

DEPARTMENT OF AGRICULTURE DEVELOPMENT
& FARMERS' WELFARE, GOVERNMENT OF KERALA



FARM INFORMATION BUREAU

KERALA KARSHAKAN

THE FIRST ENGLISH FARM JOURNAL FROM
THE HOUSE OF KERALA KARSHAKAN

JULY 2026
VOLUME 14 ISSUE 2

E-JOURNAL

INNOVATING AGRICULTURE for a Sustainable Tomorrow



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KERALA KARSHAKAN

E-JOURNAL

JULY 2026 VOLUME 14 ISSUE 2

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Innovating Agriculture for a Sustainable Tomorrow

Transforming agriculture through technology, resilience, and responsible resource management.

Agriculture is entering a new era where success depends not only on increasing production but also on embracing innovation, conserving natural resources, and building resilience against a changing climate. Farmers today face shrinking landholdings, rising input costs, labour shortages, water scarcity, and increasingly unpredictable weather patterns. Addressing these challenges requires more than technological breakthroughs alone—it calls for effective systems that translate research into practical solutions, empower rural entrepreneurship, and create opportunities for sustainable agricultural growth.

Kerala is steadily moving in this direction by fostering an ecosystem where innovation, science, and enterprise work together. From technology-driven startups and climate-smart farming practices to efficient water management,



carbon-neutral initiatives, and sustainable crop diversification, agriculture is evolving into a knowledge-driven sector. Such an approach not only enhances productivity and profitability but also strengthens the resilience of farming communities while encouraging greater participation from youth, women, and rural entrepreneurs.

The future of agriculture extends well beyond crop production. It encompasses the sustainable management of natural resources, conservation of ecosystems, development of value-added enterprises, promotion of healthier food systems, and effective management of emerging crop challenges. Integrating scientific research with traditional knowledge will be crucial in building an agricultural sector that is productive, environmentally responsible, and capable of meeting the needs of future generations.

This issue of Kerala Karshakan e-Journal reflects these emerging priorities through articles on agricultural innovation, entrepreneurship, sustainable resource management, climate resilience, nutrition, and crop health. We invite our readers to explore the pages that follow and discover how these diverse perspectives collectively contribute to a stronger and more sustainable agricultural future. By embracing innovation while safeguarding our natural resources, we can build an agriculture that is not only productive today but also resilient and future-ready.

Editor



K-AgTech Launch Pad Transforming the Rural Future or Where Innovation Meets Opportunity

Dr. ALLAN THOMAS, Dr. APARNA RADHAKRISHNAN, Dr. USHA C. THOMAS, SWETHA R. S.
K-AgTech LaunchPad Team

Agriculture in Kerala today stands at a critical juncture. Farmers across the state continue to contend with shrinking landholdings, rising input costs, a shortage of agricultural labour, and increasingly unpredictable weather patterns. For decades, the response to these challenges has come primarily from research institutions, in the form of improved crop varieties, refined nutrient management practices, and advanced cultivation techniques. However, even the most robust research findings rarely translate into sustainable livelihoods unless a structured mechanism exists to carry that knowledge from the laboratory

into the field as a viable enterprise. It is precisely this gap that K-AgTech LaunchPad has been established to address.

An Institutional Initiative of Significant Scale

Established at the College of Agriculture, Vellayani, K-AgTech LaunchPad is an agri-food business incubator developed through a collaborative initiative by NABARD, Kerala Agricultural University (KAU), and Western Sydney University (WSU), with NABARD support under the Gramaya Vikas Nidhi programme. The project has been sanctioned with a budget of ₹14.785 crore for a five-year period

commencing in August 2025. The organisation is registered as a Section 8 company and operates as a non-profit institution, with a mission to promote innovation, entrepreneurship, and startup development in the agricultural sector. In scale, it is the largest such initiative hosted by KAU, bringing together academic research, global AgTech expertise, and industry engagement within a single ecosystem.

Within 5 years, K-AgTech LaunchPad targets graduating more than 350 startups into the agri-innovation ecosystem.

Objectives and Mission

K-AgTech LaunchPad's mission

Within 5 years, K-AgTech LaunchPad targets graduating more than 350 startups into the agri-innovation ecosystem.

is to promote innovation, entrepreneurship, and startup development in the agricultural sector, translating research findings and innovative ideas into enterprises that address the real-world challenges facing Kerala's farmers. In pursuit of this mission, the incubator's primary objective is to support startups, innovators, researchers, students, and agri-entrepreneurs through incubation services, mentoring, technical guidance, infrastructure support, and market linkages. Within this framework, K-AgTech LaunchPad promotes innovation across diverse domains, including precision agriculture, climate-smart farming, value addition, digital agriculture, agricultural mechanisation, smart farming technologies, and sustainable rural enterprises, while encouraging the commercialisation of research outcomes to contribute to a resilient and future-ready agricultural sector.

These objectives are organised into five focus areas:

- end-to-end incubation support for start-ups, from ideation to market readiness;
- value addition and product diversification to enhance farmers' income;
- entrepreneurial capacity building that connects research with industry needs;
- AI-enabled smart climate adaptation technologies for resilient agriculture and
- the promotion of women-led enterprises to foster inclusive and sustainable growth.
- Centring women and marginalised communities in entrepreneurship: Innovation in agriculture has historically been concentrated among well-resourced urban startups. By anchoring its incubation infrastructure within a public agricultural university and aligning it with NABARD's rural development mandate, K-AgTech LaunchPad extends this ecosystem to students, farmers, Farmer Producer Organisations (FPOs), and young innovators who would otherwise lack a structured pathway from idea to enterprise. Importantly, women-led enterprises and startups initiated by SC/ST and other marginalised communities are at the centre of this mission, ensuring that the benefits of agri-innovation reach those who have traditionally had limited access to entrepreneurial support and capital.
- Strengthening existing farmer institutions: Rather than engaging only with individual entrepreneurs, K-AgTech LaunchPad has deliberately invested in Farmer Producer Organisations (FPOs).

Significance for Rural Communities

The significance of K-AgTech LaunchPad lies not merely in any single technology, but in the systemic transformation it represents for rural Kerala. Positioning agriculture as an enterprise: Much of Kerala's agriculture remains characterised by small landholdings and production-focused practices, with farmers seldom capturing value beyond the farm gate, particularly in processing, branding, and direct market access. By providing incubation, mentoring, technical validation, and market linkages, K-AgTech LaunchPad helps agricultural ideas mature into scalable, income-generating enterprises.



*FPO Meet 2.0 –North and South chapter
Strengthening Farmer Institutions*

The FPO Meet 2.0 – South Chapter, organised at the College of Agriculture, Vellayani, brought together representatives from around 40 FPOs, while the FPO Meet 2.0 – North Chapter, held at the Agricultural Urban Wholesale Market, Vengeri, Kozhikode, drew participation from nearly 60 FPOs across northern Kerala. Both meets deliberated on governance, financial sustainability, value addition, and market linkages, reinforcing the importance of collective enterprise models for strengthening Kerala's FPO ecosystem.

- Enabling global knowledge exchange: Through its partnership with Western Sydney University, K-AgTech LaunchPad provides Kerala's innovators with exposure to international research and industry practices, a form of engagement that has, until now, remained largely inaccessible to rural agripreneurs.
- Building capacity across the ecosystem: Recognising that sustainable agri-innovation

depends on more than a handful of successful startups, K-AgTech LaunchPad places equal emphasis on strengthening the knowledge and skills of researchers, farmers, FPO representatives, and agribusiness stakeholders across its ecosystem. To this end, it has organised the Faculty Orientation Enabler Programme, which introduces researchers to the startup ecosystem, incubation mechanisms, and technology commercialisation pathways; a Management Development Programme for FPO representatives and agribusiness stakeholders,

covering business planning, financial management, and export potential; and a monthly One-Day Training Programme on Value Addition in Coconut at the Coconut Research Station, Balaramapuram, offering hands-on exposure to coconut processing technologies.

Strengthening Physical Infrastructure

To support a pipeline of this scale, efforts are underway to establish a full-fledged Hi-Tech Unit and a dedicated Training and Value Addition Unit, both targeted for completion within the project's five-year tenure. These permanent facilities are intended to provide incubatees with hands-on access to advanced equipment and processing infrastructure, extending support beyond mentorship and ideation to the physical resources needed to convert a promising idea into a marketable product. Once operational, these units are expected to anchor K-AgTech LaunchPad as a long-term physical hub for agri-innovation in the state.

Ongoing Activities

In the interim, this vision has taken shape through a steady calendar of activities, including weekly Idea Presentation





Interim Office – Completed and Fully Functional



Incubation cubicles

and Screening Sessions, the State-Level Agri-Rural Ideathon 2026, an Ideation Workshop for PhD Scholars, the Faculty Orientation Enabler Programme, and a Management Development Programme. This is complemented by a growing portfolio of incubated ventures focused on AI-integrated farm management systems, coir-based value-added products, and solutions to wildlife intrusion and crop damage. K-AgTech LaunchPad has also showcased its vision, programmes, and startup support initiatives at the Earth Summit, Dhanam Summit, Huddle Global, VAIGA 2026, Southern Regional Agricultural Fair (SRAF) 2026, Karshakasree Mela 2026, and the Summit of Future at Jain University, thereby engaging researchers, entrepreneurs, investors, policymakers, and farmer organisations beyond the state. (A detailed account of the incubated startups, ideathons,

and pitching programmes is provided in the accompanying article.)

Administrative Structure and Facilities Established

Alongside its programmatic activities, K-AgTech LaunchPad has put in place functional administrative and physical infrastructure to support its day-to-day operations. As an interim arrangement, K-AgTech LaunchPad has established approximately 4,000 sq. ft. of facility space at the College of Agriculture, Vellayani. The facility provides a functional ecosystem for startup incubation, training, mentoring, meetings, collaborative work, and administrative support, enabling the Centre to commence incubation and innovation activities while the permanent infrastructure is being developed. This facility offers a vibrant incubation environment where startups can access mentoring,

participate in training and capacity-building programmes, engage with experts and industry stakeholders, and collaborate within the K-AgTech LaunchPad ecosystem. The interim facility ensures that incubation and entrepreneurial support services continue seamlessly while the Centre progresses towards its permanent, state-of-the-art infrastructure.

Conclusion

K-AgTech LaunchPad differs from a conventional research initiative in one critical respect: it insists that innovation does not end with discovery but must be carried forward, deliberately and systematically, into enterprise, supported by infrastructure capable of sustaining it. With a target of graduating over 350 startups within 5 years, a deliberate focus on women and marginalised communities, and permanent hi-tech and value-addition facilities under development within the same five-year horizon, K-AgTech LaunchPad is laying the foundation for an agricultural sector that is not only more productive but also more inclusive, more resilient, and better equipped to sustain the next generation of farmers. As agriculture and technology continue to converge, K-AgTech LaunchPad offers a working model of what such convergence can achieve when rooted firmly and equitably in rural soil. ■

K-AgTech LaunchPad Incubating Rural Innovation

Dr. ALLAN THOMAS, Dr. APARNA RADHAKRISHNAN, Dr. USHA C. THOMAS, SWETHA R. S.



2.1 Statoberry LLP

Among the various functions of K-AgTech LaunchPad, the incubation of startups represents its most direct and measurable contribution to Kerala's agricultural sector. The initiative has supported a range of ventures at different stages of development since its establishment, from early-stage ideation to commercialisation. This article presents a progress report on these incubated startups, outlining the current status of each venture and the milestones recorded so far.

The Incubation Pipeline

As of the latest reporting period, eleven startups have been formally inducted into K-AgTech LaunchPad, distributed across three broad stages of development.

At the commercialisation stage is Spizaar Pvt Ltd. The acceleration stage comprises Statoberry LLP, engaged in AI-driven data analytics and digital solutions for agricultural research; Taleon; Zelbytes, which also serves as a Technical Infrastructure partner

to the incubator; and Agriguru EdTech, which is progressing towards commercialisation. At the ideation and early-prototype stage are a project on sustainable production technology for saffron cultivation in Kerala, led by Dr. Smitha Bhasi; Platanus Labs, working on IoT-based technologies for precision agriculture; Enlightened Agrowia, engaged in developing a dual-purpose pot for hydroponics and smart container cultivation under Dr. Gautham Suresh; SADAKO Vet Hospital and



2.2 Zelbytes

Boarding; Leghu Avanee Ruchii; and a venture developing a multi-functional fortified food powder composition incorporating controlled nutrient integration, stability enhancement, and sustainable biodegradable packaging.

Ventures Advancing Toward the Market

Among the more advanced ventures in the portfolio,

Statoberry LLP has reported significant progress with its RAISINS platform, a statistical analysis tool for agricultural research. The platform has expanded to 58 analysis modules and has surpassed 12,000 registered researchers, with an AI-powered plotting and interpretation assistant integrated to enhance usability. It has been cited in 17 international peer-reviewed journals, including Scientific Reports (Nature),

and has secured institutional adoption by KAU, ICAR-IISR Calicut, ICAR-IIWBR Karnal, and the University of Idaho, USA. During the reporting quarter, Statoberry LLP also received the first instalment of its acceleration grant and conducted a five-day training programme on experimental design and statistical analysis, organised in association with KAU and K-AgTech LaunchPad.

Zelbytes has developed the ZelAI Platform, an integrated system that combines Edge IoT hardware (Hivemind Edge Controllers) with AI-powered cloud analytics for automated irrigation, precision nutrient dosing, and microclimate management. The venture has reported market validation through the sale of eight units to eight customers, directly benefiting six active farmers, and its core technology has been assessed at TRL 7/TRL 9 readiness. Zelbytes has cleared a ₹5 lakh ARISE Grant from the Central Government, routed through Pusa Krishi (ICAR-IARI), with the corresponding No Objection Certificate secured. It was recognised as the winner of the GCWAS 2026 Ingenious Idea Innovation Contest at the national level. The venture has also finalised a collaborative agreement with experts at KAU and developed the HiveMind self-healing mesh framework for offline-first farm automation.

Agriguru EdTech, an agri-education venture offering online coaching and career guidance for

Within 5 years, K-AgTech LaunchPad targets graduating more than 350 startups into the agri-innovation ecosystem.



2.3 Agriguru EdTech

agriculture graduates, reports reaching over 8,000 students, with more than 1,000 successful exam selections recorded across 22 live courses, supported by over 80 expert faculty members. The venture has launched a GIS for Agriculture Certification Course and an ICAR JRF 2026 Mock Test Series covering all ten ICAR disciplines, and maintains a digital learning ecosystem comprising a dedicated application, website, and a community of over 10,000 learners on WhatsApp and Telegram. Agriguru EdTech has also published Concise Cultura, with more than 2,500 copies sold, and was featured in the October 2025 edition of this magazine. A Memorandum of Agreement has since been negotiated between the venture and K-AgTech LaunchPad.

Among the early-stage ventures, Enlightened Agrowia, engaged in developing a rain-resistant, dual-purpose cultivation pot, has secured a design patent for its product and completed the

associated 3D modelling, with product validation currently in progress under the mentorship of Dr. Usha C. Thomas. Platanus Labs, mentored by Dr. Rekha V R Nair, has completed its milestone presentation and received an Incubation Support Certificate, with product validation underway at the pre-incubation stage. Taleon, mentored by Jishoy V V, has entered its acceleration phase, with patent discussions initiated and its Memorandum of Agreement signing date fixed. Spizaar Pvt Ltd. has likewise received its incubation certificate, with its Memorandum of Agreement signing scheduled.

Startups Under Discussion for Onboarding

In addition to its existing cohort, K-AgTech LaunchPad is reported to be in discussions with several additional ventures for onboarding. These include Pa Coir, engaged in coir-based value addition and sustainable

product development; Agricoops KVVVK, a cooperative-based agri-extension and farmer support initiative; Agri Flow, an AI-integrated total farm management system; and RG Integrated School, which proposes an integrated farming and agri-tourism model. Their inclusion would indicate a continually expanding pipeline within the incubation ecosystem.

Conclusion

The portfolio of startups inducted into K-AgTech LaunchPad reflects considerable diversity, spanning digital agriculture, IoT-based precision farming, agri-biotechnology, agricultural education, and sustainable product design. With ventures such as Statoberry LLP, Zelbytes, and Agriguru EdTech reporting commercially validated and nationally recognised outcomes, the incubator's early cohort offers a useful indication of the outcomes its broader, five-year objectives may yield for Kerala's agricultural economy. ■

Towards Carbon-Neutral Agriculture Kerala's Path to Sustainable Farming

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Global agriculture accounts for nearly one-third of all greenhouse gas (GHG) emissions, yet it holds extraordinary potential as a carbon sink. Kerala, India's

southernmost state, is at the forefront of translating that potential into reality. With its rich biodiversity, traditional farming wisdom and progressive governance, Kerala is charting a

credible course toward carbon-neutral agriculture — one community, one farm, and one policy at a time.

Carbon neutral farming



balances emissions produced by agricultural activities with equivalent carbon sequestration or offset, achieving a net-zero footprint. For Kerala, a state grappling with erratic monsoons, floods, and rising temperatures achieving this is not merely a policy aspiration. It is a necessity and an emerging reality.

Meenangadi: Where It Began

In 2016, Meenangadi gram panchayat in Wayanad district became India's first local body to formally commit to carbon neutrality. Facilitated by the environmental organisation Thanal, the Carbon Neutral Meenangadi Project combines afforestation through a Tree Banking scheme which offered farmers interest-free loans to plant native species, with solar energy adoption, LED lighting

and electric vehicles. In June 2024, the project inaugurated 'Thulitham', a Carbon Neutral Accelerator Lab that serves as a community innovation and learning centre. By October 2025, a real-time Augmented Weather Station was installed to support local climate-adaptive farming decisions. Meenangadi's model has since inspired climate summits and replication initiatives across Wayanad and beyond.

Okkal Seed Farm: A Certified Milestone

A landmark achievement arrived in 2024 when the Okkal Seed Farm in Ernakulam, a 102-year-old government farm which became India's first agricultural farm to receive formal carbon-neutral certification. The certification was awarded following a rigorous scientific study led by

the Centre for Water Resources Development and Management (CWRDM), conducted under IPCC guidelines and UNFCCC protocols. An independent third-party body, Carbon Check India Pvt. Ltd. (CC IPL) accredited by the Government of India, verified the findings. The assessment found that Okkal emitted 221.67 tonnes of CO₂ equivalent in 2024, with paddy cultivation alone contributing 149.25 tonnes, nearly 67% of the farm's total footprint. By deploying a combination of afforestation, organic management and renewable energy, the farm offset these emissions completely.

K.P. Sudheer, ex officio Principal Secretary of the Department of Science and Technology, described the certification as "a major milestone" in Kerala's sustainability journey. He added that carbon footprint labelling



incubating agri-tech startups to bring precision agriculture technologies to smallholders. A particular emphasis is placed on increasing productivity of staple food crops like rice while simultaneously reducing GHG emissions, a dual mandate that encapsulates the challenge and promise of carbon-neutral farming.

The Green Inheritance: Traditional Homegardens as Carbon Sinks

Perhaps the most underappreciated asset in Kerala's carbon-neutral portfolio is its traditional homegarden system. These multistory polyculture systems integrating coconut and arecanut palms, fruit trees, pepper vines, banana, medicinal plants, and timber species are found on nearly every farm and homestead across the

potentially into carbon credit markets would simultaneously reward farmers for their stewardship, generate income and provide verifiable climate benefits.

Challenges on the Path

Kerala's agricultural transition faces multiple constraints. Highly fragmented landholdings (below 0.2 ha) limit scalability, while labour shortages due to migration leave an ageing farming population less able to adopt sustainable practices. Economic challenges include high initial costs and temporary yield reductions during conversion, with uncertain price premiums or carbon credit benefits. Access to carbon markets is restricted by complex procedures and low awareness. Climate variability further complicates long-term commitments like agroforestry

on farm produce could command premium market prices, creating a direct economic incentive for other farms to follow suit. The Okkal model is now being studied as a replicable blueprint for public agricultural institutions across India.

KERA Project: Scale and World Bank Support

In October 2024, the World Bank approved a US\$200 million Kerala Climate Resilient Agri-Value Chain Modernization (KERA) Project, benefiting approximately 400,000 farmers. The KERA Project operates across several dimensions: replanting climate-resilient varieties of coffee, cardamom, and rubber; expanding Kerala's food parks into rural areas with infrastructure for water, power and waste management; and



state. Managed primarily by women, these gardens represent an ancient, empirically refined approach to sustainable land use that scientists are only now beginning to formally quantify as carbon assets. Integrating homegardens into formal carbon accounting frameworks and

or cover cropping. Overcoming these barriers requires integrated solutions like financial incentives, risk insurance, technological support, and strong community-based approaches to enable smallholders to adopt carbon-neutral farming sustainably. ■



Water as a Limiting Resource in Indian Agriculture

Emerging Challenges and Sustainable Management Approaches

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millions of lives and livelihoods are under threat. By 2030, the country's water demand is projected to exceed available supply by 2x, implying severe water scarcity for hundreds of millions of people and an eventual ~6% loss in the country's GDP2. The experience is that the availability of irrigation water in adequate quantities at the proper time is a major limiting factor.

Efficient water management for food production is becoming increasingly important amid constraints such as climate variability and change. Improving water efficiency and productivity could be a sustainable way to reduce water scarcity. Indian farmers face the challenge of maintaining or increasing crop yields and quality amid reduced or more variable rainfall. Farmers in the agricultural sector are directly connected to

water use, and their decisions on water conservation are critical to maintaining sustainable water levels. Research and innovation in sustainable water management in agriculture aim to strike a balance between maintaining and enhancing yields while reducing costs and environmental impacts.

Smart farming, digitalisation, agroecology, nature-based solutions, breeding, and the reuse of treated wastewater, among others, contribute to enhancing water-use efficiency and to climate change mitigation and adaptation in agriculture.

Keywords: Sustainability, Water Crisis, Water Management, Climate Change and Smart farming

INTRODUCTION

Agriculture is the largest user

Smart farming, digitalisation, agroecology, nature-based solutions, breeding, and the reuse of treated wastewater, among others, contribute to enhancing water-use efficiency and to climate change mitigation and adaptation in agriculture.

Abstract

Water is a life-sustaining resource used across the three primary sectors: agriculture, industry, and households. Increasing competition among these sectors could affect the availability and sustainability of water use. Water plays a fundamental role in agricultural production. Water scarcity has a significant negative impact on the quantity and quality of rainfed crop production and on irrigated crops when irrigation is unavailable or reduced.

India is suffering from the worst water crisis in its history, and



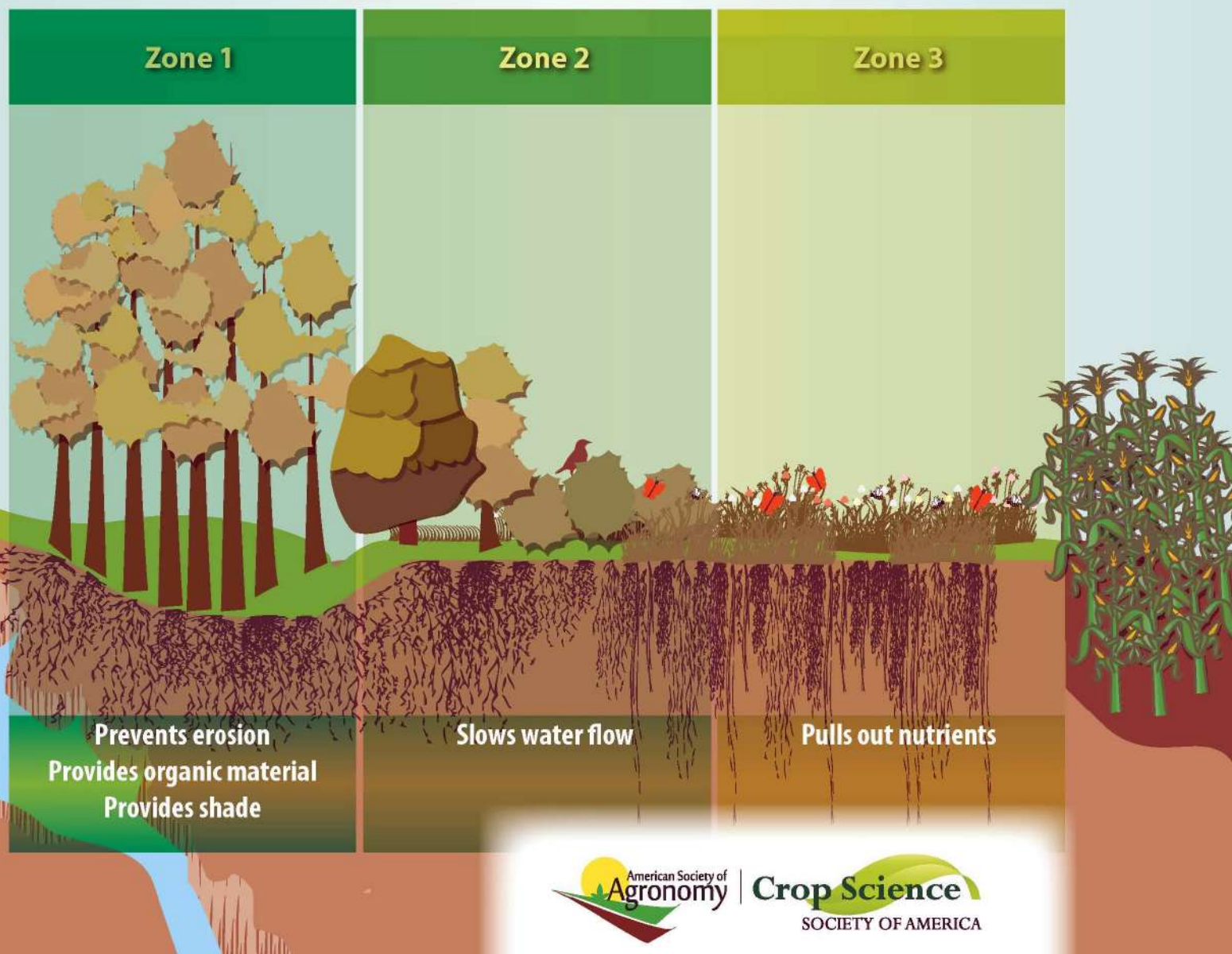
of freshwater among the three sectors, accounting for 70.00% of all water withdrawals. Water is a vital resource for agricultural sustainability and critical to ensuring food security, especially in areas with scarce or unevenly distributed water resources. Around the world, the efficient management of water in agriculture has become fundamental in increasing agricultural productivity and mitigating the effects of climatic

variability. In India, a nation with a substantial rural and agrarian populace, efficient management of water resources is essential (Singh et al., 2023; Suresh, 2021).

The competition for water will arise from rapid population growth, urbanization, and climate-related factors. The competition for water resources will have significant social impacts as water demand grows. Still, there will also be several

environmental and economic implications with the decline in water availability. Thus, policymakers need to promote the efficient and sustainable use of water resources, especially in the agricultural sector, which consumes the most freshwater. Much of the population in India, especially in rural and tribal communities, depends on agriculture as their primary source of income (Kayatz et al., 2019; Singh et al., 2023; Suresh,

Buffer Strips



| Water Management Challenge | Estimated Impact on Crop Yield (% Loss/Gain) | Proposed Solution | Expected Environmental Benefit |
|---|--|---|--|
| Climate Change & Water Scarcity | Up to 40% loss in drought-affected regions | Adaptive strategies (drought-resistant crops, efficient irrigation) | Reduces vulnerability; conserves water resources |
| Over-Extraction & Groundwater Depletion | 10-30% loss in long-term affected areas | Sustainable groundwater management, recharge initiatives | Restores aquifers; prevents land subsidence |
| Inefficient Irrigation Practices | 15-25% loss due to wastage/water stress | Modern irrigation systems (drip, sprinkler, IoT-based) | Reduces waste; increases efficiency |
| Soil Degradation & Compaction | 5-20% loss via poor water infiltration | Soil health improvement, cover cropping | Increases soil moisture retention |
| Agricultural Runoff Pollution | Varies by pollutant—yield loss plus environmental harm | Buffer strips, nutrient management, runoff capture | Protects water bodies and aquatic life |
| Poor Adoption of Technology | 10-30% potential improvement unrealized | Access to affordable agri-tech platforms | Optimizes input use; smarter resource allocation |
| Insufficient Policies & Unsustainable Practices | 10-50% compounded over time | Policy incentives, sustainable practice adoption | Ensures long-term agro-ecosystem health |

“Adopting sustainable irrigation can increase crop yields by up to 20.00% while reducing water usage in agriculture.”

2021). The effective management of water in agriculture is therefore crucial for improving agricultural productivity and farmers’ livelihoods (Kayatz et al., 2019; Singh et al., 2023; Suresh, 2021).

However, despite advancements in agricultural technologies and irrigation techniques, many regions of India, including Maharashtra, continue to struggle with water scarcity and ineffective water management (Jain et al., 2021).

The increase in food demand due to population growth will increase the need for water. More water will be needed for consumption and food production, which

could affect producers’ water-use efficiency. Efficient water management for food production is becoming increasingly important due to constraints such as climate variability and climate change. Climate change is putting tremendous pressure on water resources by reducing the amount of water available for crop production, ultimately affecting crop yields.

WATER MANAGEMENT CHALLENGES IN AGRICULTURE

Effective water management in agriculture means getting the right amount of water to the right crops at the right time while minimizing waste,

environmental pollution, and preserving precious freshwater resources for generations to come. Water scarcity was identified as a significant challenge, with farmers reporting a substantial reduction in agricultural output during the summer (February-May) due to inadequate water supply. The majority of farmers still utilizes outdated irrigation techniques, such as flood and furrow irrigation, which are ineffective and result in massive water loss.

Some of the major challenges of water management in agriculture

- **Climate change and water**

The increase in food demand due to population growth will increase the need for water. More water will be needed for consumption and food production, which could affect producers’ water-use efficiency.



scarcity: Unpredictable rainfall patterns and increasing droughts are drying rivers, straining irrigation, and making water a scarce commodity.

- **Over-extraction and groundwater depletion:** Unsustainable pumping or withdrawal for agricultural purposes depletes aquifers and can create legal and social conflict.
- **Inefficient irrigation practices:** Traditional methods result in excessive water loss through evaporation or runoff, wasting billions of gallons of fresh water annually.
- **Soil degradation and compaction:** Poor soil health and compacted fields worsen water infiltration and retention, reducing crop yields and exacerbating water scarcity issues.

- **Agricultural runoff and pollution:** Nutrients, pesticides, and sediments from fields are carried into waterways, contaminating aquatic ecosystems and reducing water quality for farms and communities.
- **Poor adoption of technology:** Despite exciting technological innovations, many farmers struggle to access or implement new solutions for efficient water use.
- **Insufficient policy and unsustainable practices:** A lack of supportive policy incentives and resistance to change make transitioning to sustainable water management complex at scale

SUSTAINABLE WATER MANAGEMENT APPROACHES

Adapting to Climate Change

and Water Scarcity

Selecting crops bred for low water requirements helps fields remain productive even in drier years. Flexible irrigation scheduling: Using satellite data and weather forecasts allows us to adapt watering times to actual conditions rather than set schedules. Rainwater collection, storage ponds, and efficient use of surface water help buffer the effects of unpredictable precipitation.

Tackling Over-Extraction & Groundwater Depletion Solutions

Over-extraction of water from aquifers can result in as much as a 30% reduction in regional crop productivity due to falling water tables and “dry wells.” Competing interests (agricultural, urban, and environmental) make balancing water demand even more challenging as rivers shrink and recharge rates drop.

Integrating technology in water management via IoT, satellite data, and automated scheduling significantly lowers costs and makes efficient water use in farming accessible for everyone.

Improving Soil Health to Boost Water Efficiency

Using green covers between primary crop cycles protects soil from erosion, conserves moisture, and boosts organic matter. Reduced tillage and controlled traffic minimized compaction and disturbance of soil structure, enabling better water infiltration and root growth. By focusing on soil health improvement, we create a self-sustaining foundation that reduces runoff, minimizes irrigation frequency, and ultimately results in more resilient, productive fields.

Reducing Agricultural Runoff Pollution

Planting grass or tree strips between fields and waterways slows runoff, capturing sediments and absorbing excess nutrients. Timing and precisely targeting fertilizers and pesticides minimizes leaching and loss. Using data-driven tools ensures we apply only what's needed—avoiding both waste and pollution. Rainwater retention and constructed wetlands can filter runoff before it reaches rivers or lakes.

Driving Change with Sustainable Policies & Best Practices

Directing subsidies or rewarding water conservation not only encourages uptake of efficient irrigation but also ensures compliance with environmental regulations. Resource management plans: Strategic

planning at the landscape or watershed level helps balance water allocation between urban, industrial, and agricultural users. Adoption of sustainable farming methods: Techniques such as AWD, cover cropping, and nutrient management reduce water demand, lower pollution, and improve soil health.

CONCLUSION

Integrating technology in water management via IoT, satellite data, and automated scheduling significantly lowers costs and makes efficient water use in farming accessible for everyone. Sustainable management of water resources in agriculture requires a multidimensional approach. Promoting micro-irrigation techniques such as drip and sprinkler systems, encouraging crop diversification toward less water-intensive crops, and strengthening watershed management practices are essential. Equally important is the integration of modern technologies, including remote sensing and decision-support systems, for efficient water planning and monitoring. Institutional reforms, participatory irrigation management, and capacity building of farmers can further enhance collective action and accountability.

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Wetlands of India

Ecological Significance, Potential Threats and Management Strategies

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Wetlands are distributed across all climatic zones of India, from Ladakh to Kerala, and occupy more than 4% of the land area. They are natural, dynamic aquatic ecosystems characterized by waterlogged conditions for much of the year. Despite their limited coverage in terrestrial ecosystems, they have the greatest capacity to sequester and retain carbon through long-term burial in soil or sediment layers. Wetlands may occur in fresh, brackish, or saline water ecosystems. Freshwater wetlands can be diverse types, such as marshes, swamps, bogs, and fens, and are part of the Teal Carbon ecology. On the other hand, brackish or saline wetlands represent Blue Carbon ecology. They may also be diverse, such as

estuaries, mangrove swamps, salt marshes, coastal lagoons, and tidal flats (Table 1). In addition to sequestering carbon, wetlands provide numerous other ecological services, as discussed in the following sections.

Carbon storage and sequestration in wetlands

Wetlands are considered concentrated terrestrial carbon sequestration sites. Although they cover only a small portion of the land area, they store nearly one-third of the global soil and sediment carbon, making them among the most carbon-dense terrestrial ecosystems. Hydrology (water saturation), vegetation type, soil and sediment characteristics,

microbial activity, climate, and anthropogenic disturbances govern the wetland carbon dynamics. The ecological carbon concentration of freshwater wetlands often exceeds that of forests, whereas coastal wetlands, such as mangroves and tidal marshes, are also considered major long-term carbon sinks. The carbon sequestration rates in wetlands vary across climatic zones, ranging from 100–250 g carbon m⁻² yr⁻¹ in temperate wetlands to 200–500 g carbon m⁻² yr⁻¹ in tropical wetlands, depending upon sustained anoxic conditions and productivity. Forested wetlands exhibit higher carbon sequestration rates than riverine wetlands.



Fig. 1. (a) Mangrove swamp, (b) riverine freshwater marsh, and (c) freshwater swamp

Table. Types of wetlands and their key characteristics

| Type of wetland | | Characteristics | Dominated vegetation | Example |
|-------------------------------|----------------|---|--|--|
| Freshwater | Marsh | Shallow water, soft sediments | Soft-stemmed herbaceous plants | Keoladeo National Park |
| | Swamp | Permanently or seasonally waterlogged, woody vegetation | Woody plants | Myristica swamps |
| | Bog | Acidic, nutrient-poor, peat accumulation, low decomposition | Sphagnum mosses | High-altitude Himalayan bogs |
| | Fen | Alkaline to neutral, nutrient-rich, peat-forming | Sedges and grasses | Loktak lake |
| Brackish water / saline water | Mangrove swamp | Tidal influence, saline water, anaerobic muddy soils | Mangrove trees | Sunderbans |
| | Tidal flats | Intertidal, exposed in low tide, high productivity | No vegetation | Rann of Kutch |
| | Salt marsh | Intertidal, high salinity | Cordgrasses | Point Calimere Wildlife and Bird Sanctuary |
| | Lagoon | Shallow, semi-enclosed, limited sea exchange | Mixed aquatic plants, reeds | Vembanad |
| | Estuaries | River-sea interface, tidal mixing, salinity gradient, nutrient-rich | Salt-tolerant vascular plants, Mangroves, Seagrasses | Ashtamudi Lake |

The carbon in wetlands may exist in multiple pools, including floral biomass carbon, carbon stored in wetland sediments, dissolved organic carbon, and microbial biomass carbon. While the photosynthesis of wetland flora assimilates atmospheric CO² into organic form, microbial processes regulate mineralization and transformation of carbon in wetland sediments. Dissolved organic carbon constitutes a major carbon fraction in wetland systems, often contributing up to 90% of total organic carbon in surface waters.

Like any other ecosystem, carbon sequestration in wetlands is governed by the balance between carbon inputs and outputs. Deposition of sediments by river and stream inflows, surface runoff, and tides (in coastal areas) is the source of allochthonous carbon. In contrast, the in situ

biomass production contributes to autochthonous carbon in wetlands. A strong relationship exists between the floral biomass and sediment carbon sequestration. Anoxic conditions further provide a favorable environment for long-term carbon sequestration, thereby enabling wetlands to act as sinks for terrestrial carbon.

However, anthropogenic perturbations significantly affect wetland carbon dynamics. Nutrient runoff from croplands and their enrichment in wetlands can enhance primary productivity and carbon accumulation. On the contrary, converting wetlands to other ecosystems can also make them a major source of carbon emissions, especially methane. Unfortunately, these anthropogenic conversions of wetlands are not uncommon in India due to population

pressure and the associated rapid urbanization and cropland expansion. The sink-and-source capacity of wetlands for carbon makes them critical in climate change dynamics.

Other ecosystem services by wetlands

Wetlands can also be used as a source for irrigation water. They can be used sustainably for fisheries, hydrological regulation (groundwater recharge, flood control), and biodiversity conservation (Fig. 2). In India, wetlands have historically supported water management. Major wetlands like Chilika (Orissa), Nalsarovar (Gujarat), Kabartal (Bihar), Kolleru (Andhra Pradesh), Loktak (Manipur), Deepor Beel (Assam), Nainital (Uttarakhand), Carambolim (Goa), Vembanad (Kerala), Dal Lake (Jammu and Kashmir)

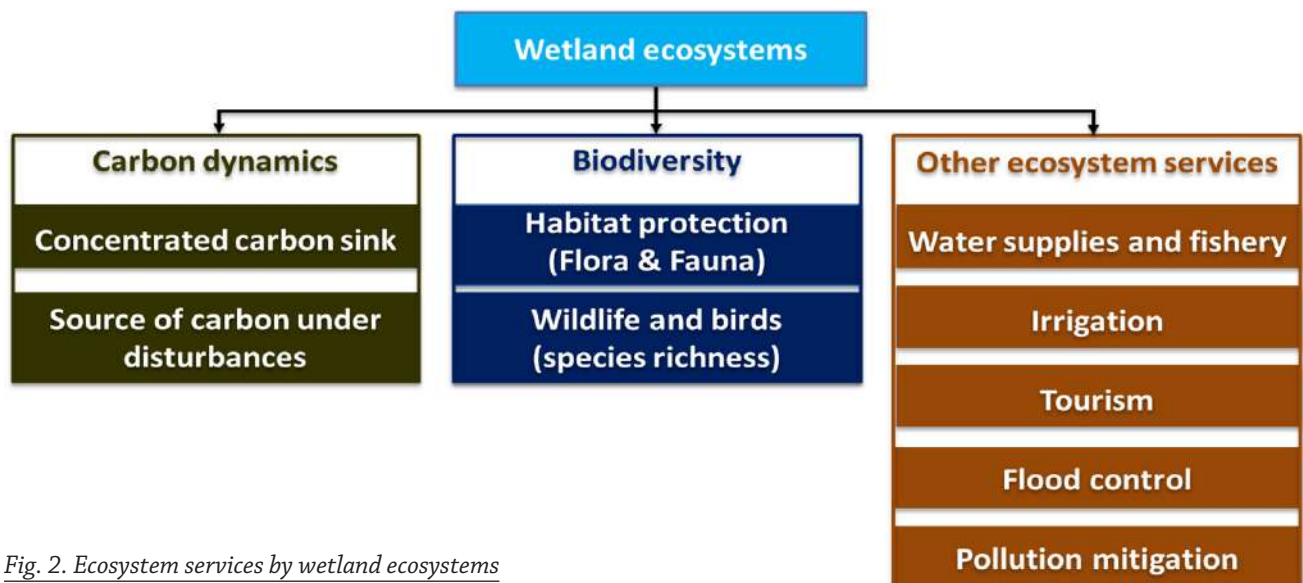


Fig. 2. Ecosystem services by wetland ecosystems

continue to support irrigation, fisheries, tourism, and domestic water supply. In coastal India, wetlands help stabilize shorelines and protect against storms. Wetlands also act as natural sinks for pollutants in urban and agricultural landscapes and provide a cost-effective means of reducing point and non-point pollution. They collect nutrients such as nitrogen and phosphorus from surface waters and runoff.

In a river-centric country like India, wetlands play a vital role in flood mitigation by buffering excess river water, slowing runoff, and trapping nutrient-loaded sediments, thereby improving downstream flow quality. They are increasingly recognized as cost-effective natural alternatives to engineered flood control systems such as dykes, dams, and embankments. Wetlands also contribute significantly to tourism, which accounts for a significant portion of India's Gross Domestic Product (GDP) and employment. Popular wetland destinations such as Kerala's backwaters, Uttarakhand's lakes, and Kashmir's Dal Lake attract millions of tourists annually. Initiatives such as the Government of India's Amrit Dharohar scheme further promote ecotourism in wetland areas. In addition, wetlands

support fisheries, with inland water bodies making significant contributions to fish production and national GDP. Wetland-based aquaculture, largely carp-based, plays a major role in livelihoods and economic growth, particularly in states like West Bengal, Kerala, Odisha, and Andhra Pradesh.

Wetlands are also considered biodiversity hotspots, supporting diverse flora and fauna, including migratory birds, native fish species, and aquatic plants. Freshwater wetlands in India host diverse biota across taxonomic groups, with aquatic plants serving as key food sources. These ecosystems support food webs, enable nutrient cycling, and serve as important breeding and feeding grounds for diverse fauna. Wetlands of India also provide critical habitats for migratory birds, with numerous species visiting annually. Overall, wetlands deliver multiple ecological and economic benefits, making their conservation essential for sustainable development and biodiversity protection.

Threats to the wetland ecosystem

Wetlands are among the most heavily utilized and exploited ecosystems, essential for human

well-being and ecological sustainability. In many regions, including North America, Europe, and Oceania, substantial quantities of wetlands have been converted over time. In India, wetland areas continue to be lost to date due to urbanization, agricultural expansion, dam construction, and other land-use changes.

In coastal regions of India, expansion of fishery practices, freshwater diversion, nutrient loading, drainage mismanagement, water extraction, sedimentation, and the proliferation of invasive species have been the major causes of wetland degradation (Fig. 3). At the same time, population growth and economic expansion have also indirectly affected wetland ecologies. Urban and agricultural expansion, pollution and subsequent eutrophication, dam construction, groundwater extraction, and the introduction of invasive species are also the major causes of the degradation of inland wetlands.

Agricultural expansion leads to wetland drainage, fragmentation, and hydrological alteration. Building canals and using wetland water for irrigation cause severe degradation of wetland health, altering vegetation structure and increasing soil erosion.

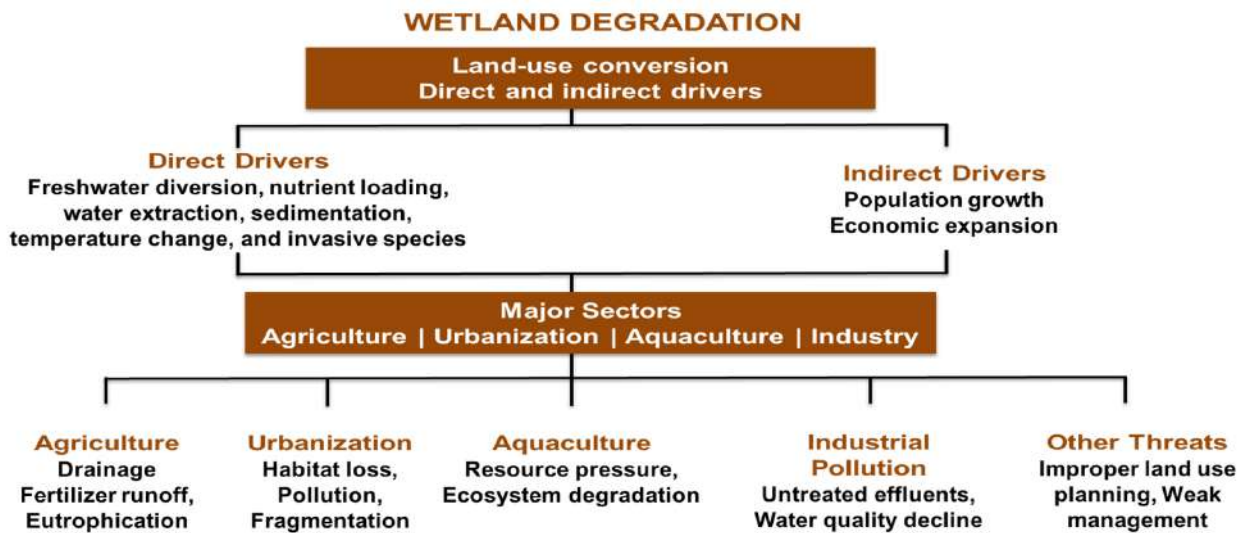


Fig. 3. Schematic representation of threats to the wetland ecosystem

Besides, the injudicious use of fertilizer contributes to nutrient runoff and eutrophication. The expansion of aquaculture also increases pressure on wetlands, often leading to ecosystem degradation. In India, unsustainable practices in some regions threaten the wetland integrity and biodiversity.

Urbanization and industrial expansion also alter wetland hydrology, structure, and function through infrastructure expansion and land conversion. Unplanned urbanization causes habitat fragmentation, biodiversity loss, and water quality degradation. Urban runoff increases the chance of heavy metal contamination in wetland ecologies, affecting aquatic life. On the contrary, industrial effluents and untreated wastewater are major sources of contamination in wetlands. In India, inadequate sewage treatment results in large volumes of untreated discharge into wetlands, severely degrading water quality and ecosystem health.

Management strategies for wetland conservation and restoration

Wetland restoration involves the ecological recovery or reconstruction of degraded

wetlands using ecological engineering, while maintaining their natural structure and minimizing human disturbance to support self-recovery processes. Management should be designed based on wetland types. Reducing pollution sources, periodic dredging, maintaining ecological flow, and biodiversity management can be key restoration strategies for riverine wetlands. In contrast, land-use regulation and maintenance of water diversion can protect a lacustrine wetland. For coastal wetlands (such as mangrove and marsh ecosystems), restrictions on land conversion for fisheries, sedimentation management, and control of pollution and eutrophication are important.

Ramsar Convention on wetland

The Ramsar Convention, signed in 1971, is one of the earliest global agreements dedicated to wetland conservation. It promotes the wise use and sustainable management of internationally important wetlands through three core objectives: international cooperation, national designation of Ramsar sites, and conservation of wetlands of international importance. Ramsar sites function as

socio-ecological systems, integrating biotic and abiotic components with demographic, cultural, and economic factors. These ecosystems are among the most productive and biodiverse habitats, providing essential services such as water supply, nutrient cycling, and livelihood support. The convention emphasized preventing wetland degradation while encouraging conservation strategies, including site protection, scientific research, funding mechanisms, and ecotourism. Despite an increase in the number and area of Ramsar sites globally, the rate of expansion has slowed in recent years. India became a signatory in 1982 and currently leads South Asia with 98 Ramsar Sites covering about 1.38 million hectares. Research under the Ramsar framework has focused on water quality, pollution control, biodiversity conservation, ecosystem services, and socio-economic values of wetlands. These studies highlighted the urgent need for wetland restoration to sustain ecological balance, particularly the global carbon cycle. Overall, Ramsar sites are critical to human survival and sustainable development, and their protected status is essential to prevent the ongoing loss and degradation of wetlands worldwide. ■

Spices and Medicinal Crops

A Profitable Opportunity in Mature Oil Palm Plantations

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Oil palm is one of the world's most productive vegetable oil crops and has become increasingly important in India's edible oil sector. Once established, an oil palm plantation remains productive for nearly three decades. During this long period, farmers often face fluctuations in palm oil

prices, increasing cultivation costs, and the challenge of utilizing the large spaces available between palm rows effectively. Unlike many perennial crops, oil palm occupies only a portion of the land surface. Even in mature plantations, considerable interspaces remain available for cultivation. However, as palms

grow older, their dense canopy creates heavy shade, making it difficult to grow conventional field crops. This has often led to the misconception that mature oil palm plantations are unsuitable for any additional agricultural activity. Recent research by the ICAR-Indian Institute of Oil Palm Research has demonstrated



that this perception is not entirely correct. Several shade-tolerant spice and medicinal crops can thrive under mature oil palm plantations, providing farmers with an additional source of income while improving overall land productivity.

Why Intercropping Matters

Intercropping is the cultivation of two or more crops simultaneously on the same piece of land. In perennial plantations, it offers numerous advantages beyond generating additional income. Properly selected intercrops make efficient use of sunlight, water, nutrients, and otherwise underutilized space. They also suppress weeds, reduce soil erosion, improve soil health, and enhance biodiversity. For oil palm growers, intercropping offers an opportunity to diversify farm income and reduce dependence on a single commodity. When market prices of fresh fruit bunches decline, intercrops can provide a valuable economic cushion.

Shade-Loving Crops Offer New Possibilities

Many medicinal and spice crops naturally grow under partial shade in tropical forests and plantation ecosystems. Their ability to tolerate low light makes them excellent candidates for cultivation beneath mature oil palm canopies. The study evaluated several commercially important species belonging to the genera *Curcuma*, *Zingiber*, and *Kaempferia*. These included turmeric, mango ginger, black turmeric, white turmeric, wild turmeric, Indian arrowroot, ginger, bitter ginger, black ginger, and aromatic ginger. These crops are already familiar to farmers because they are successfully cultivated under coconut and arecanut plantations in different parts of India. Their adaptation to shaded conditions suggested that they could also perform well in mature oil palm plantations.

A Favorable Microclimate Under Oil Palm

The dense canopy of mature oil palm modifies the surrounding environment by reducing direct sunlight while maintaining relatively cool temperatures and higher humidity. Such conditions create a favorable microclimate for many



Ginger



Mango ginger



Aromatic ginger



Bitter ginger



Turmeric



White turmeric



Wild turmeric



Black turmeric

rhizomatous spice and medicinal crops. Rather than becoming a limitation, this natural shade can actually benefit crops that are adapted to lower light intensity. Improved soil moisture conservation and reduced evaporation further support healthy crop growth throughout the growing season.

The evaluation revealed that several spice and medicinal crops adapted remarkably well to the shaded conditions. Black ginger emerged as one of the most promising intercrops because of its exceptionally high market value and excellent economic returns. Although its biological yield was moderate, its premium price made it highly profitable for farmers. Wild turmeric and white turmeric also performed very well, combining good yields with attractive market demand. Their adaptability to shaded environments makes them ideal choices for diversified oil palm farming systems. Mango ginger produced excellent rhizome yields and had a relatively shorter crop duration, allowing farmers to harvest earlier and obtain quicker returns. Turmeric demonstrated outstanding overall performance, particularly in biomass production and quality attributes. It also maintained high levels of valuable compounds such as volatile oils and oleoresins, making it suitable for both culinary and medicinal uses.

Improving Farm Profitability

One of the major concerns among oil palm growers is whether intercropping would reduce the productivity of the main crop. The study found that properly managed intercropping did not adversely affect oil palm production. Fresh fruit bunch yield remained comparable to that of monocropped

plantations, indicating that well-planned intercropping can coexist successfully with oil palm. By utilizing the otherwise unused spaces between palms, farmers can generate substantial additional income without compromising the productivity of their plantation. High-value medicinal crops such as black ginger provide particularly attractive economic returns, while turmeric and other *Curcuma* species offer stable market demand and diverse commercial applications. This diversified approach also spreads economic risk by reducing dependence on a single crop.

Environmental Benefits

Apart from economic advantages, intercropping contributes significantly to environmental sustainability. The presence of intercrops provides better ground cover, helping reduce soil erosion during heavy rainfall. Additional vegetation improves nutrient cycling, supports soil microorganisms, and enhances biodiversity within the plantation ecosystem. Diversified cropping systems are increasingly recognized as an



Indian Arrowroot

intercropping in mature oil palm plantations should select shade-tolerant species with good market demand. Proper spacing should be maintained around the palm trunks to avoid competition for nutrients and moisture. Regular irrigation, balanced fertilization, and timely plant protection measures are essential to obtain maximum benefits from both the oil palm and intercrops. The choice of intercrop should also depend on local market opportunities, availability of planting material, and farmer preferences.

generate higher farm income, improve ecological balance, and enhance the resilience of farming systems. Such integrated production systems align well with the principles of climate-smart and sustainable agriculture. The findings of this study clearly demonstrate that mature oil palm plantations need not remain underutilized. With appropriate crop selection and management, farmers can successfully cultivate valuable spice and medicinal crops while maintaining healthy oil palm production. Among the crops evaluated, black ginger, wild

Intercropping is the cultivation of two or more crops simultaneously on the same piece of land. In perennial plantations, it offers numerous advantages beyond generating additional income.

important strategy for making agriculture more resilient to climate variability. Instead of functioning as monocultures, oil palm plantations can become productive multi-crop ecosystems that support both economic and ecological sustainability.

A Practical Option for Farmers

Farmers interested in adopting

Towards Sustainable Oil Palm Cultivation

Oil palm cultivation has often been criticized for concerns related to biodiversity and monocropping. However, introducing suitable spice and medicinal crops beneath mature palms presents a practical solution that combines productivity with sustainability. Diversified plantations can make better use of available resources,

turmeric, white turmeric, and turmeric emerged as particularly promising options for profitable and sustainable intercropping. As India continues to expand oil palm cultivation under the National Mission on Edible Oils–Oil Palm, integrating suitable intercrops offers an effective pathway to enhance farmer income, improve land-use efficiency, and promote environmentally sustainable plantation agriculture. ■



Synbiotic (Pre & Probiotic) Rich Foods

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Synbiotics are formulations consisting of prebiotics (non-digestible fibers that foster the growth of probiotics) and probiotics (beneficial microorganisms- Lactobacillus, Bifidobacterium, Saccharomyces boulardii, Streptococcus thermophilus, etc.). Synbiotics concept was introduced by Gibson & Roberfroid (1995) as combinations of probiotics

and prebiotics that positively impact the host by enhancing the survival and colonization of live microbial dietary supplements in the gastrointestinal tract. They selectively promote the growth and/or activate the metabolism of specific health-beneficial bacteria, thereby improving the well-being of the host. According to International Scientific Association for Probiotics

and Prebiotics (ISAPP, 2017), prebiotic is “a substrate that is selectively utilized by host microorganisms conferring a health benefit”. Probiotics are defined as “live microorganisms that, when administered in adequate amounts, confer a health benefit on the host” (ISAPP, 2017). Moreover, ISAPP (2021) defined the ‘postbiotics’ as “a preparation

of inanimate microorganisms and/or their components that confers a health benefit on the host". These definitions are results from a consensus panel convened by ISAPP, comprising 11 participants from 10 countries, representing a diverse array of disciplines including gastroenterology, pediatrics, metabolomics, microbiology, immunology, functional genomics, probiotic-host interactions, and regulatory affairs (Vinderola et al., 2024). Moreover, these definitions were proposed to offer researchers, industry professionals, and regulators a shared understanding of the term and to establish a scientific foundation for classifying substances as prebiotic, probiotics and postbiotics. Moreover, prebiotics were characterized as substrates that incorporate not just as carbohydrates but also compounds like (poly)phenols and polyunsaturated fatty acids, which may potentially be utilized as prebiotics. Sales of fermented food and beverages indicate heightened customer demand, with the market for fermented foods and beverages expected to grow to a value of USD 1.25 trillion by 2034 with projected CAGR of 8.1% from 2024 to 2034 (Future Industry Insights, 2024). Similarly, the fermented food and beverage market in the India is expected to register a CAGR of 6.9 % between 2024 and 2034. The India's fermented food and beverage market is expanding as a result of rising demand for convenient and healthful meal options. Demand is rising because of shifting lifestyles, rising consumer spending power, and increased knowledge of preventative healthcare. The market demand is also anticipated to be fueled by the increasing demand for natural and nutrient-rich foods.

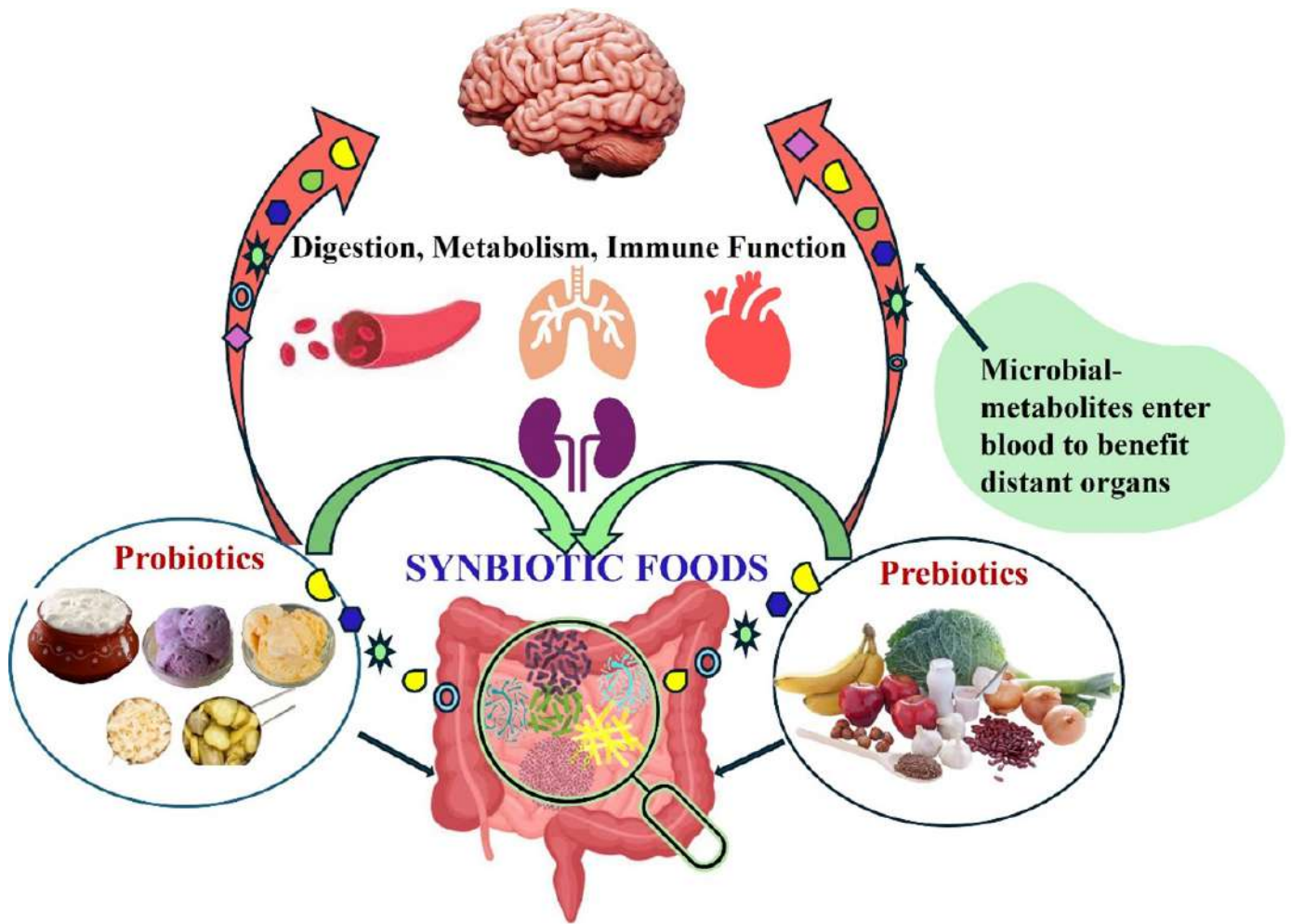
Synbiotics Support Digestion, Metabolism, and Immune Function

Synbiotics depends on the concept that probiotics proliferate in the intestines with the support of prebiotics. This combination promotes the maintenance of a balanced gut microbiome, which is thought to improve immune system function, metabolism, and gut health. In this regard, physical and mental health are greatly affected by the gut microbiome, a complex population of trillions of microorganisms, including viruses, fungi, and bacteria. This diversified and well-balanced microbiome aids in regulating metabolism, preventing dangerous infections, and maintaining a healthy digestive tract. However, any disruptions to this microbiome can lead to digestive issues, immune system imbalances, and even chronic conditions like obesity, diabetes, and autoimmune disorders. Therefore, by outcompeting pathogenic microbes (e.g., Salmonella, Shigella, Escherichia coli, Clostridium difficile, Staphylococcus, Campylobacter, etc.), probiotics help to restore equilibrium in the gut. Furthermore, prebiotics encourage the growth and activity of these good bacteria, acting as food for them.

As previously established, probiotics and prebiotics complement one another to promote nutrient absorption, strengthen the gut's natural defenses, and enhance immunological function. Research suggests that maintaining a healthy gut microbiome can improve digestion, reduce inflammation, and even enhance mental health, as the gut is often referred to as the "second brain" due to the connection between gut health and mood regulation.

By combining prebiotic and probiotic meals, synbiotics offer a more comprehensive approach to achieving and maintaining good gut health, with benefits that go far beyond digestive health. Probiotics assist in the breakdown of food, particularly complex fibers and sugars that the body may find challenging to process otherwise. They aid in the intestinal fermentation process, which transforms certain fibers into advantageous byproducts like short-chain fatty acids (SCFAs). These SCFAs enhance gut barrier function, decrease inflammation, and stimulate gut motility—all of which are critical for effective digestion.

Probiotics ferment non-digestible carbohydrates called prebiotics to produce short-chain fatty acids (SCFAs), which aid in digestion and promote the intestinal lining's health by ensuring that it absorbs nutrients as effectively. Therefore, probiotics and prebiotics work together to enhance nutritional absorption, regulate gut flora, and lower the likelihood of gastrointestinal problems like diarrhea, constipation, and bloating. Probiotics can positively impact metabolic functions by influencing the way the body processes food. Some probiotic strains are believed to improve fat metabolism [different strains of *L. plantarum* have different cholesterol-lowering capacities (Wang et al., 2021)], regulate blood sugar levels [*L. kefirifaciens*, *L. plantarum*, *Lactobacillus helveticus*, *Lactococcus lactis* (Manaret al., 2021)], cholesterol lowering capacities [*Zymomonas mobilis* (de Aguiar Silva et al., 2020)], and reduce inflammation linked to metabolic disorders such as obesity and type 2 diabetes. Moreover, about 70% of the immune system is in the gut, and the gut microbiome (*Lactobacillus johnsonii*,



Lactobacillus rhamnosus, *L. casei*, *Saccharomyces cerevisiae*, *Bifidobacterium lactis*, and *Bifidobacterium animalis*) plays a central role in immune responses. Probiotics support immune function by enhancing the activity of immune cells like T lymphocytes, macrophages, and dendritic cells (Wu et al., 2022). They can also promote the production of specific antibodies that protect against pathogens and harmful microorganisms.

Synbiotics help maintain a healthy gut microbiome by promoting the growth of beneficial bacteria while inhibiting harmful pathogens. This can lead to improved digestion, better nutrient absorption, and a reduction in digestive disorders like irritable bowel syndrome (IBS) and constipation (Kolida & Gibson, 2011). Synbiotics can reduce

systemic inflammation, which has been linked to various chronic diseases, such as heart disease, diabetes, and autoimmune conditions. By promoting a balanced microbiome, synbiotics help regulate inflammatory responses in the body (Plaza-Díaz et al., 2017). Moreover, the combination of probiotics and prebiotics in synbiotics can strengthen the intestinal lining, which acts as a barrier to prevent harmful substances from entering the bloodstream. This is particularly important for reducing inflammation and preventing conditions like leaky gut syndrome (Rose et al., 2021).

Types of Synbiotic-Rich Foods

Probiotic-Rich Foods:

- o Fermented dairy (e.g., yogurt, kefir)

- o Fermented vegetables (e.g., sauerkraut, kimchi, pickles)
- o Fermented soy products (e.g., miso, tempeh)
- o Non-dairy probiotics (e.g., kombucha, fermented grains)

Prebiotic-Rich Foods:

- o Fiber-rich fruits and vegetables (e.g., bananas, onions, garlic, leeks, sweet potatoes)
- o Whole grains (e.g., oats, barley, wheat)
- o Legumes (e.g., chickpeas, lentils, beans)
- o Nuts and seeds (e.g., almonds, flaxseeds)

Examples of Synbiotic Food Combinations

- Yogurt with added fiber (e.g., with chia seeds or oats)

- Kimchi with high-fiber vegetables
- Kombucha paired with whole grain crackers
- Miso soup with prebiotic-rich ingredients like garlic and onions

Incorporating Synbiotic Foods into regular Diet

Incorporating synbiotic foods into daily diet can be an effective way to improve gut health, boost immunity, and enhance overall well-being. These small changes, like adding fermented foods or fiber-rich fruits and vegetables to your meals, can enhance the balance of gut microbiome and promote overall well-being. Even though fermented foods are a great addition to a healthy diet, moderation is key. It's important to start slow and monitor how the body reacts. Gradually increasing intake allows digestive system to adjust, reducing the likelihood of discomfort. If digestive issues persist, it may be helpful to consult with a healthcare provider or a nutritionist to find the best approach for incorporating synbiotic foods into regular diet.

Conclusion

Incorporating synbiotic-rich foods into a balanced diet is a powerful way to support and maintain a healthy gut microbiome, which plays a key role in overall health. Synbiotics, which combine probiotics (beneficial bacteria) and prebiotics (fiber or compounds that feed these bacteria), work synergistically to improve digestive function, enhance immune health, and promote overall well-being. Importantly, exploring a variety of probiotic and prebiotic food options is a great way to support a diverse and healthy gut microbiome. Probiotic-rich foods like yogurt,

kefir, kimchi, and sauerkraut introduce beneficial bacteria to your digestive system, while prebiotic foods such as garlic, onions, bananas, and whole grains provide the fuel these bacteria need to thrive. By regularly consuming synbiotic-rich foods, can promote better digestion, strengthen immune system, and enhance overall well-being. Overall, whether through food or supplements, taking synbiotics a part of daily routine helps promote long-term well-being.

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When the Rains Misbehave

How Erratic Weather Affects Cashew Flowering and Yield

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Introduction

For generations, cashew farmers have relied on nature's rhythm. The arrival of the monsoon, followed by a distinct dry season, creates ideal conditions for flowering, pollination, and nut development. Today, however, that rhythm is becoming increasingly unpredictable. Monsoon withdrawal is often delayed, dry spells are interrupted by unseasonal showers, and prolonged droughts are becoming more common. These changes are collectively described as erratic rainfall, and they are emerging as a major challenge to sustainable cashew production. Although cashew is widely regarded as a hardy crop capable of growing under marginal conditions, its reproductive phase is highly sensitive to weather fluctuations. The success of flowering, pollination, fruit set, and nut development depends largely on favourable climatic conditions. When rainfall occurs

at the wrong time or drought persists for extended periods, the entire reproductive cycle can be disrupted, leading to substantial yield losses.

Why Flowering Determines Yield

The foundation of a good cashew harvest is laid during the flowering season. After the withdrawal of the southwest monsoon, cashew trees experience a period of physiological transition from vegetative growth to reproduction. Dry weather during this period promotes flower bud differentiation and panicle emergence. Flowering usually extends from November to March, depending on the region and variety. A single panicle may produce hundreds of flowers over several weeks. However, only a small proportion of these flowers are hermaphrodite flowers capable of producing nuts. Therefore, successful pollination and fertilization are essential for achieving good

yields (Fig. 1). A dry atmosphere, moderate temperatures, and active pollinator populations favour pollen transfer and fruit set. Any disruption during this period can significantly affect productivity.

Why Cashew Needs a Dry Spell

Unlike many crops that benefit from rainfall during flowering, cashew performs best when the weather remains relatively dry. Dry conditions favour flower initiation, pollen viability, pollinator activity, and fruit set. When unseasonal rainfall occurs during flowering, several problems arise simultaneously. Flowers remain wet for extended periods, pollen transfer is reduced, pollinator activity declines, and disease incidence increases. As a result, the conversion of flowers into nuts becomes less efficient. This explains why years with abundant flowering do not always result in high yields.



Fig. 1: Types of flowers and pollination in cashew. a-fresh male(staminate) flower with undehisced pink anther, b-fresh hermaphrodite (bisexual/ perfect) flower with long pistil and short stamen, c-honey bee visiting cashew inflorescence (panicle) for effecting open pollination, d-artificial (hand) pollination for producing hybrids (Source: Eradasappa E et al., 2016).



Delayed Flowering and Disturbed Flowering Cycles

One of the first visible effects of erratic rainfall is delayed flowering. Cashew requires a distinct dry period after the monsoon for flower bud differentiation. If rainfall continues late into the season or unexpected showers occur during the flower initiation stage, flowering may be delayed or become irregular. Delayed flowering often shortens the effective reproductive period and exposes flowers and developing fruits to higher temperatures later in the season. Such conditions can adversely affect pollination, fertilization, and fruit retention. In some orchards, flowering becomes staggered and poorly synchronized, making crop management more difficult and reducing overall productivity.

Rain During Flowering: A Costly Event

Rainfall during flowering is one of the most damaging weather events for cashew production. Tender flower panicles are highly susceptible to mechanical damage from rain. Heavy showers can wash away pollen grains, damage delicate floral structures, and increase flower shedding. Even short periods of rainfall during





Fig. 2: Flower visitors of cashew: Bees, flies and ants (Source: Vanitha K et al., 2018)

peak flowering may substantially reduce fruit set.

Pollinators: Silent Victims of Erratic Weather

Cashew flowers depend heavily on insect pollinators such as bees, flies, ants, and wasps. These insects transfer pollen between flowers and play a critical role in fruit set. Weather conditions strongly influence pollinator behaviour. Warm, dry, and sunny conditions encourage insect activity, whereas rainfall, high humidity, and cloudy weather reduce flower visitation. Fewer pollinator visits mean less pollen transfer and reduced fertilization. Recent studies on cashew pollinators have highlighted the importance of favourable

water relations, and hormone balance in cashew. These changes ultimately influence flowering, fruit retention, and yield stability. Interestingly, varieties differ considerably in their response to drought stress. Some varieties are capable of maintaining productivity under limited water availability, making them valuable genetic resources for future breeding programmes.

Building Climate-Resilient Cashew Orchards

Although rainfall patterns cannot be controlled, several management practices can reduce their impact.

Conserve Soil Moisture

Mulching with crop residues,

helps maintain pollinator populations and improve fruit set.

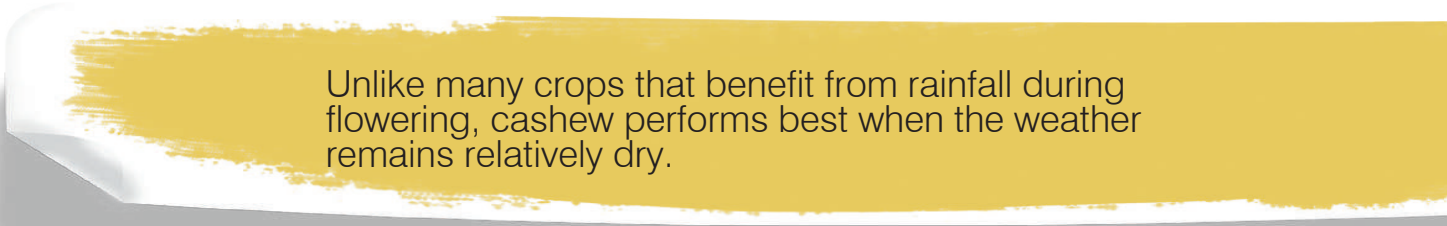
Manage Diseases Proactively

Timely monitoring and management of anthracnose and other fungal diseases become particularly important during wet flowering seasons.

Adopt Climate-Resilient Varieties

Future cashew cultivation will increasingly depend on varieties capable of maintaining flowering, fruit set, and productivity under both drought and erratic rainfall conditions.

What Does This Mean for Farmers?



Unlike many crops that benefit from rainfall during flowering, cashew performs best when the weather remains relatively dry.

weather for pollination success (Fig. 2). Conserving pollinator populations is therefore becoming increasingly important in climate-resilient cashew production systems.

Drought: The Other Face of Climate Variability

While unseasonal rainfall attracts immediate attention, prolonged dry spells can be equally damaging. Cashew is drought tolerant, but severe moisture stress during flowering and fruit development can reduce productivity. Under prolonged drought conditions, flowers dry prematurely, fruitlets drop, and nut development becomes poor. Recent physiological studies have shown that drought affects photosynthesis, nutrient uptake,

coconut husk, or organic biomass helps conserve soil moisture and moderate soil temperature. Water conservation structures such as trenches, crescent bunds, and basin management improve rainwater harvesting and reduce drought stress.

Provide Protective Irrigation

Supplemental irrigation during flowering and fruit development can significantly reduce flower drying and fruit drop. Even limited irrigation during critical growth stages can improve fruit retention and nut quality.

Protect Pollinators

Pollinator-friendly orchard management, including reduced pesticide use during flowering,

The changing climate is altering not only how much rain falls but also when it falls. For cashew, this distinction is critical. Untimely rainfall during flowering and prolonged drought during fruit development can both reduce productivity.

Farmers should therefore focus on:

- Conserving soil moisture during dry periods.
- Harvesting and storing rainwater whenever possible.
- Protecting pollinators during flowering.
- Monitoring orchards for disease outbreaks after rainfall.
- Adopting climate-resilient



HOW UNSEASONAL RAIN AFFECTS CASHEW FLOWERS

- Delays flower initiation and panicle emergence.
- Washes away pollen grains and reduce pollination.
- Increases flower and fruitlet drop.
- Reduces pollinator activity.
- Encourages fungal diseases such as anthracnose and inflorescence blight.
- Leads to poor fruit set and lower nut yield.

Key Message: In cashew, the timing of rainfall is often more important than the total amount received.

Climate change is expected to increase rainfall variability across many cashew-growing regions. As a result, erratic rainfall is likely to become one of the most important challenges facing cashew cultivation in the coming decades.

varieties and improved orchard management practices.

Looking Ahead

Climate change is expected to increase rainfall variability across many cashew-growing regions. As a result, erratic rainfall is likely to become one of the most important challenges facing cashew cultivation in the coming decades. The good news is that research is providing solutions. Advances in flowering biology, climate-resilient breeding, drought tolerance studies, and orchard management are helping scientists develop strategies to cope with changing weather conditions. By combining these innovations with climate-smart farming practices, it is possible

to reduce production risks and sustain cashew productivity. Ultimately, the future success of cashew cultivation will depend not only on how much rain falls, but also on how effectively farmers and researchers adapt to an increasingly unpredictable climate.

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Stem Canker Disease

An Emerging Threat to Dragon Fruit Farming in India

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Introduction

Stem canker of dragon fruit, caused by *Neoscytalidium dimidiatum*, has recently

emerged as a serious threat to the rapidly expanding dragon fruit industry in India. With increasing commercial cultivation across states such

as Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, and the North-Eastern region, the disease has become a major constraint to



productivity and profitability. Reports indicate that stem canker is now widely distributed in India, causing substantial yield losses, vine decline, and deterioration in fruit quality, particularly under warm and humid agro-climatic conditions (Salunkhe et al., 2023). The rapid spread of the disease is largely attributed to the use of infected planting materials, expansion of monoculture systems, and favorable environmental conditions during the monsoon season. Considering the growing economic importance of dragon fruit as a high-value crop promoted under various government initiatives, stem canker poses a significant challenge to sustainable cultivation in the country.

Symptoms

Stem canker symptoms on dragon fruit cladodes (stems) exhibit a characteristic progression, beginning with subtle early-stage indicators and advancing to severe necrotic damage under conducive environmental conditions. Initially, small, yellowish or chlorotic spots appear on the stem surface, which are often inconspicuous and easily overlooked during routine field inspection. As the infection progresses, particularly on young and succulent tissues, these spots develop into distinct whitish lesions, indicating active pathogen colonization.

With further disease development, the lesions enlarge and coalesce, transforming into reddish-brown to dark necrotic cankers. These affected areas gradually become sunken and assume a rough, scab-like appearance, frequently accompanied by surface cracking. Under conditions of high humidity, especially during the monsoon season, the formation of black pycnidia (fruiting bodies



of the pathogen) is commonly observed within the lesions, serving as a diagnostic feature of the disease.

In advanced stages, lesions may perforate, giving a “shot-hole” appearance, and severe infections can girdle stems, causing dieback or vine collapse. Such severity is more common in poorly managed orchards with dense canopy and poor drainage. Field

observations in India indicate that such severe manifestations are more prevalent in poorly managed orchards, particularly those with dense canopy growth, inadequate pruning, and insufficient drainage, all of which contribute to prolonged moisture retention and enhanced disease pressure.

Fruit symptoms, although less frequent than stem infections,



are of significant economic importance. The disease initially manifests as small whitish or pale-yellow spots on the fruit peel, which progressively enlarge

into brown, dry, and often cracked lesions. As the infection advances, these lesions may coalesce, leading to extensive surface damage. In severe

cases, the pathogen penetrates deeper tissues, causing fruit rot that renders the produce unmarketable. Such infections significantly reduce both the yield and market value of dragon fruit in affected regions.

Pathogen Biology

The causal organism, *Neoscytalidium dimidiatum*, belongs to the family Botryosphaeriaceae and is a highly adaptable fungal pathogen suited to tropical and subtropical climates. Indian agro-climatic conditions, characterized by high temperatures and humidity, are particularly favorable for its survival and rapid spread. The pathogen produces darkly pigmented, septate hyphae and arthroconidia, which enable it to withstand environmental stresses such as temperatures exceeding 35°C during summer and periods of low moisture between cropping cycles. This adaptability allows the pathogen to persist across seasons and maintain its infectivity.

Under Indian field conditions, the pathogen employs multiple survival and dispersal mechanisms. It survives saprophytically in infected cladodes and plant debris, serving as a primary source of inoculum. It can also persist as latent infections in apparently healthy nursery plants, facilitating its spread through planting material. Dissemination occurs via rain splash, irrigation water, contaminated tools, and wind-borne spores. Together, these mechanisms ensure a continuous cycle of infection and sustained

Stem canker symptoms on dragon fruit cladodes (stems) exhibit a characteristic progression, beginning with subtle early-stage indicators and advancing to severe necrotic damage under conducive environmental conditions.



disease pressure throughout the year, particularly in regions experiencing prolonged monsoon periods and high humidity, which favor pathogen growth, sporulation, and infection (Salunkhe et al., 2023).

Epidemiology

The epidemiology of stem canker in India is largely governed by seasonal and agro-climatic

conditions, with warm temperatures (25-38°C), high humidity (>80%), and monsoon rainfall creating ideal conditions for disease development and spread. Although present year-round, the disease is most severe during the hot and humid months (June–September), when rain splash enhances pathogen dispersal (Hong, et al. 2020).

Agronomic factors such as high-density planting and poor canopy management further increase disease incidence by promoting humidity and reducing air circulation. Wounds caused by pruning or environmental damage facilitate pathogen entry, while young plants (1-2 years old) are particularly susceptible. Infected plants act as primary inoculum sources, leading to rapid disease spread, highlighting the need for timely integrated management.

Impact on Dragon Fruit Production

Stem canker disease imposes significant economic constraints on dragon fruit cultivation in India, adversely affecting both productivity and long-term orchard sustainability. Under severe infection, yield losses may reach 30–60%, largely due to extensive stem damage, reduced flowering, and increased fruit drop. Beyond yield reduction, the disease also deteriorates fruit quality, resulting in blemished, cracked, or rotted fruits that are unsuitable for fresh consumption and export, thereby lowering their market value.

Rising disease pressure further escalates production costs, as farmers must invest more in fungicides, pruning, and sanitation practices. Continuous infections weaken plant vigor over time, leading to a gradual decline in productivity and ultimately shortening the economic lifespan of plantations. In many cases, this necessitates premature replanting, adding to the financial burden on growers. Field observations from key dragon fruit-growing regions indicate that, without proper management, infected vines can decline rapidly, often within two to three years of establishment. This rapid deterioration emphasizes the destructive

nature of stem canker and highlights the urgent need for effective integrated disease management strategies to sustain dragon fruit production in India.

Disease Management Practices

1. Stem canker can be effectively managed through an integrated approach (IDM) combining cultural, sanitation, biological, and chemical methods.
2. Start with healthy planting material, maintain proper spacing (2-3 m), and do regular pruning to improve airflow and reduce humidity.
3. Avoid water stagnation during monsoon and remove infected cladodes promptly to reduce disease spread (can lower incidence by 30-50%).
4. Maintain good field sanitation disinfect tools (1% bleach or 70% alcohol), avoid plant injuries, and remove infected debris.
5. Chemical control becomes essential under high disease pressure, particularly during humid monsoon periods, where fungicides such as copper oxychloride (2.5-3.0 ml/L), mancozeb (2.5 ml/L), azoxystrobin + difenoconazole, difenoconazole + propiconazole (0.5-1.0 ml/L), and prochloraz (1 ml/L) are applied at 10-15 day intervals from disease onset for effective suppression.
6. Additional fungicides including cyprodinil + fludioxonil, tebuconazole, and metiram further inhibit mycelial growth and spore germination, thereby enhancing overall disease control when integrated with other practices.
7. Apply *Trichoderma viride* or *T. asperellum* or *Bacillus subtilis* @ 2.5-5.0 kg/ha (talc-based formulation) mixed with 50 kg FYM/compost as soil application, along with foliar spray @ 5-10 g/L or 2-5 ml/L at 10-15 day intervals for effective disease suppression (~40-60%).
8. Integrated nutrient management further contributes to disease suppression, avoiding excess nitrogen reduces host susceptibility, while application of organic amendments such as farmyard manure (FYM) and compost enhances soil health and microbial activity, and micronutrients strengthen plant defense mechanisms.
9. Under Indian conditions, effective monsoon management practices including proper drainage, avoidance of overhead irrigation, and timely pre-monsoon pruning are crucial to limit disease development due to the strong association of stem canker with high humidity and rainfall.
10. A well-implemented IDM strategy integrating sanitation, cultural practices, biological agents, and judicious fungicide use can reduce disease severity by 60-80% and ensure sustainable productivity in affected crops.
11. Stem canker is an emerging and significant constraint in India, particularly under humid monsoon conditions, leading to yield losses, deterioration in fruit quality, and long-term plantation decline.
12. Future management strategies should focus on the development of resistant cultivars, establishment of weather-based forecasting systems, and promotion of eco-friendly disease management approaches for long-term sustainability.

Stem canker disease imposes significant economic constraints on dragon fruit cultivation in India, adversely affecting both productivity and long-term orchard sustainability.

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