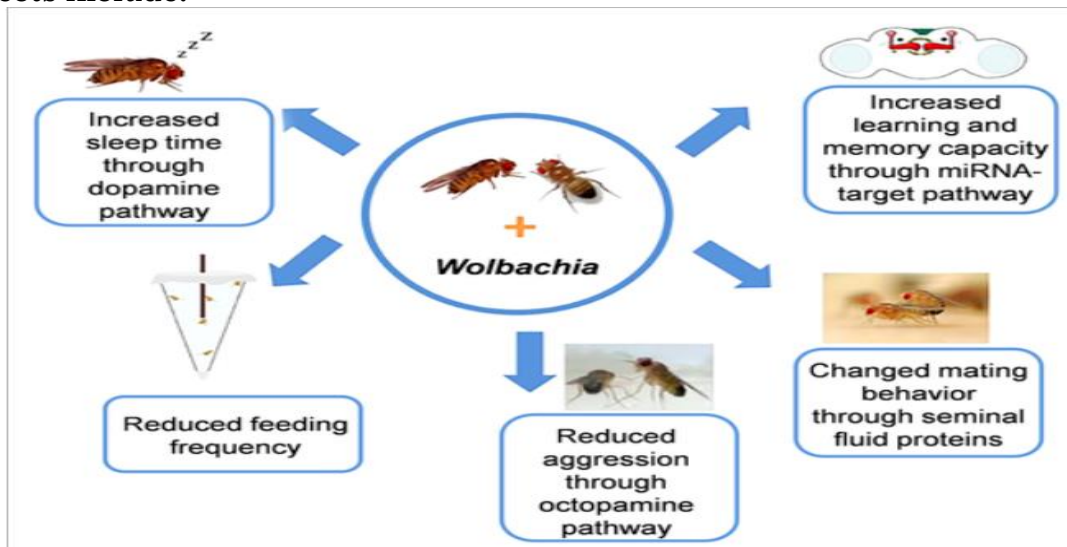
Host	Family
<i>Hypolimnna bolina</i>	Nymphalidae
<i>Eurema hecabe</i> , <i>Eurema mandarina</i>	Pieridae
<i>Cadra cautella</i> , <i>Ephestia kuehniella</i>	Pyralidae

Duploux and Hornett., 2018

4. Parthenogenesis induction: E.g.: Using parthenogenesis-inducing *Wolbachia* for the selection of optimal lines of the egg parasitoid *Trichogramma pretiosum* for use in biocontrol.



5. Other effects include:



bi and wang., 2020

Conclusion

Bacterial endosymbionts are indispensable determinants of insect physiology and evolution: they provision key nutrients and metabolic functions absent in hosts' diets, bolster immunity and defence, and modulate reproduction and development, thereby substantially boosting host fitness and enabling ecological niche expansion and fueling adaptive diversification over evolutionary time. Reproductive manipulators like *Wolbachia* further exemplify how symbionts can shape host reproduction and population dynamics. Importantly, insights into insect–symbiont biology have yielded biotechnological applications: Integrated pest management strategies that combine symbiont-based approaches with conventional methods promise more sustainable and specific control.

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Why Are Whiteflies So Invasive in India?

Article ID: 71077

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Introduction

Invasive insect pests disrupt ecosystems, reduce crop productivity, and pose persistent threats to biosecurity. Among these, whiteflies (Hemiptera: Aleyrodidae) stand out due to their rapid spread, adaptability and ability to cause significant direct and indirect damage to crops. These small, sap-sucking insects have long been a menace in tropical and subtropical agroecosystems affecting horticultural crops, ornamentals, and forestry species. Whiteflies not only weaken plants through direct feeding but also act as vectors for plant viruses, produce copious amounts of honeydew, and facilitate the growth of sooty mould. India has reported multiple whitefly invasions since the 1990s, beginning with *Aleurodicus dispersus* and culminating most recently with *Paraleyrodes pseudonaranjæ*, detected in 2025 in Bengaluru. These invasions reflect a broader trend of Neotropical species expanding into Asia. This is facilitated by increasing international trade, global warming, and the unregulated movement of plant materials, especially ornamental species.

Historical Overview and Recent Introductions

India's first major invasive whitefly was *Aleurodicus dispersus*, reported from the Western Ghats during the mid-1990s. Between 2015 and 2019, seven additional invasive species were detected, including:

1. *Aleurodicus rugioperculatus* (Rugose Spiralling whitefly)
2. *Aleurothrixus trachoides* (Solanum whitefly)
3. *Paraleyrodes bondari* and *Paraleyrodes minei* (nesting whiteflies)
4. *Tetraleurodes acaciae* (Legume whitefly)
5. *Aleurotrachelus atratus* (Palm infesting whitefly)
6. *Aleurothrixus floccosus* (Woolly whitefly)

In 2025, *Paraleyrodes pseudonaranjæ* was reported on *Duranta erecta* in Bengaluru by scientists from NBAIR, representing the ninth exotic whitefly species reported in India. The rapid succession of these introductions indicates both the increasing vulnerability of Indian agroecosystems and the role of global plant trade in facilitating pest movement.

Biological and Ecological Traits Favoring Invasiveness

Whiteflies possess a suite of biological and ecological attributes that contribute to their remarkable invasive success:

1. High reproductive capacity: Most invasive whitefly species exhibit short generation times and high fecundity.
2. Cryptic development and morphological camouflage
3. Honeydew production and sooty mould formation
4. Polyphagia and Virus transmission like begomoviruses in tomato, pepper, and other solanaceous crops.

How do Insects Acquire Endosymbionts?

The accurate identification of invasive whiteflies is complicated by their cryptic morphology and overlapping field symptoms. For example, *Bemisia tabaci* is a complex of at least 46 genetically distinct but morphologically indistinguishable cryptic species like Asia, MEAM1 and MED biotypes, which differ in insecticide resistance, fecundity, host range, gut microbial community etc. Such taxonomic uncertainty necessitates the use of molecular tools such as mtCOI DNA barcoding for reliable species discrimination. Integrative taxonomy combining morphology, genetics, and ecological data is essential for distinguishing new introductions from existing whitefly populations.

Coexistence and Competitive Dynamics

Whiteflies often coexist on the same host, occupying overlapping ecological niches. This is evident from field observations where species like *A. rugioperculatus*, *P. bondari*, *P. minei*, and *A. dispersus* were found infesting coconut and guava simultaneously. Similarly, *P. pseudonaranjae* was found co-occurring with *A. trachoides* and *P. bondari* on *Duranta erecta*. Such coexistence might be facilitated by temporal or spatial niche partitioning where species may prefer different leaf surfaces, stages of plant development, or seasons. Alternatively, it may reflect differing climatic tolerances or competitive hierarchies that shift over time. These dynamics complicate pest management because control of one species may inadvertently allow another to proliferate.

Management and Biosecurity Gaps

Their rapid establishment and invasion highlight gaps in biosecurity and pest management protocols like

1. Limited Early Detection: Lack of routine molecular diagnostics at entry points and nurseries delays species identification.

2. Biological Control Bottlenecks: While classical biocontrol agents like *Encarsia guadeloupae* and *E. dispersa* are effective against *A. dispersus* and *A. rugioperculatus*, newer invaders like *P. pseudonaranjae* lack established parasitoids in India.

3. Chemical Management Limitations: Overreliance on insecticides often results in resistance development, non-target effects, and resurgence.

4. Surveillance Gaps: Most surveys are reactive rather than proactive. A structured national surveillance program with geospatial mapping is lacking.

Urgent measures should include strengthening quarantine screening, developing species-specific diagnostics, and introducing natural enemies from the whiteflies' native ranges under regulated biocontrol programs.

Conclusion

The increasing number of invasive whiteflies reported in India over the past decade underscores the urgent need for a coordinated national response. These pests are ecologically and genetically diverse. The recent detection of *P. pseudonaranjae* is a timely reminder of the porous nature of our phytosanitary borders and the challenges posed by global trade. A shift toward proactive surveillance, integrative diagnostics including classical biocontrol and habitat-based strategies is essential. Collaboration between taxonomists, molecular biologists, plant health authorities, and policy-makers will be key in mitigating the whitefly menace and preserving India's agricultural resilience.

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Sustainable Agriculture Practices

Article ID: 71078

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Sustainable agriculture, a system of farming that strives to provide the resources necessary for present human populations while conserving the planet's ability to sustain future generations. See also organic farming, regenerative agriculture, permaculture, and agroforestry.

Importance of Sustainable Agriculture

Sustainable agriculture frequently encompasses a wide range of production practices, including conventional and organic. A regionally integrated system of plant and animal production practices are designed to produce long-term results such as:

1. Production of enough human food, feed, fiber, and fuel to meet the needs of a sharply rising population
2. Protection of the environment and growth of the natural resources supply
3. Sustainment of the economic viability of agriculture systems.

The Principles of Sustainable Agriculture

A sustainable food system is one that does not require chemicals, conserves energy and water, emphasizes local production, decreases inputs and utilizes resources more efficiently on site, values biodiversity and ecology, and works within our global natural resource limitations.

In order for agriculture to be truly sustainable, it must incorporate following principles:

- 1. The needs of people:** provide nutrient rich food for farmers, farm families, communities, help to maintain good public health, but also improving the quality of life in rural areas.
- 2. Profit:** a farming operation must be profitable, or it will go out of business quickly.
- 3. The planet and the environment:** farming practices must be ecologically sound, promoting healthy biodiversity and sensible management of natural resources.

Sustainable Farming Methods and Practices

Sustainable farming system doesn't have to be only organic agriculture. There are more methods that partly cover in many principles that are sustainable in the long-run and may be 100 percent organic or at least from the biggest part.

The following ten sustainable farming methods and practices are just a few examples of the many ways that we can achieve a much more sustainable agriculture.

1 Permaculture: Permaculture is a design system that applies principles that are found in nature to the development of human settlements, allowing humanity to live in harmony with the natural world. Permaculture principles and ethics can be applied to almost any area of living, including local economies, energy systems, water supplies, housing systems, and food production.

Foundational to producing food through permaculture is intention, design, and “**working smarter not harder**” to banish waste and to create efficient systems.

2. Biodynamic farming: Biodynamics incorporates ecological and holistic growing practices that are based upon the philosophy of “anthroposophy.” Farmers are encouraged to manage their farm as one living organism where cultivated species intertwine and support each other's health.

This includes raising animals on a farm in a way that they help replenish soil fertility and enhance plant growth. One of the building pillars of biodynamics is high biodiversity of plants, animals and beneficial insects. The goal is the creation of a resilient ecosystem that benefits us and other living organisms.

3. Hydroponics and aquaponics: These innovative farming techniques involve the growing of plants without soil, nourishing the plants through specialized nutrients that are added to water.

In *hydroponic* systems, crops are grown with the roots directly in a mineral solution or with the roots in an inert medium like gravel or perlite.

Aquaponics combines the raising of aquatic animals (such as fish) with the growing of hydroponic crops. In aquaponic systems, the water containing the waste material from the aquaculture fish is used to nourish the hydroponic plants. After the water is used by the plants, the water is then recirculated back into the system to be reused by the fish.

Both hydroponic and aquaponic systems are available in a variety of scales, from small home-scale systems to commercial-scale systems.

4. Urban agriculture: The need to localize our food system requires that we grow food much closer to home, including in cities. Since most of the global population is predicted to live in cities in the future, there is a tremendous opportunity for urban agriculture to make a significant positive impact moving forward when it comes to how we produce our food around the world.

Today, many innovative and sustainable growing techniques are already being used in cities, including backyard farms and gardens, community gardens, rooftop farms, growing crops in urban greenhouses, indoor hydroponic farms, and perhaps even growing food inside urban farm towers someday.

5. Agroforestry and food forests: Agroforestry involves the growth of trees and shrubs amongst crops or grazing land. Agroforestry systems can combine both agriculture and forestry practices for long-lasting, productive, and diverse land use when approached sustainably.

In agroforestry systems, trees create a favorable microclimate that maintains favorable temperature and soil humidity, while protecting crops from wind or heavy rain. Trees have another important role. They become stable soils, minimize nutrient runoff and improve soil structure. This is the reason why agroforestry has become one of the powerful tools of farmers in dry regions with soils susceptible to desertification.

Besides promoting healthy growth of food crops and maintaining soil fertility, trees in this farming system provide wood and fruits as an additional source of income for farmers. In these systems, there are many possibilities for product diversification. Farmers can go even as far as growing a whole edible forest.

6. Polycultures and crop rotation: Both of these techniques are trying to mimic natural principles to achieve the best yields.

Polyculture farming involves growing multiple crop species in one area. These species are often complementary to each other and aim at producing superior diversity of products from one plot while fully utilizing available resources. High biodiversity makes the system more resilient to weather fluctuations, promotes balanced diet and applies natural mechanisms to preserve soil fertility.

Crop rotation is based on growing a series of different types of crops in the same area in sequential seasons. The planned rotation may vary from a growing season to a few years or even longer periods. It is one of the most effective agricultural control strategies that is used in preventing the loss of soil fertility.

7. Growth of heirloom and older varieties: Today, due to the industrialization of the global food system, only a few varieties of our food plants are grown commercially. This situation evolved in order to meet market demand for the viability of produce to travel long distances and to be stored for long periods of time. This reduced genetic variety in our food crop species reduces those species' opportunity to adapt to changes in climate, diseases, and pest conditions in the environment. There is currently a great need to grow heirloom and older varieties of crops in order to preserve the biodiversity of seeds. If gardeners and farmers do not continue to grow heirloom and other older varieties of plants and save their seeds, many of the remaining varieties of our food plants could be lost to the world forever.

8. Natural animal raising: Sustainable animal farming is possible and is better for everyone. Not only that it is good for the environment and our nutritional needs, it is also good for the animals. Animals that are raised on the pasture or in their preferred environment live under less stress, closer to their natural way of living. They can have fulfilling social interactions with other animals and behave in a way that is natural to them (roll in the mud, pick plants they want to eat, rest side by side, play).

Allowing animals to graze and live in pasture is much healthier for animals than confined animal feeding operations are. You will even notice that these animals are cleaner, smell better and have that curious

spark in their eyes. Their health and happiness reflect in the quality of products we get from them. Tastier meat, yellower eggs, milk richer in the mineral and vitamin content.

9. Natural pest management: One of the main aims of sustainable agricultural practices is the prevention of the use of synthetic pesticides and other chemicals that should suppress pest infestations and pathogens. Applying increasing amounts of chemicals to grow food is not part of the long-term solution and doesn't help our health either. Farmers from sustainable farms, therefore, look for solutions in nature and try to recreate conditions that do not favor pests.

They achieve this through the set of practices that strengthen natural resilience of crops and practices that interrupt pest cycles.

Greater diversity of crops, intercropping and crop rotations are among the methods that have proven successful. The key to their success lies in dispersing preferred food sources of pests by blending in crops they do not favor. Additionally, diverse crops attract diverse insects and some of them are natural predators of pests, helping to keep their populations within limits, thus mimicking how the real ecosystem balances itself out.

10. Mulching, groundcovers, and manual weed control: Farmers and other growers can dramatically reduce the growth of weeds and conserve soil moisture by covering the soil around their plants through the use of mulching and ground covers.

By naturally suppressing weed growth, these practices greatly reduce, or in some cases even eliminate, the need to apply herbicides to kill weeds. And the most stubborn weeds that appear from time to time can be easily controlled by hand because their numbers are minimized.

Panchagavya: A Low-Cost Organic Input for Sustainable Crop Production

Article ID: 71079

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Abstract

Renowned for its potency in organic and sustainable agriculture, Panchagavya is a traditional Indian bio-fertilizer made from five cow-based products: milk, curd, ghee, pee, and dung. This all-natural mixture is full of growth-promoting hormones (auxins, cytokinin, gibberellin, etc.), helpful microorganisms, and essential nutrients (N, P, K, and micronutrients) that increase crop yields, improve soil fertility, and provide eco-friendly pest control. The application of Panchagavya promotes environmental sustainability by improving plant health and lowering reliance on chemical pesticides and fertilizers. It increases resilience to pests and diseases, strengthens root development, and promotes better seed germination throughout the crop's life cycle. Despite its advantages, adoption is hampered by factors like labour-intensive setup, lack of broad scientific support, and limited market awareness. Nonetheless, Panchagavya holds significant potential as an organic elixir for promoting long-term agricultural productivity, soil health, and sustainability in farming systems.

Introduction

Farmers are shifting more and more to organic practices as artificial pesticides and fertilizers have negative effects on agriculture worldwide. A traditional Indian bio-fertilizer called Panchagavya has shown to be a viable substitute that improves soil quality and increases crop production. Originating from traditional farming methods, panchagavya is today acknowledged for its medicinal, agricultural, and environmental advantages. The term Panchagavya comes from the *Sanskrit* word Pancha, which means "five," and gavya, which means "products of the cow." Panchagavya is a concoction of five substances that are generally found in cows: milk, curd, ghee, urine, and dung. In Vedas and Vrikshayurveda, Panchagavya is enumerated and its applications has been elucidated (Natarajan, 2002). Due of its benefits for pest control, soil health, crop yield, and rejuvenation, organic farmers are beginning to use it more and more. Furthermore, Dhama *et al.* (2005) stated that cow dung and urine are great sources of energy for producing biogas and power. According to Chauhan *et al.* (2004), it is also used to treat a wide range of illnesses, including allergies, asthma, wound healing, nutritional and gastrointestinal tract issues, and the flu. According to Natarajan (2002), Panchagavya is a mixed culture of beneficial and naturally occurring microorganisms that increased soil fertility. These microorganisms include photosynthetic bacteria (*Rhodospseudomonas*), actinomycetes (*Streptomyces*), lactic acid bacteria (*Lactobacillus*), yeast (*Saccharomyces*), and some fungi (*Aspergillus*).

Ingredients Used for Preparation of Panchagavya

The core ingredients of Panchagavya are all derived from the cow, long regarded as sacred and beneficial in Indian culture:

- 1. Cow Dung-** Rich in organic matter and beneficial microbes. These microorganisms help in the fermentation process by dissolving organic matter and releasing nutrients in a form that plants may easily absorbed.
- 2. Cow Urine-** It is commonly recognized that contains a wide range of minerals, hormones, and enzymes found in cow urine promote the growth of plants. It is also said to offer insect-repelling and natural pesticidal qualities.
- 3. Cow Milk-** Milk is a good source of proteins, vitamins, minerals, and other important plant nutrients.

4. Cow Curd- Cow curd contains a lot of beneficial microbes, particularly lactic acid bacteria. These bacteria help to solubilize nutrients and boost their accessibility to plants by producing organic acids during the fermentation process.

5. Cow Ghee- Because of its high lipid content, Panchagavya is combined with ghee, or clarified butter. Lipids add to the total nutritional content and contribute to the absorption of fat-soluble elements.

To improve microbial activity and fermentation, other ingredients are frequently added in addition to these five cow products:

a. Ripe Bananas- Rich in sugars, enzymes, potassium, and growth-promoting compounds, ripe bananas in Panchagavya improve fermentation and provide nutrients for plant growth.

b. Coconut Water- acts as a catalyst for fermentation.

c. Sugarcane Juice or Jaggery Solution- acts as a sugar source for microbes.

Method of Preparation

Panchagavya preparation is a straightforward yet careful procedure meant to promote microbial development and fermentation. The steps involve:

1. Ingredients and its quantity:

- Fresh cow dung – 10 kg
- Cow urine – 10 lit
- Cow milk – 2.0 lit
- Cow curd – 2.0 lit
- Cow ghee – 1.0 kg
- Tender coconut water – 3.0 lit
- Sugarcane juice – 3.0 lit
- Ripened banana – 12

The addition of sugarcane juice and coconut water speeds up the fermentation process and reduces unpleasant odours.

2. Procedure:

Thoroughly mixing of fresh cow dung (10kg) + ghee (1.0kg) in the container (Mix it twice a day).



Incubation for 3 days



Add cow urine (10 lit) + Water (10 lit)



Stir properly in morning and evening daily for a week



Add sugarcane juice (3.0 lit)



Add cow milk (2.0 lit)



Add cow curd (2.0 lit)



Add coconut water (3.0 lit)



Stir properly in morning and evening daily for three weeks



Panchagavya is ready to use

After three weeks of incubation, the entire Panchagavya solution mixture should be filtered through a double layer of muslin cloth. The prepared solution should then be kept in a compact container or bottle in the refrigerator and utilized as needed. By the end of this period, Panchagavya will be ready for use. It will

have a thick, homogenous consistency and a pleasant, fermented aroma. Before application, a 1:10 mixture is diluted with water.

Recommended Doses for Field Crops

Due to its high concentration, Panchagavya should be applied only after being diluted with water. The following dosages are advised for field crops:

- 1. Foliar Spray:** 3-5% Panchagavya solution in 100 litres of water sprayed directly on field crops.
- 2. Soil Drenching:** Apply a solution of 10–15% to the soil in the vicinity of the plant roots.
- 3. Seed Treatment:** To enhance germination, seeds are soaked in a 3% solution for 12 hours prior to planting.

The precise dosage varies according to the kind of crop and stage of growth, but for most applications, a general dilution ratio of 1:10 (Panchagavya to water) works well.

General Schedule of Application

To optimize its effects, Panchagavya can be administered at different phases of crop growth.

- 1. Seedling Stage:** Apply Panchagavya during the seed treatment and early growth stages to encourage healthy root development.
- 2. Vegetative Stage:** To promote robust development and improve nutrient uptake, apply as a foliar spray once every 15 days.
- 3. Flowering Stage:** Spray to increase flower formation and improve fruit set.
- 4. Fruiting Stage:** Drench the soil to enhance the quality and yield of fruits and vegetables.

Medicinal Value of Panchagavya

In traditional Ayurvedic methods, Panchagavya has been revered for its wide spectrum of medical effects. It is said to balance the body's three doshas (Vata, Pitta, and Kapha) and promote overall wellness. Some of its alleged medical properties include:

- 1. Detoxification:** Because cow dung and urine have antiseptic and antibacterial qualities, Panchagavya is said to rid the body of toxins.
- 2. Immunity Booster:** Panchagavya is thought to fortify the immune system because it is abundant in micronutrients, antioxidants, and advantageous microorganisms.
- 3. Digestive Aid:** By encouraging the growth of beneficial gut bacteria, Panchagavya, when consumed in moderation, is thought to enhance gut health and aid with digestion.
- 4. Mental Wellness:** It is said to have a relaxing influence that could help with stress reduction and mental acuity.

Physio-Chemical and Biological Properties

Panchagavya is rich in nutrients and microorganisms that promote plant growth. The fermentation process creates a mixture with the following characteristics:

- 1. pH:** 6.5 to 7.5, slightly alkaline, perfect for balancing the acidity of soil.
- 2. Nutrient content:** High concentrations of potassium (K), phosphorus (P), and nitrogen (N), as well as necessary trace elements like copper and zinc.
- 3. Enzymes:** Supports plant metabolism with the help of beneficial enzymes like lipase and amylase.
- 4. Microbial Load:** A high concentration of yeast, fungus, and beneficial bacteria that support nutrient cycling and soil health.

Beneficial Effects of Panchagavya on Crop and Soil

There are several advantages of Panchagavya for crops and soil.

- 1. Improves Soil Fertility:** Panchagavya increases microbial activity, which in turn improves soil fertility. The nutrient profile of the soil is enhanced by the presence of beneficial bacteria, fungus, yeast, and organic matter. These microorganisms speed up the breakdown of organic matter, increasing the

amount of nutrients-such as potassium, phosphate, and nitrogen-that are available for crop growth. By encouraging the growth of advantageous soil microorganisms in the rhizosphere of crop plants, the use of Panchagavya in agricultural fields significantly improves crop growth and productivity (**Beaulah, 2001**).

2. Encourages Nutrient Uptake: Panchagavya stimulates biological activity that guarantees the release of vital nutrients into the soil, increasing their availability for plant absorption. Better nutrient uptake efficiency results from this, and increased plant growth and yield are directly impacted.

3. Promotes Plant Growth: Plant growth-promoting compounds such as auxins, gibberellins, and cytokinin are abundant in Panchagavya. Stronger and healthier roots, stems, and leaves are formed, faster germination, and enhanced metabolism are all brought about by these phytohormones. As a result, crop show enhanced vegetative growth, flowering, and fruiting.

4. Strengthens Plant Immunity and Increases Crop Resistance to Pests and Diseases: Panchagavya, when applied to crops, increases plant immunity, and increases crop resistance to pests and diseases. Because of the mixture's inherent anti-microbial and pest-repelling qualities, fewer chemical pesticides are required. In organic farming, where chemical interference is minimized, this is extremely important.

5. Eco-friendly and Sustainable: Panchagavya is a sustainable product that is entirely natural and biodegradable. By lowering reliance on chemical pesticides and fertilizers, its application promotes sustainable agricultural methods.

6. Cost-Effective and Easily Accessible: Panchagavya is a cost-effective choice for small and marginal farmers since it is easily accessible on farms, particularly in rural areas where livestock is a crucial component of agriculture. It lowers the total cost of production by eliminating the need for pricey synthetic fertilizers and pesticides.

Constraints and Barriers in Adopting Panchagavya

Despite its numerous benefits, there are several barriers to the widespread adoption of Panchagavya.

1. Labor-intensive: Stirring must be done frequently during fermentation, and the preparation and application process takes a long time.

2. Lack of Awareness: Many farmers are unaware of Panchagavya's potential benefits, leading to low adoption rates.

3. Storage Problems: Improper preparation or storage can cause the mixture to deteriorate and lose its efficacy.

4. Scientific Validation: Although conventional wisdom encourages its application, additional scientific investigation is required to substantiate its assertions.

Conclusion

Panchagavya offers a sustainable and eco-friendly substitute for chemical fertilizers and pesticides, benefiting both agriculture and health. Its use can enhance soil fertility, improve crop yields, and promote organic farming practices. However, issues such as labour intensive, storage, and lack of awareness must be addressed to boost its popularity. With growing interest in organic farming, Panchagavya stands poised to play a key role in creating a more sustainable future for agriculture.

Jeevamrutha: A Step Towards Sustainable Crop Production and Chemical-Free Farming

Article ID: 71080

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Abstract

Jeevamrutha, a traditional Indian organic fertilizer, has emerged as a crucial component in sustainable farming practices, notably in India. Composed of cow dung, cow urine, jaggery, pulse flour, soil, and water, Jeevamrutha increases soil fertility through microbial inoculation and nutritional enrichment. As a cost-effective alternative to chemical fertilizers, it promotes crop yields, improves soil health, and lowers environmental damage. Jeevamrutha's significance in the Zero Budget Natural Farming (ZBNF) movement and its rising adoption by Indian farmers emphasizes its potential to change agriculture by encouraging sustainability, decreasing costs, and assuring food security.

Introduction

Jeevamrutha is an ancient Indian organic composition that has emerged as a popular practice in current sustainable agriculture. Jeevamrutha is formed of two words- Jeeva and Amrutham, which are taken from *Sanskrit*. The word "Jeeva" implies a living entity and "Amrutham" means the elixir up to extending life. It is popularized by the Zero Budget Natural Farming (ZBNF) movement, it is regarded a powerful bio-stimulant that promotes microbial activity in the soil, encouraging plant development and increasing soil health. Jeevamrutha is receiving interest not just due to its cost but also for its ability to minimize dependency on chemical fertilizers, thereby presenting a gateway to regenerative farming practices. India, with its enormous agrarian economy, has mounting worries over soil degradation, groundwater contamination, and falling crop yields driven by excessive use of chemical fertilizers. Jeevamrutha provides a viable solution to these difficulties, making farming not only cost-effective but also environmentally sustainable. It is simple to prepare, cost-effective, and very efficient. The important ingredients include cow dung, cow urine, jaggery, pulse flour, soil, and water-ingredients that are readily available to most farmers, especially in rural regions. The procedure of creating Jeevamrutha entails fermenting these components for a few days to produce a bio-stimulant rich in beneficial bacteria, which, when applied to the soil, boosts its biological activity. The utilization of cow dung and urine from indigenous cows is particularly encouraged, as these animals are known for the probiotic richness of their by-products.

The use of Jeevamrutha has been on the rise, particularly in areas like Karnataka, Andhra Pradesh, and Maharashtra, where natural agricultural practices are actively pushed. According to a 2023 report from the Karnataka State Organic Farming Mission, nearly 800,000 farmers in Karnataka alone have embraced Jeevamrutha in their farming operations. The research demonstrates a 25-30% rise in crop yields and a significant improvement in soil fertility. A similar study conducted by the University of Agricultural Sciences, Bangalore in 2022 revealed that Jeevamrutha users observed a 40% reduction in their input costs and a 15-20% increase in water retention in soil. As part of the ZBNF movement, Jeevamrutha is recognized as a cornerstone in promoting chemical-free farming, with over 6 million Indian farmers moving to natural farming techniques as of 2023.

Physio-Chemical and Biological Properties

1. Jeevamrutha is packed with microorganisms such as nitrogen-fixing bacteria (*Azotobacter*), phosphate-solubilizing bacteria (*Pseudomonas*), and decomposer bacteria that break down organic debris in the soil.
2. Jeevamrutha has a near-neutral pH (6.5-7.5), which is good for most crops.
3. It possesses a large population (cfu/ml) of beneficial microorganisms, such as bacteria (20.4×10^5), fungus (13.8×10^3), and actinomycetes (3.6×10^3). These microbes activate the mineralization process and offer the

plant nutrients, improving the soil biological activity. Source: (https://agritech.tnau.ac.in/org_farm/orgfarm_ofk_soil.html).

It contains essential nutrients like nitrogen (770 ppm), phosphorous (166 ppm), and potassium (126 ppm) and micro-nutrients such as iron (282 ppm), manganese (10.7 ppm), zinc (4.29 ppm) etc, albeit in smaller quantities compared to chemical fertilizers, but with more long-term benefits due to its natural, sustained release. **Source:** (https://agritech.tnau.ac.in/org_farm/orgfarm_ofk_soil.html)

Beneficial Effects of Jeevamrutha

1. Enhanced Soil Health: Jeevamrutha replenishes the soil's microbial population, which aids in nutrient cycling and enhances the soil's structure. Jeevamruth soil treatment raises pH in acidic soils, decreases pH in alkaline soils, and maximizes nutrient availability at pH 6.5 to 7.8. This generates ideal circumstances for bacteria in nutrient solubilization and mineralization (**Kulkarni S.S., 2019**).

2. Improved Water Retention: The organic matter and microbial activity help the soil retain moisture, decreasing the need for regular irrigation.

3. Increased Crop Yields: Case studies have indicated that crops including paddy, wheat, and sugarcane benefit from a 20-30% increase in yields when treated with Jeevamrutha. When Jeevamruth was applied as a soil, foliar, and seed treatment, it also indicated better growth and output. When Jeevamruth is used as a seed treatment, 5–11% of the yield is increased (**Devakumar et al, 2008**)

4. Cost Savings: Farmers claim savings of up to 40-50% on input prices due to the reduction in chemical fertilizers and pesticides.

Ingredients Used for Preparation of Jeevamrutha

Jeevamrutha is prepared using simple, farm-based ingredients that are cost-effective and readily available.

1. Fresh cow dung: Fresh dung from native cows, provides plant nutrients, helpful micro-organisms, and organic matter (**Swain, MR., Ray RC., 2009**).

2. Cow Urine: Cow urine contains important nutrients, enzymes, and helpful bacteria. Acts as a natural insecticide, increasing plant growth and nutrient uptake (**Herran J, Toress, RRS, Rojo, Ge. 2008**).

3. Jaggery: Provides carbs for microorganisms, enhances nutrients availability, boosts microbial activity, and promotes fermentation (<http://www.indiastudychannel.com>).

4. Pulse Flour: Provides protein for bacteria, promotes the growth and activity of microorganisms during fermentation, resulting in the release of important nutrients (**Boye et al, 2010**).

5. Handful soil from the bunds and forest: Introducing indigenous soil microbes, ensuring microbial diversity. Forest soil contains an abundance of naturally occurring phosphate-solubilizing bacteria, nitrogen fixers, NPK, and other beneficial microorganisms, which operate as a bioinoculant. (**Papen, H.A. et al 2002**).

6. Water: Acts as the medium for fermentation and application.

Method of Preparation

1. Mix 10 kg of fresh cow dung and 10 liters of cow ghee with 200 liters of water in a large container.
2. Add 1 kg of jaggery and 1 kg of pulse flour (typically black gram flour) to the mixture without producing any clumps.
3. Finally pour 500 grams of handful of forest soil into the container and mix it well with a stick in clockwise direction to introduce beneficial indigenous bacteria.
4. Cover with a gunny bag over the container.
5. Every day, in the morning and the evening, the mixture needs to be thoroughly stirred in a clockwise way.
6. In summer, incubate the prepared solution for 9 to 12 days; in winter, for roughly 30 days.
7. After fermentation, the solution is ready to be used either directly to the soil or diluted with water for foliar sprays.

8. A golden-brown tinted layer can be visible on the top of the Jeevamruth solution.



Recommended Doses for Field Crops

The typical dosage of Jeevamrutha for field crops is:

For Soil Application: Mix 20 litres of filtered Jeevamrutha in 200 litres of water per acre during the initial stages of planting. This can be repeated every 15-20 days throughout the growing season.

For Foliar Spray: Dilute 10 litres of filtered Jeevamrutha in 100 liters of water and spray directly on the crops. Foliar application is advised every 15-20 days, depending on the crop and weather conditions.

General Schedule of Application

First Application: One month after seed sowing or transplanting

Second Application: 20 days after the first application.

Third Application: 21 days after second spray or when the crop enters its reproductive stage.

Subsequent Applications: Every 15-20 days until harvesting.

Jeevamrutha and the Zero Budget Natural Farming Movement

Jeevamrutha is one of the key elements of Zero Budget Natural Farming (ZBNF), an agricultural methodology that promotes zero reliance on costly inputs such as chemical fertilizers and pesticides. Under the leadership of farmer Subhash Palekar, the ZBNF movement promotes the use of natural inputs like Jeevamrutha to boost yields and cut expenses. By 2023, more than 6 million Indian farmers would have embraced ZBNF methods, with Jeevamrutha playing a key role in this shift. Thousands of farmers in states like Andhra Pradesh and Karnataka have reported higher harvests and lower debt levels since they began using natural farming practices, making these states leaders in the movement.

Jeevamrutha vs. Chemical Fertilizers: A Comparative Study

Research comparing Jeevamrutha to traditional chemical fertilizers has produced solid evidence of its efficacy. In a 2022 study by the Indian Council of Agricultural Research (ICAR), fields treated with Jeevamrutha showed greater organic carbon levels, improved water retention capacity, and better microbial diversity. Additionally, the study indicated that long-term use of Jeevamrutha reduced the need for external inputs like pesticides, as healthier plants were less sensitive to pests and illnesses. Farmers utilizing chemical fertilizers, on the other hand, faced decreased soil fertility over time, requiring increasingly bigger volumes of fertilizers to sustain yields. In contrast, farmers employing Jeevamrutha reported steady or even improved yields year after year, with cheaper expenditures.

Case Study: Karnataka's Success with Jeevamrutha

Karnataka is one of the leading states in India when it comes to the adoption of organic farming practices. Research undertaken by the Karnataka State Organic Farming Mission between 2015 and 2020 found that

approximately 40% of the state's organic farmers routinely used Jeevamrutha. The results were impressive: farmers in the Tumakuru district reported a 40% reduction in input costs, a 25% improvement in soil moisture retention, and a 30% reduction in crop diseases. One farmer, Shivanna, who shifted to Jeevamrutha-based farming in 2017, related his experience: "I used to spend around ₹15,000 on fertilizers for one season of paddy. After employing Jeevamrutha, my costs have dropped down to less than ₹7,000, and the yields are much better."

Constraints in Adoption of Jeevamrutha

Although Jeevamrutha has several benefits, there are a few obstacles to its adoption:

- 1. Labor-Intensive:** Large-scale farmers may find it difficult to prepare and apply Jeevamrutha due to labor requirements.
- 2. Lack of Awareness:** Many farmers are unaware of its benefits and are hesitant to adopt organic practices due to a long-standing reliance on chemical fertilizers.
- 3. Limited Shelf Life:** Jeevamrutha has a limited shelf life and should be utilized within 7–10 days after preparation because it loses microbiological activity over time. This makes large-scale storage challenges.
- 4. Initial Training and Support:** In areas with restricted access to agricultural extension services, farmers may find it difficult to receive the initial instruction they need on the preparation and application of Jeevamrutha.

Future Prospect

The future of Jeevamrutha seems hopeful, especially as the demand for sustainable and organic farming practices develops. Government activities like the promotion of ZBNF, enhanced awareness campaigns, and scientific validation of Jeevamrutha's benefits are likely to promote its acceptance. Additionally, integrating Jeevamrutha into larger-scale organic agricultural operations could open new pathways for enhancing soil health on a national scale, minimizing the environmental effect of synthetic fertilizers, and assuring long-term food security in India.

Conclusion

Jeevamrutha stands out as a transformative solution in the domain of sustainable agriculture. By improving soil health, lowering dependency on chemical fertilizers, and boosting crop yields, it offers a promising alternative for Indian farmers. While constraints like labor intensity and limited awareness hinder widespread adoption, continued government assistance through the ZBNF initiative and farmer-driven campaigning are helping to popularize Jeevamrutha across India. As farming continues to transition towards sustainability, Jeevamrutha could become a key element in ensuring long-term food security and environmental protection.

Boosting Crop Yields Organically: The Use of Humic Acid in Modern Agriculture

Article ID: 71081

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Introduction

Considering the growing issues faces the global agriculture sector- such as degradation of soil and rising crop yield demands - humic acid is showing promise as a potent, all-natural agent for enhancing soil health and promoting plant growth. One of the main ingredients of humus, the black, organic material found in soil that is created over millions of years through the breakdown of plant and animal debris, is humic acid. It is an essential component of soil fertility that is present in soils, peat, and coal deposits. It improves soil structure, water retention, and nutrient availability. Humic acid functions by attaching itself to vital nutrients, such as nitrogen, calcium, magnesium, iron, zinc, potassium, and several other nutrients that increasing their solubility for plant roots availability. This organic chelation process increases fertilizer efficiency and boosts nutrient uptake while lowering the requirement for chemical inputs. Humic acid has been demonstrated in studies to enhance root growth, boost the activity of beneficial soil microbes that further enrich the soil, and raise crop yields by as much as 20%.

In arid and drought-prone areas, where keeping the soil moist is essential, its capacity to increase soil porosity and water-holding capacity is very beneficial. Humic acid is also a buffer, which means that it stabilizes the pH of the soil and lessens the effects of toxicity or salinity. This makes it perfect for use in extensively cultivated or degraded soils. The International Humic Substances Society (IHSS) and other research organizations substantiate the claim that humic acid supports more environmentally friendly farming practices. Humic acid provides farmers with an economical, natural substitute for synthetic fertilizers, enabling them to boost crop productivity while preserving the environment as the need for ecologically responsible farming develops. In agriculture's future, it will be a vital resource due to its function in fostering long-term soil health.

Composition of Humic Acid

Humic acid is a complex organic compound produced by the spontaneous breakdown of plant and animal matter over millions of years. It is a key component of humus, the nutrient-rich layer of soil that promotes plant growth. Chemically, humic acid is composed of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and trace amounts of sulfur. These components are organized into large, high-molecular-weight molecules, providing humic acid its distinct capacity to bond with minerals and nutrients in the soil. Humic acid's primary functional groups are carboxyl (-COOH) and hydroxyl (-OH) groups, aid in the chelation of vital elements such as calcium, magnesium, iron, zinc, and potassium.

Benefits of Humic Acid

Improves soil structure: In order to promote healthy root development, humic acid increases soil porosity, which improves aeration and water retention.

Boost nutrient uptake: Important nutrients (such as Ca, Mg, K, Fe and Zn) are chelated and increased their accessibility to crop roots, which resulting in more effective fertilizer use.

Improves microbial activity: It improves soil fertility by promoting the growth of beneficial soil microorganisms, which in turn aid in the breakdown of organic materials.

Promotes root growth: Humic acid, promotes deeper, stronger root systems in plants, which makes it easier for them to absorb moisture and nutrients.

Increases crop yields: The use of humic acid has been shown in numerous studies to improve soil health and nutrient absorption, which in turn increases crop yields.

Constraints in Adoption of Humic Acid in Agriculture

Even though humic acid has numerous advantages for enhancing crop yield and soil health, there are a number of obstacles to its widespread use in agriculture.

Cost of humic acid: It might be costly to purchase humic acid products, particularly those of superior grade. Although the initial investment yields long-term benefits, it may be too costly for small-scale and resource-limited farmers.

Limited awareness: Particularly in developing nations, humic acid and its possible advantages are unknown to a large number of farmers especially small and marginal farmers in rural areas. Insufficient education and knowledge exchange impede its application in agricultural activities.

Slow result: Humic acid improves the long-term health of the soil and acts gradually, in contrast to synthetic fertilizers that show benefits immediately. Because of the slower rate of apparent benefits, farmers hoping for quick increases in agricultural yields may be hesitant to adopt it.

Limited research: Although there is a lot of data to support the health advantages of humic acid, further research focused on specific regions is still needed. Not all farming systems may see the same outcomes, and factors such as climate, crop varieties, and soil conditions might affect how effective it is.

Methods of Application

Humic acid can be used in a variety of methods, depending on the crop, soil conditions, and desired results. Here are the most popular methods:

Soil application: Prior to sowing, humic acid is frequently added directly to the soil as powder or granular form. This enhances the availability of nutrients, water retention capacity, and soil structure during the growing season.

Foliar application: Liquid humic acid solutions can be sprayed on foliage of the plants. Fast nutrient absorption is made possible by this strategy, especially during periods of plant stress or nutrient deficiency. Applications of foliar fertilizer are particularly helpful for crops that require a quick boost in nutrients.

Irrigation system: Sprinklers or drip irrigation systems can be used to supplement irrigation water with humic acid. Humic acid increases the soil's ability to hold water, therefore this guarantees even distribution over wide areas and works especially well in areas where water management is crucial.

Seed treatment: Before sowing, seeds can be coated with humic acid which enhances resilience to environmental stressors, strengthens early root development, and increases germination rates.

Case Studies

Florida Tomato Farms: According to a University of Florida study, applying humic acid to tomato crops boosted root mass, raised yields by 15% to 20%, and decreased the need for chemical fertilizers.

Indian Wheat Fields: Farmers in India who used humic acid in their crop fields reported a production increase of 10-15% as well as improves soil fertility and texture.

China's Rice Production: Chinese trials showed that applying humic acid to rice paddies improved nitrogen use efficiency, which resulted in a 12% decrease in the amount of chemical fertilizer used without sacrificing yields.

Future Prospect

Humic acid is probably going to be used more widely as sustainable farming practices become increasingly important to address the environmental problems associated with contemporary agriculture. Ongoing research and technological developments should result in easily accessible and cost-effectiveness of humic acid. Promoting its use as part of organic farming programs is also anticipated from governments and agricultural organizations. Humic acid has the potential to play a major role in global agricultural systems as long-term benefits become more widely recognized.

Conclusion

Humic acid represents a potential and sustainable alternative to traditional farming methods. Its capacity to improve soil health, increase crop yields, and minimize reliance on chemical fertilizers makes it a

valuable tool for farmers seeking to combine productivity and environmental sustainability. However, to fulfil its full potential, there must be increased awareness, study, and assistance for farmers to use this important resource.

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Seaweed Extract: A Natural Bio-Stimulant for Sustainable Agriculture

Article ID: 71082

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Introduction

Global agriculture is at a crossroads, as farmers confront the dual challenge of increasing food production while reducing the environmental impact of farming practices. The excessive use of chemical fertilizers, pesticides, and herbicides has resulted in substantial problems, such as soil degradation, water pollution, and a decline in biodiversity. As a result, there is an urgent need to explore natural alternatives that can enhance crop yields without damaging ecosystems. Seaweed extract, a natural bio stimulant made from a variety of marine algae species, is one such substitute. Seaweed has long been utilized in coastal agricultural communities, but in recent times, its ability to encourage plant growth, enhance soil quality, and increase crop resilience has brought it gained global attention.

The Composition of Seaweed Extract: A Powerhouse of Nutrients

Seaweed extract is abundant in essential nutrients and bioactive compounds that benefit plant growth. These include:

Macro and Micronutrients: In addition to trace metals like iron, zinc, and copper, seaweed also includes nitrogen (N), phosphorus (P), and potassium (K). These nutrients are essential to the proper growth of plants.

Plant Hormones: Natural plant growth regulators that encourage cell division, elongation, and flowering, such as auxins, gibberellins, and cytokinin's, are abundant in seaweed extract. The development of roots and the general vitality of plants are greatly enhanced by these hormones.

Polysaccharides and Antioxidants: In addition to strengthening plant tolerance to environmental challenges like salinity, drought, and severe temperatures, complex sugars and antioxidants found in seaweed also aid to improve soil structure.

This unique composition gives seaweed extract the capacity to boost plant nutrition, promote growth and development, and increase resilience to both biotic (pests and diseases) and abiotic (drought, salinity) stresses.

How Seaweed Extract Boosts Plant Growth

Stimulates Root Growth: Seaweed extract has capacity to promote root development is one of its main advantages. Studies reveal that the application of seaweed extract boosts root biomass, facilitating more effective plant uptake of nutrients and water. A plant's ability to withstand drought and absorb nutrients is further enhanced by more extensive and deep root system. Seaweed extract binds with important minerals and increases their availability for plant absorption, acting as a natural chelator. For micronutrients like iron and zinc, which can be challenging for plants to absorb from the soil in some circumstances, this process is especially crucial.

Enhance Crop Yield: Application of seaweed extract has been demonstrated in numerous studies to significantly boost crop yields. In India, for instance, studies revealed that rice yields increased by up to 10-15% when using seaweed-based biofertilizers instead of traditional fertilizers. Similarly, regular application of seaweed extract increased the yields of tomatoes, potatoes, and leafy greens.

Stress Resistance: Seaweed extract has been shown to increase a plant's resistance to abiotic conditions such as heat, salinity, and drought. Because of the bioactive substances found in seaweed, plants can tolerate less-than-ideal growing circumstances by controlling their osmotic balance and water retention.

This is especially true in regions that have unpredictable weather patterns, since farmers encounter crop loss as a result of climate-related stressors.

Pest and Disease Resistance: Furthermore, studies have shown that seaweed extract strengthens a plant's immune system in addition to increasing plant development. Studies indicate that the natural defense systems of plants can be activated by the polysaccharides found in seaweed extract, assisting them in repelling pests and diseases.

Seaweed Extract: An Alternative to Chemical Fertilizers

The overuse of synthetic fertilizers and pesticides has been a significant concern in agriculture, contributing to soil degradation, water pollution, and biodiversity loss. Seaweed extract provides a sustainable alternative that reduces the need for these harmful inputs. It is not only biodegradable but also promotes soil health by enhancing the organic matter content and microbial activity.

Farmers worldwide are recognizing the value of seaweed-based products as they transition towards more sustainable practices. Unlike chemical fertilizers, seaweed extracts do not contribute to nutrient leaching or long-term damage to the soil ecosystem. Moreover, seaweed farming itself is an environmentally friendly procedure, as it requires no freshwater, arable land, or fertilizers to grow.

Application Methods

Depending on the type of crop and stage of growth, seaweed extract can be applied in several ways:

Foliar Spray: Plants can immediately absorb nutrients through their leaves when seaweed extract is sprayed on them as a foliar spray. In the early phases of plant development, this technique is especially useful for promoting growth and boosting resilience.

Seed treatment: Before planting, soaking seeds in seaweed extract can boost germination rates and encourage robust seedling growth. It has been demonstrated that this practice increases young plants' survivability under stressful circumstances and promotes better early root development.

Soil Amendment: Additionally useful as a soil conditioner, seaweed extract improves the fertility and structure of the soil. It increases the soil's capacity to hold on to water and nutrients, making them more available to plants.

Case Studies

1. Australia's Organic Vineyards: Seaweed extract has been used by Australian organic grape producers to enhance their vines' resistance to heat stress and drought. Seaweed extract, a natural bio stimulant, has increased grape yields while lowering the requirement for artificial pesticides.

2. India's Rice Fields: In India, where rice is a main crop, farmers have reported using seaweed extract in addition to conventional fertilizers to enhance yields by as much as 15%. In areas where soil fertility is decreasing, the extract's capacity to improve nutrient uptake and root growth has shown to be very beneficial.

3. UK's Potato Farms: Potato growers in the United Kingdom have been using seaweed extract to enhance tuber quality and fight against diseases such as potato blight. When seaweed extract is used as a foliar spray, field trials have demonstrated decreased disease incidence and increased overall crop health.

The Future of Seaweed Extract in Agriculture

As global population grows and agricultural practices are urged to be more sustainable, the use of natural bio stimulants like seaweed extract is expected to rise. The ongoing research into its benefits is encouraging, with more producers incorporating seaweed into their practices as part of an integrated approach to soil and plant health.

In the future, utilizing fertilizers made of seaweed may be essential to guaranteeing food security, lowering the environmental impact in agriculture, and boosting resilience to climate change. Seaweed extract is an important tool in sustainable farming practices because of its capacity to increase crop yields organically without having the negative environmental effects of chemical fertilizers.

Conclusion

Seaweed extract is a viable option for sustainable farming as the problems facing global agriculture grow. It is a desirable substitute for traditional chemical inputs due to its nutrient-rich solution, capacity to promote stress resistance in plants, increase plant growth, and improve soil health. Seaweed extract is gaining popularity among farmers worldwide as a natural bio stimulant that can boost crop yields while having a little negative impact on the environment.

With ongoing research and increasing awareness, seaweed extract could play a crucial role in molding the future of agriculture- one that is more sustainable, resilient, and environmentally friendly.

Plant Vaccines: Can We Immunize Crops Against Diseases?

Article ID: 71083

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Introduction

Just as vaccines have revolutionized human and animal health, the concept of "vaccinating" plants has emerged as a ground-breaking approach to crop protection. With increasing pressure from climate change, intensive farming, and evolving pathogens, conventional chemical-based plant protection methods are facing limitations. Plant vaccines, which aim to prime the plant's immune system against future pathogen attacks, offer a sustainable and environmentally friendly alternative. But how feasible is plant immunization? What technologies are being explored, and what are the limitations?

Understanding Plant Immunity

Unlike animals, plants do not possess specialized immune cells. Instead, their defense system relies on two main layers of innate immunity:

- 1. PAMP-triggered immunity (PTI):** Activated when plants recognize general pathogen-associated molecular patterns (PAMPs) via pattern recognition receptors (PRRs).
- 2. Effector-triggered immunity (ETI):** A stronger response initiated when intracellular immune receptors (often nucleotide-binding leucine-rich repeat proteins, NLRs) recognize specific pathogen effectors.

Plant vaccines aim to stimulate these pathways before a pathogen actually invades, allowing the plant to mount a faster and stronger defense.

What is a Plant Vaccine?

A plant vaccine refers to a substance usually biological or molecular that induces resistance in the plant without causing disease. These can include:

- 1. Pathogen-derived molecules** (e.g., avirulence proteins or non-pathogenic mutants)
- 2. RNA-based agents** (e.g., double-stranded RNA, small interfering RNAs)
- 3. Chemical elicitors** (e.g., salicylic acid, BABA)
- 4. Beneficial microbes** (e.g., *Trichoderma*, *Bacillus* spp.)

These substances activate **Systemic Acquired Resistance (SAR)** or **Induced Systemic Resistance (ISR)**, which are plant-wide immune responses similar to immunological memory in animals.

Current Examples and Technologies

1. RNA-Based Vaccines: One of the most promising developments is **RNA interference (RNAi)**. By delivering double-stranded RNA (dsRNA) targeting essential pathogen genes, plants can "silence" these genes, preventing infection. For instance, spraying dsRNA against *Fusarium graminearum* on barley and wheat has shown significant disease suppression. **Topical RNA sprays** or **nanocarrier-based delivery systems** can be used without genetically modifying the plant, making this technique more acceptable to regulators and consumers.

2. Microbial Elicitors: Certain non-pathogenic microbes stimulate ISR by producing molecules recognized by the plant as mild stress signals. For example, *Pseudomonas fluorescens* and *Bacillus subtilis* are used commercially to protect against root and foliar pathogens by priming the plant's immune system.

3. Viral Vaccines: Attenuated or mild strains of viruses have been used to immunize plants against severe infections. For example, a mild strain of *Papaya ringspot virus* was used in Hawaii to protect against the more virulent strain.

4. Synthetic Elicitors: Chemicals like **acibenzolar-S-methyl (ASM)** mimic salicylic acid and can trigger SAR. While not true vaccines in the biological sense, they act similarly by priming the immune response.

Advantages of Plant Vaccines

1. Reduced Chemical Dependency: Lower use of fungicides and bactericides leads to decreased environmental contamination.

2. Long-Lasting Protection: Once primed, plants may maintain a heightened immune state for weeks or even the entire growing season.

3. Broad-Spectrum Resistance: SAR and ISR pathways can offer cross-protection against multiple pathogens.

4. Safe and Non-toxic: Especially RNA-based and microbial elicitor vaccines are biodegradable and safe for humans and animals.

Challenges and Limitations

1. Delivery Efficiency: Ensuring uniform uptake, especially in field conditions, remains difficult.

2. Stability and Cost: RNA molecules are unstable under sunlight and may degrade rapidly unless protected by carriers.

3. Regulatory Hurdles: Plant vaccines, especially RNAi-based, fall into a gray area of regulation in many countries.

4. Pathogen Evolution: Just as in animals, pathogens can adapt to evade plant immune responses, especially if the same vaccine is overused.

Future Perspectives

Plant vaccines are an exciting frontier in sustainable agriculture. Research is advancing toward:

1. Smart delivery systems, such as nanoparticles or biodegradable polymers, for stable and targeted application.

2. CRISPR-based immunity, where genome editing enhances or mimics natural resistance genes.

3. Combined biocontrol-vaccine formulations, where beneficial microbes deliver both protection and growth promotion.

As the climate crisis intensifies and the need for eco-friendly farming rises, plant vaccines could become a cornerstone of **climate-resilient and sustainable crop protection**.

Conclusion

Yes, we can immunize crops—at least in principle. Though plants lack an adaptive immune system, they can be “vaccinated” through priming their innate defenses using biological, molecular, and synthetic tools. While several hurdles remain, ongoing research and innovation in delivery technologies and understanding plant immune signalling pathways are rapidly bringing this vision closer to reality. With proper regulation, cost management, and farmer education, plant vaccines may well redefine the future of global agriculture.

Role of Nano-Formulation in Persistence and Dissipation of Pesticide Residues

Article ID: 71084

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Summary

Nano-formulation plays a significant role in the persistence and dissipation of pesticide residues, offering both environmental and agricultural benefits. Controlled release extends the bioavailability of the pesticide, reducing the need for frequent applications. This minimizes the persistence of excess residues in the environment. By avoiding sudden surges of pesticides in the soil or water, nano-formulations reduce the likelihood of toxic build-up. Since the active ingredient is used more efficiently, the required dose is reduced, leading to fewer residues in the environment. Reduced environmental persistence translates to safer food products with minimal pesticide residue levels.

Introduction

Application of chemical pesticides for promotion of crop production and quality is inevitable and is growing globally. However, their excessive and improper use can lead to environmental contamination and residual accumulation in food products, posing risks to human and ecological health. To overcome these problems with conventional pesticides, recent trends in pest management have moved towards the development of nanotechnology-assisted formulations, which include nano-formulations of pesticides and nano-pesticides, which have the potential to offer increasing benefits and fewer side-effects, to enhance pesticide efficiency, reduce environmental impact, and influence the persistence and dissipation behavior of residues (Nehra *et al.*, 2021). One of the key strategies for enhancing the effectiveness of chemical pesticides and reducing their overall usage is through optimizing their formulations. Nano-formulations play a significant role in this process by reducing pesticide residues on crops and minimizing harm to non-target organisms. In these advanced formulations, the active pesticide ingredient is released gradually, maintaining an effective concentration on the target area for an extended duration (Memarizadeh *et al.*, 2019).

What is Nano-formulation of Pesticides?

Nano-formulations incorporate pesticides into nanostructured carriers like nanoparticles, nanoemulsions, nanocapsules, or nanogels. These carriers typically measure between 1 and 100 nanometers and are engineered to enhance the solubility, targeted delivery, and controlled release of active substances. Due to their minute size, nanoparticles find applications in diverse areas including life sciences, aerospace, electronics, chemical manufacturing, and agriculture. Various inorganic nanoparticles are used as nanomaterials; for instance, carbon nanotubes commonly serve as carriers, iron nanoparticles are favored for their magnetic properties, and silica nanoparticles are notable for their high surface area and porous structure. Research has also explored the use of copper, gold, and silver nanoparticles. Organic carriers like polymers and liposomes, valued for being renewable, biodegradable, and eco-friendly, are often employed to encapsulate pesticides (An *et al.*, 2022). These materials are also called nanostructured materials or engineered nanomaterials (Fig. 1).

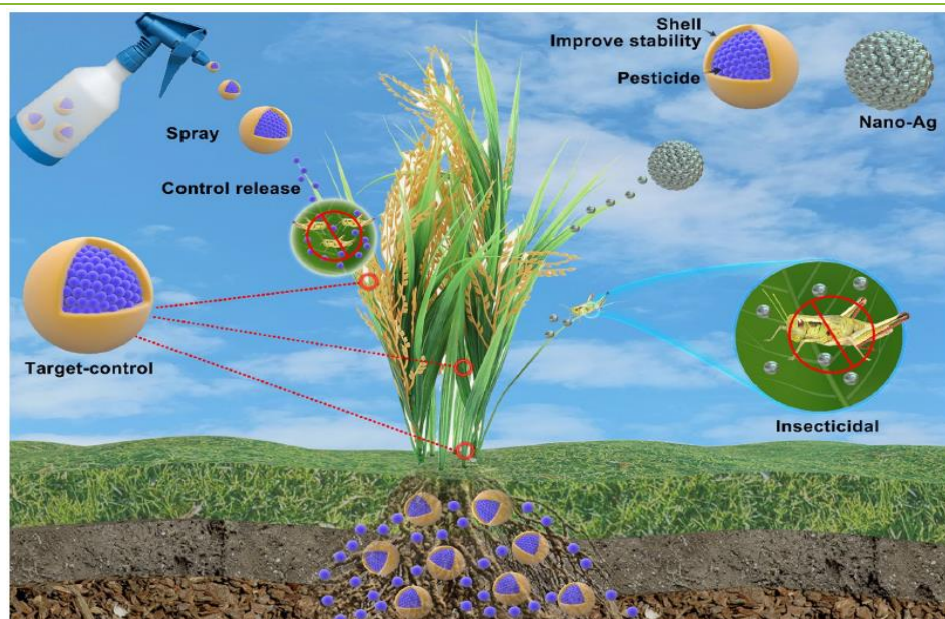


Fig 1: Nanomaterials loaded with pesticide

Mechanism of Action in Persistence and Dissipation

1. Controlled Release and Targeted Delivery: Nano-formulations enable controlled release of active ingredients, reducing the frequency of application and minimizing off-target losses. This precise delivery can result in more efficient pest control while reducing the persistence of excess residues in non-target areas.

2. Enhanced Bioavailability: Nano-carriers improve the solubility and penetration of poorly water-soluble pesticides, enhancing uptake by plants or pests. As a result, lower doses are required, which can lead to reduced residual build-up.

3. Reduction in Volatilization and Leaching: Conventional formulations are often prone to environmental losses through volatilization or leaching. Nano-formulations can stabilize pesticides, reducing these losses and indirectly influencing how long residues persist in soil or water.

4. Degradation and Dissipation Kinetics: The interaction of nano-formulated pesticides with environmental factors like UV light, microbes, and soil chemistry can be significantly altered. Some nano-formulations accelerate degradation, promoting faster dissipation, while others prolong persistence to ensure sustained pest protection.

Case Studies

1. A novel nanoformulation of pyridalyl demonstrating enhanced bioefficacy was developed by Saini *et al.* (2015). The results revealed that nanopyridalyl did not persist much longer than commercial formulation and met all safety assessment criteria.

2. The experiment done by Memarizadeh *et al.* (2019) showed that dissipation kinetics of two imidacloprid (IMI) nanoformulations (Nano-IMI and Nano-IMI/TiO₂) break down faster in vegetables than the commercial formulation, even when used at double the normal amount. This means they leave behind less residue and are safe to use at higher rates.

3. Barakat *et al.* (2023) investigated the differences in dissipation behavior between nanoformulated and conventional (synthetic) imidacloprid. Their findings revealed that the initial soil deposits of nano-imidacloprid were lower than those of the conventional formulation. Moreover, nano-imidacloprid exhibited a faster degradation rate compared to its synthetic counterpart. The enhanced degradation may be attributed to the unique physicochemical properties of nanopesticides, which can alter over time depending on their concentration and various environmental conditions.

Benefits of Nano-Formulation in Managing Residues

- 1. Minimized Residual Load:** Nano-formulations help maintain effective pest control with reduced chemical load, decreasing the risk of harmful residues in food crops.
- 2. Environmental Safety:** Reduced leaching and runoff contribute to lower contamination of groundwater and aquatic ecosystems.
- 3. Increased Shelf-life and Stability:** Nanocarriers protect active ingredients from premature degradation due to environmental factors.

Challenges and Considerations

- 1. Regulatory Uncertainty:** The novel nature of nanotechnology in agriculture poses challenges for standardization, risk assessment, and regulation.
- 2. Toxicological Concerns:** Although nanocarriers may reduce pesticide residues, their own toxicity and environmental fate need thorough evaluation.
- 3. Cost and Scalability:** Producing nano-formulations at scale while maintaining affordability for farmers remains a technological and economic challenge.

Conclusion

Nano-formulation represents a promising strategy to address the dual challenge of ensuring effective pest management and minimizing harmful pesticide residues. By optimizing persistence and promoting faster, safer dissipation, nano-pesticides could play a pivotal role in sustainable agriculture. However, their successful implementation requires comprehensive research on environmental interactions, long-term impacts, and regulatory frameworks. Therefore, understanding the environmental behavior and fate of nanoformulated pesticides is crucial for ensuring their safe use.

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Value Addition of Organic Produces to Marketable, Higher-Value Products

Article ID: 71085

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Introduction

Value addition for organic produce involves transforming raw materials into more marketable, higher-value products. This can be achieved through various processing techniques, including drying, canning, fermentation, and the creation of new product lines like jams, juices, or pickles. It also includes improving post-harvest handling, storage, and packaging to extend shelf life and maintain quality times. The drying of fruits and vegetables, more importantly, minimises losses, enhances storage stability, reduces packaging and handling requirements, and makes transportation easier and cheaper because of reduced weight and volume. The perishable commodities like fruits and vegetables must be sold for off season so to increase the income of the farmers. Till date, there is no review on the drying of vegetables like cluster beans, bhendi, turkey berry, bitter gourd, ivy gourd and fruits like mango, lemon and amla. As result of drying, the crispy brown fruits and vegetables obtained are stored in airtight containers up to a period of 6 months to one year.

Post-Harvest Handling and Storage

- 1. Proper Handling:** Careful handling during harvesting, sorting, and transportation minimizes damage and spoilage, ensuring the best quality produce.
- 2. Grading and Cleaning:** Sorting produce by size, quality, and maturity helps to create more uniform and appealing products.
- 3. Storage:** Appropriate storage methods, such as cooling or using controlled atmosphere storage, extend shelf life and preventing deterioration.
- 4. Packaging:** Using appropriate packaging materials and techniques protects the produce from damage and environmental conditions, maintaining freshness.

Processing and Value-Addition

- 1. Drying:** Dehydrating fruits, vegetables, and herbs concentrates flavors and extends shelf life.
- 2. Canning:** Canning preserves produce in sealed containers, allowing for long-term storage and easy consumption.
- 3. Fermentation:** Fermentation processes, like making sauerkraut or pickles, create new flavor profiles and extend shelf life.
- 4. Juicing and Processing:** Extracting juices or creating sauces, jams, and other processed products adds value and convenience.
- 5. Other Techniques:** Techniques like freezing, pickling, and brewing can also be used to create value-added products.



Value Addition of Medicinal Plants

Medicinal and aromatic plants offer a source of raw materials for pharmaceutical industries and are also used to develop home remedies and herbal products, as well as a source of foreign income for developing countries, as they represent a substantial portion of the global drug market. It is required for economic development and therapeutic usefulness of raw pharmaceuticals and such material at a low cost, bringing about not just monetary loss for medicinal plant growers and collectors. It ensures the quality of raw materials and thus facilitates the increase in the quality, efficacy, and safety of final plant products. It deals with the preparation of drug substances and drug products to pharmacy industry.

Benefits of Value Addition

- 1. Increased Value:** Value-added products command higher prices than raw produce, increasing farmer incomes.
- 2. Reduced Losses:** Processing helps to minimize post-harvest losses due to spoilage and damage.
- 3. Extended Shelf Life:** Processing techniques like drying and canning significantly extend the shelf life of produce.
- 4. Market Expansion:** Value-added products can reach new markets and consumers, increasing demand.
- 5. Product Diversification:** Creating a range of products from a single crop can diversify income streams and reduce dependence on a single market.
- 6. Consumer Convenience:** Processed products offer convenience for consumers, making it easier to incorporate organic produce into their diets.

Value-Added Organic Products

1. Dried fruits and vegetables
2. Jams, jellies, and preserves
3. Sauces and chutneys
4. Juices and beverages
5. Pickled vegetables and fruits
6. Infused oils and vinegars
7. Herbal teas and extracts
8. Frozen organic produce.



Benefits of Value Addition

- 1. Improved Food Safety and Quality:** Value addition in food processing can improve food safety standards and provide consumers with access to higher-quality products.
- 2. Reduced Post-Harvest Losses:** Value-added processes can help prevent spoilage and extend the shelf life of perishable goods, reducing waste.
- 3. Job Creation:** Value addition can create new employment opportunities in processing, packaging, marketing, and other related sectors.

4. Economic Growth: Increased value-added production can contribute to overall economic growth by boosting revenue, creating jobs, and attracting investment.

5. Improved Market Access: Value addition can help businesses access new markets and compete more effectively.

Conclusion

Value-added agriculture increasing the economic value of a commodity through particular production processes. It offers numerous benefits of increased market value, reduced post-harvest losses, extended shelf life, diversified product range, job creation, better market access, and economic growth. It can also lead to improved food safety, food security, nutritional benefits, and greater consumer confidence.

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Boosting Sugarcane Seedling Production by Single Eye Bud Sett Cutter

Article ID: 71086

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Sugarcane cultivation is a significant activity in Mandya, Karnataka, with the region being one of the major sugarcane-producing districts in the state. The Krishna Sagar dam provides water for irrigation, supporting the growth of this water-intensive crop. Farmers in Mandya typically plant sugarcane during the June-July season, although October-November and January-February plantings are also common. Various sugarcane varieties are grown in the region, including Co 62175, Co 86032, CoVC 14061, CoVC 16061, CoVC 16062, and VCF517 each with its unique characteristics and benefits. To ensure optimal yields, farmers in Mandya follow recommended cultivation practices, including proper fertilizer use and irrigation management. Overall, sugarcane remains a vital crop in Mandya's agricultural landscape, providing livelihoods for many farmers and contributing to the local economy.

Sugarcane cultivation traditionally relies on labor-intensive methods for seedling production, involving manual cutting of cane stalks into two- or three-budded setts for planting. However, rising labor costs and the push for agricultural mechanization have created a pressing need for efficient and cost-effective tools. The Phule Sugarcane Sett Cutter, developed by Indian Council of Agricultural Research-All India Coordinated Research Project on Farm Implements and Machinery, Mahatma Phule Krishi Vidyapeeth, Rahuri, is a game-changing innovation that precisely and quickly cuts single-eye bud setts, enhancing seedling production while reducing costs. This power-operated machine ensures each sett has a single bud, maximizing germination potential and resulting in healthier seedlings. By streamlining the sett-cutting process, this technology helps farmers improve productivity and reduce labor expenses, making sugarcane cultivation more sustainable and efficient.

Two Treatment Methods were Studied

T1: Sett cutting using a traditional bud chipper

T2: Sett cutting using the Phule Sugarcane Sett Cutter.



Plate 1: Cutting of single eye buds by manual method and sett cutter



Plate 2: Demonstration of sugarcane single eye-bud sett cutter conducted at research station

Field Testing and Performance Evaluation

To assess its real-world applicability, the Phule Sugarcane Sett Cutter was procured and tested (Plate 1 & 2) at the AICRP(FIM), Zonal Agricultural Research Station (ZARS), V.C. Farm, Mandya. The feasibility studies included controlled trials in research plots and demonstrations in farmers' fields. The machine's performance was evaluated against the conventional bud chipper method (manual and semi-mechanized).

Results

The following specifications (Table 1) and performance data (Table 2 & 3) of the Phule sugarcane sett cutter were recorded at the research station. The Phule Sugarcane Sett Cutter, developed by MPKV, Rahuri, is a power-operated machine that has been tested at research stations and farmers' fields. The device's performance was evaluated against traditional manual methods, and the results are impressive.

The Phule Sett Cutter successfully produced uniform single-eye setts measuring approximately 40-60 mm in length, with an impressive output of 6,250 buds per hour. This level of productivity is a significant improvement over traditional manual methods, which are time-consuming and physically demanding. Economically, the machine also proved its worth. Farmers using the Phule Sett Cutter can save up to Rs. 1,500 per hectare, thanks to reduced labor dependency and enhanced efficiency. These savings, combined with higher output and uniform sett size, make the machine a valuable asset, especially for sugarcane nurseries and farmers with larger holdings.

Table 1: Technical specifications of Phule sugarcane sett cutter

Particulars	Specifications
Overall dimensions Length x Width x Height (mm)	2500 x 1200 x 1350
Weight	340 kg
Cost	Rs. 75,000/-
Make of machine	MPKV, Rahuri
Address of supplier: AICRP on Farm Implements and Machinery, Dr. A. S. College of Agril. Engg. & Tech., Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar- Pin -413 722 (M.S.)	

Table 2: Summary test results of power operated sugarcane sett cutter:

Particulars	Test trials
Average output capacity machine (No of bud setts cut-h ⁻¹)	6250
Damage percentage of buds (%)	5
Energy consumption during operation (kwh)	0.245
Energy cost for operation (Rs h ⁻¹)	1.70
Rotary speed of shafts (rpm)	Driving shaft=1440, Driven shaft=48
Average shearing force (N)	456
Average cutting sett length (mm)	40
Moisture content of sugarcane, (%w.b)	72.50
Cost of operation by sett cutter (Rs ha ⁻¹)	476

Table 3: Comparative performance evaluation of sett cutter:

Parameters	Farmer's practice	Sett cutter
Variety	VCF 517	VCF 517
Mean length, mm	2700	2700
Mean diameter, mm	28	28
Mean cane weight, kg	1.58	1.58
Performance parameters		
Capacity (No. of bud setts cut-h ⁻¹)	200	6250
Average cutting sett length (mm)	40-45	40
Damage percentage of buds (%)	10	5
Labour requirement, man/ha	10	4
Germination (%)	80	98
Cost of operation (Rs ha ⁻¹)	2000	476
Net saving over farmers practice (Rs ha ⁻¹)	1524	

Inference

The Phule Sugarcane Sett Cutter is a game-changing innovation in sugarcane cultivation, offering Indian farmers a practical and cost-effective solution to boost efficiency, reduce labor costs, and improve seedling quality. By facilitating faster and more uniform sett preparation, this single-eye bud cutter empowers farmers to enhance productivity and modernize their farming practices. As the agricultural sector evolves, innovations like the Phule Sugarcane Sett Cutter will play a vital role in shaping the future of sugarcane cultivation, promoting sustainable practices, and supporting farmers across India. With its benefits extending to timely operations, better germination, and healthier seedlings, this technology is poised to revolutionize sugarcane farming and seedling production. The Phule Sugarcane Sett Cutter is an excellent option for sugarcane nurseries and farmers with large areas under sugarcane cultivation.

.....Adopting the right tools today can ensure a sweeter harvest tomorrow.....

AI and Machine Learning: Transforming Insect Identification and Crop Protection

Article ID: 71087

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Abstract

In this dynamic world, finding creative ways to boost agricultural output and satisfy the world's expanding food demand is essential, given the growing population and the constrained amount of arable land. Even with major improvements in crop security techniques, there are still large annual crop losses, mostly from pests. Crop protection methods can be revolutionised with the use of artificial intelligence (AI). AI makes it possible for accurate pest detection, risk assessment, monitoring, and forecasting with the aid of machine learning algorithms, reducing crop losses and increasing yields. Additionally, AI combines crop management features with expert and decision support systems to help farmers make timely and accurate judgments that will increase crop output. This article highlights regarding the future of crop protection involving AI in the face of changing difficulties by attempting to examine its applications, consequences, and future possibilities in the field of pest management.

Introduction

A new wave of technological advancement is being produced by the recent rapid advancements in automation and artificial intelligence (AI), which are having a noticeable impact on industrial, social, health, and environmental contexts. AI offers strong application to complicated issues, and in certain situations, its performance can rival that of humans. Due to the advantages that machine learning techniques may offer in addressing problems with pest and disease monitoring, weed control, chemical use, irrigation problems, yield prediction, precision livestock farming, and other issues, agriculture represents an application field of critical importance for artificial intelligence (**Smith, 2018**). For certain agricultural problems that are typically very dynamic and cannot be generalized to suggest a common solution, the solutions offered by artificial intelligence (AI) provides the greatest fit.

One of the most costly agricultural practices is crop protection, which is frequently caused by inappropriate techniques used as well as the inability to effectively identify and check serious pest infestations and pathogen infections (**Ghaderi et al., 2019**). Pest management is made considerably more difficult by growing environmental concerns and public pressure to use fewer harmful pesticides. The goal of integrated pest management (IPM), which is founded on suitable pest control techniques, is to provide more effective and sustainable crop protection programs. Monitoring the activity and density of pests is one of the fundamental elements of IPM. Farmers have long battled the relentless threat of insect pests, which can devastate crops and livelihoods. Traditionally, identifying these pests relied on manual inspection—a time-consuming and often imprecise process. Today, artificial intelligence (AI) and machine learning (ML) are revolutionizing pest management, offering farmers powerful new tools for real-time insect identification and targeted crop protection.

AI and Machine Learning

Artificial Intelligence (AI) is a broad field of computer science focused on creating systems capable of performing tasks that typically require human intelligence, such as reasoning, learning, perception, and decision-making. AI encompasses a variety of technologies and methods, including natural language processing, computer vision, robotics, and more, enabling machines to analyse data, understand language, recognize images, and interact with humans in increasingly sophisticated ways. Within AI, machine learning (ML) is a specialized subset that involves developing algorithms allowing computers to learn from

data and improve their performance over time without explicit programming. Machine learning systems identify patterns in large datasets and use these patterns to make predictions or decisions, powering applications like recommendation engines, fraud detection, chatbots, and autonomous vehicles. In brief, while AI aims to simulate human-like intelligence in machines, machine learning provides the data-driven methods that allow these systems to learn and adapt autonomously.

How AI and Machine Learning Identify Insects?

Modern AI-powered systems use advanced image recognition and sensor technologies to identify pests with remarkable speed and accuracy. Farmers can simply snap a photo of an insect or affected crop area using a smartphone app, such as IGKV's Crop Doctor 2.0 or Iowa State University's InsectNet. These apps analyse the image, comparing it against vast databases of known pests, considering factors like size, shape, colour, and patterns. The result: rapid, accurate identification of the pest species-sometimes with accuracy rates as high as 96% across thousands of species.

Some systems, like Farmsense's FlightSensor, go even further. They use optical sensors that detect insects as they fly through a tunnel, analysing the light patterns created by their movement. Machine learning algorithms process this data in real time, enabling instant detection and classification-even for pests that only live for a few days as adults.

Smart Farming: Real-Time Monitoring and Proactive Protection

AI and ML are not just about identification; they also empower farmers to act swiftly and efficiently:

Real-Time Alerts: AI-powered systems can notify farmers immediately when pest populations reach threatening levels, allowing for rapid intervention before infestations spread.

Precision Recommendations: Once a pest is identified, these tools can suggest the most effective and environmentally friendly control measures, reducing the need for broad-spectrum pesticides.

Predictive Modelling: By analysing weather patterns, historical outbreaks, and pest life cycles, AI can forecast future pest threats, enabling farmers to plan ahead and minimize losses.

Technologies Powering the Revolution

AI and machine learning are revolutionizing insect identification and crop protection by enabling rapid, precise, and automated solutions that were previously unattainable.

Deep Learning and Neural Networks: Convolutional Neural Networks (CNNs) excel at detecting and classifying insects in complex images, even under challenging field conditions. Recent research has achieved classification accuracy rates of up to 84.95% for dozens of pest types using deep learning models (Venkateswara and Padmanabhan, 2025).

Data Augmentation: Techniques like autoencoders generate synthetic images to balance datasets, improving the performance of AI models, especially when real-world data is limited.

Drones and Sensors: Unmanned Aerial Vehicles (UAVs) equipped with high-resolution cameras, thermal sensors, and even lidar can scan large fields, identifying pest hotspots and even applying targeted treatments with minimal chemical use (Popescu *et al.*, 2023).

Benefits for Farmers and the Environment

These tools can act as a next generation tool in the IPM component as well as provides various benefits to the farmers and the environment such as -

Faster, More Accurate Pest Control: Immediate identification and targeted recommendations mean less crop damage and higher yields.

Reduced Chemical Use: By pinpointing exactly where and when to apply pesticides, AI helps minimize overuse, lowering costs and reducing environmental impact.

Sustainable Agriculture: Smart pest management supports healthier ecosystems and more resilient farming communities.

The Future: Smarter, Safer, and More Productive Farms

As insect infestations are projected to rise due to climate change, the need for intelligent pest management has never been greater. AI and machine learning are not just futuristic concepts—they are practical, proven solutions already making a difference in fields around the world. With continued innovation, these technologies promise to make agriculture smarter, safer, and more productive for generations to come.

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Climate-Resilient Fruit Crops: Innovations in Breeding and Sustainable Management

Article ID: 71088

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Abstract

Fruit crop production globally is being severely impacted by climate change, changing temperature regimes, patterns of rainfall, and raising the frequency of extreme weather conditions. The problems require immediate innovations in breeding and cropping management practices. Fruit crops having climate resilience, bred by conventional and new breeding methods, and developed by adaptive agronomic technologies, are critical for maintaining food and nutritional security. This article discusses recent progress in breeding climate-resilient fruit crops and emphasizes integrated management strategies to maintain fruit production under fluctuating climatic conditions.

Introduction

Climate variability and change pose significant threats to global agriculture, with horticulture especially fruit cultivation being particularly vulnerable. Fruit crops are highly sensitive to fluctuations in temperature, water availability, and pest dynamics. India, one of the world's leading producers of fruits such as mango, banana, citrus, guava, and papaya, faces growing risks due to its heavy dependence on seasonal monsoons and diverse agro-climatic zones. In this context, developing and adopting climate-resilient fruit varieties and sustainable management strategies is crucial for maintaining productivity, quality, and long-term sustainability.

Effect of Climate Change on Fruit Crops

1. Temperature Extremes: Increased temperatures, particularly during the time of critical phenological stages of flowering and fruit set, adversely affect most fruit crops. In fruits such as mango and litchi, high temperatures reduce pollen viability and stigmatic receptivity, leading to ineffective fertilization and poor fruit set. This, in turn, decreases yields and also impacts fruit quality. Moreover, long heat waves can result in sunburn, fruit drop, and non-uniform ripening, leading to great economic losses to the growers.

2. Water Stress: Climate change is causing increasing droughts and irregular rainfall patterns, disturbing normal water availability crucial for healthy growth of crops. Fruit crops like banana and citrus are water-hungry, and their yield is greatly restricted under water-shortage conditions. Water stress not only decreases the size and weight of fruits but also adversely affects taste, texture, and shelf life. It causes physiological disorders in certain instances such as wilting and cracking of the fruit, particularly in papaya and pomegranate.

3. Frost and Cold Waves: In the subtropical and temperate climate regions, sudden cold waves and frosts are extremely damaging to fruit crops. Temperature-sensitive crops such as guava, papaya, and custard apple get cellular damage, flower drop, and fruit abnormalities when subjected to frosts. Young plants and upcoming buds are especially susceptible, and recurrent exposures to frost can lead to full crop loss in affected regions.

4. Pest and Disease Shifts: Climate change is changing the population dynamics and geographical range of pests and diseases, rendering their control more complex. Rising temperatures and higher humidity are conducive to the spread of insect vectors and pathogens. Fruit fly infestation in mango and guava is becoming more serious and longer in duration, whereas diseases such as citrus canker and anthracnose are spreading to newer regions. The overlapping generations of insects and longer duration of infestation require more intensive and frequent controls, adding to the cost of production and environmental hazards.

5. Carbon Dioxide Enrichment: While higher atmospheric CO₂ levels can increase photosynthesis and vegetative growth in fruit crops, they may have undesirable outcomes. High CO₂ levels can upset the balance of nutrient uptake, resulting in poor-quality fruits and reduced levels of essential minerals such as calcium and magnesium. In addition, the extra biomass could render plants more prone to lodging and disease invasion. Increased vegetative growth could also divert the energy of the plant away from reproductive growth, having a detrimental impact on yield in certain crops.

Breeding Climate-Resilient Fruit Crops

Developing new fruit crop varieties that can withstand climate-induced stresses is a long-term and essential solution. Key approaches include:

1. Conventional Breeding: Selection and hybridization efforts focus on drought- and heat-tolerant genotypes, such as hardy pomegranate and bael cultivars. Rootstock breeding in citrus and mango improves resistance to soil salinity, drought, and diseases.

2. Molecular Breeding & Biotechnology: Marker-Assisted Selection (MAS): Enables identification and incorporation of genes for stress tolerance (e.g., salt-tolerant guava). CRISPR/Cas9 Gene Editing: Facilitates precision modification of traits like flowering time, abiotic stress enzymes, and disease resistance, reducing breeding time.

3. Exploiting Genetic Diversity: Utilizing wild relatives and indigenous landraces provides novel traits for stress tolerance and disease resistance. Conservation and screening of germplasm collections under controlled stress environments help identify resilient donor lines.

Sustainable Management Practices for Climate Resilience in Fruit Production

With the occurrence of climate variability and weather extremes, sustainable agriculture practices are crucial to establishing climate resilience in fruit cultivation. While improvement at the genetic level forms the basis, adaptive field-level methods provide effective and timely measures against climate risk. Following are the important measures that are enhancing fruit production sustainability and productivity in the context of shifting climatic conditions:

Water-Smart Practices:

a. Drip Irrigation Systems: They provide accurate water application to the root zone, reducing water loss through evaporation and runoff, and are particularly ideal in water-short areas.

b. Organic Mulching: Crop residues, coconut husk, or straw application keeps soil moist, suppresses weeds, and controls soil temperature.

c. Hydrogels and Anti-Transpirants: These are increasingly being used in dry regions. Hydrogels enhance the soil's water-holding capacity, and anti-transpirants cut down on plant water loss, keeping crops going through extended dry periods.

d. Rainwater Harvesting: On-farm water harvesting facilities like farm ponds and recharge pits ensure water supply during critical crop growth phases.

Agroforestry and Intercropping Systems

a. Agroforestry: The use of fruit trees integrated with nitrogen-fixing trees such as Gliricidia or Leucaena enhances fertility of soil, produces shade, and safeguards against wind.

b. Intercropping: Producing short-season or leguminous crops within the fruit trees, as banana + cowpea or papaya + coriander, not only makes the best use of available space but also enhances biodiversity, pest management, and soil condition.

c. Microclimate Management: Canopies of trees or shade nets moderate micro-environments, which is very important for crops that are sensitive to weather, such as guava and papaya, during summer seasons.

Climate-Smart Nutrition and Pruning:

a. Soil Testing and Weather-Based Nutrient Scheduling: Fertilizing according to actual weather conditions and nutrient status in the soil prevents over- or under-fertilization and maximizes the efficiency of uptake.

b. Integrated Nutrient Management (INM): Blending organic (vermicompost, compost) and inorganic sources improves soil health and supports long-term productivity.

c. Strategic Pruning and Training: Systematic canopy management by pruning increases air movement, decreases disease pressure, and lessens heat stress by balancing the canopy density.

Protected Cultivation Techniques:

a. Polyhouses and Shade Nets: These provide tempering of temperature fluctuations, mitigation of wind and hail damage, and safeguarding of crops from insect vectors. Especially appropriate for high-value crops such as strawberries, grapes, and dragon fruit.

b. Low-Cost Structures: Tunnel houses, walk-in tunnels, and insect-proof net houses are low-cost alternatives for smallholder farmers.

c. Season Extension and Off-Season Cultivation: These technologies enable early or delayed planting, thus synchronizing fruiting periods with market demand.

Integrated Pest and Disease Management (IPDM)

Biological Controls: Parasitoid use (e.g., *Trichogramma*), predator use (e.g., *Chrysoperla*), and microbial biopesticide use (*Beauveria*, *Metarhizium*) provides environmentally friendly suppression of pests.

Climate-Resilient Varieties: Cultivars with resistance to principal pests and diseases minimize reliance on chemical interventions.

Early Warning Systems: ICT tools and pest forecasting models enable timely intervention, averting major outbreaks attributed to weather variability.

Cultural Practices: Crop rotation, trap cropping, and sanitation practices disrupt pest life cycles and minimize infection sources.

Case Studies and Success Models

Drought-Tolerant Mango Varieties: In semi-arid zones of Uttar Pradesh and Maharashtra, varieties like 'Amrapali' and 'Arunika' have shown superior performance under water-stressed conditions due to their deep root systems and adaptive traits.

Banana under Shade Nets: Tamil Nadu and Maharashtra farmers have achieved up to 25% increase in yields and decreased sunburn damage when they used 35–50% shade nets during the hottest summers.

Climate-Smart Citrus in Punjab: Experiments with salinity and waterlogging-stress-tolerant rootstocks such as Carrizo and Cleopatra mandarin have enhanced citrus yield under salinity and waterlogging stress, prevalent in canal-irrigated areas.

Policy and Institutional Support for Climate Resilience

A systemic, multi-stakeholder approach is needed to upscale climate-resilient practices:

Government Schemes: Schemes such as the National Horticulture Mission (NHM), Rashtriya Krishi Vikas Yojana (RKVY), and MIDH need to focus on subsidies and incentives for drip irrigation, polyhouse cultivation, and climate-smart varietal development.

Public-Private Partnerships (PPPs): Public-private partnerships between ICAR institutes, private companies, and FPOs can speed up the development and diffusion of innovations suited to local climates.

Capacity Building and Extension: Krishi Vigyan Kendras (KVKs), State Agricultural Universities (SAUs), and NGOs need to be strengthened to implement training, demonstrations, and digital outreach to develop awareness and skill sets among farmers.

Crop Insurance and Incentives: Weather-based insurance schemes, protected cultivation material subsidies, and incentives for adopting resilient farming practices will improve farmer confidence and minimize economic risks.

Conclusion

Adapting fruit cultivation to the realities of climate change is no longer an option it is a necessity for ensuring food and nutritional security. A combination of modern breeding technologies, traditional genetic resources, and climate-smart agronomic practices offers a robust pathway to resilience. Coupled with institutional support and proactive farmer engagement, India's fruit sector can effectively navigate climate uncertainties and emerge stronger, more productive, and more sustainable.

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Jute's Homeland: The Science behind its Affinity for Bengal's New Alluvial Zone Green Gold

Article ID: 71089

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Abstract

West Bengal is India's leading producer of jute, with the majority of its output concentrated in the New Alluvial Zone, where the fertile soils, optimal moisture, and favourable climate provide ideal conditions for jute cultivation. Expanding this crop beyond its traditional region presents challenges due to its specific environmental needs, such as soil quality, moisture, and access to suitable water for retting. However, recent advancements in agronomic practices have introduced the possibility of cultivating jute in non-traditional zones, including coastal and rainfed areas. The development of short-duration, salinity-tolerant varieties, alongside innovative retting techniques such as microbial retting, is facilitating this expansion. Government programs like Jute ICARE are playing a pivotal role by providing farmers with high-yielding seeds, advanced mechanization, and efficient retting practices, which together reduce risks and enhance profitability. These technological innovations, coupled with strategic support, are gradually extending the reach of jute cultivation in West Bengal, transforming the industry and offering new avenues for economic growth. This growing adoption of jute cultivation beyond the New Alluvial Zone holds promise for the diversification and sustainability of the state's jute economy.

Keywords: Jute cultivation, agro-climatic zones, salinity-tolerant varieties, retting, crop diversification.

Introduction

West Bengal produces over 71% of India's jute, with nearly 80% of this output concentrated in the New Alluvial Zone, particularly in the districts of Nadia, Murshidabad, Hooghly, North and South 24 Parganas, and parts of Malda (Basu et al., 2020). This agro-climatic zone, enriched by the silt-laden deposits of the Ganges and its tributaries, provides fertile alluvial soils, optimal soil texture, pH, and drainage—key edaphic factors for successful jute cultivation.

The region also benefits from a warm, humid climate and a reliable monsoon pattern that delivers the required 500–600 mm of seasonal rainfall, supporting the crop's fibre development. These conditions create a natural synergy, making the New Alluvial Zone the country's most suitable and productive jute-growing belt. The New Alluvial Zone in West Bengal is commonly known as "Green Gold" because of its fertile and nutrient-dense soils that enable the growth of valuable crops like jute, rice, and various vegetables. According to Basu et al. (2020) and ICAR-CRIJAF (2023), this agro-ecological advantage has made the New Alluvial Zone not only the core jute belt of India but also a model for sustainable green-based agrarian wealth, hence the metaphorical title "Green Gold."

Given this ecological advantage, the question arises: can other regions of West Bengal emulate this success? While zones like the Old Alluvial and Red Lateritic areas have limited jute acreage, targeted agronomic interventions, such as improved irrigation infrastructure, drainage management, and site-specific varietal selection, could allow for expansion into select pockets of these regions. However, the unique combination of flat topography, moderate water retention, and high nutrient availability in the New Alluvial Zone remains unmatched, reaffirming its centrality to Bengal's jute economy. Therefore, while jute cultivation in West Bengal is not geographically exclusive, its natural affinity for the New Alluvial Zone offers a model that can be adapted—but not fully replicated—in other agro-climatic regions of the state (Ghosh et al., 2019; ICAR-CRIJAF, 2023).

The Heart of Jute: Bengal's New Alluvial Zone

The New Alluvial Zone of West Bengal, prominently comprising districts such as Murshidabad, Nadia, North 24 Parganas, and parts of Hooghly, forms a major agro-ecological belt for jute cultivation. This region falls within the Indo-Gangetic Plain, benefiting from the annual deposition of fertile alluvium brought by the Ganges and its distributaries. The soils of this zone are characteristically light to medium-textured alluvial loams, exhibiting neutral to slightly acidic pH (6.5–7.2) and high fertility. These soils are rich in organic matter and nutrients like nitrogen and potassium, providing an ideal medium for the growth of bast fibre crops such as jute (Das et al., 2016).

Climatically, the region experiences subtropical monsoon conditions, with mean annual temperatures ranging between 24°C and 38°C during the jute-growing season (March to July). Relative humidity often exceeds 75%, and annual rainfall ranges from 1,200 mm to 1,500 mm, mostly concentrated in the monsoon months, which ensures sufficient soil moisture for jute growth (ICAR-CRIJAF, 2020). Furthermore, the widespread access to stagnant and slow-flowing water bodies such as ponds, canals, and lowlands facilitates traditional retting processes, which are critical for extracting high-quality fibre. These agro-ecological parameters make the New Alluvial Zone the country's core jute-producing belt, contributing significantly to both fibre yield and quality.

Why Other Zones Struggle with Jute Cultivation?

Jute, being a moisture-loving crop with specific temperature, soil, and retting water requirements, thrives best in the New Alluvial Zone. In contrast, other agro-climatic zones of West Bengal face critical agro-edaphic and climatic challenges that limit jute cultivation, as detailed below:

Table: Constraints of Jute Cultivation in Different Agro-Climatic Zones of West Bengal:

Zone	Major Districts	Soil & Climatic Constraints	Impact on Jute Cultivation
Old Alluvial Zone	Malda, Uttar Dinajpur, Dakshin Dinajpur	Slightly degraded alluvial soils with nutrient depletion; seasonal waterlogging due to poor drainage	Poor seedling emergence and growth; higher risk of diseases and pests
Red and Laterite Zone	Purulia, Bankura, Birbhum	Acidic soils (pH 5.0–5.5), low fertility, coarse texture, low moisture retention (20–25% field capacity)	Low fibre yield and quality; vulnerability to water stress during critical growth stages
Coastal Saline Zone	South 24 Parganas, East Midnapore	Soil salinity >4 dS/m, frequent tidal flooding, high water table; saline groundwater affecting growth and retting	Stunted plant growth, poor germination, difficulty in retting with saline water
Hill and Terai Zone	Darjeeling, Jalpaiguri, Alipurduar	Low temperatures (<20°C), sloping terrain, limited arable land; inadequate water for retting	Low biomass production, poor retting quality, and limited suitable land area for jute cultivation
Undulating Red & Gravelly Zone	Jhargram, Paschim Medinipur, Bankura	Shallow, gravelly red soils; low fertility; rainfed; undulating terrain with high runoff; poor soil moisture retention	Not suitable for jute; moisture stress, inadequate retting water, and poor soil quality hinder cultivation

Expanding Jute Production Beyond the New Alluvial Zone

Jute is traditionally cultivated in the New Alluvial Zone of West Bengal, however, with the development of new agronomic technologies and government support, expanding jute cultivation to other agro-climatic zones in West Bengal is both feasible and promising. Below are the possibilities, along with recent advancements and strategies for promoting jute cultivation in different zones of West Bengal.

Old Alluvial Zone (Malda, Murshidabad, Nadia, North 24 Parganas)

In the Old Alluvial Zone, jute cultivation can be significantly enhanced with the introduction of short-duration varieties and improved irrigation techniques. These zones typically face varying rainfall patterns, which can affect the availability of water for retting.

Strategies for Expansion

1. Short-Duration Varieties: Introducing short-duration jute varieties, including *Tossa jute* varieties like *JRO 524(Navin)*, *Chaitali Tossa*, and as well as *white jute* varieties like *JRC 212(Sabuj Sona)*, *Baldeb* etc., which mature in around 120-140 days, can help farmers better manage the available water and increase the frequency of jute cropping. These varieties are particularly well-suited for areas with uneven rainfall.

2. Microbial Retting Technology: Utilizing CRIJAF's microbial retting technique, which accelerates the retting process and improves fibre quality, can reduce the dependency on water resources during the retting process. This approach has been successfully implemented in this zone, where traditional retting is often hindered by water shortages.

3. Water Harvesting Infrastructure: Encouraging farmers to adopt small-scale rainwater harvesting systems, such as farm ponds or check dams, which can store rainwater for retting, will significantly increase the efficiency of water use in these areas.

Terai Zone (Cooch Behar, Jalpaiguri)

The Terai Zone, characterized by high rainfall and fertile soil, offers an excellent opportunity for expanding jute cultivation, particularly in flood-prone areas.

Strategies for Expansion

1. Mechanized Sowing and Harvesting: The use of advanced mechanized tools, such as combine harvesters, will reduce the labor intensity of jute cultivation and improve productivity in the Terai region.

2. Adoption of Water-Resilient Varieties: The development of varieties that are more resilient to occasional waterlogging and pests will enhance yields in the Terai zone. Varieties like *JRO 524(Navin)* can be promoted as they are adaptable to such conditions.

3. Integrated Farming Systems: Integrating jute cultivation with fish farming or rice cultivation, which is already common in this region, could diversify farmers' income streams, making jute a more viable crop for the region.

Red and Lateritic Zone (Bankura, Purulia, Birbhum)

The Red and Lateritic Zone, which experiences lower rainfall and poorer soil quality, can benefit from practices that enhance water retention and soil fertility.

Strategies for Expansion

1. Soil and Water Conservation Techniques: Introducing water-efficient practices, such as drip irrigation and soil mulching, can improve water retention and soil fertility. Also, conservation tillage practices like zero tillage will help maintain soil structure.

2. Agroforestry Models: Incorporating agroforestry practices, such as planting jute alongside nitrogen-fixing trees like *Sesbania*, can improve soil health and provide shade for jute crops, enhancing productivity.

3. Nutrient Management: Emphasizing the use of organic manures and balanced fertilizers tailored to the specific needs of jute can increase soil fertility and crop yields in these regions.

Coastal Saline Zone (South 24 Parganas, Sundarbans)

The Coastal Saline Zone, including areas like the Sundarbans, faces the challenge of soil salinity, which limits crop choices. However, jute's tolerance to saline conditions makes it an ideal crop for these areas.

Strategies for Expansion

- 1. Development of Salinity-Tolerant Varieties:** Ongoing research at ICAR-CRIJAF is focused on developing salinity-tolerant jute varieties, such as *JBO 2003-H (Ira)*, which can thrive under saline conditions. Promoting these varieties can help boost jute cultivation in coastal areas.
- 2. Rainwater Harvesting and Retting:** In coastal areas, where freshwater availability is limited, promoting community-based rainwater harvesting systems for retting can significantly reduce dependence on freshwater resources.
- 3. Polyculture Systems:** Integrating jute with other salt-tolerant crops like sesame and mustard can diversify income and improve soil health, making jute cultivation more sustainable in saline zones.

Government Support and Initiatives

- 1. Jute ICARE Scheme:** Launched by the National Jute Board (NJB), the ICARE (Improved Cultivation and Advanced Retting Exercise) scheme promotes high-yielding jute varieties like *JRO 524 (Navin)* and *JBO 2003-H (Ira)*. It encourages advanced retting methods, especially microbial retting, which improves fibre quality and reduces water use. The scheme also includes farmer training on mechanized sowing, weeding, and harvesting to boost productivity.
- 2. Jute Technology Mission (JTM):** JTM supports the development of pest-resistant, salinity-tolerant, and high-yielding jute cultivars. It advocates mechanization through seed drills and fibre extraction machines. Moreover, the mission drives R&D to diversify jute applications in sectors such as biodegradable packaging and geotextiles, strengthening jute's industrial relevance.
- 3. National Jute Board Schemes:** Programs like the Integrated Jute Development Scheme (IJDS) and Jute Diversification Promotion Scheme (JDPC) encourage organic farming, integrated pest management, and mechanization. These schemes aim to enhance farmer incomes by supporting product diversification into high-value markets and providing training and capacity building.
- 4. West Bengal State Government Initiatives:** Schemes such as *Krishak Bandhu* provide direct financial aid to farmers, while *Matir Srishti* enhances soil and water management. The *Bengal Jute Development Scheme (BJDS)* supports the adoption of modern jute farming technologies, and the *Jute-Based Agro-Industries Development Scheme* facilitates local processing units, boosting rural employment.
- 5. Pradhan Mantri Krishi Sinchayee Yojana (PMKSY):** This central irrigation scheme enhances water-use efficiency via drip and sprinkler systems, particularly useful in regions with erratic rainfall. It also promotes water harvesting infrastructure like ponds and check dams, ensuring a consistent water supply for retting and crop growth.

Conclusion

Jute cultivation in West Bengal has historically thrived in the New Alluvial Zone, particularly along the Ganges River, where the unique combination of fertile loamy soils, abundant water, and favourable climate creates optimal growing conditions. This region has long been the natural home for jute, as its environment supports the crop's specific needs, especially for retting. However, expanding jute farming beyond this traditional region poses substantial agro-ecological challenges, as jute is highly sensitive to variations in soil quality, water availability, and retting conditions, which are essential for successful cultivation.

Despite these challenges, recent advancements offer hope for the broader adoption of jute in non-traditional areas, such as coastal and rainfed districts. The development of short-duration, salt-tolerant jute varieties, coupled with innovative decentralized retting techniques, has started to make jute cultivation feasible in regions previously deemed unsuitable. Government initiatives like the Jute ICARE scheme are empowering farmers with access to high-quality seeds, microbial retting practices, and mechanization, which are crucial for reducing risks and enhancing profitability. While jute's expansion beyond its established zones is limited due to its environmental dependencies, these scientific innovations and supportive policies are progressively enabling its cultivation in new areas. This gradual shift holds the promise of a more resilient and diverse jute industry in West Bengal.

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Biosensors for Food Quality and Safety Assessment

Article ID: 71090

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Summary

Nanoparticle-based biosensors have emerged as powerful tools for assessing food quality and safety due to their unique optical, electrical, and catalytic properties. These sensors enable rapid, sensitive, and cost-effective detection of contaminants, pathogens, and food adulterants. Advances in materials like gold, silver, copper, and magnetic nanoparticles have significantly enhanced sensor performance across various platforms, including colorimetric, electrochemical, and fluorescence-based systems.

Introduction

Ensuring the consistent availability of safe and nutritious food is a major global priority. Over the past few decades, this goal has been supported by advancements in industrial food processing and robust quality management systems, including ISO standards (9000, 14000, 22000), Good Manufacturing Practices (GMP), Hazard Analysis and Critical Control Points (HACCP), and sanitation protocols. These systems are designed to reduce foodborne risks, yet challenges such as contamination, adulteration, and food fraud persist.

To address these limitations, biosensors have emerged as powerful tools in food quality and safety assurance. The integration of nanotechnology has significantly enhanced the sensitivity and functionality of biosensors. Nanoparticles owing to their unique optical, electrical, and catalytic properties are being employed to develop versatile biosensing platforms capable of detecting pathogens, contaminants, allergens, and adulterants in food systems.

Types of Nanoparticle-Based Biosensors

Metal and Metal Oxide Nanoparticles: Metal nanoparticles like gold (Au), silver (Ag), copper (Cu), and platinum (Pt) exhibit plasmonic properties due to their ability to resonate with incident light, enabling colorimetric and electrochemical sensing. These materials, especially gold and silver, are widely used in sensor design because of their stability, conductivity, and surface area for functionalization.

1. Gold Nanoparticles (AuNPs): AuNPs are extensively used in colorimetric sensors due to their visible light absorption characteristics. The color change—from red to purple upon aggregation—forms the basis for detecting analytes like vitamins and pathogens. AuNPs also serve as labels in lateral flow assays, such as dipsticks, enabling rapid visual detection of foodborne pathogens like *E. coli* and *Shigella*.

In electrochemical applications, AuNPs enhance current response by increasing electron transfer rates. This is evident in immunosensors used for *Listeria monocytogenes* detection, where antibodies immobilized on electrodes interact with the pathogen, and enzyme-tagged AuNPs amplify the signal.

In fluorescence-based sensing, AuNPs act as quenchers. For instance, in detecting Bisphenol-A, CdTe quantum dots fluoresce unless quenched by dispersed AuNPs. Aggregation of these particles in the presence of the analyte restores fluorescence, allowing quantification.

2. Silver Nanoparticles (AgNPs): AgNPs possess strong light absorption and are used in colorimetric sensors that can be fine-tuned across the visible spectrum. These nanoparticles also exhibit photoluminescence when under 2 nm, enabling their use in highly sensitive detection platforms. For example, Ag-Pd alloy nanoparticles functionalized with antibodies have been employed in electrochemical sensors to identify veterinary drug residues in meat.

AgNPs also feature in dual aptamer-based assays for *Staphylococcus aureus* detection. In this design, AgNPs act as signal reporters, and magnetic nanoparticles facilitate the separation of target bacteria, enhancing sensitivity and selectivity.

3. Copper Nanoparticles (CuNPs): CuNPs offer high electrical conductivity and catalytic efficiency, ideal for electrochemical and fluorescence biosensors. For example, Cu₂S nanorods combined with organic membranes provide a biocompatible platform for polyphenol detection. Fluorescent CuNPs have been used to identify harmful compounds like kojic acid through fluorescence quenching.

Additionally, CuNPs embedded in conducting polymers like polyaniline improve the sensitivity of sensors for detecting acrylamide, a potential carcinogen found in fried foods.

4. Magnetic Nanoparticles: Magnetite (Fe₃O₄) and maghemite (γ-Fe₂O₃) nanoparticles are prized for their superparamagnetic properties, allowing them to be magnetically directed for selective separation in complex samples. Their biocompatibility and ease of functionalization make them ideal for biosensing platforms.

Magnetic nanoparticles are used in sensors that detect xanthine in fish, a freshness marker. Coupled with xanthine oxidase and immobilized on electrodes, they significantly enhance signal response. These particles also play a key role in pesticide detection. For instance, Fe-Ni alloy nanoparticles integrated with acetylcholinesterase enable phosmet detection in olive oil through current reduction, indicating enzyme inhibition.

5. Titanium Dioxide (TiO₂) Nanoparticles: TiO₂ nanoparticles, known for their photocatalytic and light-scattering abilities, are common in food additives and sensor development. Their role in humidity sensors is well established, as water vapor alters the resistance of TiO₂ films, offering a simple and effective sensing mechanism. They are also utilized for gas sensing and chemical oxygen demand measurements due to their affinity for oxygen and organic compounds.

Advanced Biosensor Platforms

Quartz Crystal Microbalance (QCM): QCM sensors detect mass changes on a surface, translating into frequency shifts. These sensors, enhanced with AuNPs, have been developed to detect allergens like gliadin in wheat. Their precision and minimal sample preparation requirements make them suitable for food allergen testing.

Surface Plasmon Resonance (SPR): SPR biosensors detect changes in refractive index and allow label-free, real-time detection. They are highly effective in identifying foodborne pathogens like *Salmonella* and *E. coli* when coupled with AuNP-labeled antibodies in a sandwich immunoassay format.

Conclusion

Despite the adoption of strict food safety protocols globally, challenges such as contamination and food fraud continue to pose risks. Nanoparticle-based biosensors offer a sophisticated solution to these challenges by enhancing the sensitivity, specificity, and usability of traditional detection methods.

Gold, silver, copper, and magnetic nanoparticles—each with unique physical and chemical properties have significantly advanced the capabilities of colorimetric, electrochemical, fluorescence, SPR, and QCM-based sensors. Their integration with biorecognition elements like antibodies, enzymes, and aptamers has facilitated the rapid and accurate detection of contaminants, allergens, toxins, and pathogens in diverse food matrices.

As the demand for safer food grows, the evolution of nanoparticle-enabled biosensors will continue to be pivotal in safeguarding public health and ensuring food integrity.

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Importance of Biofortification in Vegetable Crops

Article ID: 71091

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Food security has been a top global concern in recent years. After making a successful lead in food security now, the developing nations are focusing on nutritional security, which includes food that has been supplemented with vitamins and minerals (Lal *et al.*, 2020). Malnutrition is a serious primary health problem that affects individuals in poor nations, particularly in India, where diets based on grain are usual and access to fruits and vegetables is limited. In order to tackle numerous health difficulties, developing nations desperately need to biofortify their vegetables with vitamins and minerals. There are three methods, which are widely used for biofortification of fruit and vegetable crops are traditional breeding, agronomic approach and genetic engineering (Reddy *et al.*, 2021). Success stories of biofortification include High-protein GM Potato, genetically modified purple tomato rich in antioxidants, β -carotene rich peppers, Vitamin A rich orange sweet potato etc. (Garg *et al.*, 2018). The targeted people are receiving enough amounts of the biofortified food crops' micronutrients, particularly in the form of grains, legumes, vegetables, and fruits. Even though transgenic research is receiving more attention, breeding has a significantly higher success rate and acceptance since it takes less time and produces better outcomes. The development of transgenic crops to increase the quantities of provitamin. Crops including tomato, potato, sweet potato, beans, and other vegetable crops have lately been the subject of several research. And those significant results showed that the increase in vitamin, minerals and protein content in vegetable crops is helpful for reducing malnutrition and hidden hunger in developing countries. Application of transgenic approach combined with biofortification can lead to the development of the new varieties from the grassroot level (Kumar *et al.*, 2019).

What is Biofortification?

The Greek word “bios” signifies “life. The Latin verb ‘fortificare’ means “to fortify.”

Definition: Biofortification is the process of growing staple crops (cereals and vegetables) with increased micronutrient content utilizing established plant breeding techniques, biotechnology, and agronomical strategies.

Why Biofortification?

1. To overcome malnutrition problem in human being.
2. Hidden hunger or micronutrient deficiency retards the growth and development of both crops and humans.
3. Increase bio-available concentrations of essential nutrients in edible portions of food crops.
4. Offers an effective way to reach hungry populations in relatively isolated rural locations.
5. WHO estimated that biofortification could help cure 2 billion people suffering from iron deficiency-induced anaemia.

Biofortification and Zero Hunger Challenge

1. The Zero Hunger Challenge was launched by United Nations Secretary in 2012.
2. The Zero Hunger vision reflects five elements from within the SDGs, which taken together, can end hunger, eliminate all forms of malnutrition and build inclusive and sustainable food systems.
3. The Second Global Conference on biofortification advised to the UN to recognize 2018-2020 as the International Years of Biofortified and Underutilized Crops.

Objectives of Biofortification for Vegetable Crops

1. To develop vegetable varieties by inducing micronutrients such as iron, zinc, calcium, phosphorous and Vitamin-A by any means for preventing global deficiency of these nutrients.
2. To screen for biofortification of vegetable crops from existing germplasms.

Importance of Biofortification

1. To improve the plant or crop quality.
2. To increase the nutritional value of daily diets.
3. To overcome malnutrition in human beings.
4. Application of biofortified crops would benefit farmers by increasing their income in the long term.

Success of Biofortification Depends on

1. Increased yields and profitability must be paired with increased nutrient density.
2. Effectiveness must be shown. Enough nutrients must be preserved during processing and cooking, and they must also be suitably bioavailable.
3. Farmers and consumers must eat biofortified foods in large quantities (Jena *et al.*, 2018).

Method of Biofortification

Biofortification with essential micronutrients into the crop plants can be achieved through three main methods, namely transgenic, conventional, and agronomic. By using crop breeding, fertilization techniques, and biotechnology, respectively (Garg *et al.*, 2018).

- 1. Agronomic Biofortification:** Involving fertilizer application of required nutrient for enrichment purposes. Sometimes assisted with different organic and inorganic amendments.
- 2. Conventional Breeding:** Conventional breeding of food crops for desired characters via controlled breeding of crop plants making them absorb and retain more nutrients.
- 3. Genetic Engineering:** Genetic engineering is the Gene manipulation of plant germplasm for introduction of desired characters.

Percentage of Different Crops Biofortified by Different Approaches

1. Cereals have been biofortified at the highest percentage by all three biofortification methods.
2. After cereal crops legumes vegetables have been targeted by all three approaches in almost equal percentage.
3. The most crops are covered by the transgenic technique.
4. Oilseeds crops have primarily been targeted by transgenic approaches because of low genetic diversity (Garg *et al.*, 2018).

Transgenic Approaches for Biofortification

Transgenic Potato (*Solanum tuberosum*): Potato is considered as world's fourth most significant source of calories, and any nutritional enhancement in potato is of great significance. By simultaneously adding the PSY gene, phytoene desaturase, and lycopene -cyclase, provitamin A (carotenoid forms) levels in potato tubers have been enhanced. By overexpressing strawberry genes, the potato has also been targeted for vitamin C (ascorbic acid) improvement (Garg *et al.*, 2018).

Transgenic Sweet Potato (*Ipomea batatas*): Sweet potato is a natural alternative source of bioenergy and antioxidants and also rich in different phytochemicals, anthocyanins, carbohydrates, potassium, vitamin C, and dietary fiber. Through the over expression of the orange IbOr-Ins gene in white fleshed sweet potatoes, its nutritional qualities have been further improved by raising the amounts of carotene, lutein, and total carotenoids in the plant

(Garg *et al.*, 2018).

Transgenic Cassava (*Manihot esculenta*): Because it can withstand a variety of pressures, cassava is a crucial staple food crop for millions of disadvantaged people throughout the world. However, some crucial elements including provitamin A, vitamin E, iron, and zinc are lacking in cassava. Cassava has been biofortified with provitamin A, iron, and zinc to help the undernourished communities with their deficiencies (Garg *et al.*, 2018).

Transgenic Carrot (*Daucus carota* subsp. *sativus*): Carrot is one of the most widely consumed vegetable crop which is rich in beta-carotene, vitamins and minerals. However, the calcium content is low in carrots. The Arabidopsis H⁺/Ca²⁺ transporter has been expressed to improve the bioavailable calcium level in transgenic carrots (Garg *et al.*, 2018).

Transgenic Lettuce (*Lactuca sativa*): This is one of the most consumed green leafy vegetable all around the world. Lettuce has a lower iron concentration than spinach. By transiently expressing a soybean ferritin gene, the lettuce's iron content, yield, and growth rate have been enhanced (Garg *et al.*, 2018).

Transgenic Cauliflower (*Brassica oleracea*): Cauliflower is a highly preferred vegetable in all around the world. Because of its richness in antioxidant and phytonutrients. By introducing a copia-like LTR retrotransposon into the or gene, mutant orange cauliflower's nutritional value has been further improved by boosting beta-carotene concentration (Garg *et al.*, 2018).

Karyotaxonomy in Fishes and its Importance

Article ID: 71092

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Abstract

Karyotaxonomy is a taxonomic branch that classifies organisms according to chromosomal properties such as type, number, arrangement, and structure. It adds to morphological and genetic data in fish taxonomy, assisting in the understanding of species differentiation and evolutionary links. Fish chromosomes come in four different types: metacentric, submetacentric, acrocentric, and telocentric, and they undergo structural modifications that contribute to genetic variation. The process of preparing a karyotype entail collecting samples (e.g., gills, liver). chromosomes are stained, examined, and arranged based on size, banding patterns, and centromere position. The karyotype is calculated by counting chromosomes and arranging them into homologous pairs. Differences in the fundamental arm number can help identify species.

Keyword: Karyotaxonomy, Chromosomal properties, Species differentiation.

Introduction

Karyotaxonomy is a modern branch of taxonomy that focuses on the classification of organisms based on their chromosomal characteristics. This approach uses the type, number, arrangement, and structural features of chromosomes to categorize and differentiate species. It is a subset of cytotaxonomy, which studies cellular structures for taxonomic purposes (Singh *et al.*, 2023.) Karyotaxonomy plays a critical role in fish taxonomy, as it complements morphological and genetic data, allowing researchers to better understand species differentiation and phylogenetic relationships (Gokhman, 2006).

Chromosomal Characteristics in Fishes

Chromosomes are structures made of DNA that carry genetic information essential for heredity, governing the traits and characteristics of organisms across generations (Khoury *et al.*, 2000). During cell division, chromosomes ensure the accurate distribution of genetic material to daughter cells (Yihun, 2021; Oegema *et al.*, 2006).

Types of Chromosomes: Fishes exhibit various chromosome types, including metacentric, submetacentric, acrocentric, and telocentric, each defined by the position of the centromere and their impact on cell division (Yihun, 2021; Bhat *et al.*, 2017).

a. Metacentric: The centromere is located in the middle, dividing the chromosome into two equal arms (p and q arms).

b. Submetacentric: The centromere is slightly off-centre, resulting in one arm being shorter than the other.

c. Acrocentric: The centromere is located near one end, creating a very short p arm and a long q arm.

d. Telocentric: The centromere is at the very end of the chromosome, resulting in no visible p arm.

Centromere: The centromere is the constricted region of a chromosome that plays a crucial role during cell division, facilitating the separation of sister chromatids.

Telomeres: Telomeres are protective caps located at the ends of chromosomes.

Arm regions: Arm regions of chromosomes are the segments between the centromere and the telomeres. These arms contain genes and functional sequences essential for cellular processes.

Chromosomal Variability: Structural changes in chromosomes, such as inversions, translocations, or deletions, contribute to genetic diversity among fish species, affecting their phenotypic traits and evolutionary processes (Bhat *et al.*, 2017).

Composition of Chromosomes

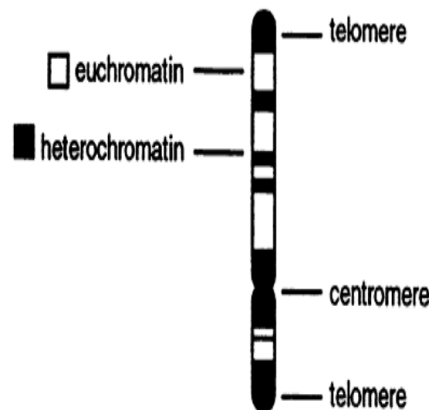
DNA Structure: The double helix structure of DNA consists of two strands twisted around each other, held together by base pairs, providing stability and enabling the replication of genetic material (Travers *et al.*, 2015).



Nucleotide Arrangement: DNA is made up of nucleotides, each comprising a sugar, phosphate group, and nitrogenous base, arranged in specific sequences that encode genetic information (Travers *et al.*, 2015).

Chromatin: There are different types of chromatin based on how tightly or loosely the DNA is packed, which influences gene expression. The main types of chromatin are:

- a. **Euchromatin** is loosely packed and transcriptionally active, facilitating gene expression (Sullivan *et al.*, 2004).
- b. **Heterochromatin** is tightly packed and often transcriptionally inactive, serving structural and regulatory roles (Sullivan *et al.*, 2004).



Preparation of Karyotype

1. Collection of samples:

- a. Gill or Fine
- b. Liver or Kidney
- c. Bone marrow or Blood.

2. Cell Culture:

- a. Collected cells are cultured in the laboratory to stimulate cell division.
- b. In fish chromosome preparation, the cells are often grown in a nutrient-rich medium to increase the number of actively dividing (Lee *et al.*, 1990, Ferguson *et al.*, 2007).

3. Cell Arrest (Mitotic Arrest):

- a. Add colchicine to the cell culture medium to arrest the cells at metaphase, where the chromosomes are most visible and condensed (Zhang *et al.*, 2013).
- b. The colchicine is typically used at a concentration of 0.1-0.2 µg/mL and incubated for 2-4 hours (Zhang *et al.*, 2013, Sharma and Sharma., 2014).

4. Hypotonic Treatment:

- a. Hypotonic solution (such as 0.075 M KCl) to the culture to cause cells to swell (Zhang *et al.*, 2013, Sharma and Sharma., 2014).
- b. Which helps spread the chromosomes Incubate the cells in the hypotonic solution for about 20-30 minutes at room temperature (Zhang *et al.*, 2013, (Sharma and Sharma., 2014).

5. Fixation:

- a. After hypotonic treatment, add methanol: acetic acid fixative (3:1 ratio) (Estandarte *et al.*, 2012, Sharma and Sharma., 2014).
- b. Centrifuge the cells to pellet them (Estandarte *et al.*, 2012, Sharma and Sharma., 2014).
- c. Place the suspension on ice for 10-15 minutes (Estandarte *et al.*, 2012, Sharma and Sharma., 2014).
- d. This preserves chromosome structure and stop the cell division (Estandarte *et al.*, 2012, Sharma and Sharma., 2014).

6. Slide Preparation:

- a. Drop fixed cells on a microscope slide (Sharma and Sharma., 2014).
- b. Dropping suspension from a used coverslip (Sharma and Sharma., 2014).
- c. Allow cells to settle and spread (Sharma and Sharma., 2014).

7. Staining of Chromosomes:

- a. Once the slide is dry, stain with Giemsa stain (Sharma and Sharma., 2014, Pearson *et al.*, 1972).
- b. Incubate the slide for 5-10 minutes (Sharma and Sharma., 2014, Pearson *et al.*, 1972).
- c. Wash with water to remove excess stain (Sharma and Sharma., 2014, Pearson *et al.*, 1972).
- d. Staining makes chromosomes visible and provides banding patterns (Sharma and Sharma., 2014, Pearson *et al.*, 1972).

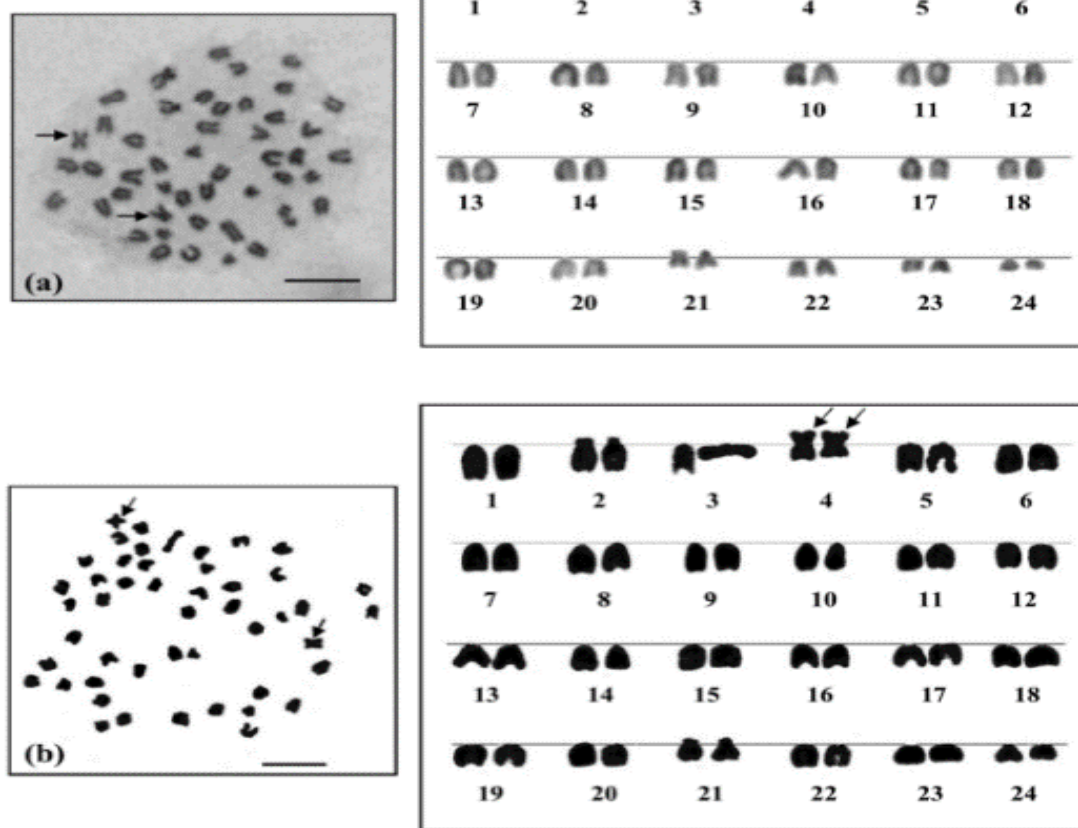
8. Microscopic Examination:

- a. Examine the stained slide under a microscope.
- b. Look for well-spread chromosomes in metaphase.
- c. Chromosomes appear as pairs with two sister chromatids.
- d. Count and organize chromosomes by size, banding patterns, and centromere position (Sharma and Sharma., 2014).

9. Karyotype Construction: The chromosomes are arranged in pairs from the largest to the smallest. (Ferguson *et al.*, 2007).

10. Final Karyotype:

- a. A karyotype can be drawn or digitally constructed by arranging the photographed chromosomes in their respective pairs (Getlekha *et al.*, 2022, Khensuwan *et al.*, 2024).
- b. The image will show the total number of chromosomes (diploid number), including autosomes and sex chromosomes (Getlekha *et al.*, 2022, Khensuwan *et al.*, 2024).



Karyotypes of male (a) and female (b) splendid snakehead fish (*Channa lucius*), 2n (diploid) = 48, (Khakhong *et al.*, 2014)

Karyotype Calculation

The karyotype calculation involves counting the total number of chromosomes and arranging them in homologous pairs.

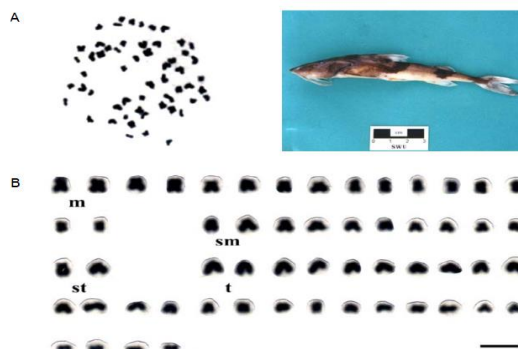
Formula

1. **Karyotype formula**= metacentric +sub-metacentric +sub-telocentric + telocentric (Getlekha *et al.*, 2022).

2. **Fundamental arm number F N**= 2× metacentric +2× sub-metacentric + sub-telocentric + telocentric (Phillips and Rab, 2001, Getlekha *et al.*, 2022).

Species Identification

Fundamental arm number F N= 2× metacentric +2× sub-metacentric + sub-telocentric + telocentric.



$(F N) = 2 \times 16 + 2 \times 10 + 2 + 28$
 $32 + 20 + 10 + 2 + 28 = 82$
 $FN = 82$ *B. bagarius*.

Species	2n	m	sm	st	t	Fn
<i>B. bagarius</i>	56	16	10	2	28	82

$F N) = 2 \times 14 + 2 \times 20 + 6 + 16$
 $28 + 40 + 6 + 16 = 90$
 $FN = 90$ *B. yarelli*.

Species	2n	m	sm	St	t	Fn
<i>B. yarelli</i>	56	14	20	2	28	90

Software for Karyotyping Analysis

Several software tools are available for chromosome analysis, including:

- 1. KaryoPlus:** Software that assists in automating chromosome identification and karyogram generation.
- 2. Band view:** A tool for analysing chromosome banding patterns.
- 3. CytoPower:** Software that helps with chromosomal abnormalities analysis.
- 4. Ikaros:** A software that assists in genetic research and chromosome analysis.
- 5. RADICAL Karyo 3.1:** A tool used for chromosome image analysis and banding pattern recognition.

These tools are essential for efficient analysis of chromosome images, making it easier to identify genetic disorders and abnormalities in a range of organisms, including fish.

Conclusion

Karyotaxonomy is critical for identifying animals, particularly fishes based on chromosomal traits such as type, number, arrangement, and structure. This strategy improves our understanding of species differentiation and evolutionary links by supplementing morphological and genomic data. The several types of fish chromosomes, such as metacentric, submetacentric, acrocentric, and telocentric, as well as their structural variations contribute to genetic diversity. The karyotype preparation process, which includes sample collection, cell culture, mitotic arrest, hypotonic therapy, fixation, staining, and microscopic examination, allows chromosomes to be organised and analysed. Researchers can effectively identify and differentiate species by estimating their karyotypes and fundamental arm numbers.

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Vegetables as Natural Antioxidant Sources

Article ID: 71093

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In today's fast-paced world, we are constantly exposed to environmental stressors such as pollution, UV rays and processed foods that can lead to oxidative stress in our bodies. This oxidative stress accelerates aging and increases the risk of chronic diseases such as heart disease, cancer and diabetes. One of the most effective ways to combat is through the consumption of antioxidants that neutralize free radicals and protect cells from damage. While antioxidants are often associated with fruits like berries, vegetables are also rich sources of these protective compounds. In fact, many vegetables offer a wide variety of antioxidants that are not only beneficial to your health but also easily accessible and affordable.

What are Antioxidants?

Antioxidants are substances that help prevent or slow the damage caused by free radicals -highly reactive molecules that are produced during normal metabolic processes or due to environmental factors. Free radicals can damage cells, proteins and DNA, leading to chronic diseases and accelerating aging.

Antioxidants neutralize free radicals by donating electrons, stabilizing these reactive molecules before they cause harm. Common antioxidants include vitamin C, vitamin E, beta-carotene and flavonoids, many of which are found abundantly in vegetables.

Top Vegetables that are Rich in Antioxidants

1. Spinach– A green powerhouse: Spinach is a nutritional powerhouse loaded with vitamin C, vitamin E, beta-carotene and lutein- an antioxidant known for protecting eye health. It is also rich in flavonoids, which have anti-inflammatory properties. These antioxidants help to neutralize free radicals and reduce oxidative stress. The high levels of folate in spinach also support heart health and reduce the risk of birth defects.

2. Kale – The king of green veggies: Kale is another antioxidant-rich vegetable that's often hailed as a "superfood." It contains vitamin C, beta-carotene, lutein and zeaxanthin, which are powerful antioxidants that support eye health and reduce the risk of age-related macular degeneration. Kale is also an excellent source of vitamin K, which helps reduce inflammation and supports bone health.

3. Broccoli – A cruciferous antioxidant: Broccoli is packed with vitamin C, sulforaphane and flavonoids. Sulforaphane is a potent compound that not only acts as an antioxidant but also has anti-cancer properties. It helps to activate the body's detoxification enzymes, which can protect against oxidative damage. The combination of these antioxidants makes broccoli an excellent vegetable for reducing inflammation and supporting overall health.

4. Red Bell Peppers – A colorful antioxidant source: Red bell peppers are incredibly rich in vitamin C, one of the most powerful antioxidants that promote a healthy immune system. They also contain beta-carotene (a precursor to vitamin A), which is essential for skin health and vision. Additionally, the red pigment in bell peppers, capsanthin, is a carotenoid that has anti-inflammatory and antioxidant properties, helps to combat oxidative stress.

5. Sweet Potatoes – A root vegetable with a nutrient punch: Sweet potatoes are loaded with beta-carotene, an antioxidant that the body converts into vitamin A, supporting healthy skin, eyes and immune function. They contain vitamin C, which helps to boost collagen production and fight free radicals. The orange color of sweet potatoes is a clear indicator of their antioxidant power, making them a great addition to any diet.

6. Tomatoes – A lycopene-rich antioxidant source: Tomatoes are packed with lycopene, a powerful antioxidant that gives them their red color. Lycopene has been extensively studied for its potential to protect against certain cancers, particularly prostate cancer. It also has anti-inflammatory effects and can

reduce oxidative damage in the body. Cooking tomatoes (such as in tomato sauce) can actually increase the bioavailability of lycopene, making it even more accessible to your body.

7. Carrots – A beta-carotene rich veggie: Carrots are perhaps best known for their high content of beta-carotene, a type of antioxidant that converts to vitamin A in the body. This antioxidant is crucial for maintaining good vision, especially in low-light conditions and for keeping your skin healthy. Carrots also contain lutein, which supports eye health and helps reduce the risk of age-related vision loss.

8. Brussels Sprouts – A small vegetable with big benefits: Brussels sprouts belong to the cruciferous vegetable family and are rich in vitamin C, vitamin K and flavonoids. The antioxidants in Brussels sprouts help to protect cells from oxidative stress and inflammation. Studies also show that the sulforaphane compound found in Brussels sprouts may help detoxify the body and reduce the risk of certain cancers.

9. Beets – The root vegetable with antioxidant power: Beets are an excellent source of betacyanins, a type of antioxidant that gives beets their deep red color. Betacyanins have been shown to reduce oxidative stress and inflammation and they also support liver health by aiding in the detoxification process. Beets are also rich in folate and fiber, making them a heart-healthy addition to any diet.

10. Red cabbage – A cruciferous antioxidant champion: Red cabbage contains anthocyanins, a group of antioxidants responsible for its purple-red color. Anthocyanins have been shown to have anti-inflammatory, anti-cancer, and anti-aging effects. Red cabbage is also rich in vitamin C, which boosts immunity and enhances skin health by promoting collagen production.



How Antioxidant-Rich Vegetables Benefit your Health?

Including a variety of antioxidant-rich vegetables in your diet can offer several health benefits, including:

1. Reduced risk of chronic diseases: Consuming antioxidant-rich vegetables regularly can help protect your body against oxidative stress, a major contributor to the development of chronic diseases like heart disease, diabetes, and certain cancers. The antioxidants in these vegetables help neutralize free radicals, reducing the damage they can cause to cells and tissues.

2. Anti-aging effects: Antioxidants play a critical role in slowing down the aging process by protecting the skin and body from oxidative damage. The vitamins, carotenoids, and flavonoids found in vegetables help prevent premature aging of the skin, promote collagen production and improve skin elasticity, leading to a more youthful appearance.

3. Improved immune function: Antioxidants like vitamin C (found in bell peppers, tomatoes and broccoli) and beta-carotene (found in carrots and sweet potatoes) are known to strengthen the immune system. These nutrients help your body fight off infections and illnesses, keeping you healthier year-round.

4. Better eye health: Many antioxidant-rich vegetables, such as spinach, kale and carrots contain lutein and zeaxanthin, which are known to protect the eyes from damage caused by UV light and oxidative stress. Regular consumption of these vegetables can reduce the risk of age-related macular degeneration and cataracts.

5. Enhanced detoxification: Certain vegetables, particularly those high in sulforaphane (like broccoli and brussels sprouts), support the body's natural detoxification processes. These vegetables help activate enzymes that neutralize toxins, aiding in the removal of harmful substances from the body.

Conclusion

Vegetables are some of the richest natural sources of antioxidants, providing a wide range of benefits from fighting oxidative stress to supporting overall health and longevity. Incorporating a variety of these antioxidant-packed vegetables into your daily diet is a simple and effective way to protect your body from disease, improve your immune system, and slow the effects of aging. Whether you prefer leafy greens like kale and spinach, colorful veggies like bell peppers and carrots, or cruciferous vegetables like broccoli and Brussels sprouts, the antioxidants in these natural foods are a powerful tool for promoting better health and wellness.

Forest-Based Livelihood: Pathways to Resilience and Sustainability

Article ID: 71094

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Abstract

Forests, covering 31% of global land, provide critical ecosystem services and support the livelihoods of over 1.6 billion people, especially in tropical and subtropical regions. Forest-based livelihoods include the extraction of non-timber forest products (NTFPs), small-scale timber harvesting, agroforestry, and eco-tourism. These practices, rooted in indigenous knowledge, offer both economic benefits and ecological sustainability. Dependence on forests can be direct such as for food, fuel, and medicine or indirect, through services like climate regulation and water conservation. Despite their importance, these livelihoods face threats from deforestation, land-use change, and weak governance. Sustainable forest management and inclusive policies are essential to ensure the resilience of both ecosystems and forest-dependent communities.

Introduction

Forests are vital life-support systems for the planet, covering about 31% of the Earth's land area and serving as home to over 1.6 billion people who rely on them for food, fuel, medicine, and income (FAO, 2020). Among these, forest-dependent communities especially in tropical and subtropical regions maintain intricate relationships with forest ecosystems through activities that provide both sustenance and livelihoods. The term forest-based livelihoods refer to the wide range of income-generating and subsistence activities derived from forests, such as harvesting non-timber forest products (NTFPs), practicing agroforestry, engaging in eco-tourism, and crafting forest-based artisanal goods.

These livelihoods are not only essential for the economic survival of rural and indigenous populations, but also for the ecological integrity of forests. When sustainably managed, forest-based livelihoods can reinforce conservation goals by reducing pressure on timber extraction, preserving biodiversity, and maintaining ecosystem services (Shackleton et al., 2011).

Local knowledge systems often guide sustainable use, with practices such as rotational harvesting, selective gathering, and sacred forest protection contributing to forest conservation over generations (Berkes, 2012).

Despite their importance, forest-based livelihoods face increasing threats from deforestation, land-use change, commercial logging, and climate change. According to the Global Forest Resources Assessment (FAO, 2020), the world lost over 420 million hectares of forest between 1990 and 2020, directly impacting the livelihoods of forest dwellers and weakening ecosystem resilience. In many regions, lack of secure land tenure, limited access to markets, and weak institutional support further marginalize forest-dependent communities.

Recognizing the potential of forests to support both livelihood security and ecosystem sustainability, numerous policy frameworks including the United Nations Sustainable Development Goals (SDGs), REDD+ (Reducing Emissions from Deforestation and Forest Degradation), and community forest rights movements have emphasized the need for inclusive forest governance and equitable benefit sharing (UNDP, 2021; Rights and Resources Initiative, 2018).

When local communities are empowered with rights, resources, and recognition, forest-based livelihood models often flourish, enhancing both human well-being and forest conservation outcomes (Agrawal *et al.*, 2008). This article explores the landscape of successful forest-based livelihoods, highlighting models from across the world that demonstrate the synergistic relationship between people and forests.

Forests Based Livelihoods: An Overview

Forests play a vital role in the lives of millions of people globally, especially in the tropics and subtropics. Beyond their ecological value, forests are deeply embedded in the economic, social, and cultural fabric of rural and indigenous communities. They serve as natural safety nets, sources of daily sustenance, and foundations of local economies. In many forested regions, people do not simply live *near* forests they live *with* them, maintaining intricate relationships that shape their identity, survival strategies, and worldviews (Berkes, 2012). Forest resources play a vital role in supporting the livelihoods of rural communities residing in forest-rich areas. In India, a forest-rich country, a significant proportion of non-timber forest products (NTFPs) is consumed locally, supporting numerous rural communities relying on forests for essential resources, such as firewood, timber, and NTFPs (Bisui *et al.*, 2024).



Fig 1: Photos showing the livelihood activities of households (a)collection of Mustard seed; (b) agricultural labor in a rice field (c) Babui collection (d)grazing cows (e)grazing goats(f) poultry farming (g) indigenous household's activities revolve around the collection of Mahul flowers (h) non-timber forest products (i) collection of dry firewood from the surrounding forests (j) collection of Sal leaves(k)rearing pig (l) selling of the firewood.

Forest-Based Livelihoods

These livelihoods encompass both consumptive uses like gathering wood, food, and medicinal plants and non-consumptive uses, such as eco-tourism, forest protection, or religious rituals tied to sacred groves. These practices are often informed by local knowledge systems, shaped by generations of interaction with the forest. The activities involved are diverse, dynamic, and influenced by factors such as forest type, land tenure rights, proximity to markets, and socio-political structures.

1. Key Components of Forest-Based Livelihoods:

a. Collection of fuelwood and fodder: In many low-income rural settings, fuelwood remains the primary source of household energy, particularly for cooking. Fodder is equally essential for sustaining livestock, which forms a major part of rural livelihoods in South Asia and Sub-Saharan Africa (FAO, 2014).

b. Harvesting of non-timber forest products (NTFPs): These include goods like wild honey, mushrooms, medicinal herbs, nuts, and plant resins. In some regions, NTFPs can contribute as much as 25–50% of household income and are often more resilient to market shocks than timber-based activities (Belcher *et al.*, 2005).

c. Small-scale timber harvesting: In community-managed or regulated forests, locals may engage in selective timber extraction for construction materials or income. When paired with sustainable practices, this can reduce illegal logging and promote forest health.

d. Ecotourism and biodiversity conservation: Ecotourism offers opportunities for income generation while preserving natural ecosystems. Activities such as birdwatching, wildlife tours, and cultural performances create employment for local youth and women, and also strengthen the case for conserving intact forest landscapes (Scheyvens, 1999).

e. Agroforestry and shifting cultivation: These systems combine trees with agricultural crops to enhance soil health, regulate water flow, and diversify livelihoods. Agroforestry helps address food security while contributing to forest cover recovery, especially when practiced on degraded lands (Garrity, 2004).

2. Types of Forest Dependence: Forest dependence varies in intensity, frequency, and purpose. It is broadly classified into direct and indirect forms of reliance, each with distinct implications for livelihoods and conservation policies.

Direct Dependence

Direct dependence refers to the regular and tangible use of forest resources to meet every day needs. This is especially prevalent among remote and marginalized communities that have limited access to markets, services, and infrastructure. Examples include:

- 1. Food and nutrition:** Wild fruits, leafy greens, mushrooms, insects, and bush meat offer important sources of protein and micronutrients.
- 2. Shelter and construction materials:** Forests supply bamboo, poles, bark, vines, and thatch used in traditional housing and fencing.
- 3. Medicinal use:** Traditional healers use forest plants for treating common ailments, and herbal remedies often coexist with or substitute modern healthcare in remote regions (Berkes, 2012).
- 4. Energy needs:** Charcoal and firewood are primary cooking fuels for over 2.4 billion people globally (IEA, 2021).

Indirect Dependence

Indirect dependence includes benefits from ecosystem services that forests provide without the need for resource extraction. These services are critical for sustaining agriculture, health, water security, and overall well-being. Examples include

- 1. Water regulation:** Forests regulate local hydrology by maintaining stream flows, reducing runoff, and improving groundwater recharge.
- 2. Climate regulation:** Forests serve as carbon sinks, absorb greenhouse gases, and help buffer communities from extreme weather events.
- 3. Cultural and spiritual values:** Many communities consider certain forest areas sacred and engage in rituals that honor forest spirits, ancestors, or deities (Berkes, 2012).
- 4. Soil fertility and pollination:** Biodiverse forests support healthy soils and serve as habitats for pollinators essential for agriculture.

These indirect forms of dependence are often invisible in national accounting systems yet are indispensable to rural resilience and long-term ecological balance.

Conclusion

Forests and livelihoods are deeply intertwined across ecological, economic, and cultural dimensions. Recognizing and respecting the multifaceted dependence on forests from tangible products to intangible services is central to advancing both sustainable development and forest conservation. Efforts to protect forests must therefore go hand-in-hand with strategies that secure and enhance the livelihoods of the people who depend on them.

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Importance of Mulching in Crop Production

Article ID: 71095

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Introduction

The climate and environment around crop plant is one the most important factor in crop production. Mulching is one of the cultural practices which can be used to increase crop productivity. Mulching is the process or practice of covering the soil/ground to make more favourable conditions for plant growth, development and efficient crop production. The mulch is a layer of organic/inorganic material spread over the soil surface or filled vertically in soil.

Types of Mulch

1. Stubble mulch: Crop residues and other plant waste products (straw, leaves, corn, cloves, peat and sawdust) are widely used as mulch. These high C:N ratio products may for a while negatively affect plant growth because bacteria and fungi that decompose the materials remove the nitrogen from the surrounding soil. These materials are cheap and often readily available. These permit water to enter in the soil easily, when maintained at an adequate level. These materials result in increased water content and reduced evaporation. The application of straw mulch @ 5 tons /ha is found to be most effective in dry farming area.

2. Vertical mulch: - Vertical mulch is a technique which consists of digging suitable trenches across the slope and thus making more surface area available for water absorption. The open trenches are likely to get silted in short period. This however can be prevented by inserting organic form waste material like straw stubbles or stalks which is called filter. The filter should be resistant to decomposition and provide service for 3 - 4 years.

3. Soil or Dust mulch: If the surface soil is loosened, it acts as mulch for reducing evaporation by breaking the capillary. This loose surface of soil is called soil mulch or dust mulch. Inter-culturing creates soil mulch in growing crops and helps in closing deep cracks in vertisols.

4. Coloured mulch: Some organic mulches are coloured red, brown, black, and other colors. Isopropanolamine, specifically 1-amino-2-propanol or monoisopropanolamine, may be used as a pigment dispersant and colour fastener in these mulches. Types of mulch which can be dyed include: wood chips, bark chips (barkdust) and pine straw. Coloured mulch is made by dyeing the mulch in a water-based solution of colorant and chemical binder. As mulch decomposes, just as with non-coloured mulch, more mulch may need to be added to continue providing benefits to the soil and plants. However, if mulch is faded, spraying dye to previously spread mulch in order to restore colour is an option.

5. Sour (anaerobic) mulch: Mulch normally smells like freshly cut wood, but sometimes develops a toxicity that causes it to smell like vinegar, ammonia, sulfur or silage. This happens when material with ample nitrogen content is not rotated often enough and it forms pockets of increased decomposition. When this occurs, the process may become anaerobic and produce phytotoxic materials in small quantities.

6. Living mulch (groundcover): the groundcovers are plants which grow close to the ground, under the main crop, to slow the development of weeds and provide other benefits of mulch. They are usually fast-growing plants that continue growing with the main crops. Cover crops are incorporated into the soil or killed with herbicides. However, live mulches may be needed to be mechanically or chemically killed eventually to prevent competition with the main crop.

7. Polypropylene and polyethylene mulch: Polypropylene and polyethylene mulch are made up of polypropylene polymers and polyethylene polymers, respectively. Polyethylene is used mainly for weed reduction, where polypropylene is used mainly on perennials. This mulch is placed on top of the soil and can be done by machine or hand with pegs to keep the mulch tight against the soil. This mulch can prevent soil erosion, reduce weeding, conserve soil moisture, and increase temperature of the soil. The black and clear mulches capture sunlight and warm the soil. White and other reflective colours will also warm the

soil, but they do not suppress weeds as well. This mulch may require other sources of obtaining water such as drip irrigation since it can reduce the amount of water that reaches the soil. This mulch needs to be manually removed at the end of the season since when it starts to break down it breaks down into smaller pieces. If the mulch is not removed before it starts to break down eventually it will break down into ketones and aldehydes polluting the soil. This mulch is technically biodegradable but does not break down into the same materials the more natural biodegradable mulch does.

8. Biodegradable mulch: Quality biodegradable mulches are made of plant starches and sugars or polyester fibers. These starches can come from plants such as wheat and corn. These mulch films may be a bit more permeable allowing more water into the soil. This mulch can prevent soil erosion, reduce weeding, conserve soil moisture, and increase temperature of the soil. Ultimately this can reduce the amount of herbicides used and manual labour farmers may have to do throughout the growing season. At the end of the season these mulches will start to break down from heat. Microorganisms in the soil break down the mulch into two components, water and carbondioxide, leaving no toxic residues behind.

Benefits of Using Mulch in Field

1. Organic mulch like straw adds organic matter in soil and increase organic carbon of soil. This helps make soil healthier and more resistant to pest and disease and saves money on pest control.
2. Organic mulches provide valuable slow-release nutrients and prevent vitamin loss in plants and saves money which spend on fertilizers.
3. Mulch helps in moisture retention in the soil for longer time. Mulch prevents evaporation by shielding the soil from the sun. It also reduces water run-off during rain or watering.
4. Mulch shades delicate seedlings of crops especially in nursery from too much sun and act as a mini umbrella.
5. Mulch act as a great insulator by regulating soil temperature. It keeps crop roots consistently cool in summer and warm in winter, hence reduces plant stress.
6. Mulch sheet provides a natural barrier to weeds from growing and competing with plants for nutrients by blocking the sunlight as every plant requires a process of photosynthesis for generation of food, which requires sunlight. The mulch sheet does not allow the sunrays to pass through it. Whereas plastic film has a unique quality of reflecting back the sunlight, which will not allow the weed to grow.
7. Prevents erosion and soil compaction particularly from foot traffic on pathways and play areas. .

Plastic mulches avoid the ripening fruits from direct soil contact. There by decreases fruit rot as well as keeps the fruit and vegetables clean. This gives quality produce and better marketability.

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Role of *Pseudomonas* spp. in Disease Management Towards Sustainable Agriculture

Article ID: 71096

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Abstract

Pseudomonas spp. wide spread in soil environments and root microbiomes, have garnered interest due to their capability to inhibit phytopathogens and boost plant health *via* multiple mechanisms. These encompass direct competition for nutrients, the generation of antimicrobial substances and volatile organic compounds, competition via type VI secretion systems and the indirect stimulation of systemic resistance. *Pseudomonas* strains successfully manage a variety of diseases in different environments. Plant species, where certain strains show effectiveness similar to chemicals fungicides. The benefits of using *Pseudomonas* for biocontrol in sustainable agriculture encompass decreased dependence on chemical pesticides, increased crop yield, and better environmental sustainability (Alattas *et al.*, 2024).

Introduction

In recent years, researchers studying sustainable agriculture play close attention to *Pseudomonas* species because of their role in promoting plant growth and induced systematic resistance (ISR) through a variety of mechanisms, such as improved nutrient uptake, phytohormone production and disease suppression. *Pseudomonas* is a gram-negative, aerobic bacterium belonging to the class *Gammaproteobacteria*, belonging to the family *Pseudomonadaceae* which includes approximately 191 varied species. *Pseudomonas* species are especially well-suited biocontrol agents due to their high growth rate, capacity to directly promote plant growth, abundance in natural soils, particularly in the rhizosphere, ability to use a variety of exudates as a source of nutrients and capacity to control diseases through a number of mechanisms. The fact that *Pseudomonas* bacteria can be altered and mutated with the use of genetic tools makes them the most researched group of bacterial biocontrol agents. The mechanisms of biocontrol by *Pseudomonas fluorescens* that are most frequently documented spp. encompass the generation of antibiotics, hydrogen cyanide and lytic exoenzymes.

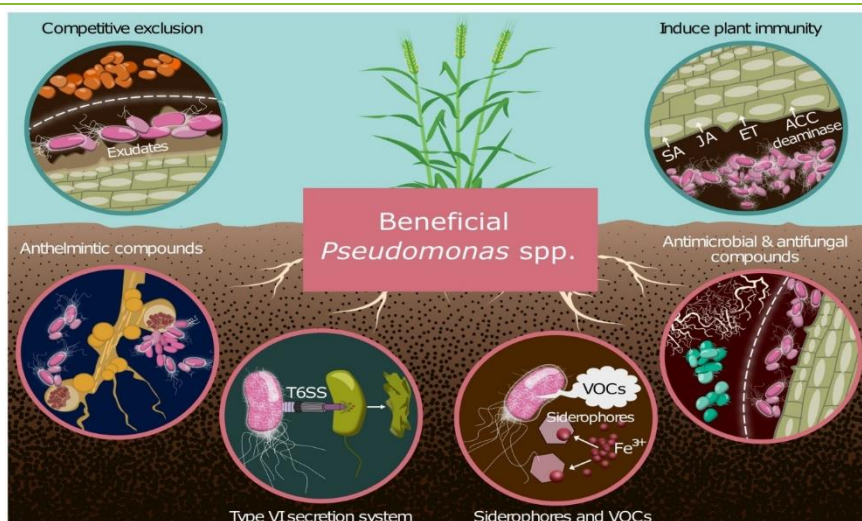
To improve plant growth and yield or manage disease, the environmentally friendly method employs plant growthpromoting bacteria (PGPB), which are among the safest and most efficient options available.

Mechanism of *Pseudomonas* Spp. as a Biocontrol

It has been acknowledged that *Pseudomonas* is a complicated group with several species that have been described. Fluorescent pseudomonads have drawn special attention as the preferred biocontrol agent among the many *Pseudomonas* species. By directly opposing phytopathogens and fostering disease resistance in the host plant, pseudomonas demonstrates its biocontrol ability. The main method of biocontrol involves either producing antibiotics or deactivating a pathogen's virulence characteristic.

Pseudomonas spp. biocontrol strains that have demonstrated efficacy in plant bioassays generate one or more antibiotic compounds. These antibiotics have been shown to be inhibitory substances in vitro, and they are also actively responding to field conditions for managing plant health. Incorporating strains that generate the antifungal chemical DAPG into the rhizosphere by seed or soil treatments is crucial in suppressing some root infections.

Pseudomonas strains shield plants from pathogens by triggering systemic resistance. Plants can develop a higher degree of resistance to pathogens following exposure to biotic signals offered by various PGPR.



(Source: Alattas *et al.*, 2024)

Role of *Pseudomonas* Spp. in Disease Management

1. According to recent estimates, infections brought on by bacteria, nematodes, fungi and other microorganisms cause enormous losses in food crops and commodities each year. Over thousands of years, plant diseases have a significant impact on food supply and the evolution of human society.
2. Due to their sustainable use and nontoxicity as naturally occurring microorganisms, these effective PGPB biocontrol agents have several advantages over traditional chemical control methods.
3. As demonstrated by the disease of wheat caused by the fungus *Gaeumannomyces graminis* var. *tritici* by the antibiotic 2,4 diacetylphloroglucinol (2,4 DAPG), which suppresses soilborne diseases and functions as a biocontrol agent, the genetic analysis of biocontrol resistant.
4. *Pseudomonas* showed a positive correlation between disease separation and antibiotic production. A genetically engineered strain of *Pseudomonas syringae*, strain 01 CE, protects a number of crop plants from freezing temperatures.
5. By converting the insoluble, non-diffusible forms of phosphorus, nitrogen and iron (Fe) in the soil into easily soluble forms, plant growth-promoting bacteria (PGPB) promote growth.
6. Clough *et al.* in 2022 reported the efficiency of eight *Pseudomonas* strains as biocontrol agents. The most effective of them was found to be *Pseudomonas protegens* CHA0, which dramatically reduced the growth of *Ralstonia solanacearum*, a pathogen that causes bacterial wilt in plants.
7. Tran *et al.* in 2007 reported that the incidence of late blight disease of tomato was significantly decreased when *P. fluorescens* SS101 cell suspensions were applied to tomato plant leaves one day prior to inoculation of zoospore of *Phytophthora infestans*.
8. *Pseudomonas* sp. PICF6 and *P. simiae* PICF7 inhibited the growth of *Verticillium longisporum* ELV25 and *V. dahlia* V937I under *in vitro* experiment condition.
9. *P. putida* KT2440 inhibit the growth of *Xanthomonas campestris* bacteria.
10. Wu *et al.* in 2018 isolated a strain of *P. mosselii* BS011 from the rhizosphere soil of rice plants and the isolate showed strong inhibitory activity against the rice blast fungus *Magnaporthe oryzae*.
11. Marrez *et al.* in 2019 evaluated the *P. fluorescens* cell-free supernatants and their fractions have antibacterial efficacy against five strains of toxic fungus and six strains of foodborne pathogenic bacteria. The Gas Chromatography-Mass Spectroscopy (GC-MS) method was used to identify the bioactive fractions. With an inhibition zone spanning 7.8 to 15.2 mm, all cell free supernatants of the *P. fluorescens* strains demonstrated antibacterial activity against every tested bacterium. However, *P. fluorescens* FP10 demonstrated antifungal efficacy against *Aspergillus steynii* and all other tested fungus, with a maximal inhibition zone of 19.3 mm. *P. fluorescens* FP6, FP7, and FP10 chloroform fractions shown strong effectiveness against the pathogenic bacteria and toxic fungi that were tested.

12. *P. fluorescens* Pf-52 inhibit the growth of fungal mycelium 30 isolate of *Magnaporthe oryzae*. Among them 12 of the isolates had a zone of inhibition caused by the bacteria that ranged between 2.5 and 3.0 cm in diameter in lab condition. While in the field trails, the bacterial strains *Pf-52* suppressed disease by 86.64%.

Conclusion

Compared to chemical fertilizers and pesticides, plant growth promoting bacteria (PGPR) are currently one of the best options for encouraging plant growth and managing disease. The rhizosphere is a vast bacterial reservoir, with the *Pseudomonas* genus being the most prevalent. *Pseudomonas* species interact with plant root exudates and aid in root colonizing activity. *Pseudomonas* has a positive impact on host plants by promoting plant development and providing biological control. In addition, *Pseudomonas* strains have been widely used to detoxify a variety of inorganic and organic water contaminants and also in the bioremediation of heavy metals and insecticides.

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Heavy Metals Removal Using Natural Based Polymer

Article ID: 71097

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Introduction

Natural polysaccharides possess many unique properties, but due some shortcoming simultaneously, particularly their low shelf life and being prone to bacterial attack have limited their use as long-lasting materials. Chemical modification of polysaccharides is useful for change in their chemical and physical properties. Because of their superior properties, the modified polysaccharides are used as a replacement to the more expensive materials. In general, the properties of natural polysaccharides are altered to a remarkable degree by the introduction of very small amounts of substituent groups of either neutral or ionic types. This modification help the polymer to exhibit extra desirable properties for various application [1-2]. Wodier gum also known as Jhingan gum is one such natural polymer which is exudate of *Lanneacoromandelica*(Houtt.) [3] that can be tailored for environmetal remediation.

Grafting of Polymer Using Cross-Linker

Wodier gum based grated polymer was synthesized following micro-wave assisted technique which relies on the energy supplied by the micro-wave. In this process a known amount of gum was dissolved in water and monomer like acrylamide was added to it. Suitable initiator like ceric ammonium Nitrate was added and cross linker borax was slowly poured into the mixture under constant stirring. Then, the reaction mixture was subjected to microwave irradiation in an oven (700 W) for 3-5 minutes under the cut off temperature of 70°C. The reaction mixture was subjected to alternate heating and cooling process for the completion of graft copolymerization reaction. After the completion of graft copolymerization reaction, the gel like mass was obtained. It was cooled and precipitated with an excess of acetone. The precipitated grafted polymer was collected and was dried in hot air oven. Subsequently, it was pulverized and sieved [4-5].



Figure 1: Synthesized Wodier gum grafted co-polymer

Removal of Heavy Metals Using Wodier Gum Grafted- Co-Polymer

Fresh river water was collected from nearby river and was treated with synthesized grafted polymer. Metal solution of known concentration containing various heavy metal was also treated with the same grafted co-polymer. The resulting concentration of the heavy metal were then evaluated with Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES) [Make: Perkin Elmer, USA; Optical 2100DV ICP-OES]. The results received from the ICP-OES are shown in the table 1 and 2.



Figure 2: Treated water sample containing heavy metals

Initial Concentrations (mg/L)				
	Cd	Cr	Fe	Pb
Metal Solution	0.001	0.015	0.755	0.417
River Water	-0.001	0.004	0.065	0.015

Table 1. Initial Concentrations

Final Concentrations after addition of grafted polymer (mg/L)				
	Cd	Cr	Fe	Pb
Metal Solution	-0.001	0.010	0.652	0.157
River Water	-0.001	-0.003	0.011	-0.013

Table 2. Final concentrations

Conclusion

From Table 1 and Table 2, it was observed that treated sample with grafted co-polymer revealed significant reduction of heavy metals concentration something which is worth to explore in various environmental remediation. The exact mechanism of how grafted co-polymer remove heavy metal is not certain, however it is assumed that the polymers ability to form chelate with metal ion is one possible mechanism.

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The Vital Role of Bees and Insects in Pollination of Cucurbit Vegetables

Article ID: 71098

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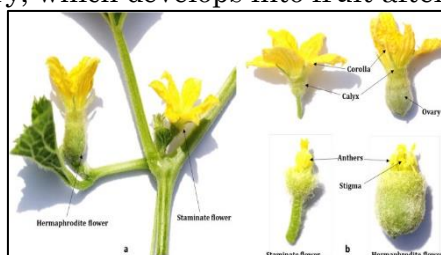
Introduction

Pollination is a fundamental ecological service that plays a critical role in agricultural productivity, especially in the cultivation of fruiting vegetables like cucurbits. Cucurbitaceous crops such as cucumber (*Cucumis sativus*), watermelon (*Citrullus lanatus*), pumpkin (*Cucurbita spp.*), bottle gourd (*Lagenaria siceraria*), bitter gourd (*Momordica charantia*), ridge gourd (*Luffa acutangula*), and sponge gourd (*Luffa cylindrica*) rely heavily on insect-mediated pollination. These vegetables are monoecious or dioecious, producing male and female flowers separately, and require cross-pollination for successful fruit set. Among insect pollinators, bees are the most efficient agents of pollination due to their foraging behavior and flower fidelity.

Floral Biology of Cucurbits

Cucurbit flowers are large, brightly colored, and typically open early in the morning. These flowers are generally unisexual:

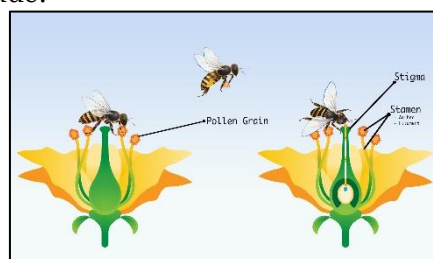
- 1. Male flowers** produce pollen.
- 2. Female flowers** contain the ovary, which develops into fruit after successful pollination.



The timing of anthesis (flower opening) and stigma receptivity is crucial, as most cucurbit flowers are receptive for a limited time, typically early in the day. This biological trait underscores the importance of having active pollinators present during this narrow pollination window.

Pollinators of Cucurbit Vegetables

A wide range of insect species visits cucurbit flowers, but bees are the primary and most effective pollinators. The key pollinators include:



- 1. Honey bees (*Apis mellifera*, *Apis cerana indica*):** Most commonly managed pollinators; they forage in groups and show floral fidelity.
- 2. Carpenter bees (*Xylocopa spp.*):** Large solitary bees that are strong fliers and effective in vibrating pollen.
- 3. Bumble bees (*Bombus spp.*):** Known for buzz pollination; effective in cooler climates.

4. Squash bees (*Peponapis* and *Xenoglossa* spp.): Specialist pollinators of cucurbit flowers, especially in the Americas.

5. Hoverflies, butterflies, beetles, and ants: Play minor or occasional roles in pollination, often serving as secondary pollinators.

Pollination Mechanism in Cucurbits

Pollination in cucurbits involves the transfer of pollen grains from the anthers of male flowers to the stigma of female flowers. Insects, particularly bees, facilitate this process by visiting flowers in search of nectar or pollen. As they move from flower to flower, pollen grains adhere to their hairy bodies and are deposited onto stigmas, resulting in fertilization.

For effective pollination:

1. A sufficient number of pollinators must be present during peak flowering.
2. Flowers should be accessible and free from pesticide residues that repel or kill pollinators.
3. Weather conditions should be favorable for insect activity.



Importance of Bee-Mediated Pollination in Cucurbit Crops

Numerous studies have shown that bee pollination significantly enhances the yield and quality of cucurbit vegetables:

- 1. Increased fruit set:** Well-pollinated plants produce more fruits per vine.
- 2. Improved fruit shape and size:** Uniform pollination ensures symmetrical and marketable produce.
- 3. Better seed development:** Essential for crops where seeds are consumed or used for propagation.
- 4. Higher yields:** Enhanced productivity, often by 25% to 60% compared to self- or wind-pollinated crops.

Insufficient pollination often results in:

- a. Deformed or undersized fruits.
- b. Poor seed development.
- c. Flower and fruit abortion.

Threats to Pollinators and Impact on Vegetable Production

Pollinators, especially bees, face multiple threats that can adversely affect vegetable production:

- 1. Pesticide exposure:** Insecticides, especially neonicotinoids and organophosphates, can kill or disorient bees.
- 2. Habitat destruction:** Monoculture farming and land-use changes reduce floral diversity and nesting sites.
- 3. Climate change:** Alters flowering patterns and pollinator activity, leading to phenological mismatches.
- 4. Diseases and pests:** Varroa mites, Nosema, and viruses affect bee colony health.

The decline in pollinator populations is a serious concern, warranting immediate attention from farmers, researchers, and policymakers.

Strategies to Enhance Pollination Services in Cucurbits

To ensure optimal pollination and protect pollinator populations, the following strategies are recommended:

- 1. Integrated Pest Management (IPM):** Use selective, bee-safe pesticides and spray in late evening when pollinators are inactive.

- 2. Habitat conservation:** Maintain hedgerows, wildflower strips, and nesting sites to support native pollinators.
- 3. Use of managed bee colonies:** Place honeybee hives near cucurbit fields during flowering to boost pollination.
- 4. Crop diversification:** Intercropping with flowering plants can attract diverse pollinators.
- 5. Education and awareness:** Train farmers on the importance of pollinators and pollination-friendly practices.

Conclusion

Pollinators, especially bees, are indispensable allies in the cultivation of cucurbit vegetables. Their role in ensuring fruit set, improving quality, and enhancing yield is well-documented. However, pollinator populations are under threat due to various anthropogenic factors. Sustainable vegetable production hinges on recognizing the value of these insects and implementing strategies to protect and promote pollination services. By doing so, we not only safeguard food security and farmer livelihoods but also support ecological balance and biodiversity.

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Comprehensive Guide to Production Technology of Solanaceous Vegetables (Tomato, Brinjal, Chili and Capsicum) – With Special Focus on Rainy Season Cultivation

Article ID: 71099

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Solanaceous vegetables—namely tomato (*Solanum lycopersicum*), brinjal/eggplant (*Solanum melongena*), chili and capsicum (*Capsicum* spp.)—are among the most widely grown and consumed vegetables in India. They are rich in vitamins, minerals, antioxidants, and are economically significant to farmers across the country.

However, cultivation, especially during the rainy season, poses several challenges due to excess moisture, pest pressure, and disease outbreaks. Therefore, adopting improved production technologies is essential for higher productivity, better quality, and sustainable cultivation.

Selection of Varieties and Hybrids

Choosing the right variety or hybrid is the foundation for successful crop production. For rainy season cultivation, disease-tolerant and climate-resilient varieties are essential.

Recommended Varieties:

Crop	Open-Pollinated Varieties	Hybrids	Remarks
Tomato	Pusa Rohini, Arka Vikas	Arka Rakshak, Abhinav, NS 4266	Choose early blight-resistant types
Brinjal	Pusa Purple Long, Arka Kusumakar	Arka Navneet, Bharat Purple King	Tolerant to fruit borer preferred
Chili	Pusa Sadabahar, Kashi Anmol	Tejaswini, LCA-334	Tolerant to leaf curl and virus
Capsicum	California Wonder, Bharat	Indra, Bomby Green	Suitable for protected cultivation

Seed Rate and Seed Treatment

Healthy seeds and proper treatment improve germination, reduce early-stage diseases, and ensure uniform plant stands.

Seed Rate (per hectare)

- Tomato:** 300–400 g
- Brinjal:** 400–500 g
- Chili:** 800–1000 g
- Capsicum:** 800–1000 g

Seed Treatment:

- Fungicide: *Carbendazim* or *Thiram* @ 2 g/kg seed
- Bio-control agent: *Trichoderma viride* @ 4 g/kg seed
- Insecticide (optional): *Imidacloprid* 70% WS @ 5 ml/kg seed
- After treatment, dry seeds in the shade before sowing.

Nursery Management (Critical in Rainy Season)

Raising seedlings in a **well-managed nursery** is crucial, especially during the rainy season, where moisture can cause severe fungal issues.

Best Practices:

- Use raised beds (15–20 cm height) for drainage.
- Cover with shade net or transparent polythene during heavy rainfall.
- Apply neem cake (200 g/m²) and *Trichoderma* to nursery beds.
- Spray Copper Oxychloride (2.5 g/L) at intervals to prevent fungal diseases.

Transplant seedlings when they are **25–30 days old** (5–6 leaf stage).

Land Preparation and Planting

- Perform deep ploughing to improve aeration.
- Incorporate 20–25 tons/ha of FYM or compost.
- Create raised beds or ridges and furrows to prevent waterlogging.

Maintain row and plant spacing:

- Tomato: 60 x 45 cm
- Brinjal: 75 x 60 cm
- Chili: 60 x 45 cm
- Capsicum: 60 x 45 cm (in open), 45 x 30 cm (in protected conditions)

Irrigation and Drainage Management

During the rainy season:

- Ensure proper drainage to avoid root diseases.
- Avoid overhead irrigation—prefer drip irrigation for controlled water supply.
- Provide irrigation only during dry spells or after heavy water runoff.

Fertilizer and Nutrient Management

Nutrient needs vary depending on the crop and soil fertility. A soil test is highly recommended.

General Fertilizer Recommendation (kg/ha):

Crop	N (Nitrogen)	P (Phosphorus)	K (Potassium)
Tomato	100	60	60
Brinjal	100	50	50
Chili	100	50	50
Capsicum	120	60	60

Apply:

- 1/3 N + full P & K as basal dose.
- Remaining N in two split doses during flowering and fruit set.
- Fertigation using drip system is ideal for efficient use of water and nutrients.

Pest and Disease Management

Common Pests:

Pest	Control Measures
Fruit & Shoot Borer (Brinjal, Tomato)	Pheromone traps (5/acre), neem oil sprays (2%), release <i>Trichogramma</i> spp.
Whiteflies / Aphids / Thrips	Yellow sticky traps, spray <i>Imidacloprid</i> 0.3 ml/L or <i>Fipronil</i> 1 ml/L
Mites (Capsicum)	Spray <i>Dicofol</i> or <i>Abamectin</i> as needed

Common Diseases:

Disease	Management
Damping-off	Soil drenching with <i>Trichoderma</i> or fungicides
Early Blight (Tomato)	Spray <i>Mancozeb</i> + <i>Carbendazim</i> @ 2 g/L
Bacterial Wilt	Use resistant varieties, crop rotation, avoid waterlogging
Leaf Curl Virus	Control vectors like whiteflies, use virus-free seedlings

Use Integrated Pest Management (IPM)—combine cultural, biological, and chemical controls for best results.

Intercultural Operations

1. Regular weeding is crucial during monsoon due to rapid weed growth.
2. Earthing-up around plants improves stability and drainage.
3. Staking and pruning for tomato and capsicum help reduce disease and improve fruit quality.
4. Remove diseased and infested fruits regularly to prevent spread.

Harvesting and Post-Harvest Management

Harvest fruits at optimum maturity:

1. Tomato: breaker or red stage
2. Brinjal: glossy, firm stage
3. Chili: green or red, depending on market demand
4. Capsicum: green, red, or yellow, depending on variety.

Use **ventilated crates** for transport.

- a. Grade fruits based on size, color, and quality.
- b. Store under cool, dry conditions or use **cold chain logistics** for longer shelf life.

Smart Technologies and Market Linkage

1. Use mobile apps for weather updates and pest alerts.
2. Install IoT sensors in greenhouses for temperature and humidity control.
3. Join Farmer Producer Organizations (FPOs) for better bargaining power.
4. Explore direct marketing, online platforms, and contract farming to boost income.

Key Tips for Rainy Season Success

- a. Avoid water stagnation with raised beds and good drainage.
- b. Timely seed treatment to prevent early disease.
- c. Choose resistant varieties and maintain clean nursery practices.
- d. Use traps, neem products, and bioagents for eco-friendly pest control.
- e. Monitor fields regularly and act early on signs of pests or disease.

Conclusion

Solanaceous vegetable production can be highly rewarding—but only if backed by scientific practices. By understanding seasonal challenges and using modern production technologies, farmers can achieve better yields, improved quality, and higher income, even during tough rainy seasons.

Adopting an integrated approach with smart planning, timely action, and resource-efficient practices is the way forward for sustainable vegetable farming.

High-Tech Nurseries: Bridging the Gap between Agronomy and Climate-Smart Agriculture

Article ID: 71100

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Introduction

Agriculture has an extraordinary challenge in the twenty-first century as it seeks to feed a growing global population while dealing with the effects of climate change. Increasing temperatures, irregular weather patterns, and soil degradation threaten food system sustainability. In response to these difficulties, the idea of climate-smart agriculture (CSA) has arisen, with an emphasis on increasing production, strengthening resilience to climatic variability, and lowering greenhouse gas emissions. However, achieving these objectives needs innovation at all stages of agricultural production, from seed to harvest. One such invention is the creation of high-tech nurseries. High-tech nurseries offer a paradigm shift in how plants are propagated and cared for during their early stages of development. In contrast to traditional nurseries, which rely heavily on manual labour and natural environmental conditions, high-tech nurseries use advanced technologies such as automated irrigation systems, climate-controlled environments, Internet of Things (IoT) devices, and precision agriculture tools to optimize plant growth. These technologies enable precise control of environmental elements such as temperature, humidity, light, and nutrient levels, ensuring that each plant has the best conditions to thrive. High-tech nurseries not only improve crop output and quality by establishing highly controlled and efficient growth environments, but they also play an important role in fulfilling some of the fundamental goals of climate-smart agriculture. For example, automated irrigation and fertigation systems reduce water and nutrient waste, thereby contributing to the CSA's goal of increasing resource efficiency. Similarly, the utilization of renewable energy sources and energy-efficient technologies in these nurseries reduces the carbon footprint of agricultural output, which is consistent with the CSA's mitigation goals. Furthermore, high-tech nurseries are helping to increase resilience to climate change. By providing a consistent environment for plant growth, these nurseries shield crops from the more unpredictable outdoor circumstances induced by global warming. This ability to adapt is critical for creating novel crop kinds that can endure droughts, floods, and temperature extremes. Plants cultivated in high-tech nurseries are frequently healthier, more uniform, and more prepared to survive and thrive when transplanted into the field, resulting in increased total agricultural productivity. The incorporation of digital technologies into agriculture, commonly known as agritech, has contributed to the rapid growth of high-tech nurseries. Advanced sensor networks and data analytics systems now enable farmers and agronomists to collect real-time data on plant health, soil conditions, and microclimates. This data-driven strategy allows for more informed decision-making, ensuring that resources are deployed exactly where and when they are required. In this approach, high-tech nurseries not only increase crop yields but also help farmers better adapt to the difficulties of climate change. Despite the potential benefits of high-tech nurseries, some hurdles must be overcome to fulfil their potential. The initial expenditures of establishing a high-tech nursery might be exorbitant, particularly for smallholder farmers in poor countries. Furthermore, the complexity of the technology necessitates specialised expertise and training. As a result, ensuring that the benefits of high-tech nurseries are available to a diverse variety of farmers will be critical to their successful integration into climate-smart agricultural policies. We will look at how technology is altering plant propagation, present case studies of high-tech nurseries from around the world, and analyze the obstacles and prospects for scaling these innovations in a variety of agricultural settings. Understanding how high-tech nurseries contribute to

climate resilience, sustainability, and higher agricultural output allows us to better appreciate their potential to transform current agriculture and secure food security in an unpredictable climate future.

Understanding High-Tech Nurseries

Definition: High-tech nurseries refer to plant-growing environments that incorporate advanced technologies for optimizing plant growth. These technologies include climate-controlled systems, automated irrigation, and digital monitoring tools.

Components:

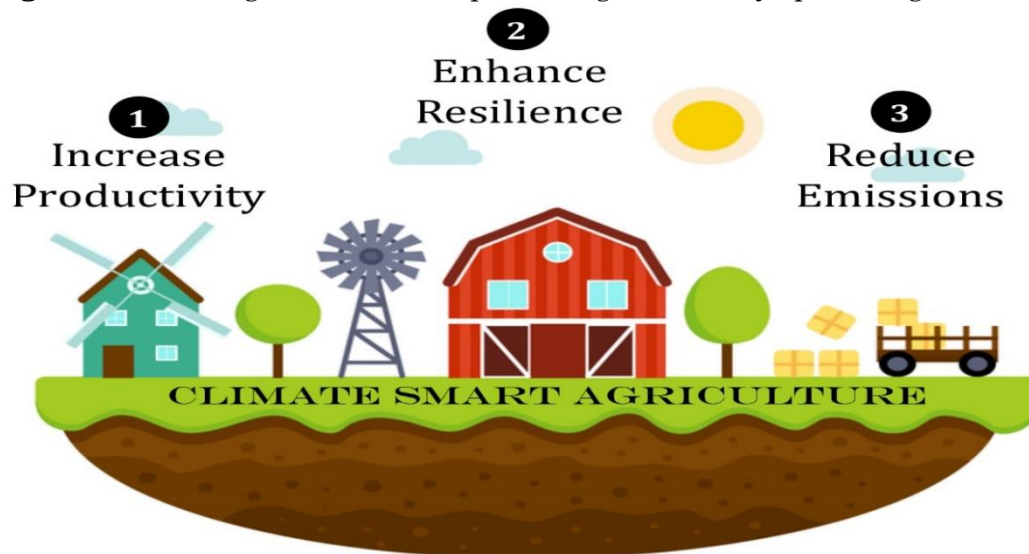
- a. Automated irrigation and fertigation systems.
- b. Sensors for monitoring soil, moisture, and temperature.
- c. IoT integration for remote monitoring and control.
- d. Energy-efficient lighting and heating systems.
- e. Drone and AI systems for plant health analysis.

The Importance of Climate-Smart Agriculture (CSA)

Definition: CSA focuses on three main objectives: sustainably increasing agricultural productivity, enhancing resilience (adaptation), and reducing or removing greenhouse gas emissions (mitigation).

Key Pillars:

- a. Productivity:** Ensuring crop yields meet food security demands.
- b. Adaptation:** Building resilient agricultural systems that can endure climate extremes.
- c. Mitigation:** Reducing the carbon footprint of agriculture by optimizing resource use.



How High-Tech Nurseries Align with CSA Goals

1. Increased Productivity: High-tech nurseries enable precise control of growing conditions, optimizing plant growth and improving yields. By using automation and precision farming techniques, they reduce human error and ensure consistency.

2. Enhanced Resilience: Climate-controlled environments and sensors in high-tech nurseries allow plants to thrive under fluctuating environmental conditions. These nurseries can simulate future climate scenarios, helping to breed and test more resilient varieties.

3. Reduced Greenhouse Gas Emissions: Advanced technologies, such as precision irrigation, reduce water and fertilizer use, which in turn lowers emissions associated with agricultural inputs. Additionally, energy-efficient systems (LED lighting, renewable energy) minimize the nursery's overall carbon footprint.

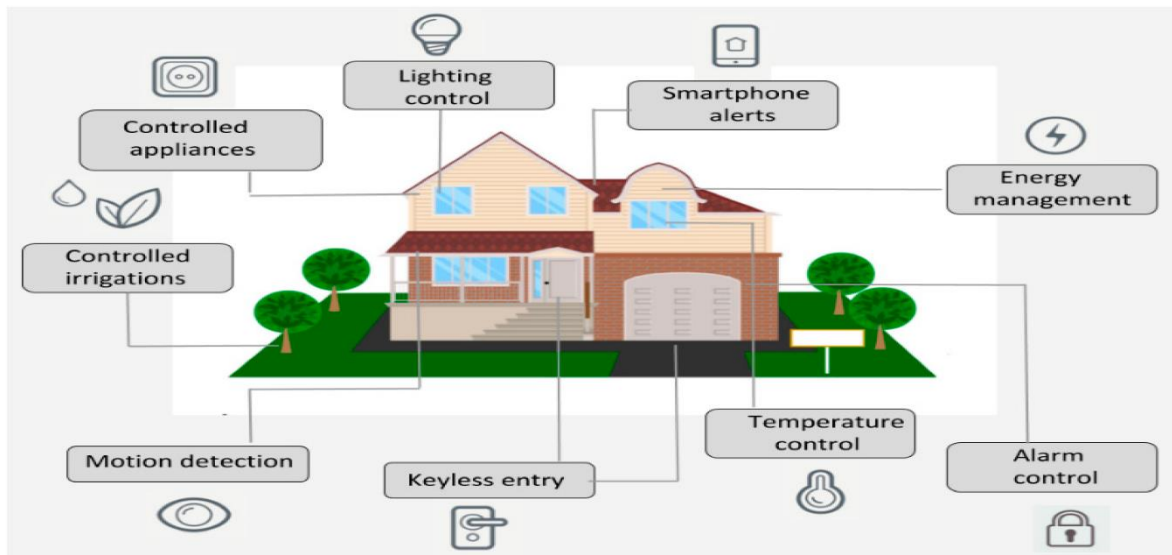
Technologies Driving High-Tech Nurseries

1. IoT and Automation: The Internet of Things (IoT) enables remote monitoring and control of environmental parameters in nurseries. Automation systems, such as robotic arms and irrigation systems, reduce labour costs and improve efficiency.

2. Sensor Technology: Sensors monitor soil moisture, humidity, temperature, and nutrient levels. Data collected helps in decision-making to ensure optimal plant growth with minimal resource wastage.

3. Artificial Intelligence and Machine Learning: AI systems analyze data trends, predict plant growth patterns, and optimize nursery management by adjusting inputs like water and light.

4. Drone Technology: Drones are used for monitoring plant health, identifying diseases, and spraying nutrients with precision, which reduces over use of chemicals and saves labour.



Case Studies of High-Tech Nurseries and CSA Implementation

Case Study 1: Smart Greenhouses in the Netherlands:

Overview: The Netherlands leads in smart greenhouse technology, using data-driven approaches for resource-efficient farming. This section would describe how advanced greenhouse technologies contribute to water and energy efficiency while boosting productivity.

Case Study 2: Vertical Farms in Japan:

Overview: Urban vertical farms in Japan use stacked layers for growing crops in a controlled indoor environment. This system uses less land and reduces water and energy consumption, making it ideal for adapting to climate change in urban areas.

Case Study 3: India's Agritech Start-ups and Small-Scale Nurseries

Overview: In India, agritech start-ups are incorporating IoT and AI into small-scale nurseries, allowing even smallholders to adopt climate-smart practices. This reduces input costs and improves crop quality.

Benefits and Challenges of High-Tech Nurseries in CSA

Benefits:

- Precision in Resource Use:** Technologies reduce wastage of water, fertilizers, and energy.
- Increased Yield:** Optimized growing conditions increase productivity per unit of land.
- Adaptation:** Controlled environments allow for breeding resilient crop varieties that can withstand climate extremes.

Challenges:

- High Initial Investment:** The cost of setting up a high-tech nursery can be prohibitive, particularly for small-scale farmers.
- Technical Expertise:** Farmers need training in operating advanced systems.
- Energy Consumption:** While many technologies reduce resource use, some high-tech systems, such as climate control, may increase energy consumption if not managed efficiently.

Future Directions: Integrating High-Tech Nurseries into Global CSA Strategies

Policy Recommendations:

- a. Governments should incentivize the adoption of high-tech nurseries by providing subsidies and technical assistance.
- b. Research and development must continue to focus on making these technologies more affordable and accessible for smallholder farmers.

Global Partnerships: Collaborative efforts between governments, NGOs, and the private sector will be essential in scaling up high-tech nursery adoption to meet CSA goals.

Table: Resource Efficiency in High-Tech Nurseries vs. Traditional Nurseries:

Parameter	Traditional Nursery	High-Tech Nursery	Efficiency Improvement
Water Usage (Litres/day)	1000	600	40% reduction
Energy Consumption (kWh/day)	50	30	40% reduction
Fertiliser Use (kg/month)	50	35	30% reduction
Labour Requirements (hours/day)	20	10	50% reduction
Yield (kg per sq. meter)	2	4	100% increase

Conclusion

High-tech nurseries are an essential link in the transition to climate-smart agriculture. These nurseries combine automation, IoT, and data-driven approaches to maximize resource consumption while simultaneously building resilience in the face of climate change. While there are hurdles, such as high costs and the requirement for technical expertise, the long-term benefits to agronomy and sustainability make them an important component of farming's future. Governments and global partners must collaborate to ensure that these advances are available to all farmers, enabling agriculture to survive in a changing environment.

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Sowing Sustainability: A Guide to Carbon Neutral Gardening Practices

Article ID: 71101

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Summary

Carbon-neutral gardening represents a transformative paradigm in sustainable horticulture, offering a proactive and practical approach to mitigating climate change at the grassroots level. This emerging discipline balances greenhouse gas emissions with carbon sequestration processes in home gardens and green spaces. By implementing ecologically sound practices such as strategic soil management, native plant integration, water conservation, biodiversity enhancement, and energy-efficient maintenance, gardeners can convert conventional residential plots into productive carbon sinks. As global temperatures rise and ecological stability becomes increasingly fragile, carbon-neutral gardening empowers individuals to participate meaningfully in climate action through localized, tangible interventions.

Introduction

In the face of accelerating climate change, environmental degradation, and biodiversity loss, traditional gardening practices are evolving into holistic systems of ecological stewardship. Often underestimated in environmental discourse, private and community gardens are now recognized as powerful allies in the global effort to reduce atmospheric carbon dioxide (CO₂) concentrations. Carbon-neutral gardening moves beyond aesthetic or food-production objectives, reimagining gardens as dynamic carbon management ecosystems. This innovative approach positions the home gardener as an ecological engineer—someone who not only cultivates plants but also manages resources with the intent of balancing emissions and sequestration.

This comprehensive article explores the scientific principles, innovative methodologies, and practical techniques underlying carbon-neutral gardening. It also provides a roadmap for homeowners, educators, urban planners, and policymakers to promote sustainable horticultural systems that regenerate soil health, enhance biodiversity, and contribute to global climate mitigation.

Understanding Carbon Neutrality in Gardening

Achieving carbon neutrality in gardening involves striking a balance between the emissions generated by gardening activities (e.g., through the use of fertilizers, power tools, and transportation) and the carbon captured through photosynthesis, biomass accumulation, and soil carbon enhancement. The fundamental strategies include:

- 1. Reducing Emissions:** Avoiding synthetic fertilizers, replacing gas-powered tools with electric or manual options, and minimizing non-renewable material use.
- 2. Enhancing Sequestration:** Maximizing photosynthetic capacity by planting trees and shrubs, increasing soil organic matter through composting, and utilizing cover crops.

Gardeners thus transition from passive hobbyists to active environmental agents—shaping carbon-efficient ecosystems and contributing to planetary health.

Soil: The Foundation of Carbon Storage

Soil is Earth's most significant terrestrial carbon reservoir, containing more carbon than the atmosphere and all plant biomass combined. Enhancing soil organic carbon (SOC) is essential for achieving carbon neutrality in gardens. Key practices include:

- 1. Composting:** Turning kitchen scraps and garden clippings into rich humus that feeds soil microbes and increases carbon retention.

2. No-Till Gardening: Preserving soil structure by minimizing mechanical disturbance, which helps prevent oxidation and carbon release.

3. Cover Cropping and Green Manuring: Sowing legumes and grasses in off-seasons to protect topsoil, fix nitrogen, and enhance microbial activity.

Additionally, biochar—a form of stable carbon produced through pyrolysis—can be incorporated into soil to sequester carbon for centuries while improving water and nutrient retention.

Native Plants: The Ecological Backbone of Sustainable Gardens

Native plants, having co-evolved with local climates and soil types, are inherently more sustainable than exotic ornamentals. Their integration into garden ecosystems contributes to:

1. Soil Stabilization: Deep root systems enhance soil structure, prevent erosion, and support microbial networks essential for carbon cycling.

2. Biodiversity Support: Native plants attract local pollinators, birds, and beneficial insects, creating a thriving web of life.

3. Low Input Requirements: Reduced need for watering, fertilization, and pesticides lowers both economic and environmental costs.

Moreover, perennial native species provide year-round carbon uptake and long-term biomass accumulation, enhancing their carbon sequestration potential.

Water Management: Conserving a Critical Resource

Water use in gardening is often energy-intensive, particularly when reliant on municipal supplies that require treatment and pumping. Sustainable water management techniques include:

1. Rainwater Harvesting: Collecting and storing roof runoff in barrels or cisterns for later irrigation use.

2. Xeriscaping: Designing landscapes that require minimal supplemental watering by using drought-tolerant plant species.

3. Drip Irrigation: Delivering water directly to plant roots, reducing evaporation losses and water waste.

Greywater reuse systems can further reduce reliance on potable water, while swales and infiltration trenches help recharge groundwater and reduce runoff.

Energy Efficiency in Garden Maintenance

Energy use is a major contributor to a garden's carbon footprint, particularly when powered by fossil fuels. Transitioning to clean energy solutions and low-impact tools is essential:

1. Manual and Solar Tools: Pruners, shears, solar trimmers, and electric mowers offer efficient alternatives with minimal emissions.

2. Passive Cooling Through Shade Trees: Strategically planted trees can reduce indoor cooling needs, lowering household energy consumption.

3. Mulching: Applying organic mulch suppresses weeds, retains soil moisture, and adds carbon-rich biomass as it decomposes.

Integrating renewable energy technologies such as solar lighting and wind-powered irrigation systems enhances sustainability further.

Biodiversity: The Engine of Ecosystem Resilience

Biodiverse gardens mimic natural ecosystems, making them more resistant to pests, diseases, and climate extremes. A well-designed biodiversity strategy includes:

1. Multi-Strata Planting: Combining trees, shrubs, herbs, and groundcovers to maximize vertical carbon capture and habitat complexity.

2. Pollinator Gardens: Incorporating nectar-rich flowering plants that support bees, butterflies, and other key species.

3. Soil Microbial Health: Encouraging a diversity of bacteria, fungi, and invertebrates that regulate nutrient cycling and soil carbon storage.

A biodiverse garden functions as a microclimate buffer, absorbing shocks from drought, floods, or temperature extremes.

Technology and Environmental Monitoring

The integration of smart technology enhances the precision and effectiveness of sustainable gardening practices:

1. Soil Sensors: Measure real-time moisture, pH, and nutrient levels to optimize inputs and avoid over-fertilization.

2. Carbon Tracking Tools: Mobile applications and online calculators estimate a garden's carbon footprint and help track improvements.

3. Smart Irrigation Systems: Automate watering schedules based on weather forecasts, plant needs, and soil moisture data.

Such innovations transform gardens into data-driven environmental systems, improving efficiency and maximizing ecological returns.

Community and Collective Action

Carbon-neutral gardening gains exponential impact when practiced at scale through community engagement:

1. Urban Greening Projects: Rooftop gardens, vertical farms, and green corridors improve city air quality and carbon sequestration.

2. Community Gardens and Allotments: Share resources and knowledge while promoting local food production and environmental education.

3. Citizen Science and Workshops: Involve residents in biodiversity monitoring, composting initiatives, and permaculture training.

Neighborhood-wide efforts foster environmental stewardship and catalyze systemic change in urban planning and green infrastructure.

Practical Steps to Implement Carbon-Neutral Gardening

To begin your journey toward a carbon-neutral garden:

1. Audit Your Current Practices: Identify emissions sources and potential areas for improvement.

2. Choose Native and Perennial Plants: Reduce maintenance and increase carbon storage.

3. Build Soil Health: Use compost, mulch, and biochar to enrich soil organically.

4. Upgrade Tools and Irrigation: Replace gas-powered equipment with manual or electric versions; install rainwater systems.

5. Educate and Involve Others: Share your knowledge and practices with friends, neighbors, and local institutions.

Conclusion

Carbon-neutral gardening is more than a trend; it is a powerful, regenerative movement rooted in science, sustainability, and community resilience. By transforming backyards, balconies, and urban green spaces into active carbon sinks, gardeners play a critical role in climate action. Every compost pile, native plant, and rain barrel contributes to a larger mosaic of ecological recovery. As individuals adopt these practices, they collectively forge a greener, more resilient future—proving that change indeed begins at home, in the soil beneath our feet.

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The Burning Issue: Understanding Open Crop Residue Burning's Impact and Mitigation Strategies

Article ID: 71102

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Summary

Open crop residue burning, particularly prevalent in India's northern states like Punjab and Haryana, offers farmers a quick solution to clear fields but has severe environmental and agronomic consequences. The practice releases harmful pollutants, degrades soil health by destroying organic matter and beneficial microbes, and depletes vital nutrients. Despite its drawbacks, farmers rely on burning due to tight crop cycles, high costs of alternatives, and lack of awareness. Sustainable solutions—such as in-situ management (Happy Seeder, mulching), bio-decomposers, and policy interventions—can mitigate these impacts by improving soil fertility, reducing pollution, and ensuring long-term agricultural sustainability. Addressing this issue requires collaborative efforts from farmers, policymakers, and researchers to promote eco-friendly practices and safeguard soil and air quality.

Introduction

The shift toward intensive farming in recent decades has popularized mechanized agriculture, especially in states like Punjab, Haryana, and western Uttar Pradesh. However, this progress has brought an unintended consequence: widespread stubble burning. Farmers resort to this quick method of clearing post-harvest residues, primarily after paddy cultivation, to prepare fields for the next crop. While cost-effective and time-saving, this practice poses severe environmental and agronomic risks.

Unlike Punjab and Haryana, Madhya Pradesh reports fewer stubble-burning incidents, but the trend is rising in key districts such as Sehore, Hoshangabad, Chhindwara, and Harda. Increased mechanized harvesting of wheat and paddy has made residue management a growing challenge. Data from the National Remote Sensing Centre (NRSC) and Punjab Remote Sensing Centre (PRSC) reveal over 3,000 farm fire incidents in Madhya Pradesh in 2023—a notable increase from previous years. Though not as severe as Punjab's crisis, localized air pollution and soil degradation are emerging concerns.

State initiatives, including awareness programs by the Agriculture Department and Krishi Vigyan Kendras (KVKs), promote sustainable alternatives like Happy Seeders, bio-decomposers, and mulching. Yet, limited machinery access and training gaps, especially in tribal and resource-scarce regions, keep stubble burning a preferred option during peak seasons.

Environmental and Soil Health Impacts

Stubble burning releases massive amounts of smoke, particulate matter (PM_{2.5}, PM₁₀), and greenhouse gases (CO₂, CH₄, N₂O), worsening winter air pollution. Beyond visible smog, the practice silently degrades soil health—a critical yet overlooked consequence. The intense heat kills beneficial soil microbes, disrupts nutrient cycles, and destroys organic matter essential for crop growth.

The topsoil layer, rich in microorganisms and nutrients, suffers the most. Earthworms, nitrogen-fixing bacteria, and fungi are eradicated, impairing decomposition and soil aeration. Vital nutrients like nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) are lost through volatilization, leaving soils less fertile. Over time, repeated burning accelerates soil degradation, increases reliance on synthetic fertilizers, and undermines agricultural sustainability.

Comparative Analysis: Burning vs. Alternatives

Factor	Stubble Burning	Sustainable Practices
Soil Temperature	Rises to 42°C; kills microbes	Stable; supports microbial life
Nutrient Loss	High (N, P, K, S, C lost)	Nutrients recycled into soil

Organic Carbon	3–3.5% decline	Improves SOC
Cost	Low upfront (high long-term costs)	Moderate (subsidies available)
Environmental Impact	Air pollution, GHG emissions	Carbon sequestration, no pollution

This article examines stubble burning's detrimental effects on soil and proposes eco-friendly alternatives, urging action from policymakers, researchers, and farmers.

1. Why Farmers Resort to Stubble Burning: Despite its harms, stubble burning persists due to economic, logistical, and policy-related challenges:

- a. Tight Crop Cycles:** The 20–25 day window between paddy harvest and wheat sowing leaves little time for residue management. Combine harvesters leave behind thick straw, making manual clearance impractical.
- b. High Costs of Alternatives:** Machines like Happy Seeders or rotavators are expensive. Subsidies exist but remain inaccessible due to bureaucratic delays or lack of awareness.
- c. Low Residue Utility:** Paddy straw's high silica content reduces its value as fodder or industrial raw material, making burning the easiest disposal method.
- d. Labor Shortages:** Post-harvest labor scarcity and rising wages deter manual residue handling.
- e. MSP-Driven Cultivation:** Punjab's MSP-backed paddy monoculture generates excess residue, exacerbating disposal challenges.
- f. Awareness Gaps:** Many farmers underestimate burning's long-term soil and health impacts, prioritizing short-term convenience.

2. Soil Health and Fertility Decline: Stubble burning inflicts multi-dimensional damage on soils:

- a. Microbial Destruction:** Soil temperatures spike to 42°C at 1 cm depth, killing beneficial microbes critical for nutrient cycling.
- b. Nutrient Loss:** Burning 1 ton of paddy straw wastes ~5.5 kg N, 2.3 kg P, 25 kg K, and 1.2 kg S, alongside 400 kg of carbon.
- c. Organic Carbon Depletion:** Punjab Agricultural University studies note a 3–3.5% decline in soil organic carbon (SOC), reducing fertility.
- d. Physical Degradation:** Heat forms a hard crust, lowering water infiltration and increasing erosion risks.
- e. Chemical Imbalance:** Elevated pH and salinity hinder nutrient uptake, while heavy metals accumulate.
- f. Fertilizer Dependence:** Nutrient losses force farmers to overuse synthetic fertilizers, raising costs and polluting groundwater.

3. Sustainable Residue Management Strategies:

- a. In-Situ Techniques:**
 - i. Happy Seeder:** Direct wheat sowing into paddy stubble.
 - ii. Super SMS:** Combine-attached systems that evenly spread straw for decomposition.
 - iii. Zero-Till Drills:** Minimize soil disturbance while incorporating residues.
- b. Biological Solutions:** Pusa Bio-Decomposer: IARI's microbial spray breaks down straw in 20–25 days, enriching soil.
- c. Composting/Mulching:** Residues converted to compost or used as mulch improve water retention and soil structure.
- d. Off-Site Utilization:** Straw as cattle feed (after silica treatment), biofuel, or industrial raw material.
- e. Policy Interventions:** Subsidies for machinery, farmer training, and stricter enforcement of burning bans.

Conclusion

Stubble burning is a lose-lose practice—harming soils, air quality, and long-term farm productivity. Transitioning to sustainable residue management requires coordinated efforts: scaling affordable machinery, incentivizing bio-decomposers, and strengthening policy frameworks. Prioritizing soil health today ensures food security and climate resilience for tomorrow.

Eco-Friendly Textile for Sustainable Growth

Article ID: 71103

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Summary

The global textile industry, while a major contributor to economic development, is also one of the largest polluters due to its heavy reliance on water, energy, and synthetic chemicals. As environmental concerns and sustainable practices take center stage, eco-friendly textiles have emerged as a viable solution to mitigate the adverse environmental impacts of conventional textile production. This review explores the concept of eco-friendly textiles, the types of sustainable materials used, advancements in green manufacturing techniques, and their environmental, economic, and social implications. The paper also discusses challenges in the adoption of eco-textiles and future directions for promoting sustainable growth in the textile sector.

Introduction

The textile industry is integral to the global economy, contributing significantly to employment and trade. However, it is also recognized as one of the most resource-intensive and polluting sectors, accounting for about 20% of global industrial water pollution and 10% of total carbon emissions (Ellen MacArthur Foundation, 2017). In response to growing environmental awareness and stricter regulations, there has been a paradigm shift toward the development and use of **eco-friendly textiles**—materials and production methods that minimize harm to the environment and promote sustainability.

Defining Eco-Friendly Textiles

Eco-friendly textiles, also referred to as **sustainable textiles** or **green textiles**, are fabrics that are manufactured, used, and disposed of in ways that reduce environmental impacts throughout their life cycle. Key characteristics include:

1. Use of renewable and biodegradable raw materials.
2. Minimal water, chemical, and energy usage.
3. Low carbon footprint.
4. Recyclability and biodegradability.
5. Safe for human health and the environment.

Sustainable Raw Materials

1. Organic Natural Fibres:

- a. **Organic Cotton:** Grown without synthetic fertilizers or pesticides, organic cotton reduces soil and water contamination.
- b. **Hemp:** Requires minimal inputs and regenerates soil, making it an eco-efficient crop.
- c. **Flax (Linen):** Grown with low water and chemical needs, offering strong biodegradability.
- d. **Coir, Jute, and Ramie:** These bast fibres are biodegradable and abundant in regions like South Asia.

2. Regenerated Cellulose Fibres:

- a. **Lyocell (Tencel®):** Derived from wood pulp using a closed-loop process with non-toxic solvents.
- b. **Modal and Bamboo Viscose:** Produced from beech or bamboo, though the sustainability depends on the processing method.

3. Recycled Fibres:

- a. **Recycled Polyester (rPET):** Made from post-consumer plastic bottles, reducing waste and petroleum usage.

b. Reclaimed Wool and Cotton: Re-spun from fabric scraps or old garments, contributing to circular fashion.

Eco-Friendly Textile Processing Techniques

1. Waterless and Low-Impact Dyeing:

- a. **Supercritical CO₂ Dyeing:** Uses CO₂ instead of water, eliminating effluent discharge.
- b. **Natural Dyes:** Derived from plants and minerals, these are biodegradable and non-toxic.
- c. **Digital Printing:** Reduces water and dye use compared to traditional methods.

2. Enzymatic and Green Chemistry:

- a. Enzymes like cellulase and pectinase replace harsh chemicals in scouring and bleaching.
- b. Green solvents and surfactants reduce toxicity and effluent loads.

3. Eco-certifications and Standards:

- a. **Global Organic Textile Standard (GOTS)**
- b. **OEKO-TEX® Standard 100**
- c. **Cradle to Cradle Certified™**
- d. These standards ensure environmental and social compliance throughout the textile value chain.

Environmental Benefits

- 1. **Reduced Water Pollution:** Eco-textiles use less water and safer dyes, curbing industrial discharge.
- 2. **Lower Carbon Footprint:** Use of renewable fibres and low-energy processes cuts GHG emissions.
- 3. **Waste Reduction:** Recycling and upcycling fabrics extend their lifecycle and reduce landfill burden.
- 4. **Biodiversity Protection:** Avoiding harmful agrochemicals supports ecosystem health.

Economic and Social Impact

1. Economic Opportunities:

- a. Green textiles open new markets for eco-conscious consumers.
- b. Boosts innovation in sustainable technologies and materials.
- c. Supports rural economies through organic farming of fibres like cotton and jute.

2. Social Implications:

- a. Promotes ethical labor practices in certified sustainable supply chains.
- b. Enhances health and safety for workers and consumers by avoiding toxic substances.

Challenges and Limitations

- 1. **High Production Cost:** Sustainable processes and materials are often costlier than conventional options.
- 2. **Limited Consumer Awareness:** Misconceptions and lack of information slow adoption.
- 3. **Scalability Issues:** Eco-textiles face production and distribution challenges in matching fast fashion demands.
- 4. **Greenwashing:** Misleading claims by brands can erode consumer trust.

Future Prospects

- 1. **Technological Innovations:** Development of bio-based dyes, microbial cellulose, and nanotechnology-based functional eco-fibres.
- 2. **Policy Support:** Governments need to incentivize sustainable practices through subsidies and regulations.
- 3. **Circular Economy Models:** Emphasis on reuse, repair, and recycling will strengthen sustainability.
- 4. **Education and Awareness:** Campaigns and curriculum integration can drive informed consumer choices.

Conclusion

Eco-friendly textiles are essential for transitioning the textile industry toward sustainability. While significant strides have been made in material innovation and green processing, widespread adoption demands coordinated efforts among policymakers, industry leaders, and consumers. With continued research, investment, and awareness, eco-textiles can not only protect the environment but also drive inclusive and sustainable economic growth.

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From Mulberry to Marketplace: Exploring the Potential of Seri-Tourism

Article ID: 71104

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Abstract

Seri-tourism, the integration of sericulture with rural tourism, offers a sustainable and experiential model for rural development in India. This article explores the potential of seri-tourism to generate income, preserve traditional silk practices, and promote eco-friendly travel. Through hands-on activities such as silkworm rearing, silk reeling, and weaving, tourists engage with the complete silk production process. The approach fosters community participation, especially of women and youth, while supporting allied sectors. Despite infrastructural and coordination challenges, seri-tourism holds promise as a viable strategy for inclusive growth, cultural preservation, and diversification of rural livelihoods in India.

Introduction

Imagine walking through lush mulberry plantations, observing silkworms spin their magical cocoons, and witnessing skilled artisans weave vibrant silk fabrics on traditional looms. This immersive experience is not from a textbook but a growing reality known as "seri-tourism", a novel blend of sericulture and tourism. As rural India seeks sustainable livelihood options and tourists look for meaningful, eco-friendly travel experiences, seri-tourism emerges as a promising bridge between the two.

Understanding Seri-Tourism

Seri-tourism refers to tourism centred around sericulture activities. It allows visitors to engage with the entire silk production process: mulberry cultivation, silkworm rearing, cocoon harvesting, silk reeling, dyeing, and weaving. Beyond observing, tourists often participate in hands-on experiences like feeding silkworms or trying out handlooms, making the visit both educational and experiential. This form of tourism offers insight into rural life, traditional knowledge systems, and the intricacies of India's silk industry.

The Science Behind Silk



Fig 1: Life cycle of silkworm (Source: Unnati silks website)

The foundation of seri-tourism lies in the fascinating science of sericulture. The domesticated silkworm, *Bombyx mori*, exclusively feeds on mulberry leaves. It undergoes a complete metamorphosis: egg, larva, pupa, and adult—spinning a cocoon made of a single thread of fibroin protein, coated in sericin. The process not only demonstrates biological wonder but also showcases the ecological harmony in which rural communities have thrived for generations. Mulberry farming, an essential component, supports biodiversity and prevents soil erosion, making sericulture an environmentally sustainable occupation.

India's Potential to Harness Seri-Tourism

India, with its vibrant silk legacy and rural foundation, is uniquely poised to embrace seritourism as a path toward sustainable rural development. Across the country, countless small and marginal farmers nurture silkworms in mulberry orchards or forest groves, keeping alive practices passed down through generations. From the golden muga of Assam to the glossy mulberry silk of Karnataka, each region tells a different silk story, rooted in nature, culture, and craft. What makes India stand out is not just the diversity of its silk varieties, but also the communities behind them -women artisans, tribal rearers, and handloom weavers whose skills offer rich experiential value for curious travellers. With government support through rural and agro-tourism schemes, and growing interest in eco-friendly, culture-based travel, India holds immense potential to turn its sericulture belts into live classrooms, heritage corridors, and economic lifelines. Seri-tourism is not just about witnessing silk making, it's about touching the soul of skills, traditions, and livelihoods of India's rural communities.

Did you know?

- ✓ India is the second-largest silk producer globally and is the only country in the world that produces all four major types of silk
- ✓ The average silkworm spins a cocoon with a thread up to 1,000 meters long
- ✓ Sualkuchi in Assam is known as the “Manchester of the East” for silk weaving

Key Activities in the Design of Seri-Tourism Centre

- 1. Mulberry farm & silkworm rearing:** Visitors are guided through mulberry farms where they learn about mulberry cultivation, silkworm rearing, and the complete lifecycle of the silkworm
- 2. Cocoon harvesting & sorting demo:** Practically teach the visitors how to carefully harvest cocoons without damage and give a demo of sorting cocoons based on quality parameters such as size, shape, and colour, highlighting the importance of quality control in silk production
- 3. Silk reeling demonstration & hands-on session:** show the visitors how silk threads are carefully reeled from cocoons in a live demonstration and gave a chance to visitors to try reeling silk threads on small hand-operated machines to feel the texture and skill involved.
- 4. Weaving and natural dyeing:** Demonstrate the visitors the art of weaving silk fabric and teach them natural dyeing to use local plants and eco-friendly methods to colour silk sustainably.
- 5. Silk product making and gift giving:** Gift a small silk souvenir like a tie, scarf, or accessory to a visitor as a memorable keepsake to take home
- 6. Farm-to-fashion shopping:** create a small showroom or stall or cooperative outlet within the centre to sell the finished silk products, allowing visitors to buy authentic silk items that directly support local producers.

7. Local cuisine food stall: arrange a food stall offering traditional local cuisine at the seri-tourism centre, enabling visitors to enjoy regional specialties during their visit

8. Other miscellaneous activities: Arrange selfie points, 3-D art installationssuch asa silk moth presenting a gift, a girl taking water from a pond, will set up around the centre. Visitors can enjoy these visually engaging spots by taking photographs that reflect the natural and cultural essence of sericulture.

Stakeholders and Community Involvement

Seri-tourism thrives on the active participation of multiple stakeholders. Farmers cultivate mulberry and rear silkworms; artisans reel and weave silk; women-led Self-Help Groups (SHGs) manage hospitality and handicraft sales; youth act as guides and interpreters. This inclusive model enhances rural incomes, generates employment, and instills pride in traditional livelihoods. It also encourages reverse migration as urban youth return to their roots with entrepreneurial aspirations.

Benefits of Seri-Tourism

1. Economic empowerment of local communities- creates additional income sources for sericulture farmers, artisans, and local businesses by attracting tourists who purchase silk products and engage in local services such as food

2. Preservation of traditional crafts and culture: By showcasing silk farming, weaving, and dyeing, seri-tourism helps preserve and revitalize traditional knowledge and artisanal skills that might otherwise decline due to modernization (Rabha *et al.*, 2022)

3. Educational and awareness opportunities: tourists gain hands-on experience and scientific insights into the sericulture process, promoting awareness of sustainable farming practices and the biology of silk production, which supports environmental stewardship

4. Strengthening rural tourism and diversification: It adds value to rural areas by diversifying tourism beyond typical sightseeing, thus spreading economic benefits more widely and reducing urban migration

5. Market expansion for silk products: Direct interaction with tourists opens new markets for local silk products, increasing demand and encouraging innovation in design and quality

6. Encouragement of women and youth participation: Seri-tourism often involves women and youth in various stages of production and tourism activities, promoting inclusive growth and skill development (Ramappa *et al.*, 2022)

7. Boost to allied sectors: The development of seri-tourism benefits allied sectors such as hospitality, transport, and handicrafts, stimulating broader regional development.

Challenges

Despite its potential, seri-tourism faces challenges such as inadequate infrastructure, limited digital outreach, lack of trained guides, and seasonal constraints in silk production (Rabha *et al.*, 2022; Ramappa *et al.*, 2022). There is also a need for better coordination among stakeholders and standardized tourism models.

Roadmap for Sustainable Seri-Tourism

To scale and sustain seri-tourism, a multi-pronged strategy is needed:

1. Develop integrated tourism circuits combining sericulture, handlooms, local cuisine, and festivals
2. Train local youth in hospitality, communication, and digital marketing
3. Leverage technology for virtual tours, online bookings, and e-commerce
4. Encourage public-private partnerships to invest in infrastructure and branding.

Conclusion

Seri-tourism is more than a journey into silk production, it is a celebration of rural ingenuity, ecological balance, and cultural richness. As India aspires for inclusive and sustainable rural development, seri-tourism offers a silk thread of opportunity connecting tradition with innovation, and communities with

global travellers. By investing in this promising sector, we can ensure that both silk and smiles are woven into the fabric of rural prosperity.

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The Role of Nutrition in Non-Alcoholic Fatty Liver Disease: A Review of the Evidence

Article ID: 71105

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Summary

Non-alcoholic fatty liver disease (NAFLD) is a growing health concern worldwide, affecting approximately 30% of the global population. Lifestyle modifications, including dietary changes and increased physical activity, are crucial for managing NAFLD. This article discusses the importance of dietary management in NAFLD treatment, highlighting the benefits of specific dietary patterns and nutrients.

Introduction

Non-alcoholic fatty liver disease (NAFLD) is characterized by excessive hepatic fat accumulation without significant alcohol consumption. Its prevalence is rising globally, paralleling obesity and type 2 diabetes epidemics. Both hereditary and environmental factors, such as nutrition and physical inactivity, have a role in the pathophysiology of NAFLD. Lifestyle modifications, particularly weight loss through dietary changes and exercise, remain the cornerstone of therapy. Caloric restriction is crucial for weight loss and hepatic fat reduction.

NAFLD is a spectrum of liver diseases ranging from liver steatosis to non-alcoholic steatohepatitis (NASH), fibrosis, and cirrhosis. The rising prevalence of NAFLD parallels the increasing rates of obesity and type 2 diabetes mellitus (T2DM), resulting in significant healthcare resource utilization and costs. An elevated risk of cardiovascular morbidity and mortality is also linked to NAFLD.

Dietary Management of Non-Alcoholic Fatty Liver Disease

Dietary strategies in NAFLD				
Low fat diet	Low carbohydrate diet	Ketogenic diet	Time restricted eating	Mediterranean diet
Carbohydrate, % 60%	Carbohydrate, % 25%	Carbohydrate, % 10%	Carbohydrate, % 40%	Carbohydrate, % 40%
Fat, % 20%	Fat, % 35%	Fat, % 55%	Fat, % 40%	Fat, % 40%
Protein, % 20%	Protein, % 40%	Protein, % 35%	Protein, % 20%	Protein, % 20%

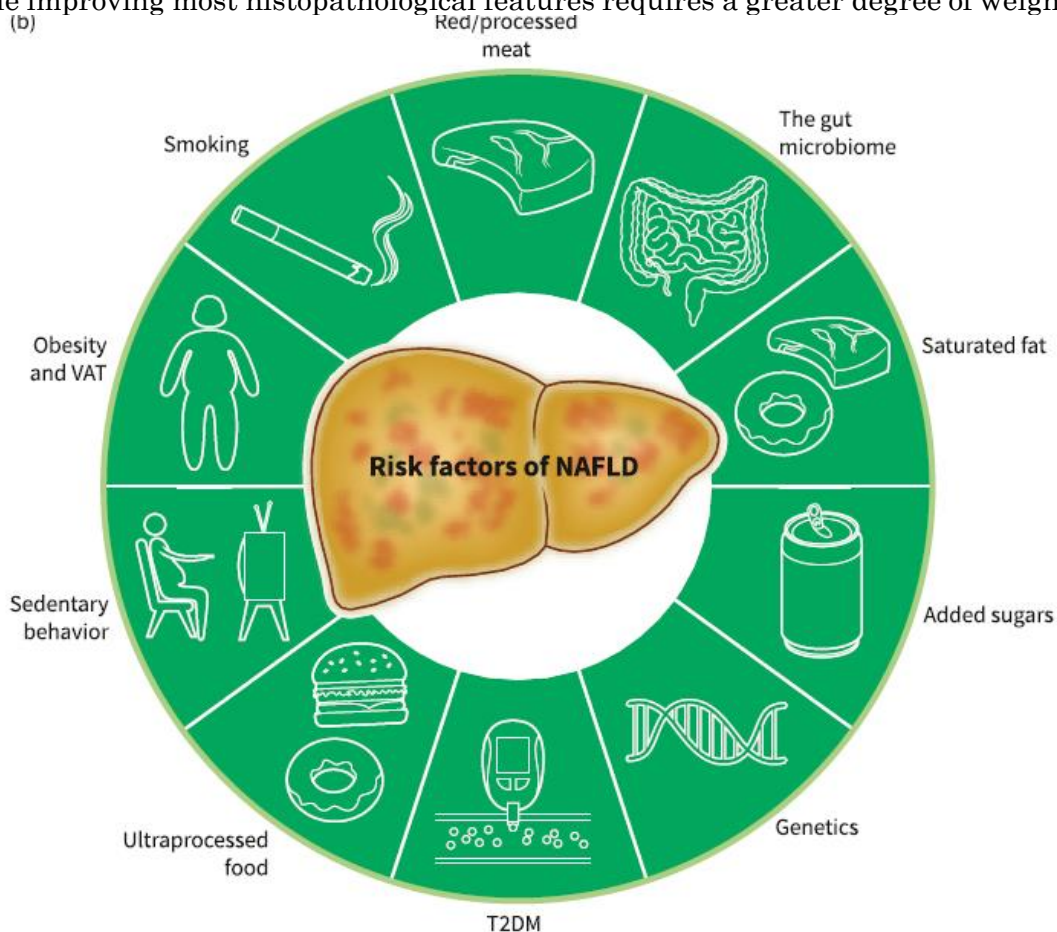
Dietary patterns and nutrients are pivotal in the development, progression, and management of NAFLD. A healthy dietary pattern characterized by high consumption of whole grains, fruits, vegetables, and

healthy fats, such as the Mediterranean diet (Med Diet), is beneficial in managing NAFLD. The Med Diet combines moderately reduced carbohydrate intake and minimal consumption of added sugars, making it an achievable and acceptable dietary strategy for patients.

Specific nutrients and foods have also been studied for their potential benefits in NAFLD management. Polyphenols, abundant in foods such as berries, nuts, coffee, tea, and whole grains, have been shown to improve glucose and lipid metabolism and may have a protective effect on NAFLD. Extra virgin olive oil, abundant in beneficial fats, has been linked to a decreased incidence of NAFLD.

On the other hand, certain dietary components have been linked to an increased risk of NAFLD. Consuming large amounts of red and processed meat, saturated fat, added sugar, and sweetened beverages has been linked to a higher risk of hepatocellular carcinoma and non-alcoholic fatty liver disease (NAFLD).

Energy restriction is a crucial aspect of NAFLD management, and gradual weight loss is recommended to improve hepatic steatosis and other histological features of NAFLD. The American Association for the Study of Liver Diseases (AASLD) recommends a total weight reduction of at least 3-5% to ameliorate steatosis, while improving most histopathological features requires a greater degree of weight loss (7-10%).



Conclusion

In conclusion, dietary management plays a critical role in the treatment of NAFLD. A healthy dietary pattern, such as the MedDiet, combined with energy restriction and increased physical activity, can help manage NAFLD and reduce the risk of associated comorbidities. Specific nutrients and foods, such as polyphenols and extra virgin olive oil, may also have beneficial effects on NAFLD. By adopting a healthy lifestyle and dietary habits, individuals with NAFLD can reduce their risk of disease progression and improve their overall health outcomes.

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Conservation Agriculture: Future for Modern Agriculture

Article ID: 71106

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Abstract

Conservation Agriculture (CA) is gaining momentum as a sustainable farming approach that aims to address global challenges such as soil degradation, climate change, and food security. Built on three key principles—minimal soil disturbance, permanent soil cover, and crop rotation—CA offers numerous benefits, including enhanced soil health, improved water conservation, and increased resilience to climate variability. This farming system promotes sustainable food production by optimizing resources, reducing input costs, and mitigating environmental degradation. Globally, CA is increasingly adopted, with notable success stories in regions like Southern Africa and India, where it has led to improved yields and soil fertility. However, challenges remain, particularly in terms of initial investment, knowledge dissemination, and policy support. The future of CA holds promise with the integration of modern technologies such as precision agriculture and Internet of Things (IoT) tools, which can optimize its practices and increase efficiency. Overall, CA presents a viable pathway toward the future of modern agriculture, fostering long-term productivity, sustainability, and climate resilience.

Introduction

As global agriculture grapples with the challenges of climate change, soil degradation, and the need for sustainable food production, Conservation Agriculture (CA) emerges as a promising solution. Defined by the Food and Agriculture Organization (FAO) as a farming system that promotes minimal soil disturbance, permanent soil cover, and crop diversification, CA aims to enhance biodiversity, improve water and nutrient efficiency, and ensure sustained crop production (Landers et al., 2021).

Understanding Conservation Agriculture

Conservation Agriculture is built upon three core principles:

- 1. Minimal Soil Disturbance:** This involves practices like no-till or reduced-till farming, which help maintain soil structure, reduce erosion, and preserve soil organic matter.
- 2. Permanent Soil Cover:** Maintaining a protective layer of crop residues or cover crops shields the soil from erosion, conserves moisture, and supports beneficial soil organisms (Mitchell et al., 2019)
- 3. Diverse Crop Rotations:** Rotating different crops disrupts pest and disease cycles, improves soil fertility, and enhances overall farm biodiversity.

Benefits of Conservation Agriculture

- 1. Soil Health and Fertility:** CA practices enhance soil structure, increase organic matter, and promote microbial activity. Over time, this leads to improved nutrient cycling and better water retention, crucial for plant growth.

2. Water Conservation: By reducing runoff and increasing infiltration, CA helps conserve water resources. The permanent soil cover minimizes evaporation, ensuring that crops have access to moisture even during dry periods (Derpsch et al., 2014)

3. Climate Change Mitigation: CA contributes to carbon sequestration by increasing soil organic carbon levels. Additionally, practices like no-till farming reduce greenhouse gas emissions, making agriculture more climate-resilient (Krishna and Veetil, 2014)

4. Economic Benefits: Farmers practicing CA often experience reduced input costs due to lower fuel and labor requirements. Over time, improved soil health can lead to increased yields and profitability (Giller et al., 2015).

Global Adoption of Conservation Agriculture

As of 2015/2016, CA was practiced on approximately 180 million hectares worldwide, representing about 12.5% of global cropland. While adoption is widespread in countries like the USA, Brazil, and Australia, it's still limited in many developing nations.

Case Study: Southern Africa: In Southern Africa, CA has been promoted to combat declining soil fertility and stabilize crop yields. Research indicates that CA increases water infiltration, reduces soil erosion, and enhances soil moisture availability. However, challenges like residue retention and weed control persist.

Case Study: India: India has seen CA adoption, especially in the Indo-Gangetic Plains, where zero-tillage and residue management have improved yields and water-use efficiency. Government initiatives like the National Mission for Sustainable Agriculture support CA practices.

Challenges in Implementing Conservation Agriculture

1. Initial Investment: Transitioning to CA may require investments in specialized equipment and training, which can be a barrier for smallholder farmers.

2. Knowledge and Awareness: A lack of awareness and understanding of CA benefits can hinder adoption. Extension services and farmer education are crucial to bridge this gap.

3. Policy and Institutional Support: Effective policies and institutional frameworks are essential to promote CA. This includes subsidies, research funding, and support for farmer cooperatives.

The Future of Conservation Agriculture

As the global community seeks sustainable agricultural solutions, CA offers a pathway to resilient and productive farming systems. Integrating modern technologies like precision agriculture and IoT can further enhance CA practices, making them more efficient and adaptable to changing conditions.

Conclusion

Conservation Agriculture stands as a beacon for sustainable farming in the 21st century. By embracing its principles, farmers can ensure soil health, conserve water, mitigate climate change, and achieve economic viability. With concerted efforts from governments, institutions, and the farming community, CA can pave the way for a resilient agricultural future.

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Bee Venom Therapy: From Venom to Medicine

Article ID: 71107

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Introduction

Apitherapy is an alternative medicine that treats a variety of human ailments by using honeybee products, most notably bee venom. Various religious texts, including the Bible, the Quran, and the Veda, mention the healing properties of honey and other bee products. The European honeybee (*Apis mellifera*) venom, propolis, and honey have all been used as medicines by humans for thousands of years; apitherapy is the practice of using honeybee products to treat illnesses. Bee venom has been used for medical purposes since ancient Egypt and Greece, and it has been used for 3,000–5,000 years in China.

Bee Venom

A gland in the bee's (*Apis mellifera* L.) abdominal cavity secretes bee venom, also known as apitoxin. Bees frequently use this clear, odorless, acidic liquid as a protection mechanism against predators. Commercially marketed as Apitox or Apitoxin, honeybee venom is a concoction of several substances. Melittin, a major component of bee venom, apamin, adolapin, mast cell degranulating peptide, and enzymes (phospholipase A2 and hyaluronidase) are among the active molecules found in bee venom, according to numerous publications. Non-peptide components include histamine, dopamine, and norepinephrine. Melittin, which makes up almost half of dry venom, and phospholipase A2 (PLA2), which makes up around 12%, are the primary components (Khalil *et al.*, (2021)).

Both *in vitro* and *in vivo* investigations have been used to examine the pharmacology of bee venom. Bee venom has a wide range of pharmacological effects, including anti-mutagenic (substances or processes that counteract or prevent the effects of mutagens), anti-nociceptive (related to or producing a reduction or blockage of the sensation of pain), radioprotective (providing protection against the harmful effects of radiation), anti-hepatotoxic (a property of a substance or compound to protect the liver from damage caused by toxins or diseases), cytoprotective (providing protection to cells against harmful substances), anti-oxidant, anti-microbial, anti-viral, anti-inflammatory, neuroprotective, anti-arthritis, anti-metastatic, and anti-tumor effects, even though there is need to conduct more scientific research on the advanced mechanism of these effects of bee venom, there are enough evidences to prove it role in the mentioned effects (Vahidinia *et al.*, (2024)).

Methods of Application of Bee Venom

The purified and sterilized bee venom is injected into the muscles at varying concentrations; oral or sublingual homeopathic preparations are also employed; and preparations such as creams and ointments are applied to the skin's surface and rubbed there to allow the venom to be absorbed through the skin; There are other sophisticated techniques such as Electrophoresis (Iontophoresis), which uses a mild electric current to help bee venom penetrate the skin; and Ultrasound-Enhanced Delivery (Phonophoresis), which uses ultrasound waves to improve the absorption of bee venom from a topical application. Direct stinging by live bees entails stinging with live bees on target areas such as below the neck, between the vertebrae of the spinal cord, knees, elbows, etc (Khalil *et al.*, (2021)).

Extraction of Bee Venom

There are several methods for removing bee venom from the bees, such as surgically removing the sting or applying pressure to the bee's abdomen until a drop of venom emerges from the sting. Electroshock extraction has been increasing in popularity since the early 1960s and is now the standard method. By touching wires covered in a tiny wire mesh that allows low-voltage electric current discharges (20–30 volts) to pass through, the bees are stimulated to release venom. The venom is then periodically collected from a glass plate underneath the wires, for example, every ten minutes. Within an hour or two, 10,000 stings yield one gram of venom.

Markovic and Mollnar were the first to describe this electroshock extraction technique (1954). This is safe for the bees because they are not hurt during the process. After three hours of harvesting, 150 milligrams of honeybee venom can be extracted. One gram of venom may be extracted from twenty hives in two hours. If bee venom is collected three to four times a month for three hours between April and October, four grams of dried bee venom can be obtained. A 10% to 15% drop in brood activity and honey output is the cost, though. Less frequent harvesting (three to four times per season) has little effect on bee productivity (Bava *et al.*, (2023)).

Limitations in the Use of Bee Venom Therapy

There are reports of allergic responses and adverse side effects in roughly 28% of persons, despite the bee venom's enormous promise and utility in treating a wide range of human and veterinary illnesses. The negative effects of bee venom can range from minor skin reactions that go away in a few days to severe anaphylactic reactions that can be lethal. Immunological systemic reactions, localized swelling or itching, allergies, discomfort, skin issues, and nonspecific reactions are some examples of these side effects. Hemolysis, Guillain-Barré syndrome, acute anaphylactic shock, and irreparable ulnar nerve damage are further possible outcomes. Hypersensitivity, chronic local inflammation, frequency of bee administration, and venom concentration may all contribute to the negative consequences of bee venom (Bava *et al.*, (2023); Khalil *et al.*, (2021)).

Before using bee venom therapy, precautions should be taken. Women who are pregnant or nursing, as well as those who have diabetes or other sensitive medical conditions, should not take it. The persons extreme bee venom allergies should not be treated with it; instead, a smaller dose of the venom should be administered to the patient 24 hours before the procedure to check the tolerance of the patient to the venom. A qualified expert or an experienced doctor must administer bee venom therapy.

Conclusion

The biological and pharmacological actions of bee venom and its constituents are diverse. Apitherapists have used it in therapeutic settings to treat a variety of illnesses. It is currently offered in markets in a variety of forms and has been licensed for use in human therapy in several nations. For the treatment of several illnesses, bee venom shows promise as a medication or adjuvant. It is very appealing for lowering the use of traditional medications and related drug-resistance issues because of its antibacterial, antiviral, and anti-parasitic properties. Furthermore, as this comprehensive dissertation on its anti-inflammatory, anti-tumor, etc., qualities demonstrates, its treatment for one illness can also have beneficial effects for other concomitant disorders. Its use in a therapeutic context must undoubtedly adhere to meticulous efficacy studies that seek to identify the optimal dosages for achieving the pharmacological response while avoiding the negative consequences of its use. To ascertain a deliberate and successful application of bee venom in veterinary clinical practice, clinical trials must be conducted after the already extensive in vitro research, much as in human medicine.

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Sustainable Urdbean Production in Changing Climatic Conditions

Article ID: 71108

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Introduction

Urd bean (*Vigna mungo*), also known as black gram, is one of the most important pulse crops cultivated in South Asia, especially in India. It serves as a rich source of protein and plays a vital role in the diets of millions. Additionally, it enhances soil health through biological nitrogen fixation, making it valuable for sustainable agriculture. However, the increasing variability of climate—marked by rising temperatures, irregular rainfall, and increased occurrence of extreme weather events—poses a serious threat to its productivity and stability. Developing sustainable strategies for urd bean production has become critical to ensure food security and farmers' livelihoods.

Impact of Climate Change on Urd Bean Cultivation

Climate change affects urd bean production in multiple ways:

Temperature Stress: Urd bean is sensitive to temperature extremes. Higher daytime temperatures can reduce flower initiation and increase flower drop, thereby reducing yields.

Rainfall Variability: Uneven distribution of rainfall can cause water stress during flowering and pod filling stages or lead to waterlogging, both of which significantly affect yield.

Pest and Disease Incidence: Warmer and more humid conditions promote the proliferation of pests like whitefly, aphids, and diseases such as yellow mosaic virus.

Soil Degradation: Erratic weather patterns contribute to soil erosion, nutrient depletion, and loss of organic matter, all of which reduce soil productivity.

Climate-Resilient Farming Practices

To mitigate these challenges, climate-resilient practices must be integrated into urd bean production systems. Some effective strategies include:

Use of Climate-Resilient Varieties: Developing and adopting Urd bean varieties that are tolerant to drought, heat, and diseases is essential. Varieties such as IPU 2-43, Pant U-19, and T-9 have shown better adaptability under climate stress conditions.

Improved Agronomic Practices:

- a. **Timely Sowing:** Adjusting sowing time to avoid peak heat or rainfall periods can minimize stress.
- b. **Seed Treatment:** Treating seeds with fungicides and biofertilizers enhances seedling vigor and reduces disease incidence.
- c. **Intercropping:** Intercropping urd bean with cereals like maize or millets can stabilize income and reduce pest pressure.

Soil and Water Conservation:

- a. **Mulching:** Conserves soil moisture, suppresses weeds, and regulates soil temperature.
- b. **Reduced Tillage:** Helps retain soil moisture and organic matter.
- c. **Water Harvesting and Micro-Irrigation:** Use of drip or sprinkler irrigation ensures efficient water use, particularly in dry areas.

Integrated Pest and Disease Management (IPDM): In the face of increasing pest pressures due to climate change, integrated pest management becomes crucial. IPDM practices include:

- a. **Use of resistant varieties**

b. Regular monitoring of pest populations**c. Biological control** using natural predators like ladybird beetles**d. Judicious use of chemical pesticides** only when pest levels exceed economic thresholds.

Nutrient Management for Resilience: Balanced fertilization is key to building resilient crop systems. The use of farmyard manure, compost, and biofertilizers like *Rhizobium* and *PSB* (*Phosphate Solubilizing Bacteria*) enhances soil fertility and supports better root development. Micronutrients such as zinc and boron should also be applied based on soil testing.

Role of Technology and Extension Services

Digital tools and extension services can enhance farmers' capacity to respond to climatic challenges:

1. Weather Forecasting Apps: Timely weather updates help farmers plan irrigation, pesticide application, and harvesting.

2. Mobile-based Advisory Services: Provide information on best practices, pest alerts, and government schemes.

3. Farmer Field Schools (FFS): Promote learning through experience and peer support.

Policy Support and Institutional Interventions

Sustainable urd bean production in changing climates also requires strong institutional support:

1. Research and Development: More investment in breeding climate-resilient varieties and sustainable farming systems.

2. Credit and Insurance: Easy access to credit and crop insurance can help farmers cope with climate-induced crop failures.

3. Subsidies for Climate-Smart Inputs: Support for drip irrigation, mulching, and biofertilizers encourages adoption.

Conclusion

The sustainability of urd bean production under changing climatic conditions depends on a combination of scientific innovations, farmer awareness, and supportive policies. By integrating resilient varieties, resource-conserving practices, efficient water use, and effective pest management, farmers can maintain productivity and safeguard their income. A collaborative approach involving researchers, extension workers, policymakers, and farmers is essential to build climate-resilient urd bean production systems. This not only ensures food and nutritional security but also contributes to environmental sustainability in the long term.

Bio-Input Resource Centres for Natural Farming

Article ID: 71109

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Abstract

Natural farming is emerging as a cost-effective, environmentally friendly, and sustainable alternative to traditional chemical farming. One of the most critical elements of this revolution is the creation of Bio-Input Resource Centres (BRCs), which are local centres for natural input production, demonstration, and distribution. The article discusses the notion, objectives, elements, and importance of BRCs in upholding natural farming throughout India, particularly in the context of govt. initiatives such as Bharatiya Prakritik Krishi Paddhati (BPKP). Incorporating BRCs into the rural agricultural economy will be key to minimalizing reliance on outside inputs, improving soil quality, and achieving long-term sustainability.

Introduction

Traditional farming practices have resulted in environmental degradation, erosion of soil nutrients, rising costs of inputs, and indebtedness of farmers. To counter this, natural farming has been put forward as a viable alternative based on low-cost, local resources and a balance with nature. Bio-inputs like Jeevamrit, Beejamrit, and Ghanjeevamrit are the pillars of natural farming. For the sake of availability and quality of these bio-inputs, the Government of India and state agricultural departments have promoted the establishment of Bio-Input Resource Centres (BRCs).

These centres play a vital role in supporting self-sufficient farming by offering training, input material, and technical advice. They also act as hubs of knowledge for farmers who are converting from chemical to natural farming.

What is a Bio-Input Resource Centre (BRC)?

A Bio-Input Resource Centre is a village-level, decentralized infrastructure established to produce and supply biological inputs for natural farming. These centres are operated by trained staff, Farmer Producer Organizations (FPOs), Self Help Groups (SHGs), or Krishi Vigyan Kendras (KVKs). A standard BRC includes input preparation, storage, packaging, and capacity-building facilities.



Source: <https://orissafoundation.org/>

Key Bio-Inputs Produced at BRCs

- 1. Jeevamrit:** Fermented microbial culture prepared from cow dung, cow urine, jaggery, pulse flour, and soil.
- 2. Beejamrit:** Seed treatment solution against seed diseases.
- 3. Ghanjeevamrit:** Solid microbial inoculum, a substitute for Jeevamrit for arid areas.
- 4. Agniastra, Neemastra, Brahmastra:** Indigenous pest repellents.

Objectives of BRCs

1. To arrange quality bio-inputs on time for natural farming.
2. To function as training and demonstration centers for farmers.
3. To facilitate the generation of employment opportunities through input production and value chains.
4. To enhance self-sufficiency in managing agricultural inputs at the village level.
5. To contribute to the reduction of reliance on synthetic fertilizers and pesticides.

Organization and Working of BRCs

1. Infrastructure: A typical Bio-Input Resource Centre (BRC) is provided with basic facilities to sustain the production and distribution of natural farming inputs. It has input production units in the form of fermentation tanks and drying sheds for the production of Jeevamrit, Beejamrit, and Ghanjeevamrit. Special room for packing and storage helps in proper handling and keeping of bio-inputs. Training halls are provided to carry out farmer workshops and demonstrations. The centre is backed by stable water and electric supply to ensure uninterrupted functioning. Also, there can be a laboratory for testing the quality of inputs for ensuring consistency, safety, and effectiveness in encouraging sustainable agricultural practices in some BRCs.

2. Capacity Building: Capacity building is one of the primary roles of Bio-Input Resource Centres (BRCs) for empowering farmers with the required knowledge and skills for natural farming. BRCs periodically conduct training programs, workshops, and field demonstrations to train farmers in the preparation and proper utilization of bio-inputs like Jeevamrit and Beejamrit. The natural means of pest and disease management also come under these training programs, which help create ecological balance. Farmers are also trained in monitoring soil health and measures to improve soil fertility in an eco-friendly manner. Through hands-on exposure and specialized mentoring, BRCs enhance farmers' self-sufficiency and promote the extensive usage of sustainable agriculture practices.

3. Management and Operation: The management and operation of Bio-Input Resource Centres (BRCs) are generally carried out by grassroots and institutional organizations to ensure thorough implementation and community involvement. Farmer Producer Organizations (FPOs) and cooperatives are frequently responsible for BRC operation, with contributions from community involvement and collective responsibility. Non-Governmental Organizations (NGOs) and Self Help Groups (SHGs) also perform a crucial role in mobilizing farmers and sustaining day-to-day activities. Krishi Vigyan Kendras (KVKs) and State Agricultural Universities ensure technical assistance, training, and research-backed advice. This inter-dependent model enables smooth operations, maximizes farmer outreach, and combines scientific expertise with traditional knowledge in order to develop natural farming at the grassroots level.

Benefits of Bio-Input Resource Centres:

Benefits	Details
Economic	Reduces cost of cultivation; improves farmer income
Ecological	Improves soil fertility and microbial activity; conserves biodiversity
Social	Enhances local employment and entrepreneurship
Educational	Acts as a hub for farmer training and community knowledge sharing
Institutional	Promotes cooperative models and farmer-led organizations

Government Policies and Support Measures:

- a. BRCs are being encouraged all over the country under the Paramparagat Krishi Vikas Yojana (PKVY) and Bharatiya Prakritik Krishi Paddhati (BPKP).

- b. The National Mission on Sustainable Agriculture (NMSA) also facilitates the establishment of natural input production infrastructure.
- c. The Indian Council of Agricultural Research (ICAR) and the state departments of agriculture are mainstreaming BRCs into extension services, ensuring technical and scientific verification and support.

Implementation Challenges: In spite of their potential, BRCs encounter a number of challenges:

- a. Lack of awareness among farmers regarding the benefits of bio-inputs.
- b. Lack of proper training and qualified manpower.
- c. Logistical issues in rural areas.
- d. Lack of certification or quality control systems.
- e. A resistance phase from chemically reliant farmers.

4. Methods of Increasing the Strength of BRCs: Increasing the effectiveness and coverage of Bio-Input Resource Centres (BRCs) requires a multi-faceted strategy. First, training and awareness campaigns need to be organised frequently to inform farmers about the advantages and methods of natural farming. Field demonstrations and neighbourhood-based training modules can instill confidence and promote adoption at the local level.

Secondly, fiscal support is essential for BRC sustainability. Government subsidies, grants, and microfinance programs must be extended to Self Help Groups (SHGs) and Farmer Producer Organizations (FPOs) operating these centres so that they can purchase equipment, raw materials, and infrastructure.

Monitoring and quality assurance systems can be put in place by creating standards for input quality with specificity and establishing laboratories for frequent testing. This helps in ensuring farmer confidence and reliability in results.

Incorporating digital platforms can greatly enhance efficiency. Digital tools and mobile apps can be employed to track inventory, organize training, monitor the production of bio-inputs, and collect farmer feedback.

Finally, policy backing and scaling-up are needed. BRC development must be incorporated into district-level agricultural planning and integrated with other rural development schemes such as MNREGA, NRLM, and RKVY in order to provide resource convergence and extensive implementation, thereby supporting sustainable and self-reliant farming communities

Conclusion

Bio-Input Resource Centres (BRCs) play a vital role in promoting the natural farming movement throughout India. BRCs empower farmers by offering affordable, environmentally friendly, and locally accessible substitutes for chemical inputs. With appropriate implementation of BRCs, India can make rapid strides towards sustainable agriculture, rural self-sufficiency, and healthier soils. Technical, financial, and policy interventions for strengthening BRCs are essential to realize a future-ready farming system that is harmonized with ecological equilibrium and food security.

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Ohmic Heating: A Revolutionary Technology in Food Processing

Article ID: 71110

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Introduction

Ohmic heating, also known as Joule heating, is an advanced thermal processing technique that has gained significant traction in the food industry due to its ability to provide rapid, uniform and energy-efficient heating. Unlike conventional heating methods, which rely on external heat transfer mechanisms such as conduction, convection, or radiation, ohmic heating generates heat internally within the food product by passing an alternating electrical current through it. This method is particularly effective for liquid and semi-solid foods, as it minimizes thermal gradients and preserves the nutritional and sensory qualities of the product (Aurina and Sari, 2022).

Historical Development of Ohmic Heating

The concept of ohmic heating dates to the 19th century when James Prescott Joule discovered that electrical resistance generates heat. The technology was first commercialized in the early 20th century for milk pasteurization, but its adoption was limited due to high energy costs and technological constraints. However, with advancements in materials and design in the 1980s, ohmic heating was reintroduced and has since been widely adopted for various food processing applications, including sterilization, pasteurization and thawing (Icier, 2012).

Principles of Ohmic Heating

Ohmic heating operates on the principle of Joule's law, where heat is generated when an electrical current passes through a conductive material (as shown in fig.1). The amount of heat produced is proportional to the square of the current, the resistance of the material, and the duration of the current flow. Mathematically, this relationship is expressed as:

$$Q = I^2 \cdot R \cdot t$$

Where,

Q = Heat generated

I = Current

R = Electrical resistance and

t = Time.

The electrical conductivity of the food material plays a crucial role in the efficiency of ohmic heating. Foods with high ionic content, such as those containing salts or acids, exhibit higher conductivity and are more suitable for this technology (Alkanan *et al.*, 2021).

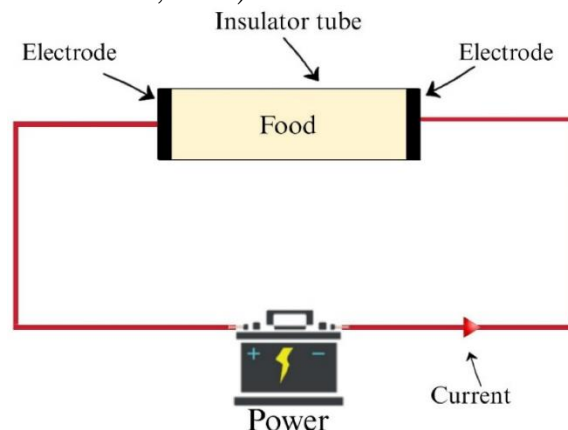


Fig.1. Schematic diagram of Ohmic heating

Applications in the Food Industry

Ohmic heating has been successfully applied in various food processing operations, including:

- 1. Pasteurization and sterilization:** Ohmic heating is widely used for the pasteurization and sterilization of liquid foods such as milk, fruit juices and soups. It is particularly effective for products containing large particulates, which are difficult to sterilize using conventional methods.
- 2. Thawing and blanching:** Ohmic heating offers a rapid and uniform thawing process for frozen foods, reducing moisture loss and preserving product quality. It is also used for blanching vegetables, where it minimizes solute leaching and enhances moisture retention.
- 3. Fermentation:** Ohmic heating has been applied in fermentation processes, such as in the production of cocoa and coffee products. The technology allows for precise temperature control, which is critical for optimizing microbial activity and enzyme stability during fermentation.
- 4. Extraction:** Ohmic heating is used for the extraction of bioactive compounds, such as pectin from orange waste and anthocyanins from black rice bran. The rapid heating process improves extraction efficiency and yield compared to conventional methods (Aurina and Sari, 2022).

Advantages of Ohmic Heating

- 1. Uniform heating:** Ohmic heating ensures uniform temperature distribution throughout the product, which is particularly beneficial for foods containing particulates. This uniformity reduces the risk of overcooking or undercooking, which is common in conventional heating methods.
- 2. Energy efficiency:** Ohmic heating converts electrical energy directly into thermal energy with minimal losses, achieving energy efficiency rates of up to 90 %. This makes it a more sustainable option compared to traditional heating methods.
- 3. Preservation of quality:** The rapid heating process minimizes the degradation of heat-sensitive nutrients, such as vitamins and antioxidants, and preserves the texture, colour, and flavour of the food. For example, ohmic heating has been shown to retain up to 90 % of vitamin C in fruit juices, compared to significant losses observed in conventional pasteurization.
- 4. Reduced processing time:** Ohmic heating can achieve high temperatures in a short time, making it ideal for sterilization and pasteurization processes. This reduces overall processing time and enhances productivity (Kaur and Singh, 2016).

Disadvantages of Ohmic Heating

- 1. Limited to conductive foods:** Ineffective for non-conductive materials like fats and oils.
- 2. Variable conductivity:** Heating efficiency depends on food composition, temperature and particle size.
- 3. Cold spots:** Difficulty in ensuring uniform heating, risking microbial survival.
- 4. High costs:** Expensive equipment and maintenance limit accessibility (Kaur and Singh, 2016).

Conclusion

Ohmic heating represents a significant advancement in thermal processing technology, offering a unique combination of rapid heating, energy efficiency and product quality preservation. As research continues to address the existing challenges, this technology has the potential to revolutionize the food industry, providing more sustainable and efficient processing methods. By combining the principles of electrical resistance, ohmic heating not only meets the demands of modern consumers for high-quality products but also aligns with the global push toward greener and more sustainable industrial practices.

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Role of UAV Integrated with Machine Learning in Agriculture

Article ID: 71111

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Introduction

Unmanned Aerial Vehicles (UAVs), when integrated with machine learning (ML) architectures, are revolutionizing modern agriculture by enabling precision farming, increasing yields, reducing costs, and promoting sustainability. An agricultural drone is an unmanned aerial vehicle used in agriculture operations, mostly in yield optimization and in monitoring crop growth and crop production. Agricultural drones provide information on crop growth stages, crop health, and soil variations.

Data Collection by UAVs

UAVs serve as powerful platforms for collecting high-resolution, real-time data using various sensors:

- 1. RGB Cameras** – Visual imaging for general crop monitoring. It depicts red, blue and green bands.
- 2. Multispectral & Hyper spectral Sensors** – Detect crop health by capturing data beyond human vision (e.g., chlorophyll levels).
- 3. Thermal Cameras** – Monitor irrigation levels, stress, and soil moisture.
- 4. LiDAR** – Generate 3D terrain and crop structure maps.
- 5. GPS & Inertial Sensors** – Ensure precise geo-tagging and mapping.

The multispectral RGB camera is given below in Fig 1.1:



Fig 1.1 Multispectral RGB camera

Role of Machine Learning in Analyzing UAV Data

The digital transformation of agriculture has evolved various aspects of management into artificial intelligent systems for the sake of making value from the ever-increasing data originated from numerous sources. A subset of artificial intelligence, namely machine learning, has a considerable potential to handle numerous challenges in the establishment of knowledge-based farming systems. The present study aims at shedding light on machine learning in agriculture by thoroughly reviewing the recent scholarly literature based on keywords' combinations of "machine learning" along with "crop management", "water management", "soil management", and "livestock management" Machine learning algorithms process and interpret UAV-collected data to derive actionable insights:

1. Crop Health Monitoring:

a. ML Models Used: CNNs (Convolutional Neural Networks), SVMs, Decision Trees

b. Applications: Classify crop health, detect diseases, and quantify nutrient deficiencies from multispectral imagery.

2. Weed and Pest Detection:

a. ML Models Used: YOLO, Faster R-CNN, Random Forests

b. Applications: Identify and locate weeds or pest infestations for targeted pesticide application.

3. Yield Prediction:

a. ML Models Used: Regression models, LSTMs (for time-series data)

b. Applications: Predict future yields based on current and historical data such as canopy size, NDVI, and growth trends.

4. Soil and Irrigation Analysis:

a. ML Models Used: K-Means Clustering, SVMs

b. Applications: Classify soil types, determine moisture levels, and optimize irrigation schedules using thermal and spectral imaging.

5. Crop Type Classification:

a. ML Models Used: Random Forest, CNNs, k-NN

b. Applications: Identify different crop types in large agricultural fields.

The figure given below is an example of application of machine learning using drone in agriculture. Smart Agriculture Drone for Crop Spraying Using Image-Processing and Machine Learning Techniques.

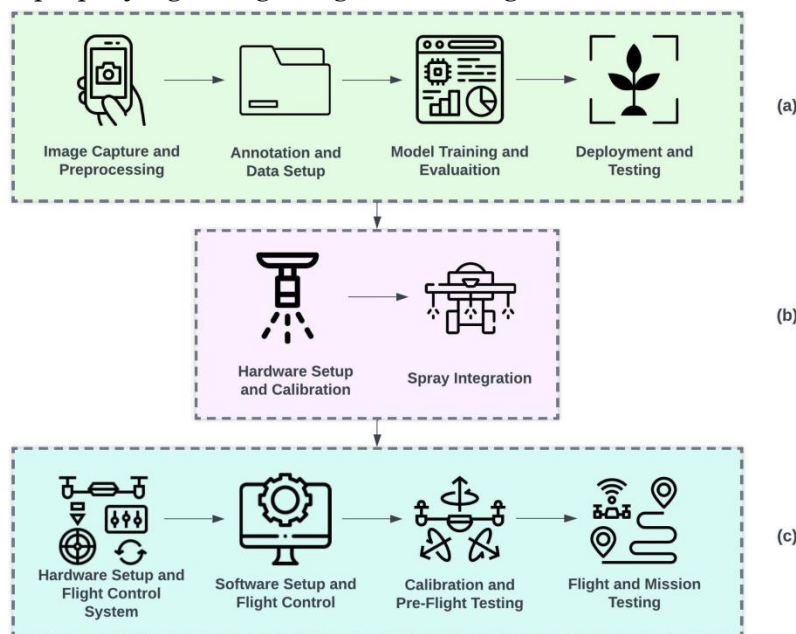


Fig 1.2 Smart Agriculture Drone for Crop Spraying Using Image-Processing and Machine Learning Techniques

Advantages of UAV + ML in Agriculture

- 1. Precision Agriculture:** Targeted interventions reduce input waste and environmental impact.
- 2. Early Problem Detection:** Spot issues like disease or water stress before they become widespread.
- 3. Labor Efficiency:** Reduces the need for manual scouting and sampling.
- 4. Scalability:** Enables monitoring of large and inaccessible areas quickly.
- 5. Cost-Effectiveness:** Minimizes unnecessary treatments and boosts productivity.

Real-World Use Cases

- 1. Vineyards:** UAVs assess grape ripeness and disease levels; ML predicts harvest time.
- 2. Rice Fields:** UAV imagery processed by ML models detects nitrogen deficiencies.
- 3. Wheat and Corn Farms:** Combine multispectral UAV imagery with ML for yield forecasting.

Challenges and Considerations

- 1. Data Quality:** Inaccurate or low-resolution data can reduce model performance.
- 2. Model Generalization:** Models may not transfer well between regions or crop types.
- 3. Infrastructure:** Requires robust data processing infrastructure (edge computing or cloud).

4. Regulations: UAV flight regulations vary by country and can limit deployment.

Conclusion

The synergy between UAVs and machine learning brings a data-driven transformation to agriculture. By automating data collection and analysis, this combination empowers farmers with timely, accurate, and actionable insights, helping ensure food security while optimizing resource usage.

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Signal Pathways in Nematophagous Fungi-Nematode Interactions: Implications for Biocontrol

Article ID: 71112

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Introduction

The interaction between nematophagous fungi and nematodes is a complex process involving various signal pathways that play crucial roles in the biocontrol of plant parasitic nematodes. This interaction is crucial for controlling nematode populations in the soil, especially in a cropping system involving field and vegetable crops. Many plants parasitic nematodes, such as *Meloidogyne* (root-knot nematodes), *Heterodera* (cyst nematodes), and *Pratylenchus* (lesion nematodes), cause significant crop damage resulting in significant yield losses. This article explores the key signaling mechanisms involved in these interactions and their potential implications for developing effective bio-control strategies offering a sustainable and environmentally friendly alternative to chemical nematicides.

Recognition and Attraction

The initial step in the nematophagous fungi-nematode interaction involves the recognition and attraction of nematodes by fungi. This process is mediated by chemotaxis, where fungi produce and secrete specific compounds that attract nematodes. Research has shown that nematophagous fungi can detect nematode-specific ascarosides, which are pheromones produced by nematodes for communication. The perception of these ascarosides triggers the production of trap structures in fungi, such as adhesive nets or constricting rings.

Example: *Arthrobotrys oligospora* produces specific compounds that attract *Caenorhabditis elegans* nematodes. The fungus detects ascarosides secreted by *C. elegans*, triggering the formation of adhesive nets.

Recent studies have identified several key genes involved in the chemotaxis process, including G-protein-coupled receptors (GPCRs) and their associated signaling components. These receptors are thought to play a crucial role in detecting nematode-derived signals and initiating the appropriate fungal response. Additionally, the production of trap structures is regulated by complex genetic networks, involving genes related to hyphal morphogenesis and cell wall remodeling.

Adhesion and Penetration

Once the nematode comes into contact with the fungal structures, adhesion molecules play a crucial role in establishing a firm connection. Lectins, a class of carbohydrate-binding proteins, have been identified as key players in this process. The fungal cell wall contains specific lectins that recognize and bind to glycoproteins on the nematode cuticle, facilitating adhesion.

Example: *Drechlerella stenobrocha* produces lectins that bind to glycoproteins on the cuticle of *Meloidogyne incognita* nematodes. The fungus then secretes serine proteases to degrade the nematode cuticle.

Following adhesion, the fungi initiate the penetration process. This involves the secretion of hydrolytic enzymes, such as proteases, chitinases, and lipases, which degrade the nematode cuticle. The production and secretion of these enzymes are regulated by complex signaling cascades, including mitogen-activated protein kinase (MAPK) pathways and cAMP-dependent protein kinase A (PKA) signaling.

Recent research has focused on identifying the specific enzymes involved in cuticle degradation and their regulation. For example, studies have shown that certain serine proteases and subtilisin-like proteases are upregulated during the infection process. Furthermore, the role of transcription factors, such as those belonging to the zinc finger family, in coordinating the expression of these hydrolytic enzymes has been elucidated.

Host Defense Response

As the fungi attempt to penetrate the nematode, the host activates various defense mechanisms. This includes the production of antimicrobial peptides, reactive oxygen species (ROS), and the activation of innate immune responses. The nematode's immune system recognizes pathogen-associated molecular patterns (PAMPs) from the fungi, triggering signaling cascades that lead to the expression of defense-related genes.

Example: When infected by *Purpureocillium lilacinum*, *Meloidogyne javanica* nematodes activate Toll-like receptors, leading to the production of antimicrobial peptides and reactive oxygen species.

Recent studies have shed light on the molecular mechanisms underlying the nematode's immune response. For instance, the role of pattern recognition receptors (PRRs) in detecting fungal PAMPs has been investigated. These PRRs, including C-type lectin receptors and Toll-like receptors, initiate signaling cascades that lead to the activation of transcription factors such as NF- κ B and AP-1, which regulate the expression of immune-related genes.

Additionally, the importance of the unfolded protein response (UPR) in nematode defense against fungal infection has been highlighted. The UPR is activated in response to cellular stress and plays a crucial role in maintaining cellular homeostasis during infection.

Fungal Virulence Factors

Nematophagous fungi produce an array of virulence factors to overcome the host's defenses and successfully colonize the nematode. These include toxins, effector proteins, and secondary metabolites. The production of these virulence factors is often regulated by quorum sensing mechanisms and global regulators such as velvet proteins.

Example: *Pochonia chlamydosporia* secretes small proteins called VCP1 (*Verticillium chlamydosporium* protease 1) that suppress the immune response of *Globodera pallida* nematodes.

Recent research has focused on identifying and characterizing novel virulence factors in nematophagous fungi. For example, studies have revealed the presence of small secreted proteins (SSPs) that act as effectors, modulating the host's immune response and facilitating fungal colonization. The role of secondary metabolites, such as nematicidal compounds, in the infection process has also been extensively studied.

Furthermore, the regulation of virulence factor production has been a subject of intense research. The involvement of epigenetic mechanisms, such as histone modifications and DNA methylation, in controlling the expression of virulence-related genes has been demonstrated in several nematophagous fungi species.

Nutrient Acquisition and Metabolism

Once inside the nematode, the fungi must acquire nutrients for growth and reproduction. This process involves the activation of nutrient sensing pathways, such as the Target of Rapamycin

(TOR) signaling pathway, which regulates cellular metabolism and growth in response to nutrient availability.

Example: During infection of *Heterodera glycines*, *Hirsutella minnesotensis* upregulates genes involved in amino acid catabolism and activates its siderophore-mediated iron acquisition system.

Recent studies have focused on elucidating the specific mechanisms by which nematophagous fungi adapt their metabolism to utilize nematode-derived nutrients. For instance, the upregulation of genes involved in amino acid catabolism and lipid metabolism has been observed during the infection process. Additionally, the role of autophagy in nutrient recycling and fungal survival within the host has been investigated.

The importance of iron acquisition in fungal virulence has also been highlighted. Nematophagous fungi have been shown to possess sophisticated iron uptake systems, including siderophore-mediated iron acquisition, which are crucial for their growth and pathogenicity.

An overview of the key signal pathways in nematophagous fungi-nematode interactions, along with examples of fungi that utilize these pathways in biocontrol.

Signal Pathway	Key Molecules Involved	Function in Fungal-Nematode Interaction	Examples of Fungi	Implications for Biocontrol
Chemotaxis and Host Recognition	G-protein coupled receptors (GPCRs), cyclic AMP (cAMP)	Fungi use these pathways to sense and move towards nematode attractants.	<i>Arthrobotrys oligospora</i>	Fungi can specifically locate and track nematodes for predation.
Conidiation and Spore Release	cAMP, MAPK signaling pathways, fungal growth regulators	Activation of conidiation (spore formation) in response to environmental cues.	<i>Dactylella bembeciformis</i>	Increased spore production improves the ability of fungi to spread and infect nematodes.
Extracellular Enzyme Secretion	Serine proteases, chitinases, lipases, and cellulases	Fungi secrete enzymes to break down nematode cuticles or digestive systems.	<i>Pochonia chlamydosporia</i> , <i>Basinia</i> sp.	Enzyme production helps fungi penetrate and immobilize nematodes, enhancing control efficacy.
Pathogenicity and Infection	MAPK pathway, cAMP signaling, secreted effectors	Activation of genes responsible for penetration and parasitism.	<i>Monacrosporium</i> spp., <i>Verticillium chlamydosporium</i>	These pathways are critical for establishing infection and controlling nematode populations.
Fungal Immune Response	JAK/STAT pathway, MAPK pathways	Helps the fungi resist environmental stress and host defenses during parasitism.	<i>Basinia species</i>	Improves fungal survival in hostile environments, such as within nematode bodies or soil.
Mycoparasitism and Predation	Calmodulin-dependent pathways, nitric oxide (NO) signaling	Mediates fungal predation of nematodes, often through specialized hyphal structures like traps.	<i>Arthrobotrys oligospora</i> , <i>dactyloides</i> A.	Enables direct capture and immobilization of nematodes, contributing to effective bio-control.
Fungal-Plant Interactions	Salicylic acid, jasmonic acid, ethylene, auxins	Fungi can affect plant growth and resistance, indirectly aiding in bio-control by	<i>Pochonia chlamydosporia</i>	Enhances plant growth and resistance, reducing nematode damage to crops.

		improving plant health.		
Nutrient Signaling	Nitrogen and carbon metabolism pathways, AMPK signaling	Involves nutrient sensing for optimal growth in environments where nematodes are present.	<i>Trichoderma</i> spp.	Facilitates efficient use of nutrients, improving fungal growth and efficacy in nematode biocontrol

Implications for Biocontrol

Understanding the signal pathways involved in nematophagous fungi-nematode interactions has significant implications for developing effective bio-control strategies against plant parasitic nematodes:

1. Enhanced trap formation: Manipulating signaling pathways involved in trap formation could lead to the development of more efficient nematophagous fungi strains with improved trapping abilities. This could involve genetic engineering approaches to overexpress key genes involved in trap formation or modifying regulatory elements to enhance their expression under specific environmental conditions.

2. Improved adhesion and penetration: Targeting genes involved in adhesion molecule production and hydrolytic enzyme secretion could enhance the fungi's ability to capture and penetrate nematodes. This might include developing fungal strains with increased expression of specific lectins or optimizing the secretion of cuticle-degrading enzymes.

3. Overcoming host defenses: Developing strategies to modulate the nematode's immune response or enhance the fungi's ability to overcome host defenses could improve bio-control efficacy. This could involve engineering fungi to produce immunomodulatory compounds or developing approaches to suppress specific nematode defense pathways.

4. Optimized virulence: Engineering fungi with enhanced production of virulence factors could lead to more effective nematode control. This might include overexpressing genes encoding nematocidal compounds or modifying regulatory networks to increase the production of effector proteins.

5. Efficient nutrient utilization: Improving the fungi's ability to acquire and metabolize nutrients from nematodes could enhance their growth and reproduction, leading to better bio-control performance. This could involve optimizing nutrient sensing pathways or enhancing the expression of genes involved in nutrient uptake and metabolism.

Conclusion

The intricate signal pathways involved in nematophagous fungi-nematode interactions offer numerous opportunities for enhancing bio-control strategies against plant parasitic nematodes. By targeting specific signaling mechanisms, researchers can develop more effective and sustainable approaches to manage nematode populations in agricultural systems. Further research into these complex interactions will undoubtedly reveal new targets for intervention and lead to the development of innovative bio-control strategies. As our understanding of the molecular mechanisms underlying these interactions deepens, we can expect to see the emergence of more sophisticated and efficient bio-control agents that can effectively manage plant parasitic nematode populations while minimizing environmental impacts. The signaling pathways and mechanisms elucidated in this system may provide valuable insights into similar processes in other pathogenic fungi, potentially leading to new strategies for crop protection and disease management. In conclusion, the continued exploration of the signal pathways involved in nematophagous fungi-nematode interactions holds great promise for advancing our understanding of microbial ecology, host-pathogen relationships, and the development of sustainable agricultural practices.

Comprehensive Guide to Biofertilizers: Formulations, Applications, and Usage Guidelines

Article ID: 71113

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Sustainable agriculture relies more on innovative nutrient management approaches that reduce environmental effects while preserving crop yield. Chemical fertilizers, although proven effective over time, have generated major ecological issues related to soil degradation, water contamination, and greenhouse gas emissions (Tilman *et al.*, 2002; Foley *et al.*, 2011). In this scenario, biofertilizers present a promising option, utilizing microbial technologies to improve nutrient accessibility and soil vitality. Biofertilizers are living microorganisms that enhance plant growth via various mechanisms, such as biological nitrogen fixation, phosphorus solubilization, and the production of phytohormones (Glick, 2012). Thirteen distinct biofertilizer types target specific crop nutritional requirements, offering advantages including reduced chemical fertilizer dependency, improved stress tolerance, and increased crop yields. Applied through methods such as seed treatment, soil inoculation, and foliar sprays, biofertilizers represent a sustainable approach to agricultural nutrient management, promoting ecological balance and crop productivity without environmental degradation. For example, studies have shown that *Rhizobium* bacteria form symbiotic relationships with leguminous plants, enabling nitrogen fixation essential for plant growth and soil fertility (Zahran, 1999). Another example is *Azospirillum* species, known to enhance root growth and nutrient absorption in crops like maize and wheat (Silva *et al.*, 2022).

Types and Classification of Biofertilizers

1. Rhizobium-Based Biofertilizers:

a. Product Name Examples: Rhizogold, Bio-Rhiz, Green Rhizobium.

b. Microorganism: *Rhizobium* spp.

c. Suitable Crops: Leguminous crops like pulses (e.g., chickpea, lentil, mung bean, pea), soybean, groundnut, and clover.

d. Function: *Rhizobium* forms symbiotic associations with the roots of leguminous plants. The bacteria convert atmospheric nitrogen into ammonia, which plants can absorb, leading to enhanced nitrogen content and improved crop yield. Rhizobium biofertilizers are crucial for legumes that are heavy nitrogen consumers.

2. Azotobacter-Based Biofertilizers:

a. Product Name Examples: Azogreen, AzotoPower, Bio-Azoto.

b. Microorganism: *Azotobacter* spp.

c. Suitable Crops: Non-leguminous crops such as cereals (wheat, maize, rice), vegetables, and cash crops like cotton, sugarcane, and tobacco.

d. Function: As a free-living nitrogen-fixing bacterium, *Azotobacter* does not require a symbiotic relationship to fix atmospheric nitrogen, making it versatile for various non-leguminous crops. It also produces growth-promoting substances like auxins, which support root development and overall growth.

3. Azospirillum-Based Biofertilizers:

a. Product Name Examples: Azospir, Green Azospirillum.

b. Microorganism: *Azospirillum* spp.

c. Suitable Crops: Cereal crops such as rice, maize, wheat, sorghum, and millets.

d. Function: *Azospirillum* associates with the roots of grasses and cereals, enhancing nitrogen availability and promoting root growth by producing phytohormones. This biofertilizer improves yield by enhancing nutrient uptake and resistance to stress.

4. Phosphate-Solubilizing Bacteria (PSB):

- a. **Product Name Examples:** PhosphoPower, PSB Plus, Eco-PSB.
- b. **Microorganism:** *Bacillus megaterium*, *Pseudomonas striata*
- c. **Suitable Crops:** Suitable for most crops, including cereals, pulses, oilseeds, fruits, vegetables, and ornamental plants.
- d. **Function:** PSBs secrete organic acids that solubilize the otherwise insoluble phosphate compounds in the soil, making phosphorus available to plants. This is especially beneficial in phosphorus-deficient soils, where it can significantly boost root development and plant growth.

5. Potassium-Solubilizing Bacteria (KSB):

- a. **Product Name Examples:** K Solubilizer, K-Bio, Bio-K.
- b. **Microorganism:** *Frateriia aurantia*
- c. **Suitable Crops:** Suitable for crops like cereals, pulses, sugarcane, cotton, and vegetables.
- d. **Function:** Potassium-solubilizing bacteria release potassium by breaking down potassium-containing minerals, making it available to plants. Potassium is essential for improving drought tolerance, enzyme activation, and disease resistance.

6. Mycorrhizal Biofertilizers (VAM – Vesicular-Arbuscular Mycorrhiza):

- a. **Product Name Examples:** MycoRhiz, VAM Bio, MycorPower.
- b. **Microorganism:** *Glomus spp.*, *Acaulospora spp.*
- c. **Suitable Crops:** Highly beneficial for horticultural crops (e.g., tomato, eggplant, and cucumber), cereals, pulses, fruit trees (mango, citrus), and ornamental plants.
- d. **Function:** Mycorrhizal fungi form symbiotic associations with plant roots, extending root surface area and enhancing the uptake of phosphorus, water, and other nutrients. These fungi improve plant resilience to drought and soil stress.

7. Cyanobacteria-Based Biofertilizers (Blue-Green Algae):

- a. **Product Name Examples:** BlueGreen Fert, Algal Biofert.
- b. **Microorganism:** *Anabaena*, *Nostoc*, *Oscillatoria*
- c. **Suitable Crops:** Primarily used in paddy (rice) cultivation, particularly in flooded fields.
- d. **Function:** Cyanobacteria (blue-green algae) are effective nitrogen-fixers in aquatic environments. They fix atmospheric nitrogen, enhance organic matter, and improve the microbial balance in rice paddies, contributing to better yield.

8. Trichoderma-Based Biofertilizers:

- a. **Product Name Examples:** TrichoPower, Bio-Trichoderma, TrichoZyme.
- b. **Microorganism:** *Trichoderma spp.*
- c. **Suitable Crops:** Suitable for a variety of crops, including cereals, pulses, oilseeds, vegetables, fruits, and ornamental plants.
- d. **Function:** *Trichoderma* species function as both biofertilizers and biocontrol agents. They decompose organic matter and release nutrients while suppressing soil-borne pathogens. This is particularly valuable for root disease prevention and soil health improvement.

9. Plant Growth-Promoting Rhizobacteria (PGPR):

- a. **Product Name Examples:** Bio-PGPR, RhizoPlus.
- b. **Microorganism:** *Pseudomonas fluorescens*, *Bacillus subtilis*
- c. **Suitable Crops:** Beneficial for various crops, including vegetables, cereals, and fruit crops.
- d. **Function:** PGPR biofertilizers stimulate plant growth by producing phytohormones, solubilizing phosphorus, and enhancing root health. Some PGPR strains also have biocontrol properties, suppressing pathogenic fungi and bacteria in the soil.

10. Compost and Organic Matter Enrichment Biofertilizers:

- a. **Product Name Examples:** Eco-Compost, GreenCompost Bio.
- b. **Microorganism:** *Trichoderma spp.*, *Bacillus spp.*
- c. **Suitable Crops:** Suitable for all crops that benefit from enriched soil organic matter, particularly in organic farming systems.
- d. **Function:** These biofertilizers speed up the decomposition of organic matter and improve the nutrient content of compost, making it more beneficial for crops when applied to the soil.

11. Azolla-Based Biofertilizers:

- a. Product Examples:** Azolla BioBoost, GreenAzolla, AzollaMax.
- b. Microorganism:** Azolla contains *Anabaena azollae*, a symbiotic cyanobacterium.
- c. Suitable Crops:** Primarily rice (paddy) crops, but can also be used in aquatic and wetland crops.
- d. Function:** *Anabaena azollae*, a cyanobacterium within the Azolla fern, fixes atmospheric nitrogen and releases it into the water, making it available to plants. Azolla is a natural green manure, increasing soil nitrogen content when decomposed. It enhances organic matter, improves soil texture, and supports higher yields in rice paddies.

12. Zinc-Solubilizing Bacteria (ZnSB) Biofertilizers:

- a. Product Examples:** Zinc Power, ZnSol, Bio-Zinc.
- b. Microorganisms:** *Bacillus aryabhattai*, *Pseudomonas fluorescens*, *Acinetobacter*, *Aspergillus niger*
- c. Suitable Crops:** Zinc-sensitive crops, including cereals (rice, wheat, maize), pulses, vegetables (tomato, spinach, potato), and fruit crops.
- d. Function:** Zinc-solubilizing bacteria help in the solubilization of insoluble zinc compounds in the soil, converting them into forms that plants can absorb. Zinc is essential for photosynthesis, enzyme activation, and resistance to environmental stress. ZnSB biofertilizers are beneficial in zinc-deficient soils, especially for crops with a high zinc demand.

13. Siderophore-Producing Bacteria (SPB) Biofertilizers:

- a. Product Examples:** IronPlus, SideroMax, Bio-Sidero.
- b. Microorganisms:** *Pseudomonas fluorescens*, *Bacillus subtilis*, *Azospirillum lipoferum*, *Trichoderma harzianum*
- c. Suitable Crops:** All crops, particularly those sensitive to iron deficiency, such as pulses, cereals, vegetables, and fruit trees.
- d. Function:** Siderophore-producing bacteria produce siderophores, iron-chelating compounds that bind to iron in the soil, making it available for plant uptake. This is especially beneficial in alkaline soils where iron availability is low. Siderophore-producing bacteria also suppress pathogens by depriving them of iron, thus contributing to disease resistance.

Types of Biofertilizer Formulations

Biofertilizers are available in different formulations, ensuring effectiveness based on storage, application needs, and environmental conditions:

- 1. Liquid Formulations:** Liquid-based bioformulation is a better option. It provides a long shelf life to microbes and maintains their survival during the whole crop cycle. It also offers temperature and stress tolerance to bioinoculants (Chandra *et al.*, 2018). Examples include liquid *Rhizobium* and *Azospirillum* formulations (Allouzi *et al.*, 2022).
- 2. Powder Formulations:** Prepared by drying microorganisms with carrier materials, commonly used due to ease of application and storage stability (Khan *et al.*, 2022).
- 3. Granular Formulations:** Granules consist of living microorganisms both within and coated with materials such as calcite, marble, silica, etc., making them simpler to manage, transport, and store. Vermiculite is a different kind of granule that resembles mica, featuring a yellowish-brown texture and moisture-retaining qualities. It has served as a transport medium for PGP bacteria, specifically *Bacillus* sp. and *Pseudomonas* sp. (Maheshwari *et al.*, 2015).

Methods of Application

The effectiveness of biofertilizers depends significantly on the application method. Choosing the correct method ensures that the beneficial microbes survive and function optimally.

- 1. Seed Treatment:** In this method, biofertilizers are mixed with seeds before sowing. This approach is commonly used for nitrogen-fixers like *Rhizobium* in legumes. A slurry is made by mixing biofertilizer powder or liquid with water and sticking it to seeds. Seed treatment is ideal because it directly introduces beneficial microbes to the root zone when the seed germinates.

Procedure:

- i. Prepare a biofertilizer slurry (usually 200 ml per kg of seeds).
- ii. Dip the seeds in the slurry and let them dry in shade for a few minutes.
- iii. Sow the treated seeds directly into the soil.

Advantages: Cost-effective, localized microbial action on germination, better root colonization.

2. Soil Application: Soil application involves mixing biofertilizers into the soil. It is suitable for biofertilizers like PSB and KSB, which need to spread through the soil to access nutrients. This method enriches the rhizosphere (root zone) where plants absorb most nutrients.

Procedure:

- i. Biofertilizer is mixed with compost or organic matter and uniformly spread across the field.
- ii. It is then mixed into the soil through light ploughing or tilling.

Advantages: Direct introduction to the root zone, improving soil fertility and microbial activity throughout the field.

3. Foliar Spray: Biofertilizers can also be applied as a foliar spray on plant leaves. PGPR-based biofertilizers and certain mycorrhizal formulations are effective as foliar sprays because they enable microbes to colonize leaves directly.

Procedure:

- i. Prepare a diluted solution of the biofertilizer.
- ii. Spray evenly on the plant's foliage using a sprayer, usually in the early morning or late afternoon to prevent leaf burn.

Advantages: Immediate absorption of nutrients, accessible for crops like vegetables and cereals, especially effective for stress-tolerant microbes.

3. Root Dipping: This method is typically used for transplanting crops like paddy, tomatoes, or vegetable seedlings. Seedlings are dipped into a biofertilizer solution before being transplanted into the main field.

Procedure:

- i. Prepare a biofertilizer solution by mixing it in water (1:10 ratio).
- ii. Dip the plant roots in the solution for 15–30 minutes.
- iii. Transplant the treated seedlings into the field.

Advantages: Ensures initial root colonization, beneficial for plant establishment and faster growth.

4. Inoculation through Irrigation: Biofertilizers can be delivered through irrigation systems, such as drip or sprinkler irrigation. This method is ideal for large-scale applications where uniform distribution is essential.

Procedure:

- i. Dilute the biofertilizer as per manufacturer instructions.
- ii. Apply through an irrigation system, ensuring even distribution across the field.

Advantages: Efficient for large areas, especially effective for mycorrhizal fungi, which spread through the root zone over time.

5. Compost Enrichment: Biofertilizers like *Trichoderma* and PSBs can be added to compost to enhance the decomposition process and nutrient release. This method boosts compost quality, enriching the soil when applied.

Procedure:

- i. Add biofertilizer to compost at the start of the composting process.
- ii. Mix thoroughly and maintain composting conditions (moisture, temperature).

Advantages: Enriches compost nutrient profile, boosts soil microbial population upon application.

Choosing the Right Method: Practical Considerations

1. Crop Type: Some crops (e.g., legumes) benefit more from seed treatment, while others (e.g., vegetable seedlings) may perform better with root dipping.

2. Soil Conditions: Dry soils may require soil application combined with irrigation, while compost enrichment is ideal for nutrient-poor soils.

3. Climate and Environmental Factors: Foliar sprays should be applied under cool temperatures to avoid evaporation losses, and biofertilizers should not be applied just before heavy rains to prevent runoff.

Key Benefits of Biofertilizers

- 1. Improved Nutrient Availability:** These biofertilizers solubilize or fix essential nutrients (e.g., nitrogen, zinc, iron), making them more accessible to plants and improving overall soil health.
- 2. Reduced Dependency on Chemical Fertilizers:** Biofertilizers reduce the need for synthetic fertilizers, leading to cost savings and less environmental impact.
- 3. Enhanced Stress Tolerance:** By enhancing nutrient availability, these biofertilizers also improve plants' resilience to abiotic stresses like drought and salinity.
- 4. Increased Crop Yields:** Crops treated with biofertilizers generally show improved growth, increased yield, and better-quality produce.
- 5. Environmentally Friendly:** Biofertilizers are biodegradable and contribute to sustainable agricultural practices, promoting a balanced ecosystem.

Do's for Biofertilizer Application

- 1. Select Appropriate Biofertilizers for the Crop:** Choose the right type of biofertilizer based on the crop's nutrient requirements and soil conditions. For instance, use *Rhizobium* for legumes and *Azospirillum* for cereals.
- 2. Apply Biofertilizers at the Right Time:** Apply biofertilizers during planting or early growth stages to ensure that plants benefit from the nutrients made available throughout the growing season.
- 3. Store Biofertilizers Properly:** Keep biofertilizer packets in a cool, dry place away from direct sunlight and moisture to maintain their viability.
- 4. Use Recommended Doses:** Follow the recommended dose as per the guidelines on the biofertilizer label or as suggested by agricultural experts. Over-application may not increase efficacy and could lead to wastage.
- 5. Handle Carefully:** When preparing and applying biofertilizers, handle them gently to avoid damaging the microbial cultures.
- 6. Keep Away from Chemical Fertilizers and Pesticides:** Apply biofertilizers separately from chemical fertilizers and pesticides, as these can harm beneficial microorganisms.

Don'ts for Biofertilizer Application

- 1. Don't Expose to Direct Sunlight:** Biofertilizers contain live microorganisms, which can be damaged by direct sunlight. Avoid exposing the biofertilizer packets and treated seeds to sunlight.
- 2. Don't Use Expired Products:** Biofertilizers have a limited shelf life. Always check expiration dates before use, as expired products lose microbial viability.
- 3. Do Not Mix Biofertilizers with Pesticides:** Mixing biofertilizers directly with chemical pesticides can kill beneficial microorganisms. Instead, apply pesticides separately if needed, allowing time between applications.
- 4. Avoid Applying Biofertilizers Directly to Non-Compatible Crops:** Some biofertilizers are crop-specific, like *Rhizobium* for legumes. Applying them to non-compatible crops will not provide the intended benefits.

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Biodynamic Seed Treatment: Unravelling the Ecological Principles of Beejamrutham

Article ID: 71114

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Beejamrutham is an Indian traditional organic Preparation that is mainly used for seed treatments to protect from soil, seed borne diseases and also improve soil health. Two Sanskrit words, "Beej," which means seed, and "Amrutham," which denotes nectar or elixir, are combined to form the name "Beejamrutham" (Palekar, 2006). This natural mixture has a long history in Indian agriculture, where it has been used for millennia to promote seed germination vigorously and improve soil vitality (Shyamsunder and Menon, 2021). Beejamrutham is cherished not only for its environmental benefits, but also for its contribution to sustainable, low-cost farming practices. Its rebirth in organic farming practices reflects a broader trend toward natural agricultural approaches that are environmentally friendly.

The renewed enthusiasm for Beejamrutham signifies a worldwide shift towards natural farming methods that emphasize environmental preservation and economical agricultural practices. Made from fresh local cow dung, cow urine, lime, nutrient-rich soil, and water, Beejamrutham represents the fusion of traditional farming wisdom and contemporary ecological demands. Its distinctive formulation brings advantageous microorganisms to seeds, forming a protective microbial shield that enhances germination rates and aids in early seedling growth (Mukherjee et al., 2022).

This classic bio-formulation supports ongoing initiatives to lessen the negative impacts of chemical fertilizers and pesticides, providing a sustainable and cost-effective alternative for farmers. Its usage goes beyond seed treatment to encompass soil drenching and foliar sprays, further boosting its versatility and effectiveness in different cropping systems.

Beejamrutham Contains the Following Ingredients (Palekar, 2006)

- 1. Cow Dung (5Kg):** Fresh dung from an indigenous cow is preferred, as it contains beneficial microorganisms that promote seed health and protect against soil-borne pathogens.
- 2. Cow Urine (5liters):** Fresh urine is preferred better and a distinct dairy product that possesses various qualities such as manure, antibacterial properties, and disinfectant properties.
- 3. Lime (50g):** Lime (calcium hydroxide) helps in balancing soil pH and provides essential minerals.
- 4. Soil (100g):** A small amount of soil is added to introduce local microorganisms that support soil and plant health.
- 5. Water (20liters):** Water is used to mix all the ingredients, creating a liquid solution that can be applied to seeds.

Preparation of Beejamrutham for Seed Treatment

- 1. Cow Dung Filtration:** Place 5 kg of fresh indigenous cow dung in a thin fabric cloth. Securely fasten the fabric cloth and hang it in a 20-liter container full of fresh water. Let it remain untouched for 12 hours to allow beneficial microorganisms to dissolve in the water.
- 2. Lime Solution:** Prepare lime solution by mixing 50 grams of lime with 1 liter of water in a separate container to decrease acidity. Allow it to sit overnight.
- 3. Extraction:** After 12 hours have passed, take out the cloth with the cow dung from the drum. Press the fabric firmly to remove as many liquids as you can into the container.
- 4. Soil Addition:** Mix in a handful of rich soil with the mixture. The soil harbours native microorganisms that are advantageous for plant development and protection against diseases.

5. Combining Ingredients: Mix 5 liters of fresh desi cow urine with the lime solution in the drum. Mix the ingredients thoroughly by stirring the mixture well.

6. Incubation: Let the solution sit overnight to encourage the growth of beneficial microorganisms, enhancing its effectiveness for seed treatment.

7. Ready for Use: The Beejamrutham solution is now ready to be used as a seed treatment. This organic mixture can be applied to seeds to promote germination, protect against pathogens, and enhance early plant growth.

Methods of Application for Beejamrutham

1. Seed Treatment: Immerse seeds in the Beejamrutham solution for 30 minutes, ensuring each seed is evenly covered. After soaking, spread the seeds out to air dry in a shaded area for a short time before planting.

2. Seedling Drench: For transplanted crops, dip seedlings in the Beejamrutham solution for 15-20 minutes before transplanting. This process aids in decreasing transplant shock, protects roots from pathogens, and promotes early root establishment.

3. Soil Drenching: Beejamrutham can be directly applied to the soil, particularly in regions where seeds or seedlings are already planted. Mix the Beejamrutham with water in a 1:10 ratio, then spread it on the soil near the plants' base and let it be absorbed. This improves the soil quality and boosts microbial functions.

4. Foliar Spray: A diluted Beejamrutham solution can be applied as a foliar spray for certain crops to boost plant health and improve disease resistance. Mix the Beejamrutham with water in a ratio of 1:20, then apply it on the leaves either in the morning or evening.

These methods ensure that Beejamrutham reaches the seeds, roots, soil, and even leaves if needed, providing comprehensive support for plant health and growth in an eco-friendly manner.

Advantages

1. Enhanced Germination: Beejamrutham promotes a higher germination rate due to the presence of natural hormones and alkaloids, which stimulate seed growth. Additionally, it neutralizes anti-germinating compounds, providing a conducive environment for seeds to sprout more effectively.

2. Protection Against Pathogens: When seeds treated with Beejamrutham are sown, beneficial fungi and bacteria colonize around the roots. These beneficial microorganisms form a protective barrier, defending the roots from harmful fungi and pathogenic bacteria, thus reducing the risk of root diseases.

3. Soil Purification: Beejamrutham helps purify the soil surrounding the seed, creating a healthier environment for plant development. The bioactive compounds in the formulation support soil health and promote a balanced microbial ecosystem.

4. Improved Seedling Health: Beejamrutham-treated seeds are better equipped to resist environmental stresses and pathogens in their early growth stages. The natural compounds in Beejamrutham strengthen the seedling, leading to more vigorous growth and resilience.

Overall, Beejamrutham serves as a cost-effective and eco-friendly seed treatment that enhances germination, protects against diseases, and supports sustainable agricultural practices.

Do's

1. Use Fresh Ingredients: Always use fresh desi cow dung, cow urine, and locally sourced fertile soil for the most effective preparation.

2. Prepare in a Clean Container: Use a clean drum or container to avoid contamination, which could reduce the effectiveness of the Beejamrutham.

3. Follow Incubation Time: Allow the solution to incubate overnight to maximize beneficial microbial growth.

4. Apply Immediately: Use Beejamrutham as soon as possible after preparation for the best results. Freshly prepared solution is more potent.

5. Dilute for Soil Drenching and Foliar Spray: If applying as a soil drench or foliar spray, dilute the Beejamrutham with water in a 1:10 or 1:20 ratio, respectively.

6. Store in a Cool, Shaded Area: If you need to store it temporarily, keep it in a cool, shaded place, but avoid storing it for more than 24 hours.

Don'ts

1. Don't Use Non-Indigenous Cow Ingredients: Avoid using cow dung or urine from non-native breeds, as these may lack the beneficial microbes present in desi cows.

2. Don't Store for Long Periods: Avoid preparing Beejamrutham in advance or storing it for more than a day, as microbial potency decreases over time.

3. Don't Expose to Direct Sunlight: Direct sunlight can kill beneficial microorganisms, so keep the solution out of sunlight.

4. Don't Apply During Peak Sun Hours: When using Beejamrutham as a foliar spray, apply it in the early morning or late evening to prevent evaporation and maximize absorption.

5. Don't Skip Filtration: Make sure to filter the cow dung properly to avoid clogging equipment if you plan to apply Beejamrutham through a sprayer.

6. Don't Mix with Chemical Pesticides or Fertilizers: Avoid combining Beejamrutham with synthetic pesticides or fertilizers, as they can harm beneficial microorganisms in the solution.

Conclusion

Beejamrutham is more than a traditional preparation; it is a testimony to the enduring wisdom of natural farming methods. Its ability to promote seed germination, enhance soil health, and combat pathogens highlights its relevance in modern sustainable agriculture. By adhering to proper preparation methods and usage guidelines, farmers can harness the full potential of Beejamrutham, contributing to environmentally friendly and economically viable farming practices. Its revival underscores a broader shift toward reducing dependency on synthetic inputs and embracing organic solutions that are both effective and sustainable.

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LoRa Communication for Agriculture 4.0

Article ID: 71115

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Abstract

Agriculture 4.0 is the incorporation of digital technology in agriculture in order to attain smart, efficient, and sustainable production. Long Range (LoRa) communication, which is one of the low-power, wide-area networking protocols, is at the forefront in allowing Internet of Things (IoT) applications over extensive agricultural land areas. This article discusses the operational basics of LoRa, its benefits over conventional wireless communication, integration with sensors and devices, and its uses in smart farming to monitor soil condition, irrigation, crop growth, and livestock.

Introduction to Agriculture 4.0

The fourth revolution in agriculture, or Agriculture 4.0, utilizes sophisticated technologies like IoT, artificial intelligence (AI), robotics, remote sensing, and big data analytics to restructure traditional farming as a precision and data-based system. With mounting pressure on food systems from climate change, population growth, and environmental degradation, smart solutions are needed to optimize input use, minimize losses, and develop productivity sustainably.

One of the fundamental technologies behind this shift is LoRa (Long Range) communication. It allows for real-time data transmission from scattered agricultural sensors to centralized servers or cloud platforms over extended distances at low power consumption—perfect for big, remote farms.

What is LoRa and LoRaWAN?

LoRa is a physical layer protocol based on Chirp Spread Spectrum (CSS) modulation to enable long-range data transmission (up to 15 km over rural terrain) with low power. LoRa works in the unlicensed Industrial, Scientific, and Medical (ISM) radio bands like 433 MHz and 868 MHz in India and Europe.

LoRaWAN (Long Range Wide Area Network) is an upper-layer protocol that sits on top of LoRa. It specifies the network structure and how devices talk to gateways and servers, controlling functionalities such as data encryption, adaptive data rate, and device authentication.

Key Features of LoRa for Agriculture

Feature	Advantage in Agriculture
Long Range	Covers wide agricultural fields and forests
Low Power Consumption	Enables years of battery life for field sensors
Low Data Rate	Ideal for transmitting small sensor packets
Scalability	Supports thousands of devices in a network
License-Free Spectrum	Cost-effective deployment
Secure Communication	AES-128 encryption for safe data transmission



Source: <https://www.linkedin.com>

LoRa Network Architecture in Agriculture

- 1. End Devices (Nodes):** These are soil moisture sensors, weather stations, crop health monitors, and livestock trackers integrated with LoRa transceivers.
- 2. LoRa Gateways:** Gateways collect messages from end devices and transfer them to a cloud-based Network Server through cellular, Ethernet, or Wi-Fi.
- 3. Network Server:** This server decrypts, processes, and transmits data to application servers and dashboards.
- 4. Application Server & Dashboard:** Farmers, agronomists, and agricultural service professionals look at actionable insights via web or mobile interfaces.

LoRa Applications in Smart Agriculture

- 1. Soil Moisture Sensing and Irrigation Management:** LoRa-based soil moisture sensors, strategically placed at different depths within agricultural fields, enable continuous and real-time monitoring of soil water content. This data allows farmers to schedule irrigation with high precision, ensuring that crops receive water only when necessary. Such targeted irrigation reduces water wastage and prevents over-irrigation, which can harm plant health. The integration of LoRa sensors with automated drip irrigation systems enhances efficiency by delivering water directly to the root zone based on actual soil moisture levels. This approach supports water-saving practices, improves crop yields, and contributes to sustainable agricultural water management.
- 2. Crop Monitoring and Disease Early Warning:** LoRa-connected sensors measuring leaf wetness and canopy temperature help detect early signs of crop stress or disease. This timely detection enables prompt and targeted spraying, reducing the need for excessive pesticide use. By addressing issues at an early stage, farmers can maintain healthier crops, improve yield quality, and minimize environmental impact, all while optimizing input costs and enhancing overall farm sustainability.
- 3. Weather Monitoring Stations:** Solar-powered LoRa weather stations collect real-time data on temperature, humidity, rainfall, and wind speed, providing critical insights for farm management. This data supports accurate pest and disease forecasting, allowing for proactive protection measures. It also aids in yield modeling, helping farmers predict harvest outcomes and plan logistics. Moreover, such data is essential for climate-smart agricultural planning, enabling farmers to adapt practices in response to changing weather conditions.
- 4. Livestock Monitoring:** LoRa-enabled GPS collars and biometric sensors offer real-time monitoring of livestock, enhancing farm security and animal welfare. These devices track animal location and movement, ensuring efficient grazing management. They also monitor breeding and health behavior, providing early

alerts for illness or reproductive activity. Additionally, the system can detect unusual movement patterns, sending straying or theft alerts to farmers, thereby improving safety and operational control.

5. Smart Greenhouses: In controlled environments, LoRa-enabled devices continuously monitor key parameters such as CO₂ concentration, light intensity, and humidity levels. This data allows for the automation of shading, ventilation, and irrigation systems, ensuring that crops grow under optimal climatic conditions. By maintaining a stable environment, these systems promote healthy and consistent plant development. Additionally, the automation reduces labor requirements, leading to minimal manual intervention and increased operational efficiency in greenhouse management.

Case Studies and Real-World Deployments

India: eNAM Integration – Pilot programs have employed LoRaWAN to provide real-time crop inputs to electronic National Agricultural Markets (eNAM) for transparent price discovery.

Netherlands: Smart Dairy Farms – LoRa sensors monitor cow health, milk production, and conditions in the barn, enhancing animal well-being and profitability.

Brazil: Sugarcane Monitoring – LoRa networks assist in monitoring temperature and soil conductivity within plantations, enhancing irrigation and fertilizer application.

Advantages Over Other Wireless Technologies

Technology	LoRa	Wi-Fi	Bluetooth	Zigbee	NB-IoT
Range	2–15 km	<100 m	<50 m	<100 m	10–15 km
Power	Very Low	High	Moderate	Moderate	Low
Cost	Low	Medium	Low	Medium	Medium-High
Infrastructure	Gateway only	Router + Power	Hub + Power	Hub + Power	Cellular Network

LoRa's long range, low power, and low cost provide it with a compelling advantage in rural and remote environments, where infrastructure is scarce.

Challenges and Limitations

- 1. Data Rate Limitations:** Not ideal for high-data volume content such as images or video.
- 2. Network Congestion:** Large-scale implementations might require careful planning to minimize interference.
- 3. Security Management:** Needs regular key management to ensure integrity.
- 4. Initial Setup Costs:** Though cheap, deploying gateways and devices at scale still involves initial investment.

Future Outlook and New Developments

With AI and edge computing integration, upcoming LoRa systems may be able to independently process sensor data and initiate action without the need for central servers. Hybrid solutions that integrate LoRa with satellite and 5G backhubs are also under development to eliminate coverage constraints.

Government and agriculture agencies are presently backing open-source LoRaWAN implementations and urging farmers to use open data platforms, enabling collective agricultural intelligence.

Conclusion

LoRa communication is becoming a revolutionizing driver of Agriculture 4.0 by providing real-time, low-cost, and wide-area data connectivity on farms. Through smart irrigation, crop monitoring, environmental sensing, and livestock management, LoRa equips farmers with data-driven tools for decision-making that improve productivity, sustainability, and profitability. With increasing infrastructure and awareness, LoRa will become a cornerstone of precision agriculture and shape the future of smart farming worldwide.

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Wetland and Carbon Sequestration

Article ID: 71116

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Introduction

Nature is the safest place to be relied on with or without certainty. Wetlands are commonly referred to as the “Kidney of the Earth.” They are sometimes described as ‘the kidneys of the landscape’ because they function as the downstream receivers of water and waste from both natural and human sources, thus ameliorating floods, cleaning polluted waters, recharging groundwater aquifers, *etc.* (Philipose and Thomas, 2003). Wetlands are the upland areas, or regions that are partially immersed in water, are covered by plants, and act as a home for animals during natural disasters. Though they cover only around 6% of the Earth’s land surface, 40% of all plant and animal species live or breed in wetlands. The Ramsar Convention of 1971 defined wetlands as regions of marsh, fen, peatland, or water, whether natural or manmade, brackish, or salt, including areas of seawater whose depth at low tide does not exceed six meters. This definition is currently generally accepted worldwide. Although wetlands are rapidly vanishing due to stress-inducing environmental and ecological changes caused by dredging and filling operations, hydrologic modifications, pollutant runoff, eutrophication, impoundment, and fragmentation by highways and ditches. Consequently, wetland conservation has garnered a lot of scientific and political attention recently to protect these invaluable natural resources and support sustainable ecosystem function in wetlands.

Status of Wetlands

Under the Ramsar Convention, 11 more wetlands in India were designated as being of international significance, an international agreement to protect the natural characteristics of specific wetland areas worldwide, which makes a total of 80. ISRO prepared a national wetlands atlas based on satellite images. Total area covered by wetlands globally: 2.5 million square kilometres. It mapped 2,31,195 wetlands in India during 2017-2018. They comprise around 4.86% of the total geographic area of India. Number of wetland sites in India under the Ramsar Convention: 75, covering an area of 13,26,677 hectares. No. of Ramsar sites globally: 2,466.

Wetlands Soil

Water buildup in specific areas of the Landscape changes the structure, chemistry, and growth of soils, resulting in a unique class of soils called hydric soils. This soil also affects the ecology and function of wetlands. The acidity of the soil defines the soil's properties and processes. It affects the soil's ability to dissolve certain elements, especially certain nutrients that are important to the ecosystem of wetlands. The availability of certain nutrients, like phosphorus, calcium, and magnesium, is limited at low pH levels. Increased soil acidity reduces microbial activity. The ratio of acidic (H^+ and Al^{3+}) to nonacidic (Ca^{2+} , Mg^{2+} , K^+ and Na^+) components maintained in a soil's cation exchange capacity determines the pH of that soil.

Hydrological Perspective

Wetlands are distinctive ecosystems in between aquatic and terrestrial ecosystems or are transitional zone ecosystems between dry land and open water bodies (Gebreslassie *et al.*, 2014). Three possible water sources for wetlands: precipitation, overland flow, and groundwater discharge. These help in maintaining the water balance and support diverse ecosystems. The hydrological perspective gives us the view that the management of the wetland is a very fundamental process. Thus, these help in water quality, flood control, biodiversity support, nutrient cycling, climate change & mitigations.

Carbon Sequestration

Carbon sequestration is the process of capturing, removing, and storage of carbon dioxide (CO_2) from the earth’s atmosphere. It is acknowledged as a key method for removing carbon from the Earth’s atmosphere. It is the process where CO_2 is stored for a very long period, such as 100, or 1000 years and is called “carbon capture and storage.” It sinks carbon deep down into different forms so that it does not get released into

the atmosphere. One of the most beneficial sequestrations is wetland sequestration, which combines the water bodies, soil, and plants. They are highly productive ecosystems that accumulate large amounts of organic matter in the soil, functioning as significant carbon sinks (Odum *et al.*, 1995; Chmura *et al.*, 2003; Mitra *et al.*, 2005). Despite covering 6-8% of the freshwater surface, wetlands are estimated to account for one-third of the world's organic soil carbon pool (Mitra *et al.*, 2005; Lal, 2007; Mitsch & Gosselink, 2007). According to Miria and Khan (2014), photosynthesis, also known as primary productivity, sedimentation, and nutrient enrichment from external causes, are the three key mechanisms that cause wetlands to sequester carbon. For instance, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicates that the atmospheric concentration of CO₂ increased from 280 parts per million in 1950 to around 400 parts per million in 2000 (Pachauri *et al.*, 2014). Furthermore, if CO₂ concentration in the atmosphere is to be stabilized at 550 ppm, or roughly twice the preindustrial level, global annual emissions during the next century must be reduced by more than 75%, according to computer models developed by the US Climate Change Science Programme (CCSP) (Sundquist *et al.*, 2008). It has been reported that with an increase in temperature, melting of the permafrost results in reduced carbon storage and carbon sequestration in the wetlands (Schuur *et al.*, 2015). As wetlands store carbon, rising temperatures may play a significant role in both sea level rise and altered precipitation patterns. These effects may be detrimental to wetlands (Junk *et al.*, 2013).

Importance of Wetlands

Mangroves and other coastal wetlands can trap carbon up to 55 times more quickly than tropical rainforests. Only 3% of the planet's surface is made up of wetlands, although they hold 30% of all land-based carbon. One of the main concerns worldwide is climate change. Temperature change, snowmelt, an increase in catastrophic events, disease outbreaks, and many more effects are already expanding. Anthropogenic emissions of greenhouse gases (GHGs) also account for most of the climate change and increased GHG emissions from the microbiological decomposition of organic waste, for instance, can lead to further global warming. Among the many economically significant applications of wetlands are for fishing; other uses include the gathering of fuel wood, the provision of water for agriculture, ecotourism, *etc.* The coastal wetland of the Gulf of Mexico provides habitat to juveniles of three species of penaeid shrimps upon which the local shrimp-fishery industry is dependent (Engle, 2011). In India, wetland-dependent fisheries are prevalent in Kerala, Goa, Odisha, Jammu and Kashmir, Assam, Bihar, Andhra Pradesh, and Gujarat (Bassi *et al.*, 2014).

Wetlands Threats

Wetlands are our most vulnerable environment, having lost 35% of their total area since 1970 and decreasing at a very high rate, three times more quickly than forests. Since 1970, the primary cause of the degradation of inland wetlands is due to the changes in land use. The most common type of land-use change, agriculture, harmed over half of the Wetlands of International Importance. And, also destructed elements, including pollution, water consumption, and infrastructure development are responsible for much of the wetlands' degradation. The construction of dams in the demand for irrigation and hydropower has manipulated the natural process of the surroundings. These habitats frequently face extreme natural hazards such as storms, floods, soil erosion, and subsidence that result from unavoidable natural processes that can harm wetland areas.

Conclusion

Wetlands provide vital socioeconomic benefits to human life by serving as sources of food, fuel, water, medicinal plants, and other sources of income. They are essential regulators of sustainability in the modern world. The conservation of natural resources through management strategies grounded in customary knowledge and resource utilization will undoubtedly accelerate biodiversity and other ecosystem functions. They also provide environmental benefits, including storing carbon, facilitating biological diversity, recharging, and discharging water, reducing the risk of flooding, *etc.* With time, humans are the proof of the changing climate 20 years back and now. To maintain and for the future development of the wetland, The Ramsar Convention and other wetland conservation programs were developed in response to the fast and ongoing loss and degradation of wetlands throughout the world.

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Post Harvest Nutritional Facts and Value Addition of Litchi Fruit (*Litchi chinensis*)

Article ID: 71117

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Introduction

In scientific language litchi is called *Litchi chinensis*. Litchi is an evergreen tree from tropical climate region with smooth leaves and branches which is famous for its attractive aroma, taste, attractive colour and heart shaped oval shaped fruit full of nutrients. The height of this tree can be around 40-50 feet. This fruit is ready in summer season in May and June. Its fruit is almost round, 3-5 cm long, 3 cm diameter and weighs 10 grams. Its outer peel is pink, inside it has pulp and seed. The length of seed is around 2 cm and diameter is 1-1.5 cm.



The production of all fruits in India is about 46.47 million tons. While in Bihar, the total land of all fruits is about 3 lakh hectares and the annual production is about 18 lakh tons.

The production of litchi in Bihar is about 3 lakh tons, about 25.27 thousand hectares of land. While 70 percent of the country's litchi is produced in Bihar.

There are many varieties of litchi, Shahi, China, Swarnrupa, Kaswa, Cardamom, Seedless, Yearly, Late, Large Red, Gulaavi, Dehradun, Bombay, Calcutta, Rose Scented, Bedana etc. Litchi fruits are being produced mainly in different states. The best production of litchi fruit in India is especially in North Bihar.

In Bihar, litchi is mainly cultivated in Muzaffarpur, Vaishali, Sitamarhi, East Champaran and West Champaran, Darbhanga and Samastipur districts. In Muzaffarpur district, the land under cultivation of this fruit is about 80 thousand hectares and the production is about 75 thousand tons, which is more than all the districts of the entire Bihar state. Keeping in mind the production, fresh fruits and processed fruits are exported to other states of the country as well as many countries. The Government of India has established a national level litchi research center in Muzaffarpur, Bihar.

Various Types of Nutrients are Found in Litchi Fruits

Nutrients:

1. Vitamin C - About 130 mg of vitamin C in one cup of fresh fruit provides 226 percent of the daily value of calories, 51 mg of vitamin C in dried litchi helps the human body develop resistance against infectious agents and strengthens teeth and bones. **2. Potassium** - The potassium present in this fruit helps in regulating body fluids and protects body components such as heart rate and blood pressure.

3. Fats and Proteins - It is a good source of vitamin B complex such as thiamine, niacin and folate, which help in the metabolism of carbohydrates, proteins and fats in the body.

4. Research has found that vasopressin, a low molecular weight compound found in litchi fruit in very high quantities, helps in protecting skin from harmful ultraviolet rays by acting as an anti-oxidant, anti-influenza virus and improving blood flow in body parts. (Reference- Bio-Science Biotechnology Biofem, 72(2), 463-476, 2008 Takuya University, Japan)

5. Litchi fruit has saturated fat/cholesterol, 66 calories per 100 grams, and is a good source of fibre, vitamins and antioxidant compounds.

Lychee fruit (**Litchi chinensis**), Fresh, Nutritive value per 100 g, (Source: USDA National Nutrient data base) as follows:

Principle	Nutrient Value	Percent of RDA
Energy	66 kcal	3.3%
Carbohydrates	16.53 g	12.7%
Protein	0.83 g	1.5%
Total Fat	0.44 g	2%
Cholesterol	0 mg	0%
Dietary Fiber	1.3 g	3.5%
Vitamins		
Folates	14 µg	3.5%
Niacin	0.603 mg	3.5%
Choline	7.1 mg	1%
Pyridoxine	0.100 mg	9%
Riboflavin	0.065 mg	5%
Thiamin	0.011 mg	1%
Vitamin A	0 mg	0%
Vitamin C	71.5 mg	119%
Vitamin E	0.07 mg	0.5%
Vitamin K	0.4 µg	0.3%
Electrolytes		
Sodium	1 mg	0%
Potassium	171 mg	3.5%
Minerals		
Calcium	5 mg	0.5%
Copper	0.148 mg	16%
Iron	0.31 mg	4%
Magnesium	10 mg	2.5%
Manganese	0.055 mg	2.5%
Phosphorus	31 mg	4.5%
Selenium	0.6 µg	1%
Zinc	0.07 mg	0.5%
Phyto-nutrients		
Carotene-β	0 µg	--
Crypto-xanthin-β	0 µg	--
Lutein-zeaxanthin	0 µg	--

Post-Harvest Challenges

1. High respiration and transpiration rates lead to quick spoilage.
2. Perishability due to moisture loss, browning, and microbial decay.
3. Sensitive to chilling injury (below 5 °C).

Value Addition of Litchi Fruit

Value addition refers to processing and product diversification to extend shelf life, improve marketability, and increase economic value.

Common Value-Added Products and Processing Techniques

1. Litchi Juice and Nectar:

- a. Extraction of pulp for juice.
- b. Pasteurization to improve shelf life.
- c. Blending with other fruit juices for flavor variety.

2. Litchi Canning:

- a. Peeled litchis canned in syrup.
- b. Sterilized to extend shelf life for months.
- c. Popular export product.

3. Litchi Dried Fruit / Dehydrated Litchi:

- a. Dehydration/drying under controlled temperature.
- b. Produces dried litchi slices or whole dried litchi.
- c. Suitable for snacks and longer storage.

4. Litchi Wine and Alcoholic Beverages:

- a. Fermentation of litchi juice to produce wine.
- b. Litchi-flavored liquors and cocktails.

5. Litchi Jam, Jelly, and Marmalade:

- a. Cooked with sugar and pectin to produce spreads.
- b. Extended shelf life and alternative usage.

6. Frozen Litchi:

- a. Quick freezing of peeled litchi.
- b. Maintains freshness for off-season use.

7. Litchi-based Confectionery and Ice Cream:

- a. Incorporation in candies, desserts, and ice creams.
- b. Flavor enhancement.

8. Litchi Seed Oil (Experimental):

- a. Oil extraction from seeds for cosmetic or medicinal use.
- b. Still under research.

Benefits of Value Addition

1. Reduces post-harvest losses.
2. Creates employment and entrepreneurial opportunities.
3. Diversifies income sources for farmers.
4. Extends availability beyond fresh season.
5. Enhances nutritional utilization.

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The Health Benefits and Risks of Drinking Honey with Lemon and Hot Water: A Natural Wellness Elixir

Article ID: 71118

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Introduction

The combination of honey, lemon, and hot water has gained popularity as a natural health drink, believed to offer a range of benefits, from boosting digestion and detoxifying the body to enhancing immunity and promoting weight management. While traditional medicine has long advocated for this mixture, scientific research provides insights into its actual health effects. This article explores the scientific basis behind the benefits and potential side effects of drinking honey with lemon and hot water, supported by research studies.

Nutritional Composition of Honey and Lemon

1. Honey: A Natural Antioxidant and Antimicrobial Agent: Honey is a complex natural sweetener rich in phenolic compounds, flavonoids, vitamins, and minerals, contributing to its antioxidant and antimicrobial properties (Ahmed et al., 2022). Studies indicate that honey contains bioactive compounds that help combat oxidative stress and inflammation, making it beneficial for immune function and wound healing (Alvarez-Suarez et al., 2013).

2. Lemon: A Vitamin C Powerhouse: Lemon is well known for its high vitamin C content, which plays a crucial role in immune function, collagen synthesis, and skin health (Carr & Maggini, 2017). Additionally, lemon contains citric acid, which aids in digestion and detoxification by stimulating the production of digestive enzymes (González-Sarrias et al., 2020).

Digestive Health and Detoxification

One of the primary reasons people drink honey-lemon water is its positive impact on digestion. Warm water helps stimulate the digestive system, while lemon enhances the production of gastric juices, improving food breakdown and nutrient absorption (González-Sarrias et al., 2020). Honey, on the other hand, contains enzymes that support gut health, ensuring smooth digestion throughout the day (Ahmed et al., 2022).

Additionally, this drink is often regarded as a natural detoxifier. Lemon's citric acid helps cleanse the liver, while honey's antioxidants assist in flushing out toxins from the body (Alvarez-Suarez et al., 2013). Regular consumption may contribute to clearer skin, improved metabolism, and enhanced energy levels.

Weight Management and Metabolism Boost

Drinking honey with lemon and hot water is frequently associated with weight loss and metabolism enhancement. Lemon juice contains pectin, a type of fiber that helps curb hunger cravings, while honey provides natural sugars that offer sustained energy without causing blood sugar spikes (Silky Mahajan, 2024).

Moreover, warm water helps increase metabolic rate, encouraging the body to burn calories more efficiently. Studies suggest that consuming warm water-based beverages can aid in fat oxidation and digestion, making this drink a beneficial addition to a balanced diet (Neeti Sharma, 2023).

Immune System Support and Cold Relief

The combination of honey and lemon is widely used as a home remedy for colds, flu, and throat infections. Honey's antibacterial and antimicrobial properties help soothe sore throats, while lemon's vitamin C strengthens the immune system (Carr & Maggini, 2017).

Additionally, honey has been found to reduce cough frequency and severity, making it an effective natural alternative to over-the-counter cough syrups (Paul et al., 2007). Drinking this mixture regularly may help prevent seasonal illnesses and improve overall immunity.

Hydration and Skin Health

Proper hydration is essential for maintaining healthy skin and bodily functions. Drinking warm honey-lemon water in the morning helps replenish fluids lost overnight, keeping the body hydrated throughout the day.

Lemon's antioxidants and vitamin C contribute to skin rejuvenation, reducing signs of aging and promoting a radiant complexion. Honey's anti-inflammatory properties further support skin health by reducing acne and irritation (Alvarez-Suarez et al., 2013).

Potential Side Effects and Considerations

While honey-lemon water offers numerous benefits, excessive consumption may lead to certain risks:

Dental Enamel Erosion: Lemon juice contains citric acid, which may weaken tooth enamel over time. Regular consumption without proper oral hygiene can lead to increased sensitivity and dental decay (Jiang et al., 2018). Drinking through a straw or rinsing the mouth afterward can mitigate this effect.

Blood Sugar Fluctuations: Although honey is a natural sweetener, it still contains fructose and glucose, which can impact blood sugar levels. Individuals with diabetes or insulin resistance should consult a healthcare professional before regularly consuming honey-lemon water (Paul et al., 2007).

Acidic Effects on Digestion: While lemon juice aids digestion, excessive consumption may lead to acid reflux or gastric irritation in individuals prone to acidic conditions such as GERD (González-Sarriás et al., 2020). Drinking in moderation and pairing it with food may help reduce acidity-related issues.

Allergic Reactions: Some individuals may be allergic to honey, experiencing symptoms such as itching, swelling, or difficulty breathing (Ahmed et al., 2022). It is important to check for allergic sensitivity before consuming honey-infused beverages.

Impact on Electrolyte Balance: Drinking excessive amounts of lemon water may lead to potassium imbalance, which can affect muscle function and overall electrolyte balance (Carr & Maggini, 2017). Maintaining dietary variety and hydration can prevent such deficiencies.

Conclusion

Drinking honey with lemon and hot water is a simple yet effective wellness practice that offers a range of benefits, including improved digestion, detoxification, weight management, immune support, and skin health. However, moderation is key, as excessive consumption may lead to acidic effects on digestion, enamel erosion, blood sugar fluctuations, and allergic reactions.

By integrating this natural elixir into daily routines mindfully, individuals can maximize its benefits while avoiding potential risks, making it a valuable addition to a holistic health regimen.

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India's Blue Economy: Transforming the Coastal Resources into Opportunities

Article ID: 71119

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Introduction

The concept of blue economy was first introduced by Professor **Gunter Pauli** during the year 1994 at the United Nations University (UNU). In India the blue revolution also called as Neel or Nili Kranti Mission was launched in 1985-1990 during the 7th Five-Year Plan. The world bank defines blue economy **“Sustainable use of ocean resources for economic growth, employment and improved livelihoods while preserving the health of ocean ecosystem.”** Oceans are vital not only to a wide array of biodiversity and ecosystems but also to the food chains, livelihoods and climate regulation for a human population. Blue economy would reinforce and strengthen the efforts of the Indian government as it strives to achieve the sustainable development goals (SDG) of hunger and poverty eradication along with sustainable use of marine resources by 2030.

India is one of the important oceanographic nations with abundant water resources in both inland and marine sector, facilitating the capture and cultured fishes. The Indian fishery sector thrives within diverse ecosystems spanning the country's geographical expanse. The fisheries sector's biodiversity encompasses various physical and biological elements, serving as a vital source of livelihood particularly those economically underprivileged populations residing in coastal regions (Guledagudda *et al.*, 2023). Additionally, it significantly contributes to the national income, exports, food security, nutritional well-being and employment opportunities within the Indian economy (Manjunath *et al.*, 2017). Components of blue economy are ship & port building, shipping & transportation, marine fisheries & aquaculture, tourism & recreation, renewable energy and minerals extraction.

Fisheries Scenario: Global, India and Karnataka

As the world is urbanizing, demand for food and supply are changing rapidly across the rural–urban continuum. As of 2023 Globally, the total fish production was dominated by Asia which accounted for 70.62 per cent of the production (130.62 million metric tonnes) and followed by America contributing 12.19 per cent of the production (22.39 million metric tonnes). Europe and Africa contributing 10.97 per cent and 7.12 per cent of the production (18.66 & 13.05 million metric tonnes) respectively. Australia & New Zealand had a relatively smaller share with 1.12 per cent of the production (1.86 million metric tonnes). Overall, the total global fish production was 186.62 million metric tonnes (Anonymous, 2023)

India emerged as a 3rd largest fish producing countries in the world accounting for 5.84 per cent to the global fish production. As of 2022, India's total fish production was 17,545 thousand tonnes which accounts 4,432 thousand tonnes of marine fish and 13,113 thousand tonnes of inland fish and country has a coastline of 8118km, 1382 islands, 13 major ports & 217 minor ports. Fishing has been a traditional occupation that has evolved over time to become a primary source of livelihood for fishing communities and provides employment of 28 million people annually. (INDIASTAT, 2023)

Karnataka is 3rd largest fish producing state and 1st in marine fish and 7th in inland fish production in country with per cent shares of 6.98 per cent to the total fish production. Karnataka produced a total of 1225 thousand tonnes of fish which includes 730 thousand tonnes of marine fish and 495 thousand tonnes of Inland fish. State has 320 km of coastline, 5.74 lakh ha of freshwater sources, 3.02 lakh ha of ponds and tanks and 2.72 lakh ha of reservoirs with 9.84 lakh fishers and 729 fishermen cooperative societies (132-marine and 597- inland). As of 2022, 1,20,427 Mt of marine products worth Rs.1962.19 crore was exported from the State. (INDIASTAT, 2023).

Transforming the Costal Resources into Opportunities

Transforming coastal resources into opportunities involves harnessing the natural and economic potential of coastal areas to promote sustainable development, boost local economies and preserve the environment. Coastal regions offer diverse resources, such as fisheries, tourism, renewable energy and biodiversity. By adopting innovative strategies, communities can create employment, enhance livelihoods and foster economic growth. The market for fisheries and fish products has experienced a notable surge in recent years, driven by increasing awareness of their health benefits and environmental sustainability. This trend is reflected across various regions from local markets to global trade platforms. The market trends include rising global seafood demand, expansion of value-added products, regional demand, export dominance and global trade growth. The major market opportunities like emerging markets and urbanization, expansion of inland aquaculture, brackish water and coastal aquaculture, seaweed cultivation and export markets which leads to economic benefits like livelihood and employment, foreign exchange earnings, food & nutritional security, export opportunities and government support. During the year 2022, India's total export quantity was 17,81,602 metric tonnes with an export value of 60,523.89 crores, among china being the largest importing country with import value of 4.79 billion followed by Japan (2.72 billion) and Thailand (2.01 billion). In global, china is the largest exporter with exports value of 15.15 billion followed by Norway (12.20 billion) and Vietnam (8.49 billion), India stands in 4th largest exporting country in world. (ITC Trade Map, 2024).

Government Initiatives for Promoting India's Blue Economy

Marine Products Export Development Authority (MPEDA, 1972): MPEDA is a statutory organization responsible for promotion of export of marine products from the country.

Indian Blue Revolution (1985-1990): - The GoI, launched 'Blue Revolution' mission with a central outlay of Rs. 3000 crores to increase the rapid fish production and to adoption of modern techniques for aquaculture and marine fishing in India.

Fisheries and Aquaculture Infrastructure Development Fund (FIDF, 2018): - Played pivotal role in addressing the infrastructure and modernization requirements of both inland and marine fisheries sectors.

Fisheries Kisan Credit Card Scheme (2018): - An extension of the popular KCC Scheme to the fishing and animal husbandry sectors and provides working capital requirements.

Pradhan Mantri Matsya Sampada Yojana (PMMSY, 2020): - Scheme launched in May 2020 under the Aatmanirbhar Bharat COVID-19 relief package and aimed to turn India into hotspot for fish and aquatic products through appropriate policy, marketing and infrastructure support.

Conclusion

India's seafood industry has demonstrated robust growth and resilience over the past few years, significantly enhancing its position in the global market. The seafood industry in India has a promising outlook and its potential contributions to food security, nutrition and employment cannot be ignored. The concerted efforts by the government, encompassing infrastructure development, aquaculture support, duty reductions, export incentives and the implementation of schemes like the Pradhan Mantri Matsya Sampada Yojana (PMMSY), have played a pivotal role in this success. As a result, India has not only increased its production and export volumes but also expanded its market reach to 132 countries across the globe.

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Cyborg Botany: Engineering Plant-Machine Interfaces for Precision Agriculture

Article ID: 71120

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Introduction

The term "cyborg," derived from "cybernetic organism," describes a living being integrated with bio-mechatronic and organic elements, resulting in restored function or enhanced capabilities through technology that includes feedback mechanisms. While often confined to science fiction, the concept of combining organisms and machines is increasingly present in reality, appearing in everyday life, the military, and popular culture since cyborg research emerged in the mid-1980s. Beyond humans, this integration extends to plants, leading to the concept of "cyborg plants." These involve incorporating electronic components like circuits, transistors, and sensors into plant structures to enable new abilities, such as conducting electricity or detecting substances. Similarly, the idea of a "cyborg farmer" has been developed, referring to farmers who effectively embody precision agriculture technologies like GPS, scans, and imaging tools, integrating these technologies with their deep, physical understanding of the farm's environment. This integration signifies a growing convergence of the living and the artificial, blurring traditional lines.

Cyborg Plants in Agriculture

The cyborg farmer integrates data and new ways of perceiving the farm provided by precision technologies with their embodied knowledge—knowledge developed through the physical act of farming, sensory experiences, and lived experience in the field over time. For example, precision technologies extend the farmer's vision, allowing them to see things not visible to the naked eye and providing new spatial dimensions through tools like drones. However, farmers validate and interpret this data by physically going into the field, walking through crops, digging soil pits, and using their senses to make sense of what the data suggests. This creates a productive tension between data-driven elements and the embodied, intuitive understanding of the farm. The cyborg farmer integrates these different forms of knowledge to form usable knowledge and maintain their agency in decision-making, resisting the idea that precision agriculture leads to the dominance of algorithmic rationality. This perspective highlights that even in futuristic scenarios involving fully data-driven farming, the embodied experience of people working in the field remains essential and could potentially be integrated with technology. The concept suggests that there is a spectrum of engagement, potentially leading to different "digital farming styles".

Sensing plants, often referred to as "cyborg plants," are being engineered through the integration of electronic components like sensors to gain new detection capabilities. This rapidly developing field is exploring several types of detection:

1. Explosives: Spinach plants have been successfully transformed into sensors capable of detecting explosives by embedding their leaves with carbon nanotubes and peptides that can detect nitro-aromatic chemicals, which are found in explosives like TNT. When these chemicals reach the leaves or roots, the plants emit infrared light that can be detected wirelessly.

2. Pollutants: Researchers believe that engineering plants with sensors is a major step towards overcoming the plant/human communication barrier, allowing plants to be used to warn of pollutants in the environment. Tiny sensors have been developed that can detect pollutants and other dangers in groundwater.

4. Environmental Conditions: The technology could allow plants to warn of environmental conditions such as drought. Plants could also potentially pick up and broadcast information about their immediate surroundings, including temperature, moisture levels, and sunlight.

5. Plant Physiology: Scientists are working on additional sensors that would give a plant the ability to monitor its own physiology, providing real-time data to botanists to understand the plant's inner workings and health.

6. Chemicals in Groundwater: Sensors inserted into living plants can scout for particular chemicals, such as those indicating the presence of explosives, in groundwater.

How do Cyborg Plants Boost Plant Efficiency and Strengthen their Resilience?

1. Increased Photosynthetic Efficiency: MIT researchers inserted carbon nanotubes into the chloroplasts of a weed, enabling the plant to use additional wavelengths of light (visible, UV, infrared) that it doesn't naturally absorb. This resulted in an increase in photosynthetic efficiency by 30%. While this didn't necessarily lead to faster growth as photosynthesis isn't always the limiting factor, it demonstrated the potential to improve a biological function.

2. Radiation Resistance: A chrysanthemum has been engineered with a molecular layer (a "metal-organic framework") covering its leaves and petals to protect it from harmful UVC radiation. This could potentially allow plants to grow in environments like Mars or the moon without needing extraterrestrial greenhouses.

3. Motion Sensing: In "cyborg botany" projects, plants have been turned into motion sensors, functioning as a sort of motion-detecting antenna. A motion-sensitive rosebush could function as a no-touch trackpad, translating hand gestures into actions on a computer, or act as a sentry sensing when a pet leaves a door.

4. Responding to Commands: Electrodes can be used to control a Venus flytrap, allowing researchers to command specific leaves to snap shut using a computer interface.

5. Soft Notifications: Researchers envision using interactive plants to provide "soft notifications" about things happening around us without the intrusive sounds or glaring displays of computers and smartphones. For example, one fern could wiggle when its paired fern is gently poked. Motion-sensing plants could also potentially alert caregivers if an older person has fallen.

6. Market Applications: Researchers believe that urban farming is the most promising market for this technology, particularly in enclosed spaces where monitoring is easier and precision agriculture is important for efficient land use. Precision agriculture more broadly is also a potential market, especially in enclosed spaces.

7. Inspiration for Robotics: Plant roots, which are effective at finding resources and avoiding obstacles, are inspiring scientists building robots. The Plantoid robot, which mimics root growth and sensing, could be used for environmental monitoring (detecting chemicals or pollutants in air and soil) or even exploring other planets.

Other examples include rechargeable electric roses created by Swedish researchers, where conductive polymers were introduced into the plant's veins to form wires capable of carrying an electrical current. These "e-plants" can conduct and store electricity. Another notable example is the cyborg spinach developed by MIT researchers, where leaves embedded with carbon nanotubes function as sensors capable of detecting explosives and wirelessly transmitting warnings. These plant sensors can detect chemicals in water that indicate the presence of explosives.

Researchers believe this technology could overcome the plant/human communication barrier, allowing plants to warn of pollutants and environmental conditions like drought. There are also experiments aiming to create plants with enhanced capabilities, such as increased photosynthetic efficiency by inserting carbon nanotubes into chloroplasts, or making plants radiation resistant.

Beyond detection and energy, "cyborg botany" projects are exploring integrating electronics for interaction, such as controlling a Venus flytrap with electrodes or using plants as motion sensors for "soft notifications". The potential market for these technologies includes urban farming and precision agriculture, especially in enclosed spaces.

Ethical Considerations in Plant Cybernetics

The development of cyborg plants, which integrate living organisms with electronic components and nanotechnology, brings forth several ethical considerations. One significant concern is the potential environmental risk of pollution posed by the artificial components if these plants are released into the wild. Scientists are also grappling with questions regarding the long-term survival and viability of plants with integrated artificial parts [Our conversation history]. This field inherently blurs the lines between the living and the artificial, leading to philosophical discussions, such as whether a plant that cannot grow or reproduce due to incorporated materials can still be considered alive. It is anticipated that if cyborg plants move beyond laboratory settings, they will likely become a source of public discussion and controversy. Furthermore, the potential for using plants as sensors raises concerns about surveillance, prompting questions about tracking individuals' movements or activities. The broader principle that scientists creating "biological machines called Cyborgs" should carry a proper amount of social responsibility suggests a need for responsible innovation in this domain.

Conclusion

Cyborg plants represent a significant advancement at the intersection of biology and engineering. While still largely in the experimental stage, particularly regarding integration into fully growing plants, the successful demonstrations highlight their potential to provide enhanced sensing capabilities for environmental monitoring and safety, contribute to energy solutions, improve plant resilience and efficiency, and even serve as new forms of human-plant interaction. The ongoing development of this technology promises to transform aspects of agriculture, environmental monitoring, and potentially our relationship with the natural world, pushing the boundaries of what plants are capable of producing.

Small Hive Beetle (SHB): A Growing Threat for Global Beekeepers

Article ID: 71121

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Abstract

The small hive beetle (*Aethina tumida* Murray) is an invasive pest that poses a significant threat to both commercial beekeeping and wild bee populations globally. First identified in 1867, the beetle has since spread to three continents, with recent outbreaks reported in Bangladesh and various districts of West Bengal, India. SHBs exhibit opportunistic predatory behavior, entering colonies through small openings and laying eggs in combs, where larvae feed on honey, pollen, and brood, contaminating honey and compromising hive integrity. Effective management strategies are crucial, including maintaining healthy colonies, regular inspections, and employing mechanical and curative measures to control SHB populations. This information is vital for beekeepers, entomologists, and extension agents to mitigate the impact of this invasive pest.

Keywords: Small hive beetle, honey bee, threat, beekeepers.

Introduction

Introduced pathogens and parasites can often switch hosts, thus posing new threats to native species. Instead, native species must rely on generalistic methods of defence, which may or may not be sufficient to provide adequate protection against the new threat. The small hive beetle (*Aethina tumida* Murray, Coleoptera; Nitidulidae) is a classic example of such a parasite, having been moved to new locations by the global trade in honey bee and hive products.

SHB exhibits distinct pheromone-related behavior. The honeybee's alarm pheromone, which is mostly secreted by the host to alert the host guardians to the presence of attackers, is detectable by them. This fitness advantage improves their ability to quickly locate and colonize the honeybee hives. Human activity such as migratory beekeeping and movement of package bees and beekeeping equipment significantly facilitates the quick spread of small hive beetles around the world. Therefore, the more study of small hive beetle (SHB) is essential in beekeeping because it poses a significant threat to honey bee colonies, leading to severe infestations and economic losses. Understanding its biology, behavior, and effective management strategies is crucial for maintaining healthy bee populations and ensuring sustainable beekeeping practices.

First Occurrence

The invasive small hive beetle seriously threatens commercial beekeeping and wild bee colonies worldwide. It was originally described as a scavenger feeding on decaying fruits and fermenting plant juices (Neumann and Elzen, 2004). It would appear that the beetle has switched hosts to honey bee colonies opportunistically, after foraging on rotten fruit and has become a minor pest of weaker colonies of *Apis mellifera* in sub-Saharan Africa (Spiewok and Neumann, 2006). It was first collected from Old Calabar on the west coast of Africa and sent to Andrew Murray in London in 1867 for identification (Murray, 1867). Nowadays, it is found on three continents and is likely to spread to new regions of the world (Hood, 2004). However, the outbreak and spread of the SHBs, followed by its invasion outside its native range, resulting in severe losses of bee colonies, has been reported by many countries, including a recent invasion and outbreak of the SHBs in *Apis mellifera* colonies from Bangladesh since 2020.



Fig. 1: Adult small hive beetle *Aethina tumida* (Cuthbertson *et al.*, 2013)

Report on our Country

During a routine survey of the ICAR-All India Coordinated Research Project on Honey Bees and Pollinators (AICRP, HBP) in 2022, researchers from the IARI, New Delhi, noted the presence of this harmful pest in *Apis mellifera* colonies from North 24 Paraganas district of West Bengal. Additionally, during 2023-2024, the outbreak and spread of SHBs were documented in commercial apiaries of *A. mellifera* and *A. cerana* in the West Bengal districts of Malda, Hooghly, Murshidabad, and Cooch Behar. It showed that the distress sale of the affected colonies from West Bengal at reduced prices and the buying of those hives by Andhra Pradesh beekeepers who were unaware of the infestation were the main causes of the establishment and spread of this pest in Andhra Pradesh. Similar to this, news reports of this pest's presence have come from colonies of *A. mellifera* and *A. cerana* in the state of Assam following the migration of afflicted colonies from West Bengal to Assam during the mustard season. (Kumaranag *et al.*, 2025).

Biology and Behavior

As opportunistic predators, SHBs get attracted to the scents of bee colonies from a larger distance. Beetle larvae are creamy-white and emerge from the egg through longitudinal slits made at the anterior end of the egg. Adult small hive beetles (Fig. 1) average 5.7 mm in length and 3.2 mm in width (Ellis *et al.*, 2002). Adult beetles are known to live for a long period, even when they are starved and may survive on a variety of different food sources. Strong flyers, adult beetles typically travel 10-12 kilometers in pursuit of bee colonies. They also display unusual behaviors that persuade worker honey bees to care for and feed them. In addition to honey bees, stingless and bumble bee colonies have also been documented to be infested and destroyed by SHBs.

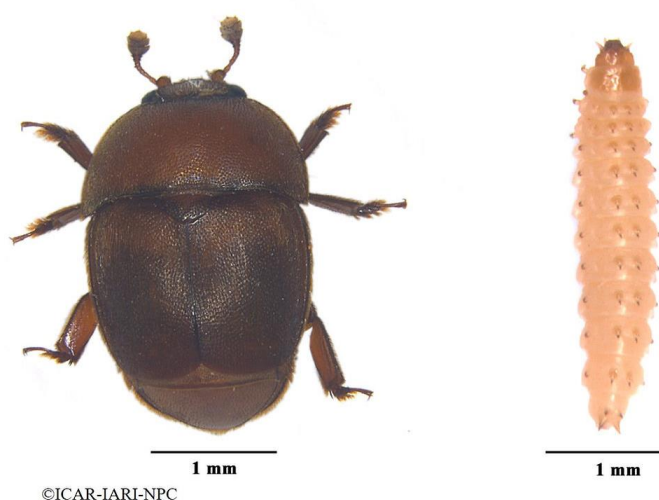


Fig. 2: Adult (left) and larva (right) of small hive beetles

Damage

Adult beetles enter the colonies by passing through the bees defenses and entering through hive openings, cracks and crevices. If a colony is strong, the adult beetles congregate on the bottom board to feed on the

hive litter and then wait for the right time to raid the colony's pollen, honey, bee bread and brood. When the colony weakens, the adult female beetles deposit their eggs inside the combs and on the frames' edges. When there are too many adult beetles, they disrupt the colony's regular operations, which makes the worker bees uncomfortable.



Fig. 3: SHB infestation in honey bee colony (white SHB larvae & brownish adults are visible)

As soon as the SHB larvae hatches, they burrow into combs to feed on pollen, honey, and bee brood. In the process, they contaminate honey with yeast, which rapidly breaks down the honey and makes it unfit for human consumption. The comb structure is broken down by the larvae's extensive tunneling. A severe infestation causes the bee colonies to disintegrate and abscond. In order to find a good place to pupate in soil, fully grown larvae tremble through the beehives and escape from the combs.



Fig. 4: Infestation caused by SHB their eggs, grubs and adult

Management Tactics

Due to its excellent capacity for reproduction, dissemination, and hidden behavior in the early stages of infection, this persistent pest is extremely difficult to eradicate once established. The following are the ad hoc integrated invasion SHB management strategies that ICAR-AICRP, HBP recommends:

1. The population build-up can be controlled by preventative measures like as keeping healthy colonies, inspecting them frequently, killing beetles by hand, and mechanically catching them with attractants like cider vinegar in the early stages of infestation.
2. In order to disrupt the development of the pupal and adult stages, curative procedures include scraping the soil surrounding the bee hives and applying diatomaceous earth.

To reduce SHB numbers, creative approaches like pheromone-based baits and UV light traps can also be tried. For the sustainable control of invasive pests, proactive pest management techniques and pest

surveillance are crucial, as demonstrated by the current small hive beetle outbreak. Beekeepers, entomologists and extension agents may utilize the current information to take the appropriate additional action.

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Shrimping for Gold - India's Lucrative Shrimp Farming Business

Article ID: 71122

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Introduction

India is endowed with a long coastline and hence offers scope for large exploitation of marine wealth. Till a few years back, fishermen in India were involving themselves in traditional marine fishing. In the seventies, fishermen started concentrating on catching prawns more commonly known as 'shrimps' due to their high profitable return on account of their export value. Shrimps are called the "**Pinkish Gold**" of the sea because of its universal appeal, unique taste, high unit value and increasing demand in the world market. Shrimp farming is popular in the coastal border of Tamilnadu and Andhra Pradesh. Because of more and more government regulations and lack of local support, shrimp farming was already in its extinct stage. But still some traditional and small land holding shrimp farmers are involved in this farming activity.



What is Shrimp?

Shrimp is one among 2,000 species of the suborder Natantia. Its close relatives include crabs, crayfish, and lobsters. Shrimps are characterized by a semitransparent body flattened from side to side and a flexible abdomen terminating in a fanlike tail. The appendages are modified for swimming, and the antennae are long and whip like. Shrimp occur in all oceans - in shallow and deep water - and in freshwater lakes and streams. Many species are commercially important as food. Shrimp range in length from a few millimeters to more than 20 cm (about 8 inches). Average size is about 4 to 8 cm (1.5 to 3 inches). Larger individuals are often called **Prawns**.



What is Shrimp Farming?

Shrimp farming is a form of aquaculture that involves cultivating, growing and harvesting shrimps in large scale. India is the 3rd largest shrimp farming country in the world. It contributes over 60 million tons each

year. To be clear, India contributes one sixth of the total shrimp production in the world. Tamilnadu and Andhra Pradesh coastal lines are famous for shrimp cultivations.



History of Shrimp Farming

In India, shrimp farming was first conducted only on an experimental scale. The first use of brackish water fish farming was demonstrated in West Bengal by the **Central Inland Fisheries Research Institute** under the Indian Council of Agricultural Research (ICAR) in 1973. Subsequently an ICAR coordinated research project on brackish water aquaculture was implemented in India during the year 1975 through project centers in West Bengal, Andhra Pradesh, Odisha, Tamil Nadu, Goa and Kerala. Simultaneously successful production of shrimp seed was demonstrated in **Naraka** in Kerala by the Central Marine Fisheries Research Institute. Thereafter commercial shrimp hatcheries were established by the Marine Products Export Development Authority (MPEDA). Semi-intensive culture technology was also demonstrated on a pilot-scale project by the MPEDA.

Requirements

There are several factors involved in shrimp farming which includes site selection, topography, climatic conditions, water quality, transport facilities, labour availability etc.

Site selection: Selection of site is the most important factor in the shrimp farming process because it is the place where shrimp seeds are reared (newly hatched shrimps used for shrimp farming are called '**Shrimp seeds**'). As we are going to grow the shrimps underwater, we can't predict the casualties around.



Topography: The best areas for shrimp culture are those with average natural ground elevations of about 1-3 m above mean sea level or at least 1 m above the highest high tide level to allow drainage and harvesting. The cost of pumping increases in highly elevated sites.

Transport: The farm must have good accessibility either by road or water and communication systems throughout the year in order to facilitate supervision and transport of materials and products. It is important that the farm be within 3-6 hours traveling time from the hatchery to avoid long transportation time of the larvae, and should be within 10 hours from the processing plant to avoid deterioration of the product.

Electricity: Unlike other farming sectors, shrimp farming doesn't have any subsidies or electricity bill reduction. Electricity bill for an average shrimp farm of 1 hectare costs around 10 lakhs per annum. Availability of relatively cheap and reliable power source is a major consideration in site selection. In areas where electricity supply exists, it is practical and beneficial to utilize electric power to run the farm, especially for the intensive culture system. It is advisable to have a back-up electricity generator as a secondary power source.

Water Supply: Site should have pollution free water supply of both freshwater and brackish water. Water quality parameters required for maximum feed efficiency and maximum growth are given below:

Water parameters	Optimum level
Dissolved Oxygen	3.5-4 ppm
Salinity	10-25 ppt
Water Temperature	26-32 (°C)
pH	6.8-8.7
Total nitrite nitrogen	1.0 ppm
Total ammonia (less than)	1.0 ppm
Biological Oxygen Demand (BOD)	10 ppm
Chemical Oxygen Demand (COD)	70 ppm
Transparency	35 cm
Carbon dioxide (less than)	10 ppm
Sulphide (less than)	0.003 ppm

Water from polluted areas containing high concentrations of suspended solids and organic wastes such as effluent water from industries, urban areas, agricultural and other farm locales should be avoided. A settling pond or a large reservoir should be used in such areas for sedimentation and treatment. In saline areas a source of freshwater is useful for adjusting the salinity in the ponds and for domestic use by farm staff. Freshwater should be good enough for use and adequate throughout the year.



Management Practices

Shrimps are naturally grown in aquatic conditions. If we are culturing them in our livelihood conditions then we have to provide the optimal conditions for their growth that resembles their own oceanic environment. Best management practices (BMPs) for shrimp farming are a standardized set of farming practices which ensure the environmental and financial sustainability of shrimp farming systems.

- 1. Aqua Care 3D:** It's a triple salt compound used to avoid pathogens.
- 2. Aqua Care Control:** it enhances healthy plankton growth that serves as a natural feed for shrimps.
- 3. Aqua Care Mineral Balance:** It balances the mineral concentration in the water environment.

Feeding Behavior of Shrimps

- In natural environmental conditions shrimps are scavenging opportunistic feeders. Under farming conditions as well they harness food particles suspended in the water column (e.g., phytoplankton, zooplankton, microbial flocs, organic detritus etc.) and food organisms living on the pond bottom (e.g., plant and animal biota), in addition to the compound feeds.
- Shrimp have poorly developed eyes with reduced vision, and hence rely primarily on chemical attraction and stimulation to locate and consume their food, including compound feeds. This necessitates the compound feeds to remain immersed in water for prolonged periods of time (typically for several hours) prior to being externally masticated and then consumed.



Essential Feed

Gamma- Skretting's feed with high protein and right pellet size are formulated with high precision to deliver balanced nutrition with equal emphasis been placed on species specific formulation. Gamma feeds promise to deliver optimal amino acid balance, immuno-stimulants and attractants which provides highly digestible and bio-absorbable nutrients along with good palatability.

SUCCESSFUL CROP - GAMMA FEED		
POND INFO	CUSTOMER NAME	MR. GIRISH PATEL
	STOCKING DATE	05/04/2020
	HARVEST DATE	07/08/2020
	LOCATION	Rajagiri, Surat, Gujarat
	POND AREA (Acres)	2
HARVESTING INFO	STOCKING QUANTITY (mn)	0.25
	DENSITY (PCS/M2)	31.25
	TOTAL HARVEST (KG)	6,224
	HARVEST SIZE (PCS/KG)	36
	ABW (gms)	27.54
	ADG (gms)	0.22
	TOTAL FEED GIVEN (KG)	8,110
	F.C.R.	1.30
	DOC (Day)	124
	SURVIVAL RATE (%)	90.40



Technology for Aeration

Pond aerator from SYNERGY AQUAPRO have been widely used for sustaining large quantities of shrimp. Paddle-wheel aerator (surface aeration system) can also be used for producing large air-water interface. Through these systems transfer of oxygen from atmosphere is enhanced.



Constraints and Challenges in Shrimp Farming

1. Climate Change: Climate change has become a serious threat to shrimp farming. Changes in seawater temperature and unstable weather conditions can disrupt the shrimp's life cycle and increase the risk of long-term stress on the shrimp, which can impact pond productivity. Climate change can also lead to extreme weather events such as tropical storms and floods, disturbing the pond water balance and damaging infrastructure. To address this farmers need to adopt shrimp farming practices that are more resilient to climate change.

2. Fluctuating Pond Water Conditions: Fluctuating pond water conditions including changes in water quality parameters are the most common challenges faced by shrimp farmers. Poor water quality can cause stress to the shrimp and increase the risk of disease outbreaks. To address the issue of fluctuating pond

conditions farmers can monitor water quality parameters regularly and take necessary actions when anomalies or changes occur in each water quality parameter.

3. Disease Outbreaks: The most serious challenge in shrimp farming is disease outbreaks. Disease outbreaks can lead to significant financial losses for farmers. Some common diseases affecting shrimp farms include **White Spot Syndrome Virus (WSSV)**, **Infectious Hypodermal and Haematopoietic Necrosis Virus (IHHNV)**, **Early mortality syndrome (EMS)**, **Enterocytozoon hepatopenaei (EHP)** and **Vibriosis**. These diseases can spread rapidly and cause mass mortality if not promptly addressed. To reduce the risk of disease outbreaks farmers need to implement good shrimp farming management practices such as daily water quality monitoring, routine health checks, biosecurity measures and high-quality feed.

Government Schemes

1. Pradhan Mantri Matsya Sampada Yojana (PMMSY): It was launched in 2020 for providing support to quality shrimp production, species diversification, promotion of export-oriented species, branding, standards and certification, training and capacity building, creation of post-harvest infrastructure through this flagship scheme.

2. Fisheries and Aquaculture Infrastructure Development Fund: Launched in 2018, FIDF provides loans to address infrastructure and modernization needs in both marine and inland fisheries.

3. Kisan Credit Card (KCC) Fisheries scheme: It provides adequate and timely credit support to fish farmers for their working capital requirements.

- New cardholders can obtain credit up to Rs. 2 lakhs with interest subvention.
- Existing KCC holders can access an increased credit limit of Rs. 3 lakhs.
- The lending rate for KCC loans is 7%, including 2% interest subvention per annum by the Government of India.

Status of Shrimp Farming in India

- India as Shrimp Exporter: India is one of the world's largest shrimp exporters.
- In 2022-23, India's seafood exports stood at \$ 8.09 billion or ₹640 billion and shrimps accounted for a bulk of these exports at \$ 5.6 billion.
- India's share of seafood exports in the U.S. market was 40% in 2022-23, far ahead of rivals like Thailand, China, Vietnam and Ecuador.
- Shrimp Producing States: Andhra Pradesh is the largest shrimp producer state in India which accounts for 70% of India's shrimp output.
- West Bengal and Gujarat are other major players in shrimp farming, with Sundarbans in West Bengal and Kutch in Gujarat being key producers.

Conclusion

Shrimp farming is one of the most profitable yet more risky venture in today's world. The capital investment, maintenance, and losses are too big in this field. In spite of that many traditional farmers are cultivating superior quality shrimps and exporting to foreign countries. Tons and tons of protein rich food source from our land is being exported every day because of our lack of attention towards this food source. If we turn our eyes towards this field, the cultivators won't depend only in exports and our country's economy can also be enhanced.

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Turning Trash into Treasure: How Agricultural Waste is Fueling the Future with Biobutanol

Article ID: 71123

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Introduction

For meeting the transport requirement of the increasing global population the demand for fuel is increasing continuously. The non-renewable fuels like petrol and diesel are still in use in major scale, which shares a major reason for global warming. There is global voice out for the replacement for these petro-fuels with bio-diesel, bio-ethanol, and bio-butanol. These biofuels are sustainable source of energy because these can be produced from numerous feed stock like; agricultural waste, municipal waste and forest residue. The best feed stock is selected for the more efficient production of biofuel. As like the feed stock selection, selection of best strain of bacteria for fermentation, like *Clostridium* is important for the effective production of biobutanol. Acetone-Butanol-Ethanol fermentation (ABE fermentation) is followed for the production of biobutanol. The major problems in biobutanol productions are product inhibition, toxicity of oxygen to the microorganism used, inefficient use of pentose sugar. The recent studies focus on mitigating these problems.

Feed Stock Used for Biobutanol Production

The feedstock used for production are generally classified into four different categories as shown in the figure below.

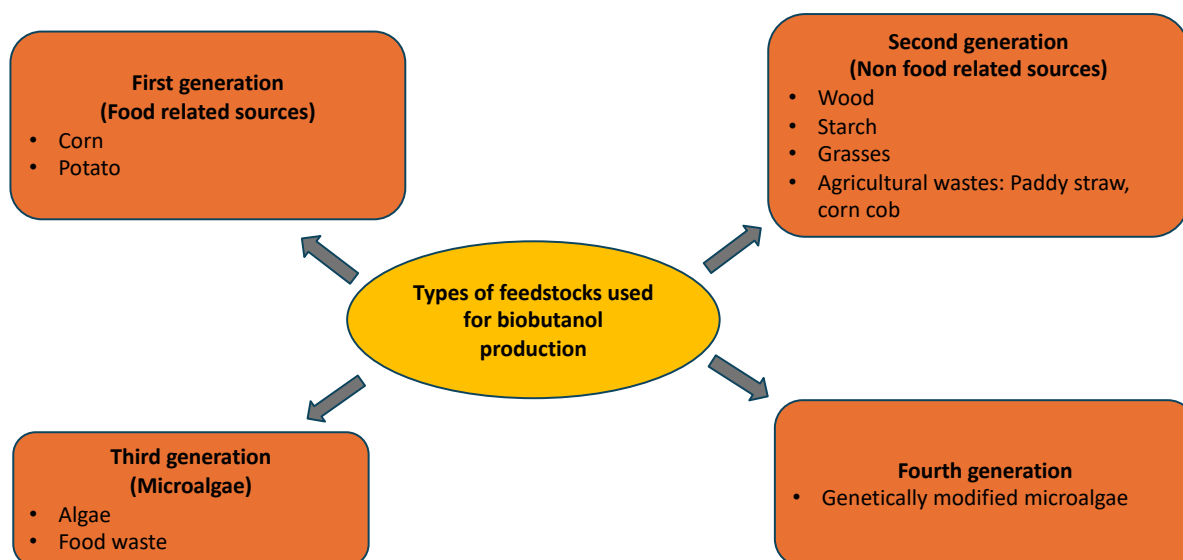


Figure 1: Classification of feedstock used for the biobutanol production

Use of the first generation feed stocks imparts threat to the global food security. To solve this problem second generation feedstocks are used and they don't have any impact on food security, where it is more sustainable approach. Here the agricultural waste materials is used and these are mainly lignocellulosic material. They are major frame work of plants, which consists of cellulose, hemicellulose and lignin. This is quite recalcitrant in nature, so that this has to go through complex upstream processing methods to make it more available to microorganism for fermentation.

Upstream Processing in Biobutanol Production from Agricultural Waste

The complex nature of lignocellulosic material makes it inevitable to do various upstream processing for making it into simpler molecules which is available for the utilization by microorganisms. This includes mainly pretreatment, hydrolysis and detoxification. Pretreatment includes the use of biological, physical, chemical or physicochemical methods for altering the structure and composition of lignocellulosic wastes. These steps make the complex lignocellulosic wastes more accessible to the fermentation step. After pretreatment hydrolysis step is done where the long chain of cellulose and hemicellulose are degraded into simpler molecules. Hydrolysis can be done enzymatically or by the use of dilute acid or alkali.

The use of lignocellulosic material as a feedstock is hindered by the production of various compounds such as furfurals, acetic acid and furan derivatives. This problem is solved by the introduction of one more step in the upstream processing which is detoxification step. Detoxification can be done by adsorption, evaporation, ion exchange resins and over liming.

Fermentation and Product Recovery

The enzymatic hydrolysis of the substrate leads to the production of simple sugars such as glucose and xylose. The *Clostridium* sp. inoculated in the culture helps in the conversion of sugars into butanol. This fermentation is called as ABE fermentation (Acetone-Butanol-Ethanol). The *Clostridium* species used mainly are *Clostridium acetobutylicum* and *Clostridium beijerinckii*. ABE fermentation has two phases; acidogenic phase and solventogenic phase, so it is called as bi-phasic fermentation.

Finally the product formed is a mixture of solvents, which can be recovered by process such as distillation, gas stripping, pervaporation or adsorption.

Conclusion

Agricultural waste is a major concern in India, where stubble burning is a widespread practice. This contributes significantly to air pollution, green-house gas emission and nutrient loss from soil. This waste can be turned into treasure by the production of biobutanol from agricultural waste.

Optimization of Working Parameters for a Tractor-Mounted Coconut Basins Lister Cum Fertilizer Dispenser

Article ID: 71124

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Abstract

Efficient management of coconut plantations requires timely basin formation and uniform fertilizer application. Traditional manual methods are time-consuming and labor-intensive. This study aims to design and optimize the working parameters of a tractor-mounted coconut basins lister cum fertilizer dispenser to mechanize these operations. Key parameters such as forward speed, depth of cut, disc angle and fertilizer discharge rate were varied and analyzed for their effects on basin formation quality, fertilizer distribution uniformity, field efficiency and fuel consumption. The results demonstrated that a forward speed of 2.5 km/h, a working depth of 20 cm, a disc angle of 35°, and a metering rate of 25 kg/min. yielded the best overall performance, reducing labor by 70% and operating costs by 40% compared to manual methods.

Introduction

Coconut is a perennial crop widely cultivated in India, Indonesia, the Philippines, and Sri Lanka. Efficient nutrient and water management are essential for sustainable coconut farming, and basin formation around each tree is a standard agronomic practice to facilitate root aeration, water retention and targeted fertilizer application.

Manual basin digging and fertilizer application remain the norm in many regions. These methods are labor-intensive, inconsistent and time-consuming, particularly in large plantations. Mechanization offers a promising alternative and the development of a tractor-mounted lister cum fertilizer dispenser presents an integrated approach for coconut basin management.

However, the performance of such an implement is highly sensitive to operational parameters. Inappropriate settings can lead to inadequate basin formation, soil inversion issues, or uneven fertilizer discharge. Thus, there is a clear need for optimizing critical parameters such as forward speed, working depth and disc angle and fertilizer flow rate.

Materials and Methods

1. Machine Description: The developed implement consists of:

- A dual-disc lister mounted on a frame suitable for three-point linkage.
- A fertilizer hopper with an adjustable metering mechanism.
- An auger-type fertilizer delivery system powered by the tractor PTO.

2. Parameters Studied: Four major parameters were selected for optimization: Forward Speed (2.0, 2.5, 3.0 km/h), Depth of Cut (15, 20, 25 cm), Disc Angle (25°, 30°, 35°), and Fertilizer Rate (15, 20, 25 kg/min).

3. Experimental Design: Field trials were conducted using a randomized block design on a 2-hectare coconut plantation. Data collected included basin dimensions, fertilizer uniformity, field capacity, field efficiency, and fuel consumption.

Results and Discussion

1. Effect of Forward Speed: Optimal speed of 2.5 km/h balanced speed and quality.

2. Effect of Depth of Cut: 20 cm depth produced the best quality with acceptable fuel usage.

3. Effect of Disc Angle: A 35° angle provided optimal basin shape.

4. Fertilizer Discharge Rate: 25 kg/min gave the best uniformity (CV < 10%).

Conclusion

This study successfully optimized the operational parameters for a tractor-mounted coconut basins lister cum fertilizer dispenser. The most effective combination—forward speed of 2.5 km/h, depth of 20 cm, disc angle of 35° and fertilizer discharge rate of 25 kg/min—ensured efficient basin formation and uniform fertilizer application.

The optimized implement achieved:

- a. 60–70% time savings
- b. 40% cost reduction
- c. Enhanced ergonomics and reduced labor.

This mechanization has strong potential for adoption in medium and large coconut farms.

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Remote Sensing in Agriculture

Article ID: 71125

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Introduction

Remote sensing has become a game-changing technology in contemporary agriculture, transforming the way data is gathered and analysed. Remote sensing, which is the science of gathering data about things or regions from a distance, usually using satellite or aviation technology, makes it possible to monitor agricultural landscapes in great detail without making direct personal contact. It has great potential to improve crop health monitoring, optimize resource use, estimate yields, and manage climate-related hazards due to its ability to collect timely and reliable data over wide areas. This study examines the many forms of remote sensing, the range of agricultural uses for it, and the difficulties in putting it into practice, emphasizing how important it is to promoting precision farming and food security.

Remote Sensing

The National Oceanic and Atmospheric Administration, or NOAA, defines remote sensing as the science of gathering data about things or regions from a distance, usually using satellites or airplanes. Remote sensing, according to India's National Remote Sensing Agency, is a method of learning about objects on Earth's surface without actually touching them.

Types of Remote Sensing

According to (Singh *et al* 2014), there are two types of remote sensing based on source of energy used i.e., Active remote sensing and Passive remote sensing.

Active sensors: To illuminate the target object, active sensors provide their own source of electromagnetic radiation. When the radiation is reflected or backscattered from the target, it is once again detected and recorded. The sensor itself produces radiation in the direction of the phenomenon or item. LIDAR (Light Detection and Ranging), radar, sounders, scatter meters, laser altimeters, and other devices are examples of active remote sensors.

Passive sensors: Solar radiation that is reflected or emitted by objects on the surface of the Earth is detected by a passive sensor. The performance of these sensors is negatively impacted by weather and cloud cover because they operate in the visible and infrared range. Accelerometers, hyperspectral radiometers, spectrometers, imaging radiometers, sounders, spectroradiometers, radiometers, and more are examples of passive remote sensors.

Remote Sensing in Agriculture

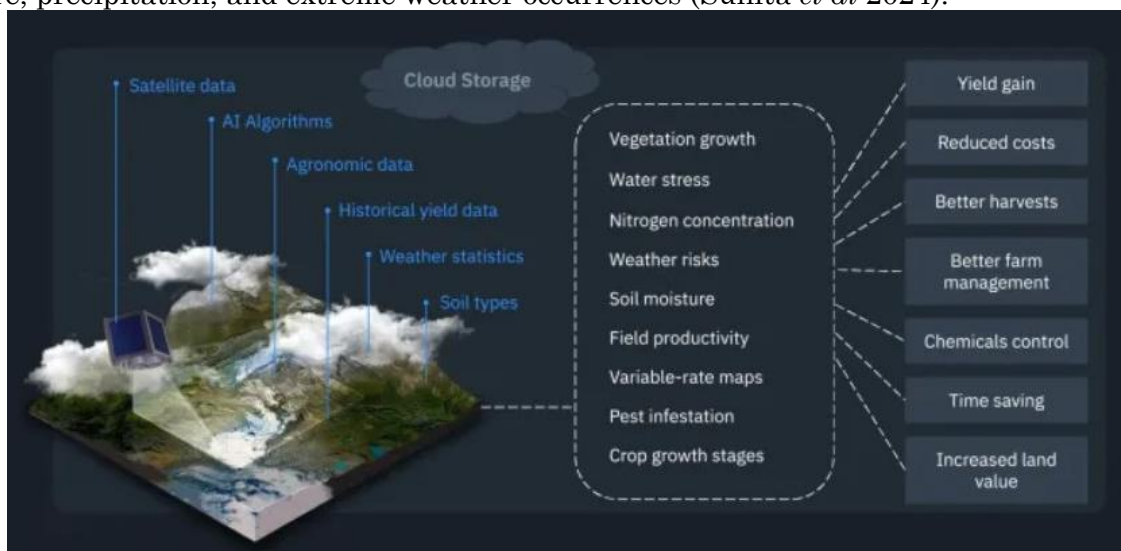
Remote sensing is currently practiced in four major areas of agriculture, which are discussed below;

1. Enhanced crop management and health monitoring: Plant protection evaluation and management depend critically on consistent, timely, effective over large regions monitoring of diseases and pests. Therefore, it is crucial to develop techniques that can evaluate the geographical distribution of pests and diseases in crop fields while making decisions and applying sprays. There are three possible outcomes when plants are exposed to solar electromagnetic energy: transmission, absorption, or reflection. Remote sensing can identify whether energy is reflected, transmitted, or absorbed by plants based on their unique properties and the energy's wavelength. The amount of energy that is reflected, absorbed, or transmitted can cause variations in leaf colors, textures, forms, and even how the leaves are linked to plants. In general, healthy plants have at least one reflection in the visible range and a higher reflection in the near-infrared region; the converse is true for infected plants (El-Ghani *et al* 2020).

2. Resource optimization and sustainability: Since the spectral responses of irrigated lands differ from those of non-irrigated croplands, remote sensing has shown to be an efficient method for monitoring irrigated lands in various parts of the world. This can be done utilising optical sensors such as Landsat, MODIS (Moderate Resolution Imaging Spectroradiometer), AVHRR (Advanced Very High-Resolution Radiometer) and SPOT (Satellite pour l'Observation de la Terre). Another method for identifying irrigated areas has been the introduction of satellite soil moisture products in recent years. To achieve sustainable agriculture, it is crucial to evaluate the environmental effects of non-point source pollution at the local and regional levels.

3. Yield prediction and food security: Predicting crop yields before harvest is crucial for planning and policymaking. Conventional approaches are expensive, subjective, and time-consuming. A number of issues also influence the development of empirical models that use meteorological data. Remote sensing data enables the creation of predictive models by continuously tracking crop conditions during the growing season. These models forecast future crop yields by utilizing historical data, vegetation indices, and weather patterns. Such projections support a more robust and adaptable agricultural system by assisting agronomists, decision-makers, and stakeholders in making well-informed choices.

4. Climate adaptation and risk management: With rising temperatures, changed precipitation patterns, and an increase in extreme weather events, climate change presents serious threats to dryland horticulture. In order to evaluate these climatic risks and develop adaptation measures that will increase the resilience of agricultural systems, GIS is essential. A significant chance to enhance climate change adaptation tracking systems is provided by remote sensing technology. GIS assists in identifying sensitive locations and evaluating possible effects on agricultural activities by including climate data, including temperature, precipitation, and extreme weather occurrences (Sunita *et al* 2024).



EOS crop monitoring data transformation flow (source: Agricaprimenews, 2022)

Challenges in Implementing Remote Sensing in Agriculture

There are a number of obstacles that must be overcome before remote sensing may be used in agriculture. Among these difficulties are:

1. Weather dependency: For data collection, remote sensing systems mainly depend on favourable weather conditions. Satellite imagery might be hampered by cloud cover, atmospheric interference, or unfavourable weather conditions. The reliability of monitoring operations may be impacted by unpredictable weather patterns that restrict the frequency and regularity of data collecting.

2. Data interpretation and analysis: The enormous volume of data produced by remote sensing necessitates specific knowledge for analysis and interpretation. It's possible that agribusinesses lack the know-how to glean insightful information from the data they collect. To close this knowledge gap, educational initiatives and training programs are needed.

3. Access to real time data: In some regions, particularly remote or underdeveloped areas, access to real-time, high-resolution satellite imagery may be limited. The quality and precision of real-time remote

sensing in agriculture are enhanced by advancements in sensor technologies and image processing methods.

4. Technical limitations: There are technical restrictions on several remote sensing systems. For instance, some sensors lack the sensitivity to identify certain soil characteristics or vegetation species.

Conclusion

In order to make agriculture a more effective, data-driven, and sustainable industry, remote sensing is becoming more and more important. Remote sensing technologies offer useful insights that facilitate well-informed decision-making in a variety of areas, including crop health monitoring, resource management, yield prediction, and climate variability adaptation. But only by tackling issues like data accessibility, weather dependence, and technological constraints can its full potential be achieved. Overcoming these obstacles will need investments in infrastructural development, technology innovation, and capacity building. Remote sensing is a crucial ally in ensuring the future of global food systems as the need for sustainable agriculture methods only increases.

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Importance of Agripreneurship Facilitation Center (AEFC) at Krishi Vigyan Kendras and Other Government Institutions

Article ID: 71126

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Concept of Agri-Entrepreneur Facilitation Centre at KVK

An agri-entrepreneurship facilitation centre is a facility based designed to support and promote agricultural entrepreneur. The centres offer various services including awareness, training, guidance and networking opportunities to help individuals or group to take-up business in the field of agricultural and allied sector to thrive.

Agri-entrepreneur facilitation centre at KVK was established in KVK with an aim to aware, encourage, motivate and to facilitate young entrepreneur. The main aim of the facilitating centre is to look the feasibility of the idea/concept of start-up, hand-holding the idea to a concrete form and forwarding the scrutinized idea to NEATEHUB for further persuasion of agri-based start-up. The facilitating centre not only prepare the concept notes of the innovation but also hand holds innovators or creators or already established entrepreneur in filling up of application in NATEHUB Portal for ISHANYA 9.0 (Rupees 5 lakhs) and SARANYA 9.0 (Rupees 25 lakhs).

Key Features and Activities of AEFCs

- 1. Training and capacity building:** AEFC in KVK provides training programme to equip individuals with the skill, knowledge and updated technologies needed to start and manage agricultural business. It facilitates individual or group to start a new start-up business related to agriculture and allied field and also guide already established entrepreneur to upscale the established idea/concept through NEATEHUB.
- 2. Mentoring and handholding:** Experienced individuals or KVK experts provide guidance and support to entrepreneur, helping them to navigate the challenges and opportunities of starting and growing a business.
- 3. Business development Assistance:** It offers complete guidance on business planning, identify market opportunity, and connect with potential partner and customer. It will create platform for entrepreneurs to network with other stakeholders in the agri-food sector, including researchers, investors and industry leader.
- 4. Networking and collaboration:** AEFC facilitate connections between entrepreneur, investor and stakeholder in the agriculture and allied sector,
- 5. Incubation and acceleration:** AEFC offers and facilitate incubation or acceleration programme to support early-stage Agri-start-ups.
- 6. Information and knowledge dissemination:** AEFC provides access to information on market trends, technologies and best practices in agriculture through experts, researcher and scholars.
- 7. Access to funding:** AEFC provide assistance in accessing funding sources, such as grant, KCC loan and other investment opportunities.

Benefits of Agri-Entrepreneurship Facilitation Centres

Agri-entrepreneurship facilitation centre offers numerous benefits, primarily focused on supporting and empowering farmers to become more profitable and sustainable agricultural entrepreneur. It provides access to resource, training, guidance, ultimately contributing to the overall economic and social well-being of rural communities.

- 1. Improved farm productivity and income:** AEFC help farmers to adopt modern agricultural techniques, access quality input, and utilize efficient farming practices, leading to increased crop yields and higher income.
- 2. Access to market and value chain:** AEFC facilitate access to local, regional and national markets, enabling farmers to sell their produce directly and potentially at higher prices. They also assist in developing value-added products and linking farmers to processing and distribution networks.
- 3. Skill development and training:** AEFC provides training programme on various aspects of agribusiness, including farming techniques, post-harvest management, marketing and business planning. This helps farmers to acquire the necessary skills to manage their agriculture ventures effectively.
- 4. Financial support and Access to credit:** AEFC can connect farmers with financial institutions and provide guidance on accessing credit and other financial resources to support their entrepreneur activities.
- 5. Technical advancement and innovation:** AEFC can promote the adoption of new technologies and innovative practices in agriculture, such as precision farming, digital marketing, and value-added processing, leading to increased efficiency and productivity.
- 6. Rural development and employment generation:** By supporting agri-entrepreneur, AEFC contribute to rural development by creating employment opportunities, improving rural livelihood and minimizing migration to other state to an extent.
- 7. Empowerment of women and youth:** AEFC can play a crucial role in empowering women and youth in agriculture by providing them with necessary knowledge, skill, resources, and opportunities to start their own agri- business.
- 8. Improved food security and nutrition:** By promoting efficient and productive farming practices, AEFC can also contribute to improved food security and nutrition by increasing the availability of affordable and nutritious food.

Conclusion

Agri-entrepreneurship facilitation centre offers promising path towards sustainable economic development, particularly in India, by revitalizing the agriculture sector including veterinary, fishery, sericulture, vermi-composting and value addition or food processing etc and thus enhancing livelihoods and thus check migration too. These centres play an important role in nurturing new generation of agriprenuer, fostering innovation/idea, and improving the overall resilience of agricultural economy. The basic facilitation of these AEFCs driven sustainable development, nurturing agriprenuer, fostering innovation and collaborate with stakeholders and Government.

Production Technology of Onion Under Saline Soil Conditions

Article ID: 71127

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Onion

Scientific name: *Allium cepa*

Common name: onion, pyaaz, kaandha

Family: Alliaceae

Chromosome no: 2n=16

Origin: Central Asia.



Introduction

Any soil is said to be saline when it has electrical conductivity (EC) more than 4 dSml⁻¹, pH less than 8.5 and cation exchange capacity less than 15%. It is one of the serious abiotic stress in crop production.

Botany

Onion is a biennial herb with a characteristic smell. The leaves are tubular and the bulbs are formed by the attachment of swollen leaf bases to underground part of stem which is small and rudimentary. Flowers are produced during second phase after formation of bulbs. Flowering structure is called an 'umbel', which is an aggregate of many small inflorescences (cymes) of 5-10 flowers. Length of peduncle commonly known as 'scape' varies with variety. Though individual flowers are hermaphrodite, they are cross pollinated due to protandry. Cross pollination is achieved by honey bees when they visit flowers for nectar. Stigma becomes receptive 3-4 days after shedding of pollen grains. Artificial selfing is done by covering all umbels of a plant together and by shaking or rubbing each other or by introducing flies.

Effect of Salinity on Onion

Onions due to their shallow root system are considered to be more vulnerable to salinity than any other vegetable crops. Salinity stress negatively affects normal onion growth reducing its bulb yield. It also decreases the content of K, Ca, N, P, Mg, Fe, Zn, Cu and B in onion bulb and at the same time increases the content of Na⁺ and Cl⁻. Plant height and volume of bulb is also triggered by salinity.

Soil Reclamation

Apply gypsum or other soil amendments to help reclaim saline soils and improve their fertility.

Climate

Onion is a cool season vegetable and grows well under mild climate without extreme heat or cold or excessive rainfall. It does not thrive when the average rainfall exceeds 75-100 cm during rainy season. The young seedlings cannot withstand freezing temperature. The ideal temperature for vegetative growth is 12.8-23°C. For bulb formation it requires long days and still higher temperature (20-25°C). Even though onion is treated as a long day plant, for bulb formation and its development, varieties differ in their response to length of day. Long day varieties will not produce bulbs under short day conditions and short day cultivars if planted under long day conditions will develop early bulbs. For seed production, temperature has more relevance.

Soil

Onion prefers a well drained, loose and friable soil rich in humus. It is sensitive to high acidity and alkalinity and the ideal pH is 5.8 to 6.5.

Land Preparation

1. Add organic matter like compost or manure to improve soil structure and fertility.
2. Incorporate gypsum or lime to reduce soil pH and neutralize sodium effects.

Variety Selection

Choose onion varieties tolerant to salt stress, such as 'Texas Grano', 'Crystal Wax', NHRDF Red (L-28), NHRDF Red-4 (L-744), GWO-1 etc.

Seedbed Preparation

Create a raised bed with a mix of soil and organic matter to improve drainage and aeration.

Method of Sowing

Three methods of sowing are generally employed in onion cultivation. These are:

1. Raising seedlings and transplanting
2. Planting bulbs directly into the field
3. Broadcasting or drilling seeds directly into the field.

Irrigation Management

1. Use drip irrigation or furrow irrigation to reduce water evaporation and minimize salt buildup.
2. Apply water at critical growth stages (e.g., bulb formation) to minimize stress.

Fertilizer Application

1. Use balanced fertilizers with a higher potassium content to help onions tolerate salt stress.
2. Generally recommended dose is 120kg N/ha, 50kg P₂O₅/ha and 160kg K₂O/ha.
3. Apply 20-25 tonnes of FYM at the time of first ploughing.
4. Fertilization with Si improved the acclimation responses of onion under stress of salinity, so the recommended dose of Si are 27.8kg/ha, under cultivation with the use of good quality irrigation water.

Mulching

Apply a thick layer of organic mulch to reduce soil temperature and moisture loss. Thereby, avoiding salt accumulation.

Crop Monitoring

Regularly monitor crop growth, soil moisture, and salt levels to adjust irrigation and fertilizer applications.



Weeding

During early stages of the crop, plants grow slowly and it is essential to remove weeds. Pre-plant incorporation of Basalin (2 kg a.i./ha) along with one hand weeding at 45 days after transplanting is recommended to control weeds. Being a shallow rooted crop, deep inter-culture operation is likely to injure roots and reduce yield. Generally, two hoeings are essential for making soil loose and to cover bulbs.

Drainage

Ensure proper drainage in the field to prevent waterlogging and salt accumulation.

Integrated Pest Management

Implement IPM strategies to manage pests and diseases that may be more prevalent under saline conditions.

Harvesting

Onion is ready for harvest in 3-5 months after transplanting depending on variety. Harvesting is done by pulling out plants when tops are drooping but still green. During hot days when soil is hard, bulbs are pulled out with a hand-hoe. Yield varies with season and variety. 15-25 tonnes of bulbs are expected from one hectare of transplanted crop. Yield of kharif crop is comparatively low.

Curing

Sprouting and rotting are common problems in storage since bulbs contain high moisture. The bulbs should be adequately cured for proper development of skin colour and to remove field heat before storage of bulbs. It is done till the neck is tight and outer scales are dried. This will prevent infection of diseases and minimize shrinkage loss. Bulbs are cured either in field or in open shade or by artificial means before storage. During kharif season, bulbs are cured for 2-3 weeks along with top. In rabi, bulbs are cured in field for 3-5 days; tops are cut leaving 2.0-2.5 cm above bulb and again cured for 7-10 days to remove field heat.

Storage

After curing, bulbs are stored in well ventilated rooms by spreading them on dry and damp proof floorings or on racks. Periodical turning of bulbs and removal of rotten and sprouted bulbs is highly essential. A pre-harvest spray of maleic hydrazide (2000-2500 ppm) prevents rotting and sprouting of bulbs stored at room temperature. At BARC, Trombay irradiation of bulbs with very low doses (4000-9000 krad) of gamma rays is effective for preventing sprouting and enhancing storage life of onion bulbs.

Socioeconomic Characterization of Recreational Fisheries in India

Article ID: 71128

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Abstract

Recreational fisheries (RF) are dynamic social-ecological systems that provide significant social, economic, and environmental benefits worldwide, with recreational fishing emerging as the fastest growing tourism sector at a 5% annual rate. Insights from the 7th World Recreational Fishing Conference highlight both the immense value and the challenges faced by RF, particularly in regions with limited data and governance. While RF supports related industries, boosts fishermen's incomes, and fosters urban-rural understanding, it can also pose ecological risks such as overexploitation and the spread of non-native species. Effective management and robust monitoring are essential to balance these benefits with conservation needs. Advances in technology and collaborative, co-management approaches engaging governments, NGOs, and anglers are improving data collection, governance, and sustainability. Anglers themselves play a crucial role in conservation and citizen science. Ultimately, sustainable recreational fisheries can enhance environmental awareness, resolve resource allocation conflicts, and deliver positive outcomes for both society and ecosystems, making RF vital for community well-being and environmental stewardship.

Introduction

Approximately 220 million people worldwide participate in recreational fisheries (RF), which include fishing activities that do not contribute to market sales or primary nutrition. Each year, RF participants catch billions of fish. In contrast to commercial and subsistence fishing, this industry mostly uses rods, reels, and different kinds of bait. RF has a substantial impact on freshwater and marine resources in developed countries, requiring efficient management to balance conservation, social, and economic objectives. There are many opportunities for sport fishing in India's varied aquatic environments, with different regions having different ideal seasons. The 8th World Recreational Fisheries Conference (WRFC) provided valuable insights into the socio-economic effects of RF practices and the behavior of anglers. The growth of the recreational marine fishing sector affects related industries more broadly. Innovative techniques and technologies are needed to maintain fisheries while generating employment as fish populations decline because of overfishing and environmental changes. Despite socioeconomic differences, RF also acts as a link between rural and urban communities, promoting understanding between them. Understanding the social and economic significance of RF, characterizing participation in it, and improving monitoring methods all depend on effective management strategies. Urbanization, fishing quality, and regulatory changes are some of the factors that affect participation rates around the world. Recreational enjoyment and enhanced well-being are examples of social benefits, and conservation efforts can be spurred by economic insights. The spatial dynamics of RF present monitoring challenges, but technological developments like smartphone applications improve the ability to collect data on angler behavior. All things considered, recreational fisheries are vital to local economies and community cohesion, but they also pose ecological challenges that need to be carefully managed to guarantee sustainability and benefit all parties (Mushtaq *et al.*, 2024).

Descriptive Features of Involvement

Recreational fisheries (RF) are crucial social-ecological systems providing global social and economic benefits, with sport fishing practiced by around 11% of the world's population. Participation is declining in developed nations due to factors like urbanization, rising costs, regulations, and demographic shifts, while

detailed data remain scarce, especially in developing regions. Studies, such as those in Taupo, New Zealand, highlight license fees, unemployment, and fishing quality as key participation drivers. RF offers accessible recreation, supporting mental and physical health, and can motivate conservation policies, as seen in The Bahamas with habitat protection for bonefish driven by the economic value of catch-and-release fishing. However, monitoring RF is challenging due to its vast scale and limited socioeconomic data. Advances like smartphone apps and citizen science projects are improving data collection and management. Effective RF management requires understanding participant behavior and socioeconomic trends to balance community benefits with ecological sustainability and maximize social and economic value.

Defining Economic and Social Value

In India, recreational fisheries (RF) provide accessible leisure and food sources, offering notable social and economic benefits. Anglers' experience improved physical and mental health through exercise, stress relief, and social interaction. Recognizing the economic value of RF can encourage policymakers to prioritize habitat conservation and sustainable management. Globally, examples like the Bahamas' transition to catch-and-release fisheries highlight how economic valuation can drive conservation, a lesson relevant for India's growing RF sector. Effective management in Indian contexts especially within Marine Protected Areas must balance biological impacts, ecosystem needs, and socioeconomic factors. However, there is a significant lack of socioeconomic data on RF in India, which hampers informed policy and management. Expenditure by recreational anglers on equipment, travel, and permits stimulates local economies, yet monitoring RF remains challenging due to its dispersed nature. Innovative tools, such as smartphone apps and citizen science initiatives, are emerging to collect data on angler behavior and fish populations. Compliance monitoring, essential for effective governance, is evolving with new methodologies to overcome biases. Ultimately, understanding the behaviors and socioeconomic dynamics of Indian RF participants is crucial for maximizing community benefits, supporting livelihoods, and ensuring the long-term sustainability of aquatic resources in the country.

Advances in Monitoring

Recreational fisheries (RF) represent a significant social and economic component of marine fisheries, characterized by participation, effort, compliance, and catch and harvest rates. Monitoring RF poses substantial logistical challenges due to their extensive spatial and temporal scales, making it more complex than commercial fishing monitoring.

1. Monitoring Approaches: Various methods for surveying fishing effort and catch rates including point cut-off, household telephone surveys, constantly moving shoreline assessments, aerial surveys, and mail surveys. Their findings highlighted the dynamics of RF and identified biases and inconsistencies in different survey methods. Holdsworth *et al.* (2018) implemented multiple concurrent survey methods in New Zealand to monitor fish harvest rates, combining on-site and off-site surveys to enhance the reliability of harvest estimates.

2. Technological Advances: The advent of smartphone applications has emerged as a valuable tool for remote data collection on angler participation and behaviors, such as effort and catch rates. While these technologies offer cost-effective alternatives to traditional survey methods, they also present challenges related to data quality, angler recruitment, retention, and integration with existing fisheries programs.

3. Compliance Monitoring: Monitoring angler compliance is crucial for assessing the efficiency of management systems. Traditional compliance research often relies on angler interviews and indirect questioning techniques like the random response method to address sensitive questions regarding regulatory adherence. However, studies have shown that these methods may not effectively capture accurate compliance data. An alternative approach using the Ballot Box method has been proposed to improve the accuracy of compliance assessments.

4. Citizen Science Initiatives: Advancements in fish population monitoring are also being explored through citizen science initiatives. Florisson *et al.* (2018) tested a citizen-science approach called Reef Vision for monitoring reef fish communities on artificial reefs in Australia. This method demonstrated the potential for significant resource savings while effectively gathering geo-spatial data on coastal fish assemblages.

5. Genetic Monitoring: Elliot and Russello (2018) focused on genetic monitoring by employing advanced molecular markers to differentiate between hybrid sockeye salmon (*Oncorhynchus nerka*) and wild kokanee salmon populations. This research is vital for assessing reintroduction efforts and understanding the status of wild fish populations. In conclusion, effectively managing recreational fisheries requires innovative monitoring techniques that address the unique challenges posed by this sector. By leveraging technology and engaging citizen scientists, fisheries management can improve data collection and enhance sustainability efforts while balancing social and economic benefits within local communities.

Stock Enhancement

Stock enhancement in recreational fisheries (RF) involves the release of hatchery-raised or wild-captured fish into aquatic ecosystems to supplement existing fisheries or create new ones. This practice dates to the early 19th century and aims to provide fishing opportunities, particularly in "put-and-take" fisheries. However, it may lead to negative biological impacts, such as the spread of pathogens, reduced genetic diversity in wild populations, and increased competition for resources without necessarily enhancing reproductive capacity. Despite these potential drawbacks, many management agencies continue stocking efforts at significant financial costs to maintain RF opportunities. In central Europe, private organizations have initiated voluntary stocking programs that offer social, psychological, and conservation benefits beyond mere fishing opportunities. Ongoing research seeks to understand factors influencing stocking success, including fish growth, survival rates, and angler effort responses. For instance, studies have shown that stocking larger trout in smaller water bodies at lower elevations yields higher angler return rates. Triploid (sterile) rainbow trout have been found to outperform diploid individuals in terms of growth and survival, enhancing fishing quality while mitigating risks of genetic deterioration in wild stocks. Marine recreational fishing also plays a role in bridging urban-rural divides by increasing awareness of marine environments. The demand for quality aquatic habitats is crucial; even slightly polluted waters deter recreational fishing activities. Stakeholders must prioritize environmental health to enhance marine recreational fishing and foster public awareness of marine ecosystems. In summary, effective management of stock enhancement practices is essential for sustaining recreational fisheries while minimizing negative biological impacts. Engaging stakeholders and utilizing research findings can help optimize stocking strategies and promote a healthier aquatic environment for both fish populations and recreational anglers.

Recreational Fishing Spots in India

Sport fishing and angling in India present significant opportunities due to the country's extensive coastline, numerous rivers, lakes, and reservoirs. Fishing is a year-round activity, with optimal conditions for sport fishing occurring in October-November and mid-February to mid-May when waterways are well-stocked. The Himalayan rivers, along with major rivers like the Mahanadi, Yamuna, Cauvery, Ganges, and Brahmaputra, are popular among recreational anglers. Notably, the Mahseer is revered as India's premier sport fish, while trout fishing thrives in Kashmir's Indus River system, often referred to as "Angler's Paradise". To promote ecotourism and recreational fishing in northeastern India, an Aqua Tourism Centre (ATC) has been established in Assam. This center focuses on breeding Mahseer and hosts an annual fishing festival each October, attracting enthusiasts from across the region. As interest in sport fishing grows, Sikkim is poised to become a globally recognized destination for anglers. The potential for sport fishing in India is amplified by its diverse climatic conditions, which influence the best fishing seasons across different regions. For instance, the optimal times for Himalayan rivers differ from those in southern India. As the sector develops, it can contribute not only to local economies but also to conservation efforts by raising awareness about aquatic ecosystems. In summary, India's rich aquatic resources and favorable conditions for sport fishing offer substantial potential for recreational fishing tourism. Strategic management and promotion of these resources can enhance both economic benefits and ecological awareness among participants.

Table 1: Recreational fishing areas and sport fishes of India:

State	Sport fishes	Recreational fishing sites
Himachal Pradesh	Trout, Mahseer, Snow trout	Beas, Sutlej, Tirthan, Sainj, Uht, Baspa, Pabar, Lambadug, Giri, Rana, Nugal gai, Banerand Bata

Jammu and Kashmir	Snow trout, Mahseer, Trout	Bringhi, Sindh, Aru, Kishanaganga, Lidder, Boniyar, Sagwan, Erin, Vishansar, Kishansar, Gangabal lake, Ikhnee nallaand Anji
Uttarakhand	Brown trout, Rainbow trout, Mahseer	Ramganga, Sharda, Dodital, Dhoon Valley, Bhagirathi, Birehi, Pinder rivers
Assam	Mahseer, Katli	Jiabhoroliikapili, Manas
West Bengal	Katli, Indian trout, Goonch, Mahseer, Red finned Mahseer, Golden Mahseer	Jaldhakra, Forsa, Rangit, Gadadhar, Sankosh, Teesta
Sikkim	Mahseer, Katli, Goonch, Snow trout	Teesta, Rangit
Arunachal Pradesh	Mahseer, trouts	Brahmaputra tributaries, Subansiri, Kameng, Lohit, Tirap, Tezu, Tipi, Bhalukpong, Pashighat, Panging, Boleng
Tamil Nadu	Trout	Mukurthi lake, Avalanche Lake, Emerald Lake, peermund, kalkundi, portimund, Chembar streams, Mekod river
Kerala	Trouts	Elephant lake, Devikolam lake, Munnear high ranges, Kadallar, Pettimundi, Rajamalley
Karnataka	Mahseer	Bheemeshwari, Doddamakati, Galbore
Maharashtra	Miñnows, Olive barbs	Powai lake

Implementing Effective Angling Practices for Sustainable Fishing

Transferring best angling practices to anglers is essential for improving fishing skills and fostering conservation-minded behaviors. While legal frameworks, such as mandating circle hooks, can reduce fish injuries, the diversity of environments, species, and angler cultures complicate universal regulation. Overly complex rules may discourage participation and lead to non-compliance, threatening sustainability. Voluntary institutions and local angling clubs, through joint learning and active engagement, often prove more effective than passive education. Multifaceted educational approaches including in-person, print, and online resources are vital for reaching diverse anglers. Integrating scientists into fishing communities and leveraging social media can further promote conservation practices. Social norms and community cues significantly influence angler behavior, while competitive leagues and local rules can reinforce positive changes. However, engaging less organized anglers remains challenging. As more fishermen transition from commercial to recreational fishing, fostering environmental awareness and sustainable practices is crucial for both enhancing recreational opportunities and supporting broader conservation goals.

Conclusion

Recreational fisheries are vital for ecological sustainability, economic growth, and social well-being. Despite challenges like data gaps and ecological risks, advances in technology, governance, and collaborative management are enhancing their sustainability. Engaging anglers and stakeholders through co-management and citizen science fosters conservation-minded practices and improves monitoring. Sustainable recreational fishing not only supports livelihoods and tourism but also strengthens environmental awareness and urban-rural connections. To ensure long-term benefits, continued efforts in research, effective governance, and education are essential. Ultimately, balancing recreational fisheries' social, economic, and ecological dimensions will secure their role as valuable resources for future generations.

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