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SOUVENIR &ABSTRACTS BOOK

AGRIVISION-2026

10th National Convention

on

Reimagining Indian Agriculture : TradiTech-led Transformation

भारतीय कृषि की युगीन परिकल्पना : व्यवसाय व तकनीक का बदलता परिदृश्य

13-14 October 2026





VENUE

Bharat Ratna C. Subramaniam Auditorium, ICAR-NASC, Pusa, New Delhi

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TRANSFORMING BHARAT THROUGH AGRICULTURE

10th National Convention: AGRIVISION-2026 "Reimagining Indian Agriculture: TradiTech-led Transformation"
October 13-14, 2026

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Message

It gives me great pleasure to extend my greetings to the organisers, delegates, scientists, teachers and students of the 10th National AgriVision Convention, to be held on 13-14 October 2026 on the theme 'Reimagining Indian Agriculture: Tradi-Tech-led Transformation." The Convention offers a valuable opportunity to bring traditional knowledge, scientific evidence and emerging technologies together to shape the future of Indian agriculture.

Indian agriculture must secure food and nutritional security, improve farmer incomes and respond to climate change, soil degradation, water scarcity and loss of agrobiodiversity. Our vision for Viksit Bharat calls for agriculture that is productive, profitable, resilient and inclusive. Achieving this requires research that responds to farmers' needs and translates innovation into measurable benefits on the ground.

The Convention's seven themes connect well with this vision. Traditional farming knowledge offers valuable insights into local resources, crop diversity and adaptation. Its integration with modern science requires careful validation under different farming conditions. Digital tools, artificial intelligence, remote sensing and precision agriculture offer new opportunities to improve decisions, use inputs efficiently and manage risks. Their value lies in making reliable knowledge accessible and useful to farmers, including smallholders.

Agricultural education is central to this transformation. We need young professionals who combine scientific understanding with practical skills, an entrepreneurial outlook and close engagement with rural communities. Learning must connect classrooms and laboratories with farms, enterprises and field problems. I encourage students and young researchers to pursue solutions that farmers can afford, adopt and sustain.

Livestock, dairy and allied enterprises are vital to diversified livelihoods and nutritional security. Progress in these sectors requires an integrated focus on breeding, nutrition, animal health, resource efficiency and market access. Similarly, agricultural startups and incubation must help move promising technologies from research to viable enterprises, supported by field validation, partnerships and effective technology commercialisation.

Securing farmer incomes and food and nutritional security demands attention to yield stability, production costs, post-harvest losses, value addition and access to markets. Soil health, efficient water and nutrient management, climate-resilient varieties and sustainable farming practices must advance together. An inclusive agricultural ecosystem must give women, rural youth and small and marginal farmers a meaningful role in shaping and benefiting from this progress.

ICAR's research, education and extension efforts provide a strong foundation for this endeavour. Closer collaboration among researchers, farmers, educators, industry and policymakers will help turn shared priorities into practical outcomes. I hope the Convention identifies clear opportunities for collaborative research, student engagement and solutions that can be tested and taken to scale.

I congratulate the organisers for bringing these important themes together and convey my best wishes for a successful and productive Convention. Let us build an agricultural future rooted in India's knowledge traditions, strengthened by science and guided by the aspirations of our farmers.

Jai Kisan, Jai Vigyan, Jai Anusandhan!

(M. L. Jat)

Dated the 7th October, 2026
New Delhi

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MESSAGE

I extend my warm greetings to the young minds, faculty members and scientists participating in the **10th National AgriVision Convention** to be held on 13–14 October 2026 on the theme "Reimagining Indian Agriculture: Tradi-Tech-led Transformation." A Convention conceived by students and for students is a powerful statement about the future paradigms of Indian agriculture — a future that will be shaped in our classrooms, laboratories and experimental fields.

Every transformation in agriculture begins with human capital. The National Agricultural Education System, comprising 80 State Agricultural Universities, Deemed Universities, Central Agricultural Universities and Central Universities with Agricultural Faculty, together with 114 ICAR's research institutes, remains the bedrock on which the Indian Agriculture stands. In alignment with the National Education Policy 2020, the Agricultural Education Division of ICAR is working to make curricula multidisciplinary, skill-oriented and globally competitive, to strengthen quality assurance and accreditation and to promote experiential learning and entrepreneurship through programmes such as Student READY.

The idea of *Tradi-Tech* in the convention places a special responsibility on our education system. Tomorrow's agricultural graduate must be equally at ease with the soil, the software and future security - able to respect and adapt indigenous knowledge and at the same time apply genomics, data science, Artificial Intelligence, drones, precision tools and nature positive technologies to real farm and ecological problems. Equally, our students must appreciate the interconnectedness of crops, livestock, environment, human health and technologies in a One Health perspective as India's livestock sector continues to grow in scale and significance in Indian economy.

Sustaining and growing in the scenario of emerging technologies, problems and constraints in Indian Agriculture will need graduates who are not only job-seekers but job-creators, ready to lead agri-start-ups, research enterprises and farmer-facing services.

I appreciate the organisers for creating such a vibrant academic forum and encourage every student present to actively participate, learn continuously and serve the farmer with humility.

My best wishes for the grand success of the Convention.

(Yashpal S. Malik)

Dated 7th October, 2026
New Delhi

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Dated: 6th October, 2026

Message

I am happy to learn that the **10th National AgriVision Convention** will be held on 13–14 October 2026 on the theme "Reimagining Indian Agriculture: Tradi-Tech-led Transformation." The real test of any technology lies not in the laboratory but in the field — in whether it reaches the farmer in time, in a form he or she can use, and at a cost that makes sense. It is from this lens of **lab-to-land** that I view the deliberations of this Convention.

ICAR's **agricultural extension system**, anchored by **731 Krishi Vigyan Kendras** and coordinated through the **Agricultural Technology Application Research Institutes (ATARIs)**, serves as the bridge between science and society. Through **frontline demonstrations, on-farm testing, capacity building and farmer–scientist interfaces**, KVKs bring improved varieties, resource-conserving practices and integrated farming models to the farmer's doorstep. Initiatives such as **Farmer FIRST** and **ARYA (Attracting and Retaining Youth in Agriculture)** further ensure that technology delivery is participatory and that rural youth find meaningful livelihoods in farming and allied enterprises.

The *Tradi-Tech* approach is, in many ways, the natural language of extension. Farmers trust what they have practised for generations; they adopt what they can see working in their neighbour's field. By validating **traditional and natural farming practices** scientifically, and delivering them alongside **AI-based advisories, mobile platforms, drone demonstrations and digital crop-health services**, our extension network is making modern science both credible and accessible. The visible outcomes — record foodgrain and horticulture production in 2024-25, India's position as the world's largest milk producer with 247.87 million tonnes, and the steady reach of PM-KISAN to more than 11 crore farmer families — reflect what research and extension can achieve together.

Extension is also central to building an **inclusive agri-ecosystem**. With agriculture engaging nearly 46 per cent of India's workforce, special attention to **women farmers, smallholders, Farmer Producer Organisations and agri-entrepreneurs** is essential, so that innovation and start-up solutions translate into higher incomes at the grassroots.

I compliment the organisers for this timely initiative and urge the young participants to spend time in villages, listen to farmers and carry their learning back into research. My best wishes for a fruitful and successful Convention.

Jai Kisan, Jai Vigyan, Jai Anusandhan!

(Rajbir Singh)

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Message

I am delighted to convey my warm greetings and wishes for the upcoming **10th National Convention AGRIVISION-2026**, to be held from 13-14 October 2026, on the timely theme **"Reimagining Indian Agriculture: TradiTech-led Transformation."** I compliment the organisers for creating a forum where scientists, policymakers, entrepreneurs and students engage as equals.

The journey towards **Viksit Bharat 2047** cannot be completed without a prosperous, resilient and knowledge-driven agriculture sector. India is among the world's youngest nations, and its agriculture, which supports nearly **46 per cent** of the workforce, needs the energy, curiosity and innovation that only the young can bring. The Convention's seven themes reflect this need.

Roots to Routers reminds us that our traditional knowledge systems, which the National Education Policy 2020 also encourages us to embrace, can be strengthened by digital and emerging technologies. **Cultivating Minds, Empowering Futures** places agricultural education and human capital at the centre of reform. **White and Blue Revolutions 2.0** highlights livestock, dairy and fisheries, where India is already the world's largest milk producer with over **25 per cent** of global output. **From Fields to Founders** recognises the young agri-entrepreneur as the new engine of rural prosperity.

Prosperity for the Plough keeps the farmer's income and dignity at the heart of policy, as reflected in schemes such as PM-KISAN, which has reached more than **11 crore** farmer families. **Nourishing a Nation** reaffirms that food and nutritional security remain a national responsibility, with India leading the world in pulses and millets. **One Table, One Future** calls for an inclusive ecosystem in which farmers, youth and consumers are partners in progress.

Akhil Bharatiya Vidyarthi Parishad has always believed that student power is a **constructive national force**. Together with platforms like AGRIVISION, ABVP seeks to channel youth energy into research, innovation, rural engagement and service, so that classroom learning translates into solutions for the field. I call upon the agricultural students of Bharat to be thinkers, innovators and torchbearers of change.

I extend my best wishes to the organisers, speakers, volunteers and every participant, and I am confident that the ideas generated here will contribute meaningfully to the prosperity of our farmers and the building of a self-reliant India.

Jai Kisan, Jai Vigyan, Jai Bharat!

(Prof. Raghuraj Kishore Tiwari)

PREFACE

It is a matter of immense pride and pleasure to present the Souvenir and Abstract Book of the 10th National Convention of AGRIVISION-2026, held on 13–14 October 2026 at the National Agricultural Science Complex (NASC), New Delhi, on the theme "Reimagining Indian Agriculture: TradiTech-led Transformation." This landmark convention brings together young scholars, agricultural scientists, academicians, policymakers, industry experts, and agripreneurs from across the country to deliberate on emerging opportunities, address contemporary challenges, and explore innovative pathways for transforming Indian agriculture.

Over the years, AGRIVISION has evolved into a significant national platform for fostering intellectual exchange, collaborative learning, and purposeful engagement among students, researchers, and professionals in the agricultural sector. The 10th National Convention marks an important milestone in this journey, reaffirming our commitment to placing youth at the forefront of agricultural transformation. It recognizes young people not merely as beneficiaries of development, but as catalysts of innovation, entrepreneurship, and sustainable change. By emphasizing technological advancement, skill development, and agripreneurship, the convention seeks to inspire a new generation of agricultural leaders capable of contributing to rural prosperity, resilient food systems, and the broader vision of a Viksit Bharat.

This Souvenir and Abstract Book capture the intellectual richness and thematic diversity of the convention. It brings together scholarly contributions, expert perspectives, and scientific abstracts addressing critical areas such as agri-startups, digital agriculture, climate-resilient farming, agricultural value-chain development, technological innovation, and skill-based capacity building. These contributions reflect the growing enthusiasm, research excellence, and entrepreneurial spirit of India's agricultural community, while providing valuable insights into the future directions of agricultural development. On this occasion, we express our sincere gratitude to all distinguished guests, eminent speakers, authors, researchers, participants, organizing committee members, institutional partners, and sponsors whose valuable contributions and support have made this convention possible. We also acknowledge the collective dedication of everyone working towards strengthening AGRIVISION as a platform for agricultural education, innovation, and youth empowerment.

We firmly believe that this compilation will serve not only as a lasting record of the academic deliberations of AGRIVISION-2026 but also as a source of knowledge, inspiration, and motivation for students, researchers, and practitioners. May the ideas and insights presented herein encourage meaningful collaborations, innovative solutions, and sustained action towards building an agricultural sector that is technologically advanced, environmentally sustainable, economically viable, and socially inclusive. Together, let us empower youth, embrace innovation, and reimagine Indian agriculture for a prosperous and self-reliant Bharat.

Organizing Committee
AGRIVISION-2026

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Reimagining Indian Agriculture for Viksit Bharat 2047

ICAR's Role in Advancing Farmer Prosperity and Youth Leadership

Mangi Lal Jat

Secretary, Department of Agricultural Research and Education and Director General, Indian Council of Agricultural Research

The agriculture of 2047 will be shaped by the choices young people make today. India's journey towards Viksit Bharat 2047 needs agriculture, that is productive, resilient and rewarding for farm families. The AGRIVISION 2026 theme, 'Reimagining Indian Agriculture: Trade-Tech-led Transformation', connects the knowledge of farming communities with modern science. ICAR's role in this transformation spans research, education, extension and enterprise with farmer prosperity and youth leadership at its centre.

50.8 → 376.56 Mt Foodgrain output, 1950-51 to 2025-26 (est., Third Advance Estimates)	~4.5% Annual agricultural growth since 2015	₹13.85 | ₹7.40 Est. returns per rupee in research | extension	2029 ICAR centenary - milestone to 2047

1. What developed agriculture must mean

A developed India needs farmers who earn a fair livelihood and face the future with confidence, with dignity of work, good health, a healthy environment and the ability to educate their children. Dr M S Swaminathan's Evergreen Revolution paired lasting productivity with ecological responsibility, and his idea of bio-happiness linked biological resources with employment, income and well-being echoing our aspiration, *sarve bhavantu sukhinah*. Dr R S Paroda sees farmers as Annadata, Poshandata and Urjadata providers of food, nutrition and energy, and custodians of natural resources.

So, ICAR judges a technology by its usefulness on the farm, not only by yield and novelty: Does it improve net returns? Reduce risk or labour? Conserve water and soil health? Is it affordable and accessible?

2. Standing on strong foundations

India's National Agricultural Research, Education and Extension System organised science around national needs: agricultural universities united teaching, research and extension; ICAR institutes-built expertise across crops, livestock, fisheries and natural resources; All India Coordinated Research Projects (AICRPs) tested technologies across diverse environments; and Krishi Vigyan Kendras (KVKs) took learning to farmers. This turned improved varieties into the Green Revolution through science, farmers' effort, irrigation, quality seed, fertilisers and supportive policy followed by growth in horticulture, dairying, poultry and fisheries. The predecessors' enduring gift was the capacity to renew institutions as needs change.

Foodgrain production rose from about 50.8 Mt in 1950-51 to an estimated 376.56 Mt in 2025-26. The launch of India's first genome-edited rice varieties in 2025 shows the promise of frontier science which still needs careful evaluation, reliable seed systems, appropriate regulation and clear communication. Today's challenges are climate change, nutritional security, resource conservation and profitable farming on small holdings.

3. Reading the changing agrifood system

Our analysis identifies three phases: technology-driven cereal intensification (1967-1995), demand-led diversification (1996-2014) and sustainability-led diversification (2015 onwards), when growth accelerated to about 4.5 per cent annually. Research must sustain staple gains while serving horticulture, livestock, fisheries and nutritious foods across the whole value chain quality, food safety, storage, processing and market access. Input subsidies and price support should gradually align with resource conservation and climate resilience; ICAR supplies the evidence, while changes need coordination with ministries and States and protection of farmers during transitions.

An ICAR study estimated returns of about ₹13.85 per rupee invested in research and ₹7.40 in extension sector-wide estimates, not assured returns from every project. The message: science and delivery both deserve sustained investment, because a good technology brings little benefit if farmers cannot access it.

4. TradiTech: where tradition meets technology

Farming communities hold valuable knowledge of local varieties, mixed farming, seasons, water harvesting and biological resources. The approach is to document, understand and test such practices measuring yield, cost, labour, nutrient balances and water use across seasons with farmers as participants who receive proper recognition. In regenerative landscapes, crop diversification, conservation agriculture and integrated farming must suit local soils, water and resources, with gains in soil carbon or biodiversity rigorously verified alongside production and income.

Digital tools, remote sensing for crop stress, sensors for irrigation, AI for timely advice help only when they are accurate, affordable, available in local languages and lead to a clear action. Trust rests on reliable advice, accountable providers and responsible use of farmers' data.

5. A farmer-guided, mission-oriented ICAR

The Viksit Krishi Sankalp Abhiyan has strengthened farmer-scientist dialogue; next, concerns raised must become research priorities, demonstrations and solutions that are re-assessed with farmers. Under One Team One Task, a pulses mission brings together breeders, soil scientists, agronomists, plant protection specialists, economists and extension teams, with seed multiplication and market links because farmers experience it as one production system.

Solutions must fit the farm: marginal farmers need low-cost, low-risk options and year-round income from crops, livestock or other enterprises; small farmers gain from machinery services, collective marketing and producer organisations; specialised farms need precision tools, quality assurance and market intelligence. Water, labour, skills and market access matter as much as farm size. Women's leadership through training, suitable machinery, finance and decision-making roles must be built in, and technologies assessed for their effect on women's workload and control over income. Frontier science (biotechnology, genomics, microbiome research, digital decision support) needs sound evidence and enabling regulation, with priorities on pulses and oilseeds, resource-use efficiency, animal health and the agriculture nutrition and health link.

6. The centenary roadmap: seven priorities

At ICAR's 98th Foundation Day (July 2026), the Union Minister for Agriculture and Farmers' Welfare set seven priorities for *Viksit Krishi* and *Samruddh Kisan*:

- 100+ Climate Smart Villages before the centenary, demonstrating integrated farming, resource conservation and risk reduction.
- One Institute One Grand Innovation, a transformational innovation from each institute within two years.
- ICAR technologies to reach at least 100 million farmers by the centenary.
- Mission ICAR 100, KVKs as hubs of innovation, climate advice and enterprise, with each KVK visiting at least 100 villages in a Foundation Day outreach fortnight.
- An ICAR Open Digital Knowledge Platform for free access to scientific advice and technologies.
- Stronger action against counterfeit seeds and pesticides, with practical tools to assess input quality.
- A proposed ₹10,000 crore in internal resources by 2029 through commercialisation and licensing, alongside government support.

Reach must lead to useful adoption, demonstration villages must generate evidence others can use, and commercialisation must widen access while safeguarding essential public research outputs.

7. Strengthening institutions for the next century

- **Integrated AICRPs** with rigorous multi-location testing, shared platforms for genomics, phenotyping, speed breeding and data analysis, standardised data, farmer-participatory trials and periodic outcome reviews.
- **District-level links** between national science and State delivery. A proposed Indian Agricultural Research Service with a district role merits careful examination of mandate, staffing, financing and accountability; the immediate priority is better coordination within existing institutions.
- **Research leadership** young scientists leading interdisciplinary teams, with mentoring, cross-institution and international exposure, recognition for quality, technology and farmer benefit beyond publications, and equal access for women scientists.
- **Funding** rising progressively towards the proposed aspiration of 1 per cent of agricultural GDP, complemented by commercialisation, industry partnerships and transparent intellectual property arrangements.
- **Outcomes that matter** net income, income stability, resource-use efficiency, soil health and participation of women and youth, possibly through a farmer well-being framework that includes farmers' own assessment without excessive reporting burdens.

8. Young people: the leaders of agriculture 2047

Some of you will enter research or public service; others will build enterprises in machinery services, seed production, livestock health, processing, logistics or digital advice all strengthening the farm economy. The difficulties are real: climate variability, fragmented holdings, and gaps in credit, skills and markets. An innovation succeeds only when it addresses these as carefully as the technical problem.

Education must prepare you for this reality crop, soil, animal and fisheries sciences combined with climate science, data analysis, entrepreneurship and communication, with field experience at the core. Understand how farmers decide when cash, labour and water are limited. Work with KVKs and producer organisations to identify a problem, build and

test a solution, and assess its economics; visit processing units, service enterprises and markets. Mentoring must continue beyond competitions into early business. The Attracting and Retaining Youth in Agriculture (ARYA) programme provides a foundation, with incubation, licensing and start-up partnerships linked to finance, quality assurance and buyers - and access to research data and technologies under appropriate agreements that protect genetic resources and farmers' interests.

Opportunities for young agri-entrepreneurs

- Machinery and drone services (where viable)
- locally useful digital advice
- seed and nursery systems
- dairy, fisheries, mushrooms, beekeeping and food processing
- climate and soil-health services with credible methods and clear farmer value.

Good business plans need evidence of demand and realistic costs.

Our message to you:

- Learn from farmers' experience.
- Ask difficult questions.
- Test your ideas honestly.
- Build solutions that people can afford and trust.
- Your contribution will be judged by the work it enables and the lives it improves.

The Convention can link students with farmers, mentors, researchers and enterprises around specific problems, so participating institutions carry forward collaborations tested in the field giving this dialogue a life beyond AGRIVISION.

Our responsibility towards 2047

ICAR's centenary in 2029 is a milestone on the road to Viksit Bharat@2047. A developed agriculture will sustain food and nutritional security, conserve natural resources, give farm families secure livelihoods, offer young people worthwhile careers and give women a stronger role in decisions and enterprise. With farmer-guided research, rigorous science and a new generation prepared to lead, ICAR and the national agricultural system can make a lasting contribution to a prosperous India.

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Reimagining Indian Agriculture: Tradi-Tech-Led Transformation

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Summary

Indian agriculture is at a critical crossroad, rapidly transitioning from traditional subsistence to a technology-led industry. It is taking important resilience in the midst of climate change and shrinking land areas through marriage of traditional Indigenous Technical Knowledge and modern advances such as artificial intelligence and Internet of Things. In this process, the Indian Council of Agricultural Research and its Agricultural Education Division are playing a pivotal role in updating the curricula of universities through the National Education Policy 2020 and through a number of practical initiatives. Ultimately, the blend of traditional wisdom and contemporary science is nurturing a dynamic Agri-startup ecosystem, guaranteeing enduring food security and economic resilience as the nation progresses toward Viksit Bharat 2047.

Keywords: Agriculture; Entrepreneurship; Agricultural Education; ICAR; Tradi-Tech.

Introduction

Indian agriculture has a long history of the Indus Valley Civilization with early innovations in water management and domestication. For thousands of years, agriculture has depended on Indigenous Technical Knowledge – tried and tested, environmentally friendly practices handed down through generations, such as organic pest repellents and traditional water-harvesting systems. The sector has moved from subsistence methods to intensive, high-yielding systems driven by the Green Revolution and is now changing into a technology-driven paradigm powered by artificial intelligence, IoT and precision farming.

The transformation of great importance; agriculture remains a pillar of rural livelihoods, food security and national economic stability. The farmer today has a tough set of conditions to contend with: shrinking and fragmented land, erratic weather, serious soil depletion and scarce water. But the real opportunity lies in integrating proven farming knowledge with modern digital devices. Agricultural development experts often stress that long-term sustainability is not the result of science alone, but requires a practical balance between cutting edge innovation and the hard-earned resilience of farming communities on the ground. This synergy brings about a climate-smart, future-proof agricultural landscape that will be able to ensure long-term food security and increase prosperity for farmers.

In the end, the 'Tradi-Tech' synthesis presents an ecosystem based on collaboration in which traditional knowledge directs modern innovation instead of being superseded by it. We are able to deal with the current vulnerabilities in ways never before possible by incorporating data analysis, drone surveillance, and automated sensors into the existing tradition of ecological stewardship. The fact that farmers are given these two tools not only helps to bridge the gap between generations in terms of agricultural methods but also opens the way to an inclusive and self-sufficient agricultural economy that can cope with the uncertainties of the future.

Bridging Tradition and Technology: The Role of ICAR's Agricultural Education Division in Shaping Future-Ready Ecosystem

The Agricultural Education Division (AED) of the Indian Council of Agricultural Research (ICAR) has been the structural back-bone of the development of human capital of the farming community in the country. With a dynamic network of agricultural universities, the AED has methodically woven foundational agricultural heritage into a technologically advanced education ecosystem. This evolution takes advantage of the dynamics of state-of-the-art agricultural research to transform the way future professionals approach farming challenges.

A major shift in this journey is the embedding of the frameworks of the National Education Policy (NEP) 2020 in the core curricula through successive ICAR Deans' Committees (such as the 6th Deans' Committee) that embed flexibility, multi-disciplinary learning and digital skill development. Practical pedagogy has been revolutionized by programs such as the Student READY (Rural Entrepreneurship Awareness Development Yojana) with the introduction of hands-on training, rural awareness work experience (RAWE) and entrepreneurial incubation in undergraduate studies. In addition to, scholarship programs like the NTS, JRF, and SRF are crucial for driving advanced graduate research. They give students the space to combine age-old farming practices with powerful modern tech—like AI, IoT networks, and smart data analytics.

ICAR's educational initiatives are aimed at synergizing rigorous professional training with contemporary digital competencies to build a technology-driven and self-reliant Indian agriculture sector. Ongoing commitment to these dynamic agricultural educational transformations ensures a strong and prosperous future.



From Field to Founders: Catalysing Farmer Prosperity, Research Excellence and Agri-Startups in India

Over the years, monumental milestones like the Green Revolution (which brought national food self-sufficiency), the White Revolution (making India the world's leading milk producer), the Blue Revolution and the Yellow Revolution have fundamentally transformed rural economies from subsistence to surplus production. This developmental trajectory has at its heart the premier research domains of the Indian Council of Agricultural Research (ICAR). The vast network of ICAR research institutes, commodity boards and specialized laboratories across the country constantly churn out climate-resilient crop varieties, advanced livestock health protocols and resource-efficient farming implements.

Today, the rich heritage of agricultural institutional research is merging dynamically with a vibrant entrepreneurial ecosystem. ICAR's educational efforts combine rigorous professional training and contemporary digital competencies to contribute directly to a technology-driven, self-reliant Indian agriculture sector. A sustained commitment to these dynamic education reforms will secure a resilient and wealthy future. Evolution of Indian agriculture is a testimony of strategic policy making, institutional resilience and visionary scientific leadership. The agriculture of today is moving from "field-to-fork" supply chains to "field-to-founders" models. Across the country, there are thousands of Agri-startups that are being supported by focused government initiatives like the Agri-Business Incubators (ABIs) and the Rashtriya Krishi Vikas Yojana - Remunerative Approaches for Agriculture and Allied Sectors Rejuvenation (RKVY-RAFTAAR) programs. These ventures employ cutting-edge technologies, such as IoT-based soil testing, drone surveillance, blockchain traceability and precision marketplaces, to transform laboratory innovations into real-world solutions for millions of smallholder farmers.

The coming together of multi-sectoral agricultural revolutions, institutional research breakthroughs and Startup-driven innovation does more than modernize production – it catalyses the emergence of new markets. Full income and nutritional security provide an immediate bulwark of the country's twin pillars of economic stability and public health. India is successfully building a robust, self-reliant agrarian economy with real-time market access to farmers, climate smart inputs and higher-value crop diversification to feed future generations sustainably.

Leading the Path Forward: A Strategic Blueprint for Viksit Bharat 2047

Indian agriculture has come a long way from the indigenous roots and subsistence models of the past, driven by survival, through the successive revolutions in production to emerge as a modern economic powerhouse. But modern challenges – such as accelerating climate change, decreasing arable land and groundwater depletion – still threaten sustainability in the long term. To meet these challenges and the vision of Viksit Bharat 2047, the country needs a futuristic integrated strategic roadmap. The blueprint should seamlessly weave together traditional agricultural wisdom, nascent agricultural infrastructure, AI-driven precision farming and youth-led Agri-enterprises, making for a climate-resilient, self-reliant and globally competitive agricultural ecosystem by the centenary of India's independence.

To realize this ambitious vision, a number of different stakeholders need to support it, empowering farming communities at the grassroots level through strong policy support, access to digital public infrastructure and specific investments into rural areas. Public private partnerships should be promoted and grass root innovation encouraged so that India may tap the entire potential of its agricultural sector.



Most importantly, this forward-looking plan will not only secure food and ecological security for India in future generations but also position India as a global leader in sustainable, technology-enabled agriculture.

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Tradition Meets Technology: Transforming Indian Agriculture

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ABSTRACT

Indian agriculture stands at a critical transition point, shaped by food-security achievements, climatic variability, market disruptions and structural changes in rural economies. India has emerged as a major producer of food grains, milk, horticultural commodities and fisheries, supported by a strong agricultural research and extension system. However, fragmented landholdings, natural-resource degradation, climate risks, labour constraints, price volatility, unequal technology access and persistent knowledge gaps continue to constrain sustainable agricultural development. The next phase of transformation therefore requires more than technological modernisation; it calls for the strategic integration of traditional agricultural knowledge, ecological practices, farmer institutions and locally adapted production systems with contemporary science and emerging digital technologies. This article proposes ***Tradi-Tech Led Transformation (TTLT)*** as an integrative framework that converges traditional ecological knowledge, indigenous farming practices, scientific innovations and digital technologies to enhance productivity, profitability, resilience, resource-use efficiency and inclusiveness. Building on the NextGen Extension perspective, the framework views digital technologies as complementary to, rather than substitutes for, human expertise, local knowledge and trusted institutions. Emerging evidence suggests that digital information interventions can contribute to improved input adoption, productivity and farmer income, although technology adoption remains influenced by affordability, infrastructure, digital capability, trust and institutional readiness. India's Digital Agriculture Mission, AgriStack, AI-enabled advisory systems, remote sensing, IoT, drones and multilingual digital platforms provide important foundations for this transformation. The article analyses the strengths, weaknesses, opportunities and threats of Indian agriculture, proposes a Tradi-Tech architecture, identifies pathways across production, resource management, markets and extension, and outlines strategies for inclusive scaling. The central proposition is a hybrid agricultural paradigm in which traditional knowledge provides ecological and contextual intelligence, science provides validation, and digital technologies provide scale, precision, connectivity and decision intelligence.

Keywords: Tradi-Tech; traditional knowledge; digital agriculture; artificial intelligence; smart farming; Agriculture 4.0; farmer-centric innovation

Introduction: From Agricultural Modernisation to Agricultural Re-imagination

Indian agriculture has historically evolved through continuous interaction between ecological knowledge, farmer experimentation, institutional research and technological change. Traditional farming communities developed sophisticated knowledge of soils, seeds, rainfall, crop combinations, livestock integration, pest management, water conservation and landscape management. The Green Revolution subsequently introduced improved varieties, irrigation, fertilizers, plant protection and mechanisation, enabling India to move from chronic food shortages towards food self-sufficiency. This shift can be understood as a movement from production-led extension toward market-led extension, knowledge management and a more farmer-led approach (Rivera, 1997; Duraisamy, 2007). The contemporary agricultural challenge is qualitatively different. Farmers must simultaneously respond to climate variability, water scarcity, soil degradation, emerging pests, rising input costs, labour shortages, fragmented holdings, market volatility and changing consumer demand. Consequently, the central agricultural question is no longer merely *"How can India produce more?"* but

increasingly *"How can India produce more value, nutrition and resilience with fewer resources and greater ecological sustainability?"*

The first generation of agricultural ICT initiatives focused on reducing information asymmetry. Early Indian examples included Village Knowledge Centres, Bhoomi, i-Kisan, e-Choupal and Kisan Call Centres, while later initiatives expanded into mobile applications, e-governance, digital marketplaces, social media and location-aware services. Evidence from the Indian mobile-agriculture literature shows a transition from one-way messaging toward mobile applications capable of delivering dynamic weather, market and advisory information, while also highlighting the importance of two-way communication for day-to-day farm decision making (MANAGE, 2017). An Indian ICT adoption study identified market and weather information as high-priority needs and reported illiteracy, cost, infrastructure, awareness and training among major adoption constraints (Patil *et al.*, 2008). The present wave is qualitatively different. Agriculture is increasingly connected to digital public infrastructure, remote sensing, geospatial datasets, sensors, AI/ML, multimodal content and increasingly conversational interfaces.

The Government of India's Digital Agriculture Mission, approved in 2024 with an outlay of Rs. 2,817 crores, explicitly seeks a robust digital agriculture ecosystem through AgriStack, a Krishi Decision Support System and comprehensive soil fertility and profile mapping. By 2025, the policy architecture had also set a target of creating 11 crore Farmer IDs by 2026-27. In 2026, Bharat-VISTAAR was launched as a nationwide AI-powered, voice-first, multilingual digital public infrastructure platform designed to deliver real-time, location-specific and personalised agricultural advisories through multiple channels. (Government of India, 2024a, 2025, 2026a).

These developments create an important research and policy question: what should "Extension" mean when data, algorithms, platforms, experts, markets and farmers are increasingly connected? The central proposition is that digital transformation is not primarily a technological substitution; it is an institutional redesign of extension work. The extension functionary becomes a connector between farmer and digital system, a validator of machine-generated recommendations, a curator of local content, an interpreter of data, a facilitator of learning and a steward of trust. This article therefore proposes the concept of ***Tradi-Tech Led Transformation***. The term is used here as a proposed analytical framework rather than as an established technical classification. It represents a transition in which *traditional knowledge + modern science + digital intelligence + farmer institutions* are deliberately integrated. The objective is not to assume that every indigenous practice is scientifically optimal. Similarly, technological sophistication alone cannot guarantee better agricultural outcomes. Instead, the objective is to identify, validate, adapt and scale practices that combine the strengths of both knowledge systems.

The Strength of Indian Agriculture: A Foundation for Transformation

- **Production diversity and scale:** India possesses extraordinary agroecological diversity, extending from the Himalayan ecosystems to tropical coastal regions, arid zones and humid northeastern landscapes. The Economic Survey 2025–26 reported average annual growth of approximately *4.4% in agriculture and allied sectors over the preceding five years*, while food-grain production reached approximately *357.7 million tonnes in 2024–25.*
- **Scientific and institutional capacity:** India has an extensive agricultural research and extension network comprising ICAR institutes, State Agricultural Universities, Krishi Vigyan Kendras, agricultural departments, Farmer Producer Organisations, cooperatives and private-sector actors. In 2025–26, ICAR reported the release of

hundreds of new crop varieties, including a substantial proportion with climate-resilience and biofortification attributes.

- **Digital infrastructure:** India has also developed an increasingly sophisticated digital ecosystem for agriculture. The Digital Agriculture Mission, AgriStack, Farmer IDs, georeferenced village maps, Crop Sown Registry, National Pest Surveillance System, e-NAM and AI-enabled advisory platforms are creating the foundations for a data-enabled agricultural economy. By February 2026, more than *8.48 crore Farmer IDs* had reportedly been generated under AgriStack-related initiatives. These strengths create an unusual opportunity: India does not need to construct its agricultural future from scratch. It needs to *connect and recombine assets that already exist.*

Tradi-Tech Led Transformation

Tradi-Tech Led Transformation may be conceptualized as *farmer-centred process of agricultural transformation that systematically integrates validated traditional and indigenous knowledge with modern agricultural science, digital technologies, artificial intelligence, precision tools and institutional innovations to improve productivity, profitability, resilience, sustainability and equity.* The framework therefore does not imply a return to pre-modern agriculture. Rather, it seeks *evidence-based modernisation of useful traditional practices.*

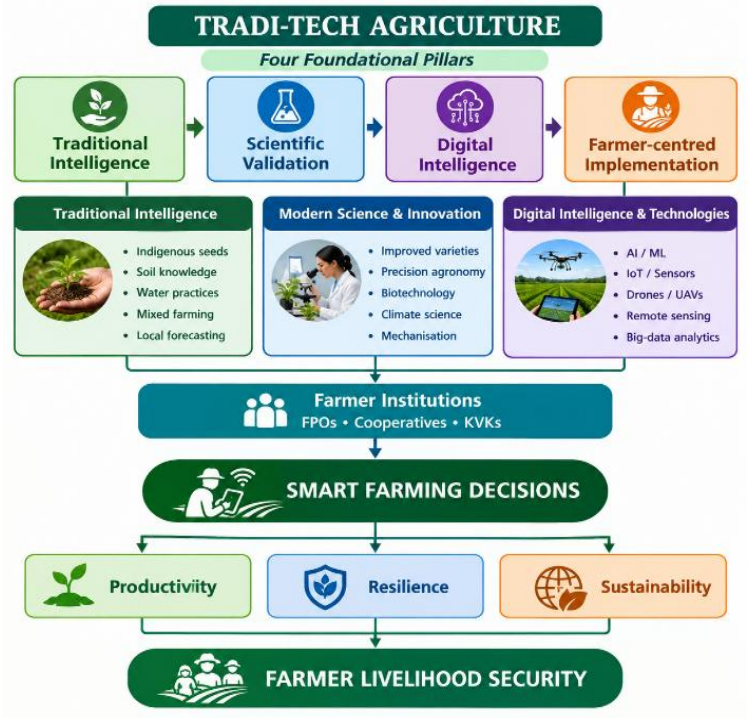


Figure 1: Four Pillars for Tradi-Tech Transformation in Indian Agriculture

Traditional Knowledge Matters in the Digital Age

Traditional agricultural knowledge contains locally accumulated information about ecological relationships that may not always be represented in formal databases. Farmers have historically developed practices related to seed selection, mixed cropping, crop rotations, livestock integration, organic nutrient recycling, rainwater harvesting, agroforestry and landscape management.

- The value of this knowledge lies particularly in its *local specificity.* A farmer's understanding of soil behaviour, rainfall patterns, pest occurrence, crop combinations and landscape-level water movement can complement scientific datasets.
- However, traditional knowledge should be treated as a knowledge resource requiring documentation, validation and contextualisation, rather than as an unquestionable repository of truth.
- Digital technologies can help transform dispersed traditional knowledge into structured knowledge assets. Farmer interviews, geotagged observations, multimedia

documentation, participatory mapping and community knowledge repositories can create searchable databases of local agricultural practices.

- Artificial intelligence can potentially assist in identifying relationships between traditional practices and environmental variables. But scientific validation remains essential before recommendations are generalised.

Thus, the appropriate pathway is: ***Document → Validate → Digitise → Contextualise → Demonstrate → Scale***

Technology as the New Agricultural Intelligence Layer

Digital agriculture introduces a fundamentally different capacity to integrate multiple sources of information around specific farm decisions, enabling a transition from fragmented advisory to data-driven, context-specific support. The six-layer architecture of digital public infrastructure, sensing and connectivity, intelligence, service interfaces, human institutions, and outcome-feedback systems can therefore be extended to Tradi-Tech agriculture. *Artificial Intelligence (AI)* can support pest diagnosis, crop-health assessment, yield forecasting, weather-risk interpretation, market intelligence, and personalised advisory, while recent research highlights the potential of AI, IoT, UAVs, and deep learning for precision agriculture, alongside persistent implementation challenges. *Internet of Things (IoT)* technologies enable continuous monitoring of soil moisture, temperature, humidity, microclimate, irrigation, greenhouse conditions, livestock, and storage environments, shifting agriculture from periodic observation towards continuous sensing. Remote sensing and drones provide spatial information on crop stress, water stress, nutrient variability, disease patterns, and crop damage; however, their adoption in India continues to face technical, economic, behavioural, operational, and implementation barriers. Digital advisory systems, including mobile applications, social media, voice interfaces, and AI assistants, can deliver location-specific information, with farmer engagement influenced by technical quality, language, content design, timeliness, self-efficacy, credibility, and perceived benefits. Finally, digital markets connect production decisions with market information and transactions. e-NAM exemplifies this transition towards digital price discovery and market integration, with official information reporting 1,656 integrated mandis and more than 1.8 crore registered farmers by March 2026.

SWOT Analysis of Indian Agriculture for Tradi-Tech Transformation

The SWOT perspective indicates that India possesses many of the foundational assets required for transformation, but these assets need integration. The challenge is therefore less about creating isolated technologies and more about developing *interoperable agricultural systems*.



Figure 2: SWOT Analysis of Indian Agriculture for Tradi-Tech Transformation

Pathways for Tradi-Tech Transformation

India's agricultural transformation requires a coordinated strategy that combines traditional knowledge, modern science, digital technologies and human expertise. A key priority should be the development of a ***National Tradi-Tech Knowledge Grid*** containing structured and scientifically validated repositories of indigenous agricultural practices, including traditional crop varieties, indigenous pest-management methods, local water-management systems, agroforestry practices, traditional livestock systems, indigenous weather indicators, traditional food and nutrition systems, and community seed systems. Such knowledge should be geographically indexed and linked with climatic, crop and soil information so that validated practices can be applied according to local conditions. The objective should therefore move beyond preservation towards scientific validation followed by context-specific application**.**

The second strategic priority is the development of an ***AI–Farmer–Expert hybrid advisory system***. Rather than viewing artificial intelligence as a replacement for extension personnel, the future model should follow a human-in-the-loop approach in which farmers interact with digital systems, AI analyses available information, experts validate recommendations, farmers implement appropriate actions, and feedback is incorporated into subsequent advisories. Human validation, accountability and trust are particularly important when recommendations may have economic, environmental or health implications.

This transformation should also reposition Krishi Vigyan Kendras (KVKs) as district-level Tradi-Tech innovation and validation hubs. KVKs can demonstrate AI-enabled crop diagnosis, drones, IoT-based irrigation, climate-risk advisories and indigenous knowledge documentation while providing digital-literacy training, FPO technology incubation, digital market support and participatory technology validation. This would shift extension from a predominantly information-delivery function towards an innovation function**.** At the same time, precision agriculture must be redesigned for smallholders through shared-service models. FPOs, cooperatives and Custom Hiring Centres can provide drone scouting, soil testing,

satellite-based crop monitoring, weather alerts, machinery booking, AI diagnosis and digital marketing as technology-as-a-service. Such institutional arrangements can reduce individual capital requirements while expanding access to advanced technologies.

Digital transformation must further adopt ***voice-first, multilingual and low-bandwidth approaches*** using text, voice, video, IVRS, WhatsApp, assisted digital centres and human experts. This is essential for overcoming disparities in literacy, connectivity and digital access. Agricultural intelligence should also integrate soil, weather, crop, pest, water, market, finance, insurance and logistics information, thereby moving farmers from isolated digital information towards integrated digital decision intelligence.

Finally, Tradi-Tech programmes should be evaluated through an ***impact-oriented framework*** rather than platform metrics alone. Assessment should progress from reach and understanding to adoption, productivity, profitability, resilience, sustainability and equity**.** This approach can ensure that technological transformation remains farmer-centred, context-specific and outcome-oriented, while strengthening the integration and interoperability of India's agricultural innovation ecosystem.

- **Tradi-Tech and Climate-Resilient Agriculture:** Climate change makes integration of traditional and technological knowledge particularly relevant. Traditional systems often contain practices associated with diversification, mixed cropping, local seed conservation, agroforestry and water conservation. Modern technologies can enhance these systems through early warning, climate forecasting, soil monitoring and precision irrigation.
- **Tradi-Tech for Women, Youth and Smallholders:** Women farmers, tenant cultivators, tribal communities, older farmers and farmers in remote areas may face unequal access to devices, finance, connectivity and training. The response should not be to create separate low-quality systems. Instead, mainstream platforms should be designed for accessibility. Priority measures include: ***voice-based interfaces; women-led digital advisory groups; village digital facilitators; community technology centres; FPO-based shared equipment; youth as agri-digital entrepreneurs; local-language content; offline functionality; assisted access.*** Young rural people can become the bridge between agricultural tradition and emerging technologies. This creates opportunities for a new occupational category: *Agri-Digital Knowledge Entrepreneurs.*

Governance and Institutional Architecture for Tradi-Tech Transformation

Technology-driven agricultural transformation cannot be sustainable without appropriate governance. A ***Tradi-Tech ecosystem*** must therefore establish clear principles that protect farmers, strengthen institutional accountability and ensure responsible use of digital technologies. ***Data ownership and informed consent*** should be central, with farmers clearly understanding what information is collected, why it is required, who can access it and how it may be used. This is particularly important for sensitive agricultural information such as farm location, cropping patterns, financial records and market transactions.

Scientific validation is another essential requirement. AI-generated recommendations, particularly those involving consequential production, environmental or health decisions, should be traceable to validated scientific evidence, institutional knowledge or clearly identified data sources. *Algorithmic accountability* should also be established through mechanisms that allow farmers and extension personnel to report inaccurate recommendations, seek clarification and escalate complex cases to qualified experts.

Interoperability is necessary to prevent fragmented digital ecosystems. Government, research institutions, extension agencies, FPOs and private platforms should adopt common standards that enable appropriate data and service integration. Finally, strong *cybersecurity and data protection* safeguards are required to prevent unauthorized access, manipulation or misuse. Thus, privacy, consent, data quality, accountability, accessibility, interoperability and cybersecurity should function as cross-cutting foundations of responsible Tradi-Tech agricultural transformation.



Figure 3: Governance and Institutional Architecture for Tradi-Tech Transformation

Towards a Tradi-Tech Agriculture 2047

The long-term transformation of Indian agriculture requires a shift from conventional input-driven production systems towards knowledge-intensive, connected, intelligent, inclusive and outcome-oriented agricultural ecosystems. Digital technologies, artificial intelligence (AI), data analytics, remote sensing, mobile platforms and farmer-centric extension systems can accelerate this transformation. However, technology should complement scientific knowledge, local experience and human advisory services rather than operate in isolation. The transformation can be organised around the following major transitions:

- ***From Input-Intensive to Knowledge-Intensive Agriculture:*** Indian agriculture is gradually moving beyond an exclusive focus on increasing the use of seeds, fertilizers, pesticides, irrigation and machinery. The future will depend increasingly on knowledge, skills, data and timely decision-making. Farmers will need access to information on soil health, weather, markets, crop nutrition, pest surveillance, resource-use efficiency and climate risks. Knowledge-intensive agriculture can enable farmers to use inputs more precisely and efficiently, thereby improving productivity while reducing avoidable costs and environmental pressures.
- ***From Farm-Level Isolation to Connected Agricultural Ecosystems:*** Digital connectivity can transform individual farms into components of a broader agricultural ecosystem involving farmers, extension agencies, researchers, markets, financial institutions, input providers and government services. Mobile applications, digital advisory platforms, farmer groups, online marketplaces and data-enabled services can facilitate continuous interaction and knowledge exchange. Such connected ecosystems can strengthen coordination across the agricultural value chain and reduce information gaps between scientific institutions and farming communities.

- ***From Static Advisory to Dynamic Decision Support:*** Traditional agricultural extension often provides general recommendations at predetermined times. Future advisory systems can become dynamic and responsive, integrating real-time weather, soil, crop, pest, market and farm-level information. AI-enabled decision-support systems can help generate timely recommendations for activities such as sowing, irrigation, nutrient application, pest management and harvesting. Human experts will remain essential for interpretation, validation and handling complex situations.
- ***From Technology Ownership to Technology-as-a-Service:*** The future of agricultural digitalisation need not require every farmer to individually own sophisticated technologies. Instead, technology-as-a-service models can provide access to drones, sensors, precision equipment, digital platforms, diagnostics and AI tools through cooperatives, Farmer Producer Organisations, Custom Hiring Centres, service providers and public institutions. This approach can improve access to advanced technologies while reducing the financial burden associated with individual ownership.
- ***From Information Transfer to Intelligence and Learning:*** Agricultural extension is evolving from simply transferring information towards creating systems that support continuous learning and intelligent decision-making. Digital platforms can combine scientific research, validated traditional knowledge, farmer experiences and field data. When appropriately validated and contextualised, this knowledge can support location-specific recommendations and facilitate two-way learning between farmers, extension professionals, researchers and AI systems.
- ***Towards Context-Specific, Human–AI and Outcome-Oriented Agriculture:*** These transitions also point towards a broader transformation. Uniform recommendations can give way to context-specific recommendations based on agroecology, resources, farmer needs and local socioeconomic conditions. Human-only advisory systems can evolve into human–AI hybrid advisory models, where AI supports information processing and prediction while agricultural experts provide validation, interpretation and accountability.

Similarly, traditional knowledge should move from isolated knowledge silos towards digitised, documented and scientifically validated knowledge systems. Agricultural development must also expand beyond production alone to encompass nutrition, income, livelihood security and resilience. Ultimately, the success of digital agriculture should not be measured merely by the number of apps, users, downloads or digital interactions. The emphasis should shift from digital activity metrics to measurable agricultural outcomes—including improved productivity, profitability, resource-use efficiency, nutritional outcomes, technology adoption, climate resilience and livelihood security. This outcome-oriented approach can place farmers, rather than technologies, at the centre of India's agricultural transformation. The objective should not be to make every Indian farm technologically sophisticated. Rather, the objective should be to ensure that *every farmer can access appropriate intelligence when a decision has to be made.*

Conclusion

Indian agriculture does not need to choose between tradition and technology. Its future lies in their intelligent integration. India possesses powerful foundations: agroecological diversity, farmer knowledge, indigenous practices, agricultural research institutions, a large domestic market, expanding horticulture and allied sectors, a nationwide extension network and rapidly developing digital public infrastructure. Recent evidence demonstrates that digital agricultural information can improve important farm outcomes, while research simultaneously shows that adoption depends on affordability, infrastructure, digital capability, perceived usefulness, trust

and institutional support. The proposed *Tradi-Tech Led Transformation* provides a framework for bringing these dimensions together. Its central principle is simple: *traditional knowledge should provide contextual and ecological intelligence; modern science should provide validation and innovation; digital technologies should provide scale, precision and connectivity; and farmers and their institutions should remain central to decision-making.*

The transformation should therefore move beyond the simplistic idea of "digitising agriculture". The real objective is to create a *learning, adaptive and intelligent agricultural ecosystem* in which farmers can combine local experience with scientific evidence and real-time digital intelligence. Artificial intelligence should not replace agricultural experts. Drones should not replace farmers. Digital platforms should not replace KVKs or FPOs. Instead, each should strengthen the capabilities of the others. The future Indian farm can therefore be envisioned as a ***Tradi-Tech farm****:* rooted in local ecological wisdom, strengthened by scientific knowledge, connected through digital infrastructure, monitored through intelligent technologies, supported by human expertise and linked dynamically to markets and institutions. In this paradigm, the defining transformation is not from "traditional" to "modern", but from *fragmented knowledge to integrated intelligence; from reactive farming to anticipatory decision-making; from technology adoption to technology-enabled empowerment; and from production-centric agriculture to resilient, profitable, sustainable and farmer-centred agricultural systems.* India's agricultural transformation will ultimately succeed not when technology becomes ubiquitous, but when technology becomes *useful, trusted, affordable, locally relevant and demonstrably beneficial to the farmer.*

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Agricultural Education and Youth Participation: Pathways to Agrarian Transformation in North East India

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ABSTRACT

Food and nutritional security are a basic human need, emphasized by the UN General Assembly as Sustainable Development Goals (SDGs), and agriculture is central to achieving these goals. Feeding a global population of about 10 billion people by 2050 will necessitate a drastic shift in how food is produced, processed, exchanged, and eaten. In India, the agriculture sector contributed 57.70 per cent to the GDP in the 1950s, but it has since been on a downside, currently contributing about 19.19 per cent. Attracting the best talent to agricultural education demands multipronged approaches and strategies to generate quality manpower for the sustainable development of food production systems. This is particularly critical in the North Eastern Region (NER) of India, where agriculture remains largely subsistence-oriented despite rich natural endowments. This paper explores the current state of agricultural education, the structural and systemic issues impeding youth participation, and strategic pathways at the university, government, and policy levels to foster youth-led agrarian transformation in the NER.

Keywords: *agricultural education, agripreneurship, North East India, agrarian transformation.*

Introduction: The Agrarian Landscape of North East India

The North Eastern Region (NER) of India encompasses eight states and serves as a strategic gateway to Southeast Asia, representing a treasure trove of rich biodiversity, cultural heritage, and vast natural resources. Covering approximately 2.62 lakh square kilometers, the NER is home to around 45.5 million people, of which more than 70% rely on agriculture and allied activities as the primary backbone of their livelihood. The region boasts four distinct agro-climatic zones, making it an ideal ecosystem for diverse agriculture, horticulture, and forestry. It holds about a third of the country's water resources and receives between 2,480 and 6,350 mm of rainfall annually.

Despite being endowed with abundant rainfall, fertile soils, and unique indigenous farming systems like the Apatani paddy-cum-fish culture and the Zabo system of Nagaland, agriculture in the NER remains largely subsistence-oriented. Net sown area is only about 14 to 15 per cent of the geographical area against roughly 42 to 43 per cent nationally. The region imports a significant share of its staple food and processed products from outside, while many of its own high-value products leave as raw commodities with little value addition. At the same time, youth participation in agriculture is declining. A growing cohort of educated youth sees farming as a low-status, high-drudgery, and low-return occupation, looking instead to government jobs, urban services, or migration.

Agricultural Education: Current Status in the NER

Transforming the agrarian scenario requires a paradigm shift from traditional farming to scientific, climate-resilient, and market-driven agriculture, making agricultural education the cornerstone of change. Agricultural education in the NER is delivered through a layered set of institutions, including the Central Agricultural University (CAU) in Imphal, state agricultural

universities like Assam Agricultural University (AAU) in Jorhat, ICAR institutes, and Krishi Vigyan Kendras (KVKs).

A review of institutional profiles highlights expanding capacity. Established in 1993, CAU Imphal now operates through 13 constituent colleges across seven NER states, delivering specialized education in disciplines ranging from horticulture and forestry to food technology and veterinary sciences. In 2024-25, CAU had 2,982 students from 28 states. AAU Jorhat reported a sanctioned intake of 781 undergraduate and 301 postgraduate seats for 2024-25. Furthermore, to address the critical gap in advanced agricultural research infrastructure in North-East India, the Government of India established the ICAR-Indian Agricultural Research Institute (IARI) campus at Dirpai Chapori, Gogamukh, Assam. Inaugurated in September 2020, this strategic initiative decentralizes India's premier agricultural education system to the NER to develop location-specific, climate-resilient crop varieties and promote organic farming practices.

The demographic makeup of agricultural classrooms in the region is highly diverse. At CAU, 1,731 (58 per cent) of the enrolled students are women, and 1,470 (49 per cent) belong to Scheduled Tribes. However, the education pyramid narrows quickly; postgraduate and doctoral students together represent only about a quarter of enrolment, with the postgraduate intake being about 39 per cent of the undergraduate intake.

At the secondary and higher secondary school levels nationally, out of 2,85,223 schools, only 11,038 schools (3.86%) have vocational courses. Furthermore, the supply and demand of the agriculture sector require the assistance of skilled manpower with diploma-level qualifications, but states like Sikkim, Assam, Mizoram, Manipur, Nagaland, and Arunachal Pradesh record very low diploma enrolment.

Issues and Challenges in Agricultural Education

To chart a successful path forward, we must confront the systemic deficiencies and realities of the agricultural landscape.

- **Systemic Deficiencies and Terrain Restraints:** The region's terrain is predominantly hilly, with small, fragmented landholdings that severely constrain commercial farming and the adoption of modern, mechanized technology. Deeply ingrained traditional practices, such as shifting (Jhum) cultivation, have become ecologically harmful due to drastically shortened fallow cycles of 2-3 years, leading to severe soil erosion and biodiversity degradation.
- **Infrastructure Deficits:** Poor road connectivity, inadequate cold storage, and minimal agro-processing facilities lead to high post-harvest losses and limit market access. These systemic challenges deter the youth from viewing agriculture as a viable career.
- **Curricular Mismatch and Fragmentation:** Syllabi often replicate national templates centered on cereals and plains cropping systems, while topics central to the region, such as hill agriculture, agroforestry, jhum improvement, bamboo, and spice value chains receive limited coverage.
- **The Placement Paradox:** Agriculture graduates overwhelmingly prefer public employment. CAU's profile records 1,933 graduates placed in government service, 269 in the private sector, and 213 in self-employment. More than 73 per cent of passed-out students are absorbed into government departments. While an achievement for first-generation graduates, a region cannot farm its way to prosperity solely through a salaried civil service.
- **Youth Unemployment:** In the Periodic Labour Force Survey for 2023-24, youth (15 to

29 years) unemployment stood at 10.2 per cent nationally, but was significantly higher in the NER, reaching 22.9 per cent in Manipur, 27.4 per cent in Nagaland, and 13.3 per cent in Mizoram.

Strategies for Attracting Talent and Fostering Youth Agripreneurship

The lack of talented students in adequate numbers in the frontier areas of agricultural science is a major constraint for achieving farm prosperity. The National Education Policy (NEP) 2020 offers an important opening by emphasizing multidisciplinary learning, vocational integration, and local-context curricula. A three-tier strategic approach is necessary to attract talent and foster transformation.

School Boards and University Level

- **Integrating Agriculture in the School Curriculum:** Primary and high school education could include modules on farming, from growing to marketing crops, helping young people consider agriculture as a potential career. Vocational agriculture streams in secondary schools, aligned with the National Skills Qualifications Framework, can offer a credible pathway into higher education or direct enterprise.
- **Anchor Colleges in Production Clusters:** Every college should adopt a cluster in its own territory and place Student READY programs and rural work experience inside real enterprises there.
- **Teach the Whole Value Chain:** Smallholders lose margin in storage, aggregation, processing, compliance, and marketing. Curricula must treat FPO governance, quality standards, cold-chain basics, and GI branding as core skills for crops like the Queen pineapple of Tripura and the Kachai lemon of Manipur.
- **Regionalize curricula:** To ensure the curricula adopted by the Higher Agricultural Education Institutions are location specific, academic institutions should encourage region-specific syllabi and electives in NER institutions**.** Core modules on hill and slope agriculture, agroforestry, jhum transition, organic farming, and non-timber forest products should be mainstreamed. Traditional systems like the Apatani paddy-cum-fish culture must be studied, documented, and improved with modern science.
- **Digital and Market-Facing Skills:** High mobile penetration is an under-used asset. Training in digital marketing, e-commerce, drones, and sensor applications makes farming legible to a connected generation. CAU's mobile advisory platform has already registered 44,259 farmers.
- **Inclusive Participation:** With women making up 58 per cent of students and tribal students nearly half at institutions like CAU, inclusion must be a design principle. Education and enterprise programs should recognize women's roles as decision-makers and address tenure and credit barriers.
- **Promotion of Diploma Education:** All State Agricultural Universities need to introduce diploma courses in agriculture and allied sciences based on the needs of stakeholders, delivered in local languages.

Government Level

- **Improve the Sectoral Image:** Farming is rarely portrayed in the media as a potential option for aspirational youth. Greater awareness must be generated regarding emerging opportunities for market engagement and farming as a business. Success stories of educated, enterprising young farmers must be highlighted to change perceptions.

- **Incentives for Agricultural Education:** A national-level strategy is needed to provide support to meet the tuition fees of meritorious and marginalized sections. Fee reimbursement schemes adopted by some states shall be used effectively to enhance agricultural higher education as a viable option.

Policy Options

- **Institutionalization of Synergy (Academia-Industry-Government):** The linkages between these three pillars are vital. Universities and ICAR institutes must partner with village institutions, youth clubs, and FPOs for demonstration, mentoring, and applied research. Linkages with the North Eastern Council and the Ministry of Development of North Eastern Region can ensure trained youth access finance and infrastructure.
- **Mainstreaming Skill Education in Higher Agricultural Education Institutions:** Establishing a College of Skill Education in Agriculture and Allied Sciences or initiating a new undergraduate vocational programme (B.Sc. (Ag) Vocational Degree) at Higher Agricultural Education Institutions in North East India is essential to transform the region's rich biodiversity into sustainable economic growth. While traditional academics build necessary theoretical foundations, this specialized college will bridge the critical gap by producing market-ready agripreneurs through immersive experiential learning. The curriculum will focus on hands-on competencies such as value addition for underutilized native crops, scaled bio-input production for natural farming, and localized agri-tech. By equipping rural youth with these advanced vocational skills, the college will directly address unemployment and out-migration. Ultimately, this strategic initiative will position the institution not just as an educational hub, but as the primary economic engine for modernizing agriculture across the North Eastern region.
- **Land and Incentives for Graduate Entrepreneurs:** Customary and community tenure can limit the ability to use land as collateral. A reserved window within state industrial land banks for graduate-led agri-enterprises, alongside leasing support, would address holding constraints.
- **Fostering Entrepreneurial Ecosystems:** There is a need to build a strong ecosystem for nurturing innovation and start-ups that will drive sustainable economic growth. Agri-incubators and accelerators, preferably hosted by universities and linked to KVKs, can offer technical mentoring, seed funding, shared processing facilities, and market access.
- **Patient Finance:** Formal credit is difficult to access without land titles, and agri-enterprises have long gestation periods. Seed capital and credit guarantee specifically designed for agricultural enterprises in hilly terrain are needed to take start-ups from incubation to scale.
- **Digital Platforms for Market Access:** Better logistics and digital platforms are essential to bypass traditional supply-chain barriers. Initiatives like the North East Region Agri Commodity E-Connect (NERACE) portal successfully onboarded nearly 6,896 sellers and 737 buyers by December 2025, facilitating direct market access and bulk orders.

Conclusion

The agrarian transformation of North East India is not merely a goal of increasing crop yields; it is a holistic mission to empower communities, preserve ecological balance, and secure regional economic prosperity. While historical neglect and geographical constraints have posed formidable challenges, the concerted efforts of educational institutions, dedicated policymakers, and local communities are rewriting this narrative.

Agrarian transformation in the NER will be driven by people before it is driven by technology or capital. By continuing to strengthen agricultural education, actively nurturing the entrepreneurial spirit of our youth, and linking experiential learning with real-world value chains, we can transition the NER from a region of subsistence farming to a high-value agricultural powerhouse. The region's youth are educated, connected, and aspirational. If we succeed in providing a clearer mandate to build enterprises and a policy environment that rewards it, the region's young will not be asking where the jobs are—they will be creating them.

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Reimagining Indian Agriculture: Tradi-Tech Led Transformation

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1. Introduction: The Need for a New Agricultural Paradigm

Agriculture and allied activities contribute nearly one-fifth of India's economy while supporting 46.1% of the country's workforce. This makes agriculture central to India's food security, rural livelihoods and inclusive growth. However, Indian agriculture continues to face challenges of growing numbers of small landholdings, rising input costs, shrinking water availability, climate change and stagnating productivity in several key crops.

The challenge facing India, therefore, is not simply to produce more, but to build an agricultural system that is resilient to climate and resource pressures, environmentally sustainable, and economically rewarding for farmers. Addressing these challenges need not begin with a radical departure from India's rich agricultural heritage. Rather, the way forward lies in recognising the value of knowledge and practices developed by generations of farmers and agricultural experts and combining this traditional wisdom with recent advances in science and technology. Such an approach can help modernise agriculture while retaining the local adaptability, diversity and resource efficiency embedded in India's traditional farming systems.

This is where the concept of "Tradi-Tech" becomes relevant—integrating traditional agricultural wisdom with modern science and technology. The approach seeks to combine farmers' understanding of local ecosystems with the analytical and technological capabilities of modern agriculture to create farming systems that are more productive, resilient, resource-efficient and suited to India's diverse agro-ecological conditions.

2. India's Agricultural Heritage: An Underutilised Knowledge Base

Over generations, Indian farmers and agricultural experts have developed practices closely adapted to local ecosystems, encompassing cropping systems, income diversification strategies, indigenous seed conservation, traditional water-harvesting structures, and the use of locally available resources. The relevance of this knowledge is becoming increasingly evident amid climate uncertainty and resource constraints. However, traditional knowledge should neither be romanticised nor treated as unquestionable truth. Its true potential lies in being systematically documented, scientifically validated, and strengthened through contemporary technology and research.

India's agricultural heritage includes indigenous seeds and crop diversity, mixed and intercropping systems, traditional soil and pest-management practices, diversified livelihoods, traditional food systems, and knowledge associated with forest, medicinal and aromatic resources. Bundelkhand's traditional Haveli system is one example of how farming communities adapted agricultural practices to local climatic and ecological conditions. Such knowledge provides an important foundation, but its wider relevance depends on understanding what works, where it works and how it can be strengthened or scaled through modern science.

3. From Traditional Knowledge to Tradi-Tech

The central idea of the Tradi-Tech approach is that farmers need not choose between traditional agriculture and modern technology. Instead, the two can complement each other. Traditional knowledge provides an understanding of local ecosystems, crop diversity, soil behaviour and community practices, while modern science provides tools to measure, validate, improve and scale this knowledge. Indigenous seed varieties that have historically adapted to local climatic conditions can be scientifically characterised, conserved and used for modern breeding. Traditional cropping and soil-management practices can be strengthened through soil testing, improved agronomy and precision nutrient management. Farmers' knowledge of local pests and weather can be combined with biological control, meteorological information, AI-based forecasting and digital advisories. Traditional water systems can be supported by GIS, remote sensing and sensors, while diversified livestock and farming systems can be enhanced through improved breeds, scientific feeding, health management and mechanisation.

The Tradi-Tech model should therefore be farmer-centric rather than technology-centric. Farmers should not be viewed simply as beneficiaries waiting to adopt innovations developed elsewhere; they should participate in designing, testing and refining agricultural technologies. Artificial intelligence, satellite imagery, drones, IoT-based soil sensors, precision irrigation, digital marketplaces and data-driven advisories offer powerful tools to enhance the efficiency, resilience and profitability of Indian agriculture. Integrating these emerging technologies with farmers' traditional knowledge and locally adapted practices can create a more responsive, resource-efficient and farmer-centric agricultural system.

ICAR institutes and State Agricultural Universities have demonstrated this potential across diverse regions. In Chizami, Nagaland, community-based seed conservation is being strengthened through organised seed banks preserving more than 200 indigenous crop varieties, while in Longleng, traditional diversified farming and wild-bee honey collection are being complemented by improved crop varieties and scientific livestock management. In Sikkim, traditional hill farming is being complemented by integrated crop–livestock–horticulture systems; in Mizoram, indigenous jhum-based knowledge is being adapted through integrated agri-horti-livestock systems, protected cultivation and residue recycling; and in Car Nicobar, traditional tribal farming practices are being supported through improved varieties, bio-inputs, protected cultivation and small-scale mechanisation. In dryland regions of Andhra Pradesh and Karnataka, traditional millet cultivation is being strengthened through improved varieties and scientific agronomic practices. In Odisha, rice-based systems are being diversified through vegetables, pulses, dairy and fisheries, while in Manipur, traditional onion cultivation has been combined with improved varieties and scientific crop management. In Bundelkhand, the traditional Haveli system has been strengthened through modern watershed science. Together, these experiences illustrate how indigenous knowledge, local resources and farmer experience can be integrated with improved varieties, scientific extension, precision agriculture and digital tools.

The objective is not to replace traditional knowledge with technology, but to make useful knowledge more measurable, adaptable, scalable and economically valuable. This convergence of inherited knowledge and contemporary science provides the foundation for a Tradi-Tech approach that is local, adaptive, inclusive and farmer-centric.

4. From Farm to Market: Creating Economic Value from Traditional Knowledge

The Tradi-Tech approach can extend across the farm-to-market ecosystem by combining traditional knowledge and locally evolved production systems with modern

technologies for traceability, quality assurance, processing, branding and market access. India's diverse agricultural and ecological regions have produced a wide range of traditional products based on generations of knowledge—from indigenous crop varieties, traditional foods and naturally grown or organically produced commodities to non-timber forest products, medicinal and aromatic plants, herbs and other bioresources. Much of the value of these products remains under-realised because their provenance, production practices, nutritional or therapeutic attributes and cultural significance are often poorly documented and inadequately connected to modern markets. Digital traceability, scientific quality assessment, nutritional profiling, geographic identification and appropriate certification can help authenticate these products and communicate their distinctive attributes to consumers.

Realising this potential requires development of the entire value chain—from local production and community-level aggregation to processing, packaging, branding, storage, logistics and retail. FPOs, cooperatives, tribal organisations and community enterprises can provide the scale required to connect dispersed producers with organised markets, while modern processing and packaging technologies can increase shelf life and create higher-value products from traditional crops, forest produce and medicinal plants. Digital platforms can provide market intelligence, enable direct consumer access and create transparent traceability from the source to the final product. The objective is therefore to move from a "produce and sell" model towards a "produce, authenticate, add value, brand and earn" model, allowing a greater share of value to reach farmers and local communities.

5. Building the Tradi-Tech Ecosystem: Challenges and the Road Ahead

Despite its potential, the Tradi-Tech transformation faces several structural and institutional challenges. India's small and fragmented landholdings can make individual access to advanced technologies expensive, while gaps in digital connectivity, electricity, digital literacy and technical capacity can create a new technology divide. Traditional knowledge is often undocumented, dispersed across communities and difficult to scientifically validate, creating challenges for wider adoption and commercialisation. There is also a risk that traditional knowledge may be adopted without adequate recognition or economic returns to the communities that have preserved it. On the technology side, concerns around the reliability of AI-based advisories, ownership and use of farm data, cybersecurity and commercially driven solutions need attention. Technology alone cannot overcome weak extension systems, inadequate rural infrastructure, limited access to finance or poorly developed value chains.

The way forward requires a combination of public investment, private innovation, scientific research and community participation. Agricultural technologies can be made accessible through FPOs, cooperatives, custom-hiring centres and shared-service models, while extension systems need to facilitate the integration of scientific and farmer knowledge. India also needs systematic documentation and scientific validation of traditional crops, farming practices, food products, medicinal plants and forest-based knowledge, along with appropriate mechanisms for intellectual-property protection and benefit sharing. Partnerships among farmers, ICAR institutions, agricultural universities, startups, FPOs, tribal and local communities can help develop region-specific Tradi-Tech solutions and take successful innovations to scale. Ultimately, success should be measured not by technology adoption alone, but by higher and more stable farm incomes, lower dependence, better resource efficiency, stronger climate resilience, improved market opportunities and greater value for the knowledge and resources held by farming and local communities.

6. Expanding the Scope of Agricultural Research, Education and Extension in Bundelkhand: A Tradi-Tech Perspective

6.1. Reorienting Agricultural Research towards Regional Priorities

Bundelkhand represents an potential landscape for agricultural transformation through integration of traditional knowledge, scientific research and modern technology. Characterised by erratic monsoon, climatic extremities, soil degradation and underdeveloped soils, the region requires an agricultural research agenda that goes beyond yield maximisation. There is need to reorient agricultural research from yield maximization to developing of farming systems that are resource-efficient, climate-resilient and economically viable. Agricultural research in Bundelkhand should therefore resource efficient farming, soil and water conservation, drought-resilient crops, integrated farming systems, livestock development and income source diversification.

Firstly, attention should be given to *pulses, oilseeds, millets* and other crops that can contribute to nutritional security, diversify farm income and reduce dependence on water-intensive cropping systems wherever these alternatives are agronomically and economically suitable.

A second priority is the conservation and *improvement of locally adapted crop varieties* and traditional farming practices. Indigenous knowledge of crop selection, mixed cropping, crop sequencing, fodder management and the use of locally available organic resources should be systematically documented and evaluated through participatory approaches. Promising practices can be combined with modern improved varieties, soil testing, balanced nutrient management, integrated pest management and climate-informed crop planning. This would create a practical Tradi-Tech research framework in which traditional knowledge provides locally grounded hypotheses and modern science helps establish their effectiveness.

Research must also extend beyond individual crops to *whole-farm systems*. The research needs to focus on reducing farmers reliance on climate sensitive farm activities like crops production and facilitate shift towards diversification led by less sensitive enterprises like livestock, horticulture, agroforestry and suitable small-scale enterprises can distribute production risks and create multiple income streams.

6.2. Transforming Agricultural Education through Experiential and Regional Learning

Agricultural education in Bundelkhand needs to prepare a new generation of agricultural professionals who understand both modern scientific methods and the realities of resource-constrained farming. Conventional classroom-based instruction should be complemented by field work, problem-solving exercises and engagement with farmers in joint problem solving.

ICAR institutes and agricultural universities can establish *field-based learning modules* on watershed management, dryland agronomy, climate-smart agriculture, integrated farming systems, agricultural entrepreneurship and digital agriculture specifically targeting agroecological conditions of the region.

An important educational priority should be to integrate emerging technologies into agricultural curricula. Training in remote sensing, GIS, drone applications, artificial intelligence, digital soil mapping, weather-based advisories and precision nutrient management can help students understand how data-driven tools support agricultural decisions. However, technology education must also address the limitations of these tools, including data quality, local calibration, affordability, digital access and the need for field verification. Technology should be taught as an instrument for informed decision-making rather than as a substitute for indigenous knowledge system or farmers' experience.

6.3. Strengthening Agricultural Extension through Digital Approaches

Digital extension offers significant opportunities to strengthen farmer outreach subsequent to emergence of AI enabled technologies that facilitate real-time, location-specific agricultural advisories delivered in local languages through multiple communication channels. Range of information starting from weather forecasts to crop-specific recommendations can now be tailored to the prevailing agroclimatic conditions and the specific needs of farmers. From modern AI enabled mobile applications to conventional village-level extension workers can be now used together to ensure timely and inclusive dissemination of information. Satellite imagery, weather stations, remote sensing and GIS-based tools can further strengthen the farmers ability to make informed decision.

7. Conclusion: Building an Indian Model of Agricultural Transformation

India's agricultural future does not have to be a choice between the traditional and the modern. The country's opportunity lies in combining the two: traditional knowledge can provide local intelligence, modern science can provide validation, technology can provide scale, and markets can provide economic value. The Tradi-Tech approach seeks to bring these strengths together—not by romanticizing traditional farming or blindly adopting every new technology, but by identifying what works, validating it scientifically and scaling it intelligently. In this model, the farmer remains the knowledge-holder and decision-maker, with technology functioning as an enabler rather than a replacement for human knowledge and experience.

Such a transformation can help India move towards an agricultural system that is productive without being excessively resource-intensive, technologically advanced without becoming exclusionary, and modern without losing its ecological and cultural roots. The larger opportunity is not merely to modernise Indian agriculture, but to build an agricultural model that uses India's accumulated knowledge intelligently combining the wisdom of the soil with the intelligence of technology to create a more resilient, sustainable and economically rewarding future for farmers and rural communities.

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Pioneering University Practices in Realizing the Vision of Atmanirbhar and Swavalambi Bharat

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Introduction

The national vision of Atmanirbhar Bharat, a self-reliant India, and Swavalambi Bharat, an India that stands on its own capabilities, can only be realised if universities become engines of self-reliance in knowledge, skills, seeds, technologies and enterprise. The idea of a "best university" should therefore be understood more broadly than rankings, buildings or enrolment. A good university is one that continuously improves the quality of teaching, research, extension and governance; a great university is one that converts those strengths into measurable social and economic value.

For agricultural universities, this responsibility is even more direct. Their work touches food and nutrition security, farm incomes, natural resources, rural employment, climate resilience and the competitiveness of agri-value chains. Universities must step up as the primary engines of national self-reliance, actively generating the knowledge, agricultural innovations, and entrepreneurial spirit India needs to stand on its own.

Today's agricultural landscape is defined by climate volatility, digital disruption, shrinking landholdings, and globalized supply chains. It crucially demands a departure from this fragmented approach. We can no longer build a self-reliant agricultural sector using 20th century pedagogical models. To produce the agile technocrats and agri-preneurs required for a Swavalambi Bharat, our academic architecture must urgently transition from rote, siloed instruction to dynamic, cross-disciplinary problem-solving. It is within this context of necessary institutional disruption, shifting from static research plots to living, data-driven ecosystems, that we must recalibrate our approach to higher education.

Realising this shift will require more than isolated reforms or incremental adjustments. It calls for a coherent policy framework that can align curricula, pedagogy, research priorities and institutional governance with the needs of a self-reliant agricultural economy. Fortunately, India already has such a framework in place, National Education Policy (NEP) 2020, which offers the structural foundation on which agricultural universities can build this transformation.

1. Operationalizing NEP 2020 to Drive Best Practices

The National Education Policy (NEP) 2020 provides a strong framework for this transformation. Its emphasis on multidisciplinary education, flexibility, experiential learning, skill development, technology-enabled learning, research, innovation and holistic student development creates an opportunity to redesign universities as vibrant knowledge and innovation ecosystems. In agriculture, these principles can be translated into education that connects classroom learning with farms and enterprises, research that responds to real field problems, and extension that makes knowledge accessible in locally relevant forms. NEP 2020 and the vision of Atmanirbhar Bharat reinforce each other. The policy builds the capable individual; the mission of self-reliance gives that individual a purpose and a field of work. Swavalambi Bharat, in turn, reminds us that self-reliance must reach the graduate, the farmer and the institution itself.

Harnessing Real-World Data and embedding Data Science

Under the NEP 2020 framework, experiential pedagogy can be enhanced by harnessing the vast volumes of real-world agricultural data generated daily across India. The example of available data includes multi-spectral satellite imagery and automatic weather station feeds to millions of Soil Health Card records, drone sensor logs, high-throughput crop phenomics databases, and large data sets of AICRP programmes available over the years. Instead of running routine, simulated practical exercises, students can be trained to work directly with live datasets that can be used to build predictive machine learning models for early blight detection, local evapotranspiration calculation, market price trend forecasting, spatial soil-moisture maps, and deep learning algorithms to genomic selection that can assist be targeted development of needed varieties.

Artificial Intelligence (AI) and Machine Learning (ML) offer practical tools for addressing priority challenges across the agricultural value chain. Illustrative applications can be explored across diverse fields. To make such learning systematic rather than ad hoc, agricultural universities should embed data science, and AI/ML, within degree programmes. can be achieved through credit-based core and elective courses, project-based learning, hackathons and capstone problems drawn from real field challenges. Flexible NEP instruments such as the Academic Bank of Credits allow students to accumulate micro-credentials in these emerging areas alongside their disciplinary training. Faculty capacity must be built in parallel, through training programmes, joint appointments, and integration of Honorary Professors from the technology and agri-tech sectors. Effective data-driven education requires quality digital infrastructure: high-performance computing facilities, secure data repositories, standardised and interoperable datasets, and access to open public data platforms. Collaboration with national research organisations, technology firms, start-ups and farmer organisations can provide both datasets and real problem statements. Such partnerships also create a pathway from classroom prototypes to deployable digital advisory tools that reach farmers in local languages and in formats they can readily use.

This approach bridges theory and practice, wherein the students get skilled as analytical problem-solvers who can make decisions using farm data, precision agricultural tools, and digital advisory platforms.

Expanding to Dual Degree and Sandwich Degree Models

To break academic insularity and expose scholars to diverse institutional ecosystems, universities must institutionalize collaborative degree pathways. A dual degree programme allows a student to concurrently or sequentially work toward two distinct academic degrees, either within complementary disciplines or across two partner institutions. This facilitates completion of both programmes within a structured, optimized timeframe. A sandwich degree programme enables a student registered at a home university to spend an intermediate period (typically six months to a year) in an external research laboratory, partner university, or industry R&D facility to conduct specialized research or training before returning to defend the degree. The benefits are immediate, wherein students gain exposure to frontier infrastructure without redundant capital expenditure. The cross-disciplinary research outputs increase besides improvement in employability of graduates, in addition to the sustainable academic partnerships that the host institution builds.

Beyond multidisciplinary flexibility, NEP 2020 introduces structural instruments that set new benchmarks for university governance and student autonomy. The establishment of the Academic Bank of Credits (ABC), combined with the Multiple Entry and Multiple Exit (MEME) framework, provides flexible educational timelines, allowing learners to pause, and accumulate verified micro-credentials. Furthermore, the systematic integration of credit-based apprenticeships and rural internships into formal degree requirements elevates hands-on

training to an evaluated core pillar rather than an extracurricular add-on. Furthermore, with the revival of validated Indian Knowledge Systems in sustainable organic practices, bilingual academic resource options, and the inclusion of new initiatives like Professors of Practice from corporate and farming communities, NEP 2020 provides a comprehensive blueprint to transform agricultural universities into responsive, learner-centric, and self-sustaining institutions.

A policy framework, however well designed, delivers results only when institutions put it into practice. Translating the vision into measurable outcomes calls for deliberate, well-structured action across the university system. Drawing on the national priorities of Atmanirbhar and Swavalambi Bharat, the good practices discussed in this article are organised around a set of institutional pillars. The first concerns the way a university governs and renews itself, because self-reliance in knowledge and enterprise cannot be built on slow, opaque or under-resourced systems.

2. Pillar One: Self-Reliant, Transparent Governance and Mandatory Capacity Building

Self-reliance in a university begins with the way it runs itself. Delays, paper trails and departmental silos drain energy that should go into teaching and research. Universities therefore should adopt the e-Office platform for paperless governance and the Integrated University Management System (IUMS)/SAMARTH Portal which brings academics, finance, examinations, student services and administration onto one digital ecosystem. Real-time tracking of files accelerates decisions and brings greater transparency and accountability to routine approvals.

Beyond foundational digitization, universities must proactively integrate Artificial Intelligence (AI) applications to build smart governance facilities. AI-driven predictive analytics can optimize institutional resource allocation, automate complex administrative workflows (such as smart procurement, faculty appraisal tracking, and research grant management), and provide real-time, data-driven dashboards for university leadership. Deploying AI-powered smart helpdesks can seamlessly handle routine student services, substantially reducing the manual burden on administrative staff. By embedding AI into the governance architecture, universities can transform passive digital records into decision-support tools, ensuring agile, responsive, and error-free institutional management. Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa: The university has established the groundwork for smart governance by deploying the e-Office platform for paperless file processing and the Integrated University Management System (IUMS) to unify academic, financial, and student operations into a single digital ecosystem. While its administrative AI applications are still developing, RPCAU is actively integrating AI into its core scientific mandate by partnering with IIT Ropar and NIT Patna.

The continuous evolution of agricultural science demands that the capacity building of scientific and supporting staff is treated as an absolute must, not an optional activity. There must be specific, mandated provisions and budgetary allocations for all scientific and administrative personnel to attend advanced capacity-building programs. This ensures the entire institutional workforce remains competent in the latest analytical techniques, digital tools, and governance protocols. The Indian Institute of Public Administration (IIPA) has set up a Centre of Excellence in Artificial Intelligence, "AI for Sushasan" (AI4Sushasan), to promote the use of AI for good governance. The Centre aims to identify AI use cases in coordination with ministries and state governments and to train government officers in AI, thereby building institutional capacity for technology-enabled administration.

3. Pillar Two: Education for Swavalambi Bharat and the "Living Lab" Ecosystem

Swavalambi Bharat will be built by young people who are confident, skilled and ready to take initiative. Education must begin that journey on the very first day. Initiatives like "Deeksharambh" Student Induction Programme, introduces new undergraduates to the university ecosystem, academic expectations, skill-building opportunities, life skills and value systems. Apart from this, universities should do complete disbursement of scholarships and fellowships through the National Scholarship Portal, which enhances financial self-reliance of students. Integration of the SWAYAM platform into curricula, in the spirit of NEP 2020, allows students to take courses from national experts at their own pace and breaks the boundaries of the traditional classroom.

The university campus itself must operate as a "Living Lab." This concept transcends traditional demonstration plots by converting campus infrastructure into active, student-managed commercial testing grounds. University farms, dairy units, and polyhouses must operate as commercial enterprises with real profit-and-loss accountability managed by students. Hostel waste systems should function as closed-loop bio-methanation research units, and campus water grids should serve as live sensor-testing environments, ensuring students learn within a functioning, scalable agricultural ecosystem.

4. Pillar Three: Research for Self-Sufficiency

No country can be Atmanirbhar in agriculture without its own varieties, technologies and data. Research must therefore be both rigorous and relevant. A university should maintain an updated portal and list of the ten most pressing problems of farmers in its region, drawn from farmer meetings, KVKs and market data, and should ask every department to say which of them its work addresses. Research agendas then begin with a problem and not a publication. A dedicated team for intellectual property, licensing, business mentoring and seed funding can turn laboratory results into products, and transforms scholars into agri-preneurs.

The universities can appoint Professors of Practice i.e. seasoned industry professionals into the classroom. Progressive farmers, food processors, seed entrepreneurs, drone operators and Agri-bankers can teach what textbooks cannot, and can co-design courses that employers actually need. An agricultural university should treat its alumni as lifelong partners, maintain an endowment for scholarships and chairs, and invite industry and corporate social responsibility support for well-defined missions. A good agricultural university should offer seed, food and water testing facilities to farmers, FPOs and startups at fair rates, and should publish its field data, weather records and trial results in usable form. Shared resources multiply the impact of every rupee invested. A university should invite external advisory councils, periodic peer review of departments and a farmer advisory panel, and should track what its graduates earn and do five years after leaving. It should also reward faculty for extension and technology transfer, not only for papers.

Perpetual University Research Endowments: To achieve true autonomy and insulate long-term scientific investigations from the volatility of standard grant cycles, agricultural universities must build self-sustaining financial models. Universities must establish formal Perpetual Research Endowments. This is achieved by corporatizing the technology transfer process and actively mobilizing funds from Corporate Social Responsibility (CSR) mandates of leading agribusinesses, heavy industries, and financial institutions.

Agriculture is rapidly becoming a data-driven enterprise through satellite and drone-based remote sensing, IoT sensors, GIS and artificial intelligence (AI). These technologies enable crop-area and health monitoring, early detection of pests and diseases, drought and flood assessment, real-time soil and weather monitoring, and site-specific irrigation and nutrient

management. The Government of India has recognised this transformation through initiatives such as the Digital Agriculture Mission and AgriStack. Together, these technologies provide the foundation for precision agriculture, efficient resource use and climate-resilient farming.

5. Pillar Four: Bridging Fundamental Inquiries with Applied Research and Niche Specialization

No nation can achieve self-sufficiency in agriculture without owning its foundational data, native technologies, and high-yielding varieties. Research must be both highly professional and directly responsive to field challenges.

Integrating Fundamental Inquiries with Applied Science: A premier university cannot survive solely on routine, short-term varietal trials. There must be a highly professional, rigorous emphasis on integrating fundamental research inquiries with applied research. Basic scientific investigations into epigenetic based stress resistance, molecular plant-microbe signalling, machine learning-based model training and AI based predictions, besides genome editing, and targeted breeding for development of varieties with multiple stress tolerance and good quality must be applied seamlessly into translational research programs, ensuring that breakthrough discoveries reach commercial deployment.

Mandatory Niche Specialization to Prevent Inbreeding: We need to make each scientist a specialist in a specific field. To drive global excellence, scientific inbreeding must be actively avoided. Every faculty member and researcher must carve out a highly specific, deep-domain specialization rather than operating as a generalist. Based on need and government priorities, these highly specialized scientists can then be dynamically associated to collaborate on multidisciplinary task forces, ensuring that institutional responses to national crises are built on unparalleled, specialized expertise. However, bringing deep specialists together only works if they can actually understand and communicate with one another. This requires a scientist who combines absolute mastery of a single domain with a broad working knowledge of other critical fields. For example, a modern plant breeder must be an absolute authority in crop genetics. Yet, to tackle complex climate and yield challenges, they cannot operate in isolation. They must be actively associated with advances in bioinformatics to analyze massive genomic datasets, ML to make targeted selections across large panel of lines, microbiology to understand soil-root interactions, agronomy for practical field execution, and even animal breeding to adapt successful genetic selection strategies across disciplines. While they remain the ultimate expert in their specific niche, this broader cross-disciplinary fluency gives them the vocabulary to reach across the table, connect their research to wider technological realities, and function seamlessly within a multidisciplinary team to solve real-world agricultural challenges.

6. Pillar Five: Extension and Enterprise

The last mile of research is the farmer's field. A university that stops at the laboratory or the classroom has completed only half its task. Agricultural universities should therefore treat extension and enterprise as a core pillar and not as an afterthought.

First, extension must reach every farmer in a form that suits them. Universities should combine digital channels, such as video programmes, mobile advisories and social media, with community radio, so that both the connected youth and the household without internet receive timely advice on weather, pests, markets and crop practices. Second, universities should build skills for the new rural economy. Training students and rural youth in drone operation, farm machinery, food processing, protected cultivation and digital tools turns the national emphasis on agricultural technology into local jobs. Certified training programmes, ideally developed with industry partners, ensure that standards match regulatory and commercial requirements.

Third, universities should nurture startup facilitation centres, incubators, student-run production units and links with industry and banks, that help graduates become job creators and not only job seekers. Selecting a few flagship commodities and supporting the whole value chain, from seed and production to processing, branding and marketing, gives farmers a larger share of the value they create. Participatory seed production, in which farmers multiply quality seed alongside the university, is a particularly powerful way to speed up varietal replacement and strengthen self-sufficiency in crops such as pulses and oilseeds.

7. Setting Standards of Good Practices at RPCAU, Pusa

Dr. Rajendra Prasad Central Agricultural University, Pusa, has tried to be an early mover in putting these ideas into practice. It carries the legacy of the Agricultural Research Institute and College established at Pusa in 1905, and it has sought to honour that heritage through reform and innovation. A few illustrative practices follow.

- **Digital governance and capacity building:** The university uses e-Office for paperless governance and the Integrated University Management System for academics, finance, examinations and student services, along with progressive digitisation of records. These tools have speeded up decisions, introduced real-time tracking and created clear audit trails. Staff are encouraged to complete and exceed their training hours on the iGOT Karmayogi platform, and a one-month Guru Dakshata induction orients new faculty to the university's teaching, research and extension mandates.
- **Student-centred education:** The university places students at the centre of its academic ecosystem, beginning with the three-week **Deeksharambh induction programme**, now in its fifth consecutive year, which helps new undergraduates adapt to university life, academics, extracurricular activities and other important opportunities. Scholarships are disbursed through 100% Direct Benefit Transfer on the National Scholarship Portal, and SWAYAM is integrated into the curricula. o transforms students from theoretical learners into skilled professionals and agri-entrepreneurs, the university mandates a **20-week Rural Agricultural Work Experience (RAWE) programme**, including an intensive **8-week village stay** during which students undertake SWOT analyses and conduct technology demonstrations in real farming situations. The university has also updated its academic regulations to align with the National Education Policy (NEP) 2020 and the 6th Dean's Committee Report, introducing a supplementary examination system for UG programmes that allows students to clear up to 5 courses throughout their degree without losing a year. At RPCAU Scholarly integrity and access are supported by an RFID-enabled library, global databases, the MyLOFT mobile app, and Turnitin-based plagiarism checking, which has fostered exceptional academic impact reflected in an h-index score of 61 and over 4,500 citations in the year 2025 alone.
- **Pioneering New Degree Programmes and Institutional Synergies:** The university actively responds to emerging agricultural paradigms. The School of Natural Farming, established in 2023, offers a B.Sc. (Hons.) Agriculture programme in Natural Farming, and its first graduating batch achieved 100% placement. Building on this success, the Academic Council approved the introduction of a 2-year M.Sc. (Ag.) in Natural Farming starting from the 2026-27 academic session. To bridge the gap between core agriculture and frontier technology, RPCAU signed an MoU with NIT Patna to launch a joint 4-year B.Tech. Degree Programme in Digital Agriculture. This innovative programme splits the study period equally between NIT Patna (for electronics and computer science courses) and RPCAU (for basic engineering and agriculture courses),

featuring multiple exit options aligned with NEP 2020, such as a Certificate in AI & Robotics after one year and a Diploma in Digital Agriculture after two years.

- **Rigorous, mission-mode research:** Two Research Council Meetings are held every year, one for Kharif and one for Rabi. Every project is vetted at the departmental and Dean levels and then reviewed by the Vice-Chancellor with eminent subject experts. Ten Centres of Excellence focus on areas such as mushrooms, water management, climate change, wealth from waste, food processing, millets, indigenous breeds and makhana. The Advanced Centre for Makhana Research and Development was set up with an outlay of Rs. 209 lakhs, and the university produced Eastern India's first Sahiwal calves through IVF and Ovum Pick-Up technologies under the Rashtriya Gokul Mission.
- **Shared advanced infrastructure:** A Central Instrumentation Facility has been set up that gives every scholar access to high-end equipment on campus. The university also operates 5G and AR/VR laboratories. In a landmark collaboration with ISRO's Space Applications Centre (SAC), the university commissioned an Eddy Covariance Tower that performs 25-parameter monitoring, providing students with advanced hands-on green-skill training in carbon sequestration, water vapour fluxes, and energy-balance assessment within the rice-wheat system.
- **Seed and farmer outreach:** Through the Directorate of Seed at Dholi and the national Seed Hub on Pulses, farmers join in multiplying quality seed of pulses and oilseeds, which reaches growers under the "Rajendra Pusa Beej" brand. The Media Cell's YouTube programmes, such as the Pusa Show and Krishi Connection, and Radio Pusa 89.6 FM bring timely advice to farmers regardless of internet access.
- **Skills and startups:** The Centre for Start-up Facilitation and Agri Innovation and Incubation Centre (AIIC) of RPCAU has successfully onboarded 69 agri-tech startups across ideation, prototype, and scaling stages, earning it the #1 ranking for incubation centres in Bihar. To build modern vocational capacity, the DGCA-approved Remote Pilot Training Organization at RPCAU, set up with Dornier Aviation, has trained over 430 certified drone pilots and 24 specialized drone flight instructors for precision agriculture applications. To boost rural employment, specialized 6-month certificate courses are conducted across its constituent colleges, covering practical skills like Artificial Insemination & Embryo Transfer Technology, Mushroom Cultivation, Sugarcane Farming, and Ornamental Fish Rearing. Each of these practices responds to a real need: faster decisions, confident students, relevant research, local capability and rural employment. Together they show that the framework proposed above is practical and not merely aspirational.

8. Conclusion

Atmanirbhar Bharat and Swavalambi Bharat are powerful ideals, but they cannot survive on rhetoric alone. True self-reliance is built on the ground It takes shape when academic institutions commit to changing how they govern, research, and connect with communities' day in and day out. Because we stand right where academic knowledge meets the farmer's field and where young talent meets rural challenges, agricultural universities are obligated to lead this charge, given they have distinct advantage.

The pillars of transparent administration, empowering education, targeted research, and robust extension serve as a compass, guided by the NEP 2020. However, every university must adapt

these principles to fit its own regional realities and resource constraints. No institution needs to overhaul its entire system overnight. What truly matters is breaking the institutional inertia. The ultimate goal is simply to cultivate a habit of continuous improvement, to hold ourselves strictly accountable to the results we deliver to the farming community, and to always remain willing to learn from each other's successes and failures.

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Artificial Intelligence: A New Partner for the Indian Farmer's

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ABSTRACT

Indian agriculture is changing rapidly, with farmers increasingly using data and modern technologies to make farming more efficient and productive. Traditional farmer knowledge always important, but climate change, water scarcity, soil degradation, rising input costs, labour constraints and changing market demands require more timely and precise decision-making. Artificial Intelligence (AI) can be an opportunity to transform diverse agricultural data into actionable information to Indian farmers. AI can help crop and disease diagnosis, pest surveillance, irrigation and nutrient management, crop monitoring, yield forecasting, precision farming, market intelligence and supply-chain management. Integration with drones, remote sensing, GIS, sensors and digital platforms can enable need-based resource management, improve input-use efficiency and strengthen early risk detection in farmer's field. Generative AI can facilitate multilingual and farmer-friendly agricultural advisory services on their mobile phones. However, effective adoption of this requires reliable and locally available datasets, scientific validation, affordable technologies, digital infrastructure and most important skilled human resources.

Keywords: Artificial Intelligence, Indian agriculture, GIS, farmer-friendly technology

Introduction

Being one of the oldest sectors and the backbone of the country Indian agriculture is much more than an economic activity; it is closely connected with the country's food security, rural livelihoods, culture and social fabric. For generations, Indian farmers have developed a profound understanding of soil, weather, crops, water and local farming practices through experience and continuous interaction with nature. This gathered knowledge continues to be an important foundation of Indian agriculture. However, the conditions under which farming is practiced are changing rapidly due to climate change, irregular rainfall, rising temperature, declining water resources, soil degradation, increasing agricultural input costs, labour shortages, population growth, food security concerns and changing consumer and market demands are creating new challenges to farmers. These challenges require decisions that are not only timely but also increasingly precise and informed.

Meanwhile, agriculture is generating large amounts of information through satellites, drones, remote-sensing systems, soil and weather sensors, farm machinery and digital platforms that are producing valuable data on crops, soils, weather and farm operations. The emerging challenge is to transform this large and complex volume of information into knowledge that can be understood and used effectively at the farm level without any further assistance.

Artificial Intelligence (AI) provides an important opportunity in this direction. By analyzing large datasets, recognizing patterns, identifying emerging risks and generating predictions, AI can support decision-making across different stages of agricultural production. Its applications are expanding from crop monitoring and disease diagnosis to precision irrigation, nutrient management, pest surveillance, yield forecasting, market intelligence and digital agricultural advisory services. The significance of AI, lies in whether it can help farmers make better decisions at the right time and with greater confidence. AI should therefore be viewed not as a replacement for the farmer, but as a technological partner that complements farmers' experience

with scientific knowledge and evidence-based information.

For India, this distinction is particularly important because, Indian agriculture is diverse, with millions of small and marginal farmers operating under different agro-climatic, socio-economic and production conditions. Therefore, the future of AI in agriculture must be farmer-centred, affordable, locally validated, accessible in regional languages and responsive to real field conditions. Technology must adapt to the farmer rather than expecting the farmer to adapt to technology.

The integration of farmer knowledge, agricultural science and artificial intelligence can open a new pathway towards more efficient, resilient and sustainable agriculture. In this emerging landscape, AI has the potential to become a new partner for the Indian farmer-not a replacement for the farmer. Therefore, this article explores the use of artificial intelligence in Indian agriculture as technology partner.

From farm raw data to smart agriculture

Artificial Intelligence can analyse large and complex datasets, recognize patterns, identify risks and support predictions much faster than conventional approaches. Recent research showed that agricultural AI is moving beyond individual applications towards integrated systems that combine sensors, machine learning, Internet of Things (IoT), remote sensing and automated decision support. Applications now extend across crop monitoring, irrigation, nutrient management, pest and disease detection, yield prediction, phenotyping and robotics. This transition represents an important shift-from simply observing what is happening in a field to anticipating what may happen next and how we can take the good decisions based on the data. For farmers, such predictive capability can be valuable, early identification of water stress, nutrient deficiency, pest outbreaks or disease risk can create an opportunity for timely intervention and reduce avoidable losses.

Artificial intelligence in precision farming and disease diagnosis and their management

AI can combine information from soil tests, weather forecasts, crop images, satellite observations and sensors to support field-specific decisions. Research data showed yield increases of 20 to 30 percent by using AI-based tools. In irrigation, AI-enabled sensor systems can use real-time soil-moisture and weather information to improve irrigation scheduling and avoid unnecessary water application. In nutrient management, machine-learning models can integrate soil and crop information to support more site-specific fertilizer decisions. Recent research on AIoT highlights these applications while also pointing to challenges related to connectivity, sensor reliability, cost and scalability, particularly for smallholder farming systems. The same approach can be applied to pest, disease and weed management. Drones and satellite platforms can identify variations within a field, while AI can analyse images to detect crop stress, disease symptoms, nutrient deficiencies or pest-affected areas. When such information is combined with field observations and expert knowledge, it can support early detection and timely intervention. This creates the possibility of moving from blanket application towards targeted and need-based management, potentially reducing unnecessary use of water, fertilizers and plant-protection inputs while improving resource-use efficiency.

AI can also help farmers move from reactive to preventive crop management. Instead of waiting for visible symptoms or severe crop damage, predictive models can combine weather, crop-growth and historical information to identify areas or periods of increased risk. Such early-warning systems can support timely scouting and appropriate management decisions. Integration with variable-rate technologies may further allow inputs to be applied according to the actual requirement of different parts of a field.

Recent systematic research on AI-based crop disease detection shows rapid progress in computer vision and deep-learning approaches. However, the effectiveness of these systems depends heavily on the quality, size and diversity of training datasets. Datasets need to represent different crops, varieties, growth stages, disease severities, soil types, lighting conditions, geographic regions and real field environments. Models trained mainly on laboratory or limited image datasets may perform well under controlled conditions but may show reduced accuracy when exposed to complex field conditions. Therefore, developing large, diverse, high-quality and locally representative agricultural datasets should become a priority. Continuous field validation and farmer-level testing are equally important before AI-based recommendations are widely adopted. The future of precision agriculture will depend not only on better algorithms, but also on better data, reliable sensors, strong field validation and the ability to convert complex analyses into simple, affordable and actionable recommendations for farmers.

1. The Farmer must remain at the Centre

Despite the rapid development of AI, agriculture cannot be reduced to algorithms and datasets. A farmer's decision is influenced not only by crop and weather conditions but also by family needs, labour availability, financial resources, markets, local practices and risk. Therefore, a technically advanced system may have limited value if it does not fit the realities of the farming community. AI-generated recommendations also require good interpretation and professional judgement. A disease-detection model may identify a possible symptom, but confirmation may require an agricultural scientist or extension professional. A weather-based recommendation may indicate a risk, but the farmer must consider field conditions.

The human dimension of agriculture must therefore remain central to the design and application of AI. Farmers should be involved in identifying problems, testing technologies and evaluating whether recommendations are practical and useful. Local knowledge can also provide valuable context that may not be captured in digital datasets. Similarly, agricultural extension personnel can act as an important bridge between AI-generated information and field-level decision-making. This participatory approach can improve trust, usability and acceptance of emerging technologies.

Recent research therefore increasingly emphasizes explainable, reliable and trustworthy AI, particularly where recommendations directly influence farm management. AI systems should provide information that farmers and agricultural professionals can understand, question and evaluate rather than presenting automated recommendations as unquestionable decisions. The objective should not be to replace human judgement but to strengthen it with scientific evidence, local knowledge and timely analysis. Ultimately, technology will be most valuable when it works with farmers, understands their realities and helps them make better decisions with greater confidence.

2. AI as a service provider

For millions of small and marginal farmers, owning sophisticated equipment may not be economically feasible. An alternative is to develop AI as a service.

Farmer producer organisations, cooperatives, custom hiring centres, krishi vigyan kendras, agricultural universities, start-ups and rural entrepreneurs can provide access to drones, sensors, digital advisory and data-analysis services. Instead of investing individually in expensive technologies, farmers can access these services when and where they are needed. This shared-service model can make advanced technologies more affordable and practical, particularly for small land holder farming communities. AI-enabled service centres can provide location-specific crop monitoring, soil and crop diagnostics, weather-based advisories, pest and disease surveillance, irrigation support and yield assessment. Such services can also strengthen the role

of local extension systems by connecting farmers with scientific information and expert guidance. Importantly, local service providers can understand the specific needs of their farming communities and help translate complex digital information into simple, actionable recommendations. This approach can create new opportunities for rural youth as drone operators, precision-farming service providers, GIS technicians, digital extension professionals, data analysts and agri-entrepreneurs. With appropriate training and institutional support, young agricultural graduates can become technology facilitators between research institutions and farming communities.

3. Responsible and Sustainable AI

The digital transformation of agriculture must also address questions of data ownership, privacy, cybersecurity, transparency and equitable access. Farmers should have clarity about what information is collected from their farms, how it is used and who has access to it. AI systems should communicate their limitations, and agricultural decisions should not depend blindly on automated outputs. Recent research emphasizes that the successful integration of AI requires not only technological progress but also appropriate governance, infrastructure, skills and stakeholder trust. Responsible AI also requires attention to the diversity of Indian farming systems. Algorithms developed using limited datasets may not perform equally well across different crops, soils, climates, varieties and farming practices. Therefore, AI models should be continuously tested and validated under real field conditions, with farmers and agricultural experts involved in their development and evaluation. Capacity building is equally important so that farmers and extension professionals can understand both the benefits and limitations of AI-based recommendations. At the same time, digital agriculture should contribute to environmental sustainability rather than encouraging excessive dependence on technology and external inputs. AI can support more efficient use of water, fertilizers, pesticides and energy, while helping farmers respond to climate-related risks. Therefore, the goal should not be technology for technology's sake. The goal should be responsible technology that improves resource-use efficiency, strengthens climate resilience, reduces avoidable risks and contributes to sustainable and economically viable farming.

Conclusion

Artificial Intelligence is opening a new chapter in Indian agriculture by enabling more timely, precise and data-driven decision-making. Its applications in crop monitoring, pest and disease diagnosis, irrigation, nutrient management, yield forecasting, precision farming and agricultural advisory can improve resource-use efficiency and strengthen resilience to emerging challenges. However, the success of AI will depend not on technological sophistication alone, but on its relevance to farmers' real needs. AI solutions must be affordable, accessible, multilingual, locally validated and scientifically reliable. Strong data systems, digital infrastructure, capacity building and responsible data governance will be equally important. Agricultural universities can play a central role by combining agricultural expertise with AI, remote sensing, GIS, IoT and data science, while strengthening collaboration among farmers, researchers, government institutions, start-ups and industry. The ultimate value of AI should be measured by its contribution to farmers' lives-better use of water and inputs, early identification of risks, improved productivity, reduced losses and more sustainable livelihoods. The future of Indian agriculture is therefore not about replacing farmers with machines. It is about empowering farmers with better knowledge and better decisions. The farmer brings experience and local wisdom; science provides evidence and validated knowledge; and AI provides the capacity to analyse information rapidly and generate timely insights. Together, these strengths can create a more productive, resilient and sustainable agricultural system. The future of Indian agriculture will be strongest when farmer intelligence, scientific knowledge and artificial intelligence work

together.

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New Paradigms of Competency and Training for Youth Leadership in Agriculture

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Introduction

India's youth are central to the country's transition towards Viksit Bharat 2047. India stands at a critical juncture where its demographic strength must be converted into a competency, productivity and entrepreneurship dividend. The country has one of the world's largest youth populations, but demographic advantage by itself does not guarantee economic transformation. The central challenge is to ensure that young people possess the capabilities required by a rapidly changing economy shaped by artificial intelligence, digitalisation, climate change, automation, green transition and new forms of enterprise.

The International Labour Organization (ILO) estimates that India will continue to add around 7–8 million people to its labour force every year. At the same time, the share of youth in India's population is projected to decline from about 27% in 2021 to 23% by 2036. Thus, the window for converting India's youth population into a productive demographic dividend is finite. The issue is not simply whether young people receive more training. The more fundamental question is: Are we training youth for the jobs, enterprises and societal challenges of the future? This requires a transition from a conventional training-centric paradigm to a competency-centric, employment-linked and entrepreneurship-oriented learning ecosystem.

Youth in Agriculture: A brief account

Indicator	Present quantitative picture
India's population	~146.4 crore
Workers aged 15+	~61.6 crore
Workers as % total population	~42.1%
Agriculture share of workforce, PLFS 2025	43.0%
Agriculture workforce	~26.5 crore
Agriculture workforce as % total population	~18.1%
Agriculture share, PLFS 2023–24	46.1%
Youth population 15–29, 2021	~37.1 crore / 27%
Youth WPR, PLFS 2025	41.4%
Indicative youth workers	~15.4 crore
Historical youth share in agriculture	~37–40%
Indicative youth in agriculture	~6.0–6.3 crore
New labour-force entrants annually	~7–8 million
Formal vocational/technical training, 15–59	4.2%
Formal vocational/technical training, youth 15–29	5.0%
Students in agricultural higher educators	~4.0 lakh
Agricultural universities	80
Agricultural colleges	About 800

Significant progress, with a larger structural gap

India has built a large skilling ecosystem. NITI Aayog's 2026 report notes that more than 7.67 crore people have been trained since 2014–15. Yet the report concludes that outcomes

remain uneven because curricula are not always aligned with emerging jobs, practical exposure is insufficient, delivery is fragmented and pathways between education, skills and employment remain weak. The Economic Survey 2024–25 provides another important signal: 90.2% of India's workforce has secondary education or below, and 88.2% is engaged in elementary or semi-skilled occupations. Only 2.5% falls in the high-competency occupational category. India does not have merely a training deficit; it has a competency and employability deficit. Agriculture presents an even more complex challenge because its workforce is large, geographically dispersed and heterogeneous, while the emerging opportunities increasingly require specialised competencies.

India has a two-level human-resource pyramid which are as follows:

Level 1: ~26.5 crore people working in agriculture and allied activities—many requiring basic, intermediate and advanced skills.

Level 2: A much smaller pool of professionally qualified agriculture and allied graduates—with an estimated demand-supply gap of nearly 49%.

Workforce Vs Agricultural Professionals

This distinction should be central to the national policy. India does not need to convert 26.5 crore agricultural workers into degree holders. Instead, we need a four-layer human-capital architecture:

Layer	Target group	Required intervention
I	Farmers/agricultural workers	Basic & advanced skills
II	Rural youth/technicians	NSQF vocational certification
III	Graduates	Professional/technology/enterprise competencies
IV	PG/PhD/scientists	Advanced research, AI, biotechnology, policy & innovation

This is the architecture of a future-ready agricultural workforce.

Industry/Service-Sector Demand

The earlier NSDC sector studies provide an important structural lesson. The NSDC's sectoral projections for 2013–22 estimated that agriculture's employment base would decline from 240.4 million to 215.6 million, giving a negative incremental HR requirement of approximately 24.8 million, while sectors such as transportation/logistics, retail, food processing, education, healthcare and construction were expected to expand significantly. Employment is moving from primary agricultural production towards agricultural value chains and the wider rural/agri-food services economy. That is precisely where India's future workforce strategy should concentrate.

Emerging Skill Demand Within Agriculture

The Agriculture Skill Council of India has already identified large incremental skill requirements in emerging areas. Its farm-mechanisation skill-gap assessment, for example, identified substantial requirements for custom-hiring centre operators, mechanics and technicians, CHC entrepreneurs, protected cultivation technicians, controlled-environment agriculture personnel, agro-processing operators and managers and service providers. This is important because these are non-traditional agricultural jobs. The future agricultural workforce will increasingly consist of agricultural service providers rather than only agricultural producers.

Reorientation of skilling strategy for youth in agriculture

The agricultural economy of the future will not be confined to crop production.

The emerging opportunity is an Agrifood Economy, extending from: soil, seed, production, mechanisation, data, aggregation, processing, logistics, markets, nutrition, waste, and circular economy. Consequently, youth need industry competencies not only in farming but also in: precision agriculture, drones and remote sensing, AI and agricultural data analytics, farm mechanisation, soil and water management, climate-smart agriculture, natural and regenerative farming, livestock and fisheries, food processing, cold-chain management, agri-logistic,; FPO management, digital marketing, agricultural finance, agri-insurance, agritourism, carbon and ecosystem services, and entrepreneurship and innovation. This creates a major opportunity to transform agriculture from a subsistence-oriented occupation into a technology-enabled employment and enterprise ecosystem.

Rapid transformation is underway

i) India has already started this transition. NEP 2020 has created the policy foundation for vocationalisation, experiential learning, flexible learning pathways and integration of academic and skill education.
ii) National Credit Framework (NCrF): NCrF provides an opportunity to integrate academic, vocational, experiential and workplace learning and enable mobility between different learning pathways.
iii) Agricultural education reform through the Sixth Deans' Committee has significantly strengthened skill orientation in agricultural education. The restructured UG curriculum includes skill-enhancement courses, practical application, projects and internships, with the fourth year specifically providing advanced skill enhancement through projects and internships and preparing students for both employment and entrepreneurship.
iv) ICAR's Student READY programme already provides agricultural graduates with practical exposure, rural entrepreneurship awareness and hands-on experience for self-employment.
v) MoU in AUs with industries and organizations is an important emerging model. It links agricultural skill training with NSQF, NCrF, industry-aligned certification, entrepreneurship and rural livelihoods.
vi) The Viksit Bharat Young Leaders initiatives and recent ICAR engagement with young agricultural leaders demonstrate increasing recognition that youth should become active contributors to agricultural transformation, rather than passive recipients of government schemes.

Thus, the foundation exists. The challenge now is scale, collaboration, convergence, quality, competency and outcomes.

Gaps to be addressed

1. Training be linked to actual employment opportunities: Many programmes are still designed around available courses rather than emerging occupations. Now vocation-based industry linked courses and their linkage with job roles need to be rolled out and be made available.
2. Competency focussed Agriculture education: A degree demonstrates academic achievement but does not necessarily demonstrate whether a young person can operate a drone, analyse farm data, manage an FPO, establish an enterprise or solve a farmer's problem. Every youth should graduate with a portfolio of demonstrable competencies, not merely a certificate.

3. Industry and Field exposure be multiplied: Agriculture is a highly practical sector. Skills are best acquired by doing. NITI Aayog's 2026 apprenticeship report identifies structural, regulatory, industry-engagement and apprentice-level constraints in India's apprenticeship ecosystem. It recommends stronger alignment of apprenticeship with education and the National Credit Framework. Every agricultural skill training or academic programme should contain meaningful workplace, field or enterprise exposure.
4. Alternative paths of jobs: Agriculture has insufficient scope to absorb every educated young person into conventional salaried employment. A basket of options for self-employment, entrepreneurship, and opting for Agricultural Service sector must be provided. One trained drone operator or FPO manager can create economic value for hundreds of farmers.
5. Competency assessment be widened: Written examinations cannot adequately measure agricultural employability. It needs to be transformed to a 360° feedback along with the transcript.

Introducing 360-degree competency assessment for agricultural youth

This is the time for transition to develop a 360-degree Youth Competency Assessment Framework for all the youth in agriculture sector. A young person's competency should be assessed from six perspectives:

1. **Self:** Self-learning, adaptability, discipline and identification of competency gaps.
2. **Faculty/Mentor:** Technical knowledge, analytical ability, scientific approach and professional behaviour.
3. **Peer:** Teamwork, communication, collaboration and leadership.
4. **Industry/Employer:** Practical skills, workplace readiness, professionalism and productivity.
5. **Farmer/Community:** Ability to understand farmer problems, communicate effectively and develop locally relevant solutions.
6. **Objective proof of work:** Practical examination, field project, enterprise project, prototype, simulation or demonstrated skill.

This creates the ecosystem for the development of true competency: The both industry and service sector competency component is particularly important for agricultural youth in changing paradigm of work opportunities.

Closing the Competency Gap: From Existing Initiatives to the Next Generation of Reforms

India is already moving from a conventional training system towards a more flexible, competency-oriented and technology-enabled ecosystem. However, the critical issue is the gap between policy intent and scale, integration and measurable outcomes.

The recently released NITI Aayog report, *Reimagining Skilling for Viksit Bharat@2047* (2026), provides an important national diagnosis. It identifies weaknesses including inadequate workplace alignment, limited practical exposure, insufficient proof of work, weak job-readiness and entrepreneurship pathways, fragmented delivery systems, uneven implementation of the National Credit Framework (NCrF), and insufficient coordination among education, skilling and employment systems.

Therefore, the next phase should not simply introduce more training programmes. It should close the structural gaps in the existing system (Table-1).

Table 1: Major gaps and the required paradigm shift

Present gap	Change underway	Measures to be adopted
Training measured by enrolment/completion	Increasing emphasis on competency and outcomes	Measure employment, income, enterprise creation and productivity after training
Theory–practice gap	Internships, experiential learning and Student READY	Make meaningful industry/apprenticeship/enterprise exposure compulsory
Degree-centric employment	NCrF and multiple learning pathways	Promote skills-first recruitment and recognition of competency
Fragmented skilling programmes	Integrated skilling architecture proposed	Establish convergence among ICAR, universities, MSDE, industry and states
Outdated curricula	NEP 2020 and curriculum reforms	Annual/biannual curriculum review based on emerging job roles
Weak digital competency	Digital platforms and online learning	Introduce AI, drones, GIS, IoT, remote sensing and data analytics systematically
Limited entrepreneurship	Incubation and startup initiatives	Link every agricultural institution with incubation, finance and market access
Certificate-oriented learning	Micro-credentials and credit-based pathways emerging	Introduce stackable competency credentials
Weak industry participation	Industry attachments and emerging PPP models	Give industry co-ownership of curriculum, assessment and apprenticeship
Youth treated primarily as job seekers	Entrepreneurship and self-employment programmes	Develop youth as job creators and rural service providers
Limited climate competency	Climate-smart/natural/regenerative agriculture initiatives	Make resilience and sustainability core competencies in agricultural education
Gender and access barriers	Women-focused skilling initiatives	Dedicated pathways for rural women, mobility, finance and digital access

Way Forward

1. **Job forecast and availability of information on National Agricultural Future Skills and Jobs Framework**: The Ministry of Skill Development, ICAR, agricultural universities, industry, FPOs and states, should identify 25–50 priority emerging agricultural job roles. Examples: precision agriculture technician; drone-based farm service provider; agricultural data technician; FPO manager; natural/regenerative farming advisor; food-processing technician; agri-logistics manager; cold-chain technician; agri-fintech service provider; climate-risk advisor; agricultural machinery service provider; and digital agricultural marketing specialist.

   For each occupation, university websites should have the information on Job role, competency, qualification, practical training, assessment, certification, and employment pathway. It builds on the existing NSQF/NCrF architecture rather than creating another parallel system. System needs to scale up & reorient the system in this direction.

2. **Make Every Agricultural Training Programme "Learn–Do–Demonstrate–Earn":** Agricultural skills in academic programmes as well as vocational programmes should move around four stages:
    a. Learn the scientific and technical knowledge.
    b. Do the field, laboratory, industry and enterprise experience.
    c. Demonstrate the practical competency assessment and proof of work.
    d. Earn the employment, entrepreneurship, service delivery or enterprise creation. Agricultural universities can use Student READY, RAWE, internships and projects as the foundation, while skill institutions can provide occupational training. Agricultural skill certificate without demonstrated practical competency.
3. **Institutionalise 360° Competency Assessment**: This can be piloted immediately in selected agricultural universities and skill centres.
4. **Youth Competency Profile:** Every trainee should receive a Youth Competency Profile as per following details:

S.No.	Competency	Assessment Parameter
1.	Technical	Faculty + practical test
2.	Digital	Objective demonstration
3.	Field skills	Supervisor
4.	Teamwork	Peer
5.	Leadership	Mentor
6.	Entrepreneurship	Enterprise project
7.	Farmer orientation	Farmer/community
8.	Industry readiness	Employer
9.	Sustainability	Project assessment
10.	Self-learning	Self-assessment

The result should be used developmentally, not merely for ranking. If a young person is weak in data analytics but strong in Agronomy, the system should prescribe the relevant training and allow reassessment. Thus: our present system should relook at the assessment, gap, training, practice, and reassessment becomes a continuous cycle.

5. **Youth Agrifood Enterprise Hubs**: Every major agricultural university, ICAR institution and selected skill centres should progressively become a Youth Agrifood Enterprise Hub. The hub should connect training, incubation, mentoring, finance, technology and market in the emerging technologies and national priorities. This approach is visible in the present agri-education system but at a limited scale and project to project basis in fragmented way. This will shift the policy from "training youth for jobs" to "training youth to create economic opportunities." This also needs structural reorientation of infrastructure, competency of teachers and goals of the skill centres.
6. **Focused Youth–Industry–Farmer Apprenticeship**: We need a specific apprenticeship architecture for agriculture and allied sectors. The apprentice should not be placed merely in an institution. The model should include youth, Farmer/FPO, Industry, and Agricultural University/Skill Institution. For example, a youth training in precision agriculture should spend 25% in classroom/digital learning, 25% in laboratory/simulation, 25% with industry, and 25% in farmers' fields/FPOs and the apprenticeship should carry recognised credits and contribute to the youth's competency portfolio. This directly addresses the theory–practice gap and creates an employment pipeline. NITI Aayog's 2026 apprenticeship recommendations provide a useful national foundation for this approach.

Conclusion: India has the largest network of Agri-education system in the world. There is a need to reorient and scale up on the foundations created so far in NAREES by changing skill and competency work culture. India's agricultural system must move from training people for agriculture to building a skilled human-capital ecosystem for the entire agrifood economy. The opportunity is enormous because agriculture already represents 46.1% of India's workforce, MSDE brings the national competency and skilling architecture, ICAR brings scientific and technological knowledge, Agricultural Universities bring education and youth, industry brings technology and employment, FPOs and farmers bring real-world problems and markets, financial institutions and incubators bring enterprise capital, and states bring implementation and local labour-market intelligence. Together, these can create a new youth- skills-agriculture enterprise ecosystem. This will help to excel our youth in the work and livelihood paradigms and this creates a pathway for effective youth leadership in agriculture at the national and international level. Youth will lead every job/vacation/enterprise.

The future of Indian agriculture will be determined not only by technology, irrigation, inputs and infrastructure, but by the competency and quality of its human capital.

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Trends in Female Enrolment in Higher Agricultural Education in India

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Agricultural education in India is supported through the collaborative efforts of the Indian Council of Agricultural Research (ICAR) and the Agricultural Universities (AUs) system, comprising 69 State Agricultural Universities (SAUs), four ICAR research institutes with Deemed-to-be-University (DU) status, three Central Agricultural Universities (CAUs), and four Central Universities (CUs) with agricultural faculties. These institutions play a pivotal role in developing skilled human resources in agriculture and allied sciences by providing quality education, promoting academic excellence, and strengthening the country's agricultural research and education ecosystem.

To develop a talented and competent pool of professionals in agriculture and allied disciplines, the Agricultural Education Division of ICAR has been conducting national-level entrance examinations since 1996–97 for centralized admission to undergraduate (UG), postgraduate (PG), and doctoral programmes offered by Agricultural Universities under the ICAR-AU system. These examinations facilitate admission to 20% of UG seats across 14 disciplines (increased from 15% in 2022-23) and 30% of PG seats (increased from 25% in 2022-23), covering approximately 80 subjects in agriculture and allied sciences. The primary objective is to promote academic mobility, reduce academic inbreeding, encourage merit and talent, foster national integration, and ensure uniform admission standards across universities, thereby enhancing the overall quality of higher agricultural education in the country.

Since 2019-20, ICAR has been conducting its national-level entrance examinations through the National Testing Agency (NTA) in Computer-Based Test (CBT) mode, ensuring greater transparency, efficiency, and standardization in the admission process. Further, from the academic year 2023-24, ICAR integrated undergraduate admissions in agriculture and allied sciences with the Common University Entrance Test (CUET) conducted by NTA, aligning agricultural education with the broader national framework for higher education admissions.

Women's education is a powerful driver of social transformation, economic growth, gender equality and sustainable development. Greater participation of women in higher education contributes to individual empowerment, strengthens families and communities, enhances workforce diversity and promotes inclusive economic development. Women also play a crucial role in the generation, application and dissemination of knowledge, particularly in agriculture and allied sectors, where their participation can contribute significantly to innovation, productivity and sustainability. Encouragingly, female enrolment in higher education in India has shown substantial growth over the years. According to the Ministry of Education's *All India Survey on Higher Education (AISHE) 2021-22*, female enrolment in higher education increased by approximately 32% between 2014–15 and 2021-22, reflecting significant progress towards greater gender inclusion in the country's higher education system.

Higher agricultural education is an integral component of India's education system and plays a vital role in preparing skilled professionals, advancing agricultural innovation and addressing emerging challenges related to food security, climate change, natural resource management and sustainable rural development. Within this context, increasing female participation in agricultural education is particularly important for building an inclusive, diverse and future-ready agricultural workforce.

Against this background, the present analysis examines trends in female participation in higher agricultural education in India using data from ICAR's national-level entrance examinations over five academic years, from 2019-20 to 2023-24. The analysis presents key facts and figures relating to female participation in the admission process, highlighting emerging trends and the growing representation of women in agricultural and allied science disciplines. It seeks to provide insights into progress towards gender equity in higher agricultural education and its implications for strengthening human resource development in India's agricultural sector.

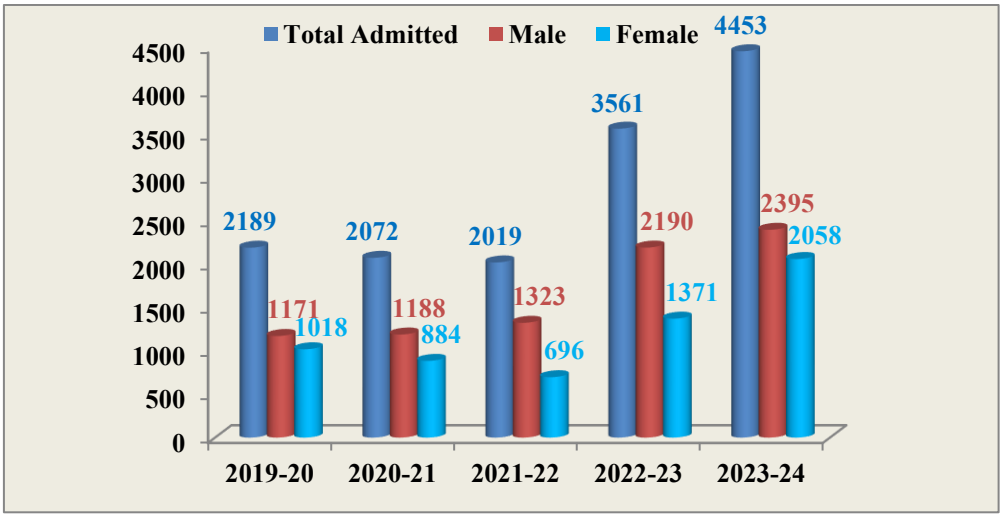
Important Highlights

- Female enrolment in professional higher agricultural education has shown a steady increase over the years, reaching 46% in 2023-24, reflecting growing participation of women in undergraduate agricultural education.

- The share of female enrolment in Master's programmes increased to 49.5% in 2023-24, indicating a narrowing gender gap and growing interest among women in pursuing advanced education in agriculture and allied sciences.

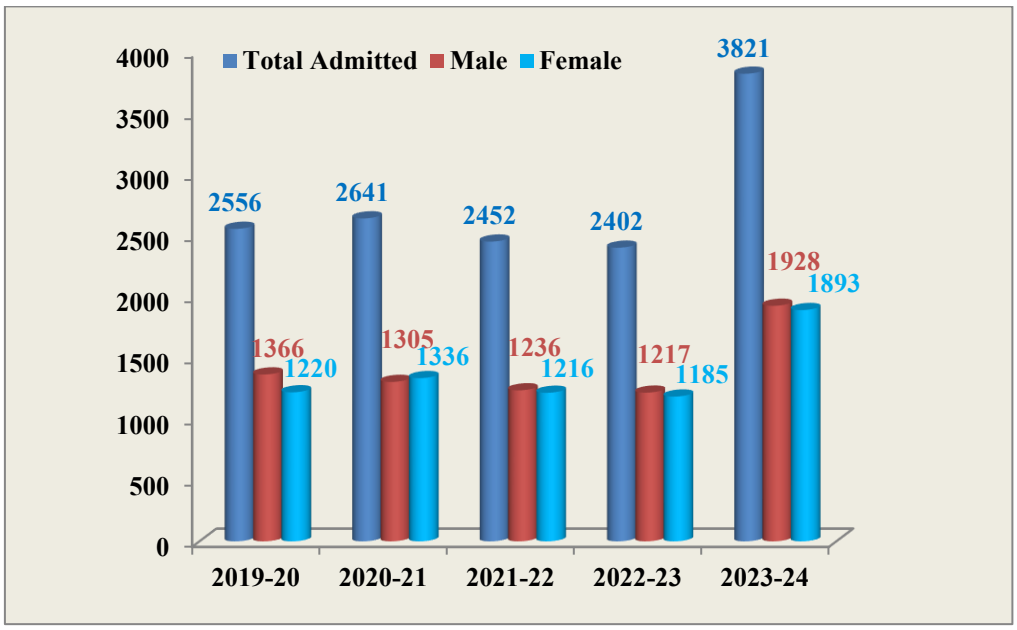


- Female enrolment in Ph.D. programmes surpassed male enrolment, with women accounting for 53.4% of total enrolment in 2023-24. This represents a significant milestone in women's participation in advanced agricultural education and research.
- Across all three levels, UG, Master's and Ph.D., the combined share of female enrolment reached 48.6% in 2023-24, highlighting sustained progress towards gender parity in higher agricultural education in India.
- Agriculture continues to account for the largest share of female enrolment in undergraduate agricultural education and Horticulture remains the second most preferred discipline These trends suggest a gradual diversification of female participation across other agricultural and allied science disciplines.
- Bihar, Kerala and Rajasthan are the major contributing states, collectively accounting for more than 50% of female students in undergraduate agricultural education.

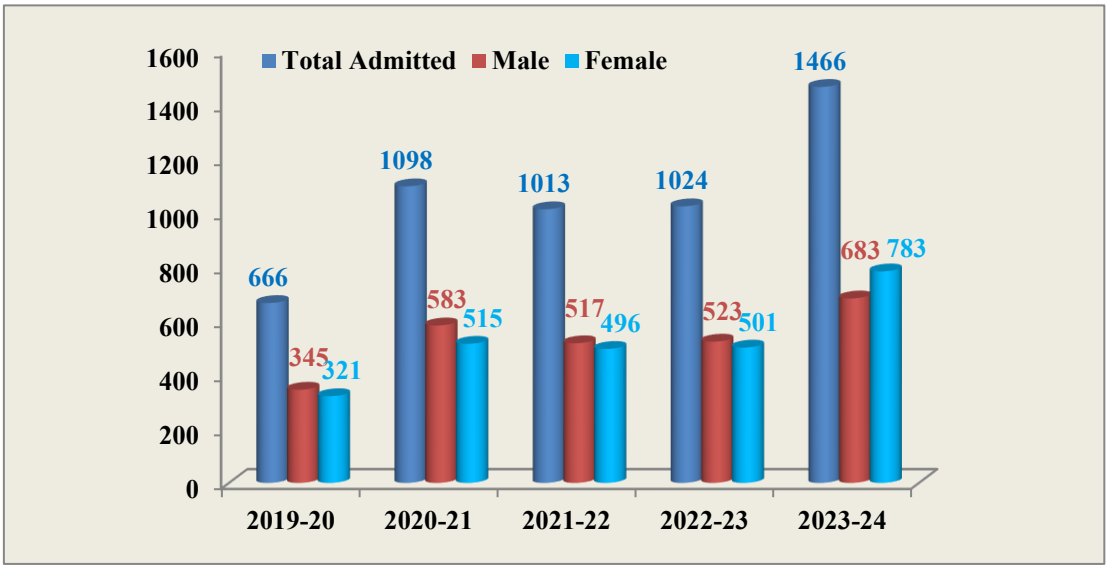


Gender-wise Distribution of Number of Students Admitted in Bachelors Programmes over Years

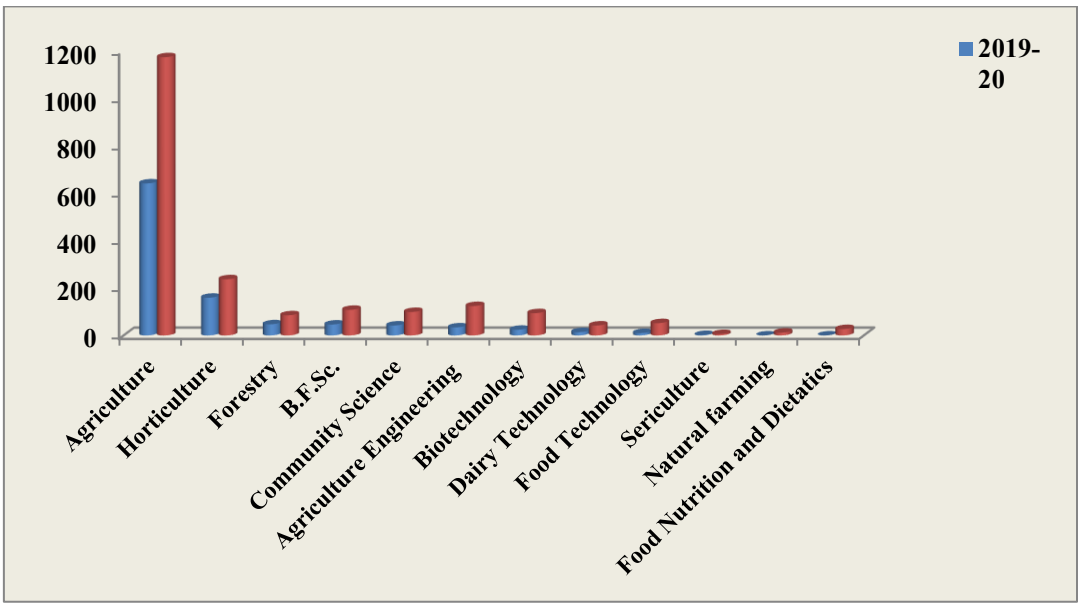
Overall, these trends reflect a positive transformation in India's higher agricultural education system, with women approaching parity in undergraduate and postgraduate programmes and achieving majority representation at the doctoral level. This growing participation is an encouraging indicator of greater gender inclusion and the expanding role of women in agricultural education, research and professional development.



Gender-wise Distribution of Number of Students Admitted in Masters Programmes over Years



Gender-wise Distribution of Number of Students Admitted in Doctorate Programmes over Years



Discipline-wise Distribution of Female Students Admitted in Bachelors Programmes

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Aligning Agricultural Education course curriculum for quality human capital

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Indian Council of Agricultural Research under the aegis of department of Agricultural Research and Education, Government of India has been working as per assigned mandate to plan, undertake, coordinate and promote research and technology development for sustainable agriculture. Further, ICAR has been assigned the responsibility to aid, impart and coordinate agricultural education to enable quality human resource development. As per the recommendations of NEP-2020, the ICAR shall act as a Professional Standard Setting Body (PSSB) for Agricultural Education to develop the curricula and lay down academic standards for the agricultural education. As a member of the proposed General Education Council (GEC), the ICAR shall take necessary steps through PSSB for making a uniform academic structure across the country both in public and private institutions offering academic programmes in agricultural sciences.

In order to address the real issues of farming community and considering long term feedback received from stakeholders in agricultural education, ICAR has introduced several academic reforms to cater the everlasting needs of agricultural education sectors. In the changing scenario where agriculture is rapidly evolving through AI, precision farming, drones, biotechnology, digital platforms, climate-smart practices, food processing and agri-

fintech. Agricultural education must therefore prepare youth for these emerging opportunities.

Young people should be positioned not merely as future farmers or employees, but as agri-entrepreneurs, innovators, technology professionals, researchers, start-up founders and rural change agent. The emphasis needs to shift from knowledge acquisition alone towards competency-based, experiential, multidisciplinary and outcome-oriented learning. Moreover, agricultural education should showcase diverse and rewarding career pathways in agritech, food and value chains, biotechnology, climate services, digital agriculture, agri-business, rural finance and entrepreneurship. Further, the agricultural universities should work closely with industry, start-ups, FPOs, farmers, financial institutions and technology companies so that students learn from real-world agricultural problems and market requirements. Future-ready agricultural human capital will be essential for achieving higher productivity, sustainability, food and nutritional security, rural prosperity, employment generation and global competitiveness. Below are the key aspects and innovations shaping the future of learning to make the education as a mean of shaping the young generation as future ready work force. Today, there is a network of 66 State Agricultural Universities, three Central Agricultural Universities, four ICAR- Institutes having Deemed-to-be-University status and four Central Universities with Agriculture faculty. In addition, there are more than 500 agricultural colleges and Departments affiliated to agricultural universities and general (non-agricultural) universities, both in public and private sectors, offering degrees in higher agricultural education.

The new aspects integrated in the course currulcum of the UG in agriculture and allied fields with focus on skill development and employment of the future ready force include:

- **Building a Digital and skilled based Agricultural Learning Ecosystem**: In the current scenario, **digital** Technology-Enabled Learning ecosystem are central to the future of education, with new role of education to redefine how knowledge is delivered, accessed, and experienced. Thus, digital education using AI, big data, VR/AR, and smart digital platforms become integral to learning ecosystem in agricultural education. Furthermore, skilled based courses have been integrated in the Ug courses to make them future ready force. In addition, high-quality learning ecosystem have also been introduced to make education universally accessible, supporting lifelong learning, national and international collaboration.
- **Emphasis on competency-based and outcome-oriented education**: The emphasis is not only to shifts the focus from merely completing courses to developing measurable knowledge, skills, competencies and professional capabilities among students. Learning outcomes need to be re-defined, assessed and aligned with the needs of industry, society, emerging technologies and national priorities. This, the transformation enhances employability, practical problem-solving, entrepreneurship and lifelong learning, while ensuring that agricultural graduates are job-ready, industry-relevant and capable of addressing real-world agricultural challenge.
- **Enhancing communication skills**. This type of educational shift is to focusses on the development of essential competencies such as critical thinking, problem-solving, creativity, communication, and practical skills.
- **Aligning the courses with industry and global standards:** The main advantage aligning with industry needs, societal expectations, and global standards, competency-based education equips students to be future-ready, adaptable, and capable of continuous learning in a rapidly changing world with better competency to solve the problems in real time. Moreover, this can bridge the gap between classroom learning and the rapidly changing

requirements of the agricultural sector by bringing real-world skills, technologies and industry practices into the curriculum. It can make agricultural education more practical, competency-based, innovation-driven and employment-orient. The aspects and elements of academia–industry collaboration are aligning curriculum with emerging technologies, market needs and with evolving job opportunities through joint industry-linked curricula, internships, apprenticeships and live projects. In addition, there is need to have collaboration on Joint research, innovation, skill development and professional mentoring which can strengthen practical competencies and entrepreneurship. This integration will create industry-ready, employable and entrepreneurial graduates capable of driving transformation in agriculture.

- **Innovation & Problem-Solving** – Encourage students to develop solutions for real agricultural challenges through multidisciplinary projects and innovation challenges. Furthermore, innovation and problem-solving skills are essential for developing a future-ready agricultural workforce capable of addressing complex challenges such as climate change, resource scarcity, food security and changing market demands. Agricultural education should promote design thinking, multidisciplinary learning, field-based problem solving, innovation challenges and entrepreneurship. This will enable youth to move from being technology users to innovators, solution providers and job creators in the agriculture sector.
- **Reorientation of education with Experiential and Hands-On Learning :**Experiential and Hands-on-Learning which Comprises several segment viz Fieldwork, internships, apprenticeships, student-led projects, hackathons, innovation challenges, curriculum co-designed with industry, real-world problem solving, joint research and innovation labs, experiential learning nits (ELUs), on-farm learning, technology incubation, agri-startups etc. hold special significance for agricultural education, especially in the context of NEP 2020, which emphasizes learning by doing, skill development, and real-world exposure. Agriculture, being a practical and field-oriented discipline, requires students to gain direct experience with crops, livestock, technologies, and farming systems. NEP 2020 reinforces this need by promoting internships and vocational exposure as essential components of curricula to ensure students acquire practical competencies, entrepreneurial abilities, and problem-solving skills relevant to farmers' needs and agri-industry demands. This approach enhances employability, nurtures innovation, and aligns agricultural graduates with the rapidly transforming landscape of modern, technology-driven, and sustainable agriculture.
- **Flexible and Personalized Learning for Next-Generation Agriculture:** As the basic aspect in NEP 2020 is to have flexible learning pathways, multiple entry–exit options, and customized learning experiences tailored to individual interests and career goals. In agriculture, this is especially important because the sector is rapidly changing due to climate challenges, technological advancements, and emerging fields like precision farming, agri-tech, and sustainability. Personalized learning allows students to choose specialized areas such as soil health, agri-business, biotechnology, or digital agriculture based on their strengths and aspirations. It lays emphasis on continuous reskilling and upskilling, learning through open universities, online platforms (SWAYAM, Coursera, edX) and learning beyond age boundaries. Focus is also on inclusive and accessible learning using assistive technologies for differently-abled learners, developing content in regional languages and using multimodal teaching tools. Meanwhile, the emphasis on lifelong learning ensures that agricultural professionals continuously upgrade their skills through online courses, micro-credentials, and hands-on training. This adaptability strengthens the agricultural workforce, enhances innovation, and prepares graduates to respond effectively to new challenges and opportunities in India's dynamic agricultural landscape.

- **Reshaping education with Multidisciplinary and Holistic Education approach:** This aspect emphasizes the transformative changes in learning, aiming to prepare students for the complexities of the modern world by breaking rigid subject boundaries and promoting integrated knowledge. This approach encourages learners to draw connections across disciplines—such as science, technology, humanities, arts, and vocational fields—enabling deeper understanding, creativity, and problem-solving. Holistic education emphasizes the development of the whole individual, including intellectual, emotional, social, ethical, and physical dimensions. By blending multiple perspectives and nurturing diverse competencies, this model supports flexible thinking, adaptability, and real-world application of knowledge. As an innovation, it shifts education from rote learning to meaningful, inquiry-based, and experiential learning, equipping students with broad-based skills essential for lifelong learning and future careers.
- **Globalization of Education**: NEP-2020 envisions the globalization of education as a pathway to make India a vibrant hub of knowledge and innovation. The policy promotes internationalization through collaborations with foreign universities, academic credit transfers, joint degree programmes, global class room, access to global MOOCs courses and faculty–student mobility. It encourages top global universities to establish campuses in India which at present scenario is very encouraging while supporting Indian institutions to expand their global presence. By aligning curricula with international standards and fostering multicultural exposure, NEP-2020 aims to enhance the quality, competitiveness, and global relevance of Indian higher education. In agriculture and other disciplines, these initiatives enable access to cutting-edge research, advanced technologies, and global best practices, preparing students for a globally connected future**.**
- **Entrepreneurship & Innovation** – Entrepreneurship and innovation can transform agricultural youth from job seekers into job creators and solution providers by fostering creativity, risk-taking and business-oriented thinking. Agricultural education should promote start-ups, incubation, agri-business, technology commercialization and innovation-led enterprises. This will create new employment opportunities, attract youth to agriculture and enable them to develop solutions for emerging challenges across the agricultural value chain. Promote agri-start-ups, incubation, innovation challenges, agribusiness and job-creation opportunities for rural youth.

Conclusion

Empowering youth through future-ready agricultural education requires an integrated approach combining incorporation of digital skills, re-structuring future-ready curriculum, which is based on competency-based learning ecosystem, experiential learning, academia–industry linkages, entrepreneurship and innovation. It should promote career-oriented, personalized and lifelong learning, while developing leadership, problem-solving and social responsibility among youth. Such an ecosystem will enhance employability, create job creators and attract a new generation of skilled, innovative and socially responsible professionals to agriculture, contributing to Viksit Bharat 2047.

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Krishi Shiksha: Empowering Youth through Skills, Innovation and Entrepreneurship for Resilient Agriculture and Rural Prosperity

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Background

With a large and youthful population, rapid technological advancement, evolving food systems, climate variability and growing pressure on natural resources, Indian agriculture is undergoing a significant transformation. In this situation, agricultural education has a broader and more strategic role to play in preparing youth for emerging opportunities and challenges. The changing employment scenario, marked by relatively fewer public-sector opportunities and growing demand across agro-industry, food processing, agribusiness, services and other allied sectors, requires agricultural graduates to develop strong technical and professional competencies along with entrepreneurial capabilities. With the implementation of NEP 2020, agricultural education is making concerted efforts in this direction. The education system is moving beyond conventional classroom-based learning by providing greater opportunities for hands-on, experiential and field-based learning. This chapter attempts to reimagine Krishi Shiksha as a platform for empowering youth through skills, innovation, entrepreneurship and leadership, enabling them to contribute to resilient agriculture, rural prosperity and the broader vision of Viksit Bharat@2047.

Reimagining Krishi Shiksha for a Changing Agriculture

India's agricultural education system has made significant contributions to national agricultural development by creating skilled human resources, generating knowledge and technologies, and supporting farmers and rural communities. Over the decades, ICAR institutions Agricultural Universities and have played an important role in transforming Indian agriculture and strengthening the country's food and nutritional security. However, agriculture is undergoing rapid transformation. Emerging technologies such as artificial intelligence, precision farming, drones, remote sensing, digital platforms and data-driven decision-making and together with changing market dynamics are creating new opportunities as well as challenges. At the same time, farmers continue to face constraints related to fragmented landholdings, limited resources, rising input costs, climate risks, post-harvest losses and market access.

These changes require agricultural graduates to possess competencies that extend beyond conventional disciplinary knowledge. With the implementation of NEP 2020, Krishi Shiksha is increasingly shifting from a degree-oriented approach towards competency-based, experiential and multidisciplinary education. Agricultural education is providing students with exposure to real farm situations and opportunities to address practical agricultural challenges. Students are being equipped to apply knowledge, use emerging technologies, analyse markets and business opportunities, develop enterprises and provide leadership for sustainable rural development. In this chapter an attempt has been made to address the issues of developing future-ready agricultural professionals capable of working across disciplines and sectors and contributing effectively to resilient agriculture and rural prosperity.

Experiential Learning in Krishi Shiksha: From Practical Skills to Employability and Entrepreneurship

As employment opportunities increasingly diversify beyond the public sector into agro-industry, agribusiness, agricultural services and self-employment, agricultural graduates need

practical knowledge, professional confidence and entrepreneurial skills. Recognizing this need, ICAR has been implementing the Student READY (Rural Entrepreneurship Awareness Development Yojana) Programme, which provides students with opportunities for experiential and hands-on learning. The experiential learning initiative, introduced during the Xth Plan, facilitated the establishment of facilities such as experiential learning farms, model plants, workshops, veterinary clinics and plant clinics in Agricultural Universities.

With the implementation of NEP 2020, agricultural education is increasingly emphasizing practical skills, professional competencies, entrepreneurship and employability. The Experiential Learning Programme under Student READY provides an effective mechanism for bridging the gap between classroom learning and field-level practice. It follows a learning cycle of instruction, conceptual understanding, hands-on practice, reflection and application, enabling students to develop competencies through real-life experiences.

The programme could be further strengthened by providing structured training in selected employable and enterprise-oriented vocations, covering the complete value chain - from planning and procurement of inputs to production, processing, value addition, marketing and enterprise management. The main objective is to develop competent agricultural professionals equipped with practical skills, and entrepreneurial capacity required for employment, self-employment and sustainable agricultural development.

The specific objectives of ELP are to Integrate hands-on and experiential learning into undergraduate education in agriculture and allied sciences; develop industry-relevant technical and professional competencies aligned with emerging employment opportunities; build entrepreneurial skills, business management capabilities and confidence among students for self-employment and enterprise development; enable students to apply classroom knowledge to real-life agricultural and rural challenges and develop practical solutions; provide exposure to the complete enterprise cycle, from production and processing to value addition, marketing and management; strengthen linkages among Agricultural Universities, industry, farmers, enterprises and rural institutions.

Scope of Experiential Learning

The programme provides hands-on training in identified and employable vocational areas through instructional farms, model plants, engineering workshops, veterinary and plant clinics, processing units and other appropriate facilities. The scope may include:

- Production of crops, fruits, vegetables, ornamentals, medicinal and aromatic plants, forestry and other commercial crops.
- Integrated farming systems involving fish, poultry and livestock for milk, meat, eggs etc.
- Food processing, value addition, packaging, product diversification and quality management.
- Farm machinery and equipment operation, fabrication, maintenance and repair.
- Plant health, veterinary care and other agricultural and allied services.
- Agribusiness, marketing, entrepreneurship and enterprise management.
- Technology transfer, extension and rural development activities.
- Internships and field exposure with private and public farms, industries, processing units, agribusiness enterprises and other relevant organizations.

Students receive practical training in enterprise planning and management, including preparation of project feasibility and implementation reports, record keeping, inventory management, costing, accounting, marketing, financial management and assessment of

business performance. In this way, Learning by Doing can become a strong bridge between agricultural education and transforming knowledge into skills, skills into enterprise, and enterprise into employment and rural prosperity.

Bridging Agricultural Education and Rural Realities

The Rural Agricultural Work Experience (RAWE) Programme is an important component of undergraduate agricultural education that provides students with practical exposure to real-life farming situations and rural communities. It aims to bridge the gap between classroom learning and field-level application by enabling students to understand farmers' needs, agricultural practices, rural livelihoods and the challenges faced by farming communities.

Under the RAWE programme, students are placed in villages and interact directly with farmers, agricultural extension personnel, local institutions and other stakeholders. They participate in agricultural operations, study farming systems, observe the adoption of improved technologies, identify production and marketing constraints, and understand the socio-economic conditions of rural households. Students also gain experience in technology dissemination, farmer advisory services, demonstrations, surveys and other extension activities.

RAWE helps develop essential competencies in communication, problem-solving, teamwork, leadership and participatory learning. It also sensitizes students to local agricultural needs and encourages them to develop practical, location-specific solutions. By engaging with farmers, students gain a deeper understanding of the realities of agriculture and the importance of integrating scientific knowledge with farmers' experience and indigenous technical knowledge. Thus, RAWE serves as a vital link between agricultural education, research, extension and farmers' prosperity.

Youth Leadership for Resilient Agriculture and Rural Prosperity

Agricultural education is equipping students to understand both the potential and limitations of emerging technologies and apply them to develop locally relevant, affordable and scalable solutions for Indian agriculture. Students are encouraged to view agricultural challenges not merely as problems, but as opportunities for innovation, entrepreneurship and value creation. Agricultural universities are advancing ecosystems where ideas generated by students and researchers can be translated into practical solutions and enterprises. Students are also gaining foundational exposure to entrepreneurship, business planning, financial management, market assessment, branding, IPR and commercialization. The objective is not to make every graduate an entrepreneur, but to nurture an entrepreneurial mindset - enabling youth to identify opportunities, solve problems, take informed risks and create value, thereby becoming employment and opportunity creators.

Youth can play a pivotal role in transforming Indian agriculture by adopting emerging technologies, experimenting with innovative approaches and connecting farmers with new markets, knowledge and institutional support. Young agricultural professionals can serve as effective bridges between farmers, scientists, technologies, markets and institutions. Krishi Shiksha is encouraging students to address practical rural challenges, including enhancing farm profitability, reducing production costs, improving water-use efficiency, strengthening FPOs, minimizing post-harvest losses, developing rural enterprises, improving market linkages and promoting value addition. A successful rural enterprise can generate employment not only for the entrepreneur but also for farmers, workers, transporters, processors and service providers. Thus, youth-led entrepreneurship can create a multiplier effect, generating income, employment and new opportunities across the rural economy.

Conclusion

The journey towards empowering youth through skills, innovation and entrepreneurship for resilient agriculture and rural prosperity requires a transformative shift in India's agricultural and rural economy. This transformation cannot be achieved without reimagining how the country's youth are educated, skilled and empowered. With the implementation of NEP 2020, Krishi Shiksha is moving beyond the conventional objective of producing graduates and emerging as a catalyst for skills, innovation, entrepreneurship and leadership. Youth are being empowered to address real-world agricultural challenges, create opportunities and contribute to rural prosperity through knowledge, technology and enterprise. The journey is therefore a journey from degrees to competencies, from competencies to innovation, and from innovation to resilient agriculture, rural prosperity and inclusive national development.

The journey towards empowering youth through skills, innovation and entrepreneurship for resilient agriculture and rural prosperity requires a transformative shift in India's agricultural and rural economy. This transformation begins with reimagining how the country's youth are educated, skilled and empowered. With the implementation of NEP 2020, Krishi Shiksha is moving beyond the conventional objective of producing graduates and emerging as a catalyst for developing skills, innovation, entrepreneurship and nurturing leadership. It aims to equip youth with the knowledge, competencies and confidence to address real farm challenges, harness emerging technologies, create new opportunities and contribute to rural prosperity. The journey of Krishi Shiksha towards empowered youth, is a transition from degrees to competencies, from competencies to innovation, and from innovation to resilient agriculture, sustainable rural prosperity and inclusive national development.

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Organic Farming and the Rise of India's Agri-Entrepreneurs

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Introduction

In India, agriculture traditionally has been perceived as a subsistence business, not a business of entrepreneurship. This perception is now starting to change and organic farming opens up new opportunities for the farmers to become entrepreneurs and to change the process of agricultural production into viable business enterprises.

Indian agriculture has been influenced by the use of chemicals over the years, in the context of the Green Revolution, and is experiencing a gradual shift towards organic farming practices. Economic opportunity opportunities are as important as environmental sustainability, though it is an important consideration. The demand from consumers, higher market prices, and increased market access at home and abroad are making organic farming a viable way of achieving agricultural entrepreneurship and sustainable rural development.

What Is Organic Farming, and Why Does It Matter?

Organic farming is an agricultural system that excludes synthetic fertilizers, artificial pesticides, and genetically modified seeds. In their place it relies on compost, farmyard manure, vermicompost, bio-pesticides, and natural pest management. The approach sustains soil fertility, protects water sources from contamination, and delivers healthier food to consumers.

The costs of chemical-intensive agriculture in India are now plain to see: declining soil fertility, nitrate contamination of groundwater, mounting farmer debt, and public health concerns. Returning to organic methods offers a single response to this cluster of problems.

India is home to more organic farmers than any other country in the world. In 2016, Sikkim became India's first fully organic state, an achievement that has become a source of inspiration far beyond its borders.

A New Path for Entrepreneurship

Organic farming has narrowed the distance between the traditional farmer and the modern entrepreneur. Today's agri-entrepreneurs do not simply grow crops; they process, package, brand, and sell directly to consumers. They exercise control over the entire "farm to fork" value chain.

Three groups define this emerging class of entrepreneurs:

- **Traditional farmers,** who have farmed for generations and are now adopting organic methods, in many cases doubling their incomes.
- **Young returnees,** who have left urban careers to come back to the village and run their farms like start-ups.
- **Corporate professionals,** who view organic agriculture as an investment opportunity.

Stories of Inspiration

Subhash Palekar: Pioneer of Zero-Budget Natural Farming
Vidarbha, Maharashtra

Subhash Palekar of Maharashtra developed the "Zero-Budget Natural Farming" model, in which a preparation called *jeevamrit* is made from the dung and urine of indigenous cows. Lakhs of farmers have adopted his model and freed themselves from dependence on chemical inputs. He has been honored with the Padma Shri.

Rahul Chaudhary: From IIT to the Farm
Uttar Pradesh
After earning an engineering degree from IIT, Rahul Chaudhary left a position at a multinational company to begin organic farming. Today his brand, "Prakriti Farm," delivers fresh organic vegetables directly to hundreds of families across Delhi-NCR. His annual turnover exceeds ₹50 lakh.

Sunita Devi: A Model of Women's Enterprise
Jharkhand
Through a self-help group, Sunita Devi of Jharkhand brought together 200 women farmers. Her collective now grows organic turmeric, ginger, and medicinal herbs, selling online and through export channels, with annual business of ₹30 lakh.

Where Digital Technology Meets Organic Farming

The greatest strength of the 21st-century agri-entrepreneur is digital capability. Smartphones, the internet, and e-commerce platforms have all but eliminated the distance between farmer and consumer.

Farmers can now sell organic produce directly on platforms such as Amazon, Flipkart, BigBasket, and JioMart. Others run "vegetable subscription" models through WhatsApp groups, delivering weekly organic boxes to hundreds of households. AgriTech start-ups such as Dehaat, AgroStar, and Ninjacart play an important role in connecting farmers to markets.

Government Policy and Support

The Government of India has launched several significant schemes to promote organic farming. Under the Paramparagat Krishi Vikas Yojana (PKVY), farmers receive support of ₹50,000 per hectare over three years. The National Programme for Organic Production (NPOP) simplifies the process of organic certification. Under the Agricultural Export Policy of 2018, exports of organic products receive special encouragement.

State governments have been equally active. Uttarakhand, Himachal Pradesh, Madhya Pradesh, and Rajasthan have made organic farming a central pillar of their agricultural policy. Through Farmer Producer Organizations (FPOs), small farmers are being aggregated and connected to larger markets.

The Export Opportunity

Global demand for Indian organic products is growing rapidly. The United States, the European Union, Canada, Switzerland, and Japan show particularly strong demand for spices, tea, coffee, rice, pulses, and medicinal herbs. According to APEDA data, India's organic exports have crossed $600 million.

Indian organic basmati rice, Darjeeling tea, Kerala black pepper, and Kashmiri saffron are recognized in global markets as "Indian premium" products, and they command prices many times higher than their conventional counterparts.

Challenges and Solutions

The path of organic farming is not an easy one. Complex certification procedures, lower yields during the conversion period, the absence of a cold chain, and competition from counterfeit

"organic" products all discourage farmers. Yet these obstacles can be overcome through collective action. By forming Farmer Producer Organizations, farmers can share the cost of certification. Through the Participatory Guarantee System (PGS), small farmers can obtain certification at low cost.

The Road Ahead

Over the coming decade, the organic sector will open new dimensions for India's agricultural economy. As climate change intensifies, organic farming may be the only sustainable option for long-term food security. Three forces, namely young people's return to the land, the expansion of digital marketplaces, and growing consumer awareness of health, will carry organic agri-entrepreneurship to unprecedented heights.

Conclusion

Organic farming is more than an agricultural method; it is a philosophy. It builds a balanced and respectful relationship among nature, the farmer, and the consumer. India's organic agri-entrepreneurs are pairing that philosophy with commercial success, and they are demonstrating that a connection to the soil, concern for the environment, and entrepreneurial drive can advance together.

In doing so, these farmer-entrepreneurs are helping to realize Mahatma Gandhi's vision of *Gram Swaraj*, or village self-rule. They are not only improving their own livelihoods; they are guiding India's food system toward a healthy, sustainable, and self-reliant future.

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New Indian Agriculture: Prosperity with Sustainability

Reimagining Indian Agriculture through Tradi-Tech-led Transformation

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ABSTRACT

Indian agriculture is moving from a production-centred paradigm to one that must deliver farmer prosperity, nutritional adequacy and ecological sustainability together. This chapter is synthesised around the seven themes of the 10th National Agri-Vision Convention: digital and emerging technologies rooted in traditional wisdom; agricultural education and human capital; livestock, dairy and fisheries; agri-innovation and start-ups; farmer incomes; food and nutritional security; and an inclusive agri-ecosystem. Food grain output reached a record 357.7 million tonnes in 2024-25 and is estimated at 376.6 million tonnes in 2025-26, while livestock (7.1% per annum) and fisheries (8.8%) have outpaced crops (3.5%) over the past decade. The evidence shows that physical abundance has been achieved, whereas income security, dietary quality and resource sustainability remain the unfinished agenda. The chapter argues that a Tradi-Tech approach, in which validated traditional practices are scaled through digital public infrastructure and frontier science, offers the most credible pathway.

Keywords: Tradi-Tech; digital agriculture; natural farming; livestock and fisheries; agri-start-ups; farmer income; nutritional security; Viksit Bharat

1. Introduction: Why a Tradi-Tech Pathway?

Few sectors illustrate India's development story as clearly as agriculture. A country that once depended on food imports now produces an estimated 376.56 million tonnes of foodgrain (2025-26, Third Advance Estimates), compared with 265.05 million tonnes in 2013-14, an increase of about 42% [1]. Agriculture and allied activities still support about 46.1% of the workforce, and their gross value added (GVA) at current prices is estimated at ₹52.08 lakh crore in 2025-26, up from ₹20.94 lakh crore in 2014-15 [1]. The Economic Survey 2025-26 records average real growth of 4.45% per annum in agriculture and allied activities between 2015-16 and 2024-25, the highest of any decade it compares, with livestock growing at 7.1%, fisheries and aquaculture at 8.8% and crops at 3.5% [2].

The same Survey also signals caution: growth in the second quarter of 2025-26 was 3.5%, below the five-year average of 4.4% [2]. Production records therefore do not settle the larger question of whether agriculture can sustain prosperity for farm families while protecting soil, water and climate. Prosperity requires remunerative incomes, risk protection and value addition; sustainability requires efficient use of natural resources, resilience to climate stress and nutritionally diverse diets. These objectives sometimes pull in different directions, and reconciling them is the central challenge of what may be called New Indian Agriculture.

The theme of the 10th National AgriVision Convention, "Reimagining Indian Agriculture: Tradi-Tech-led Transformation", offers a useful organising idea. *Tradi* refers to

India's accumulated knowledge systems, such as diversified cropping, indigenous breeds, millets, natural farming and community water management. *Tech* refers to digital public infrastructure, genomics, precision tools and data-driven advisory. The premise is not that tradition and technology are alternatives, but that traditions gain scale and credibility when tested and delivered through technology, while technology gains local relevance when anchored in farmers' knowledge. Table 1 summarises the headline trajectory; the sections that follow examine each of the seven convention themes.

Table 1. Headline indicators of Indian agriculture and allied sectors

Indicator	Baseline	Latest	Change
Agriculture and allied GVA (₹ lakh crore, current prices)	20.94 (2014-15)	52.08 (2025-26 est.)	+149%
Foodgrain production (million tonnes)	265.05 (2013-14)	376.56 (2025-26 TAE)	+42%
Horticulture production (million tonnes)	280.70 (2013-14)	377.78 (2025-26 SAE)	+35%
Oilseeds production (million tonnes)	27.51 (2014-15)	43.06 (2025-26 TAE)	+57%
Milk production (million tonnes)	146.31 (2014-15)	247.87 (2024-25)	+69%
Fish production (lakh tonnes)	95.79 (2013-14)	197.75 (2024-25)	+106%
Agricultural exports (USD billion)	32.08 (2014-15)	54.70 (2025-26)	+71%

Sources: PIB Factsheet (Aug 2026) [1]; Basic Animal Husbandry Statistics 2025 [3]. TAE and SAE denote Third and Second Advance Estimates

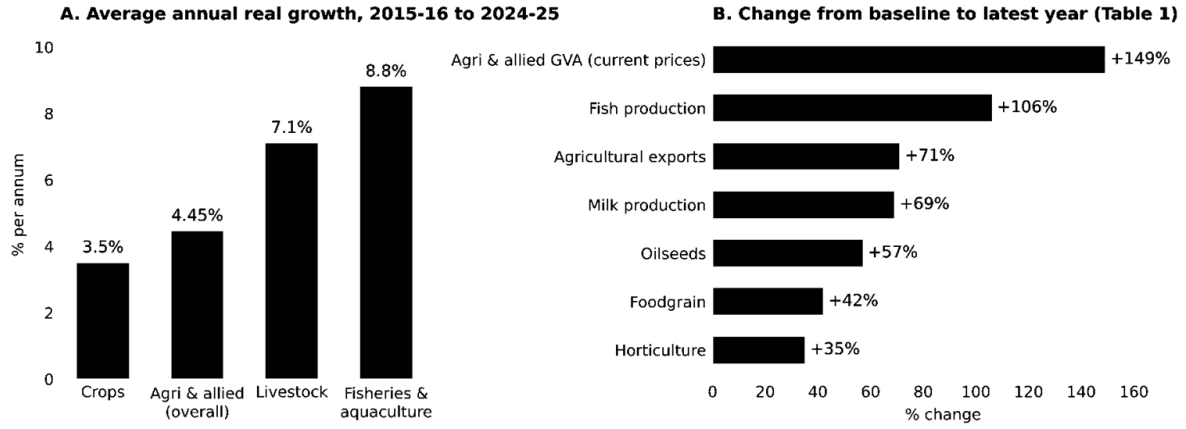


Figure 1. (A) Real growth by sub-sector; (B) change in headline indicators. GVA change is at current prices (nominal) and is not comparable with the real growth rates in panel A. Sources: Economic Survey 2025-26 [2]; PIB Factsheet [1]; BAHS 2025 [3]; author's computation.

2. Roots to Routers: Reviving Traditional Wisdom through Digital and Emerging Technologies

2.1 Rooting innovation in traditional systems

Traditional practices such as crop diversification, mixed farming, organic recycling and local seed selection are being re-examined as tools for reducing input costs and restoring soil health. Under the National Mission on Natural Farming, 10.32 lakh hectares and 20.93 lakh farmers were covered in 2025-26, and a further 33.89 lakh farmers have been sensitised to the approach [1]. Millets, long cultivated in rain-fed regions, have returned to policy attention after

the International Year of Millets 2023, and ICAR-IIMR, Hyderabad, has been recognised as a Global Centre of Excellence for Millets [13].

The scientific task is to convert enthusiasm into evidence. Multi-location, multi-season trials that measure yield stability, soil organic carbon, water productivity and net returns are needed before practices are recommended at scale. Traditional wisdom becomes a durable asset only when it is documented, tested and refined in the same way as any other technology.

2.2 Digital public infrastructure for agriculture

The Digital Agriculture Mission, approved in September 2024 with an outlay of ₹2,817 crore (central share ₹1,940 crore), is the backbone of the "router" layer [8]. Its core, AgriStack, comprises a Farmers' Registry, geo-referenced village maps and a Crop Sown Registry, complemented by a Krishi Decision Support System and soil profile mapping across about 142 million hectares [8]. By 3 August 2026, over 10.31 crore Farmer IDs had been created against a mission target of 11 crore, and the Digital Crop Survey in Rabi 2025-26 covered 648 districts and more than 31.3 crore plots [1]. The National Pest Surveillance System is used by over 10,000 extension workers across 73 crops and 436 pests, and BharatVistaar has handled over 72 lakh farmer queries [1]. In parallel, over 25.17 crore Soil Health Cards had been distributed by July 2025 [4].

Table 2. Digital agriculture: selected indicators

Instrument	Status (as reported)
Digital Agriculture Mission outlay	₹2,817 crore (Centre ₹1,940 crore), approved Sept 2024
Farmer IDs created	Over 10.31 crore (3 Aug 2026); target 11 crore
Digital Crop Survey, Rabi 2025-26	648 districts; over 31.3 crore plots
National Pest Surveillance System	Over 10,000 extension workers; 73 crops; 436 pests
BharatVistaar advisory	Over 3 lakh farmers served; over 72 lakh queries
Soil Health Cards distributed	Over 25.17 crore (July 2025)

Sources: [1], [4], [8].

2.3 Emerging technologies

ICAR has combined conventional and frontier breeding. In August 2024, 109 high-yielding, climate-resilient and biofortified varieties of 61 crops (34 field and 27 horticultural) were released [6]. In 2025, ICAR announced two genome-edited rice varieties, DRR Dhan 100 (Kamala) from ICAR-IIRR, Hyderabad, and Pusa DST Rice 1 from ICAR-IARI, New Delhi, developed with SDN-1 and SDN-2 genome editing for improved yield-related and stress-tolerance traits; such techniques were exempted from stringent genetically modified organism regulation in 2022 [7]. Civil-society groups have questioned the safety and necessity of these varieties [7], which underlines the need for transparent biosafety evaluation and clear communication with farmers and consumers.

Beyond breeding, remote sensing, drone-assisted spraying, sensor-based irrigation scheduling and AI-driven advisory can raise input-use efficiency, particularly where they are combined with geo-referenced crop and soil data. The value of such tools lies in decisions they improve: when to irrigate, how much nutrient to apply, which pest to scout for. Their adoption depends on affordability, shared-service models for small holdings and extension workers who can interpret outputs. The inclusion of 73 crops and 436 pests in the national pest surveillance platform [1] show how traditional field observation, systematically recorded and digitised, can become an early-warning system.

A recurring lesson is that the "router" must serve the "root". Digital tools succeed when they are interoperable, available in local languages, consent-based and designed around the small and marginal holder, rather than imposed as parallel systems.

3. Cultivating Minds, Empowering Futures: Reimagining Agricultural Education and Human Capital

India possesses one of the world's largest agricultural research and education systems. Established in 1929, ICAR coordinates 113 institutes and a system of 74 agricultural universities, comprising 63 State Agricultural Universities, 3 Central Agricultural Universities, 4 deemed universities and 4 central universities with agriculture faculties; 731 Krishi Vigyan Kendras and 11 ATARI centres carry knowledge to the field [4]. The number of ICAR-accredited private agricultural colleges rose from 5 in 2020-21 to 22 in 2024-25 [4].

Table 3. The agricultural education and extension network

Component	Scale
ICAR institutes	113
Agricultural universities	74 (63 SAUs, 3 CAUs, 4 deemed, 4 central universities with agriculture faculty)
Krishi Vigyan Kendras / ATARI centres	731 / 11
ICAR-accredited private agricultural colleges	5 (2020-21) to 22 (2024-25)
KVK trainees	58.02 lakh (2021-22 to 2023-24)
ATMA trainees	About 1.27 crore (2021-22 to Jan 2025)
Stay-in-rural-youth training (STRY)	Over 51,000 since 2021 (Dec 2024)

Source: PIB Factsheet, Agricultural Education & Training in India (Nov 2025) [4].

Scale, however, is not the same as readiness. The transformation described in this chapter needs graduates fluent in data science, genomics, remote sensing, agribusiness and natural-resource management, and extension professionals able to interpret digital advisories for farmers. Three of the 25 technology innovation hubs under the National Mission on Interdisciplinary Cyber-Physical Systems focus on IoT and AI in agriculture, and four IoT centres of excellence have been established [4]. The Digital Agriculture Mission also expects to generate work for about 2.5 lakh trained local youth and Krishi Sakhis in crop surveys [8], an early example of digital agriculture creating rural skilled employment.

Extension deserves equal attention. KVKs trained 58.02 lakh farmers between 2021-22 and 2023-24, roughly 19 lakh a year (author's computation), and ATMA trained about 1.27 crore farmers between 2021-22 and January 2025 [4]. Farm mechanisation training reached 57,139 persons over 2021-25 [4]. These numbers demonstrate reach; the next step is to measure effect, by tracking adoption, yield and income changes among trained farmers. Combining KVK demonstrations with digital advisory and peer-to-peer learning among progressive farmers would deepen the impact of training.

Reimagining education therefore implies integrating experiential and entrepreneurial learning into curricula, strengthening industry and farm internships, updating faculty skills, and tracking graduate outcomes. A consolidated, public record of enrolment, placement and entrepreneurship outcomes across the system would allow the sector to measure whether education reform is translating into human capital.

4. White and Blue Revolutions 2.0: Transforming Livestock, Dairy and Allied Enterprises

Livestock and fisheries are now the most dynamic parts of the agrarian economy. Livestock GVA grew by nearly 195% between 2014-15 and 2023-24; livestock contributes about 31% of

agricultural GVA and 5.5% of national GVA at current prices [3]. Fish production nearly doubled, from 95.79 lakh tonnes in 2013-14 to 197.75 lakh tonnes in 2024-25, and seafood exports rose from USD 3.64 billion to about USD 8.46 billion in 2025-26 [1].

India remains the world's largest milk producer. Production reached 247.87 million tonnes in 2024-25, a rise of 3.58% over the previous year, with per capita availability of 485 g/day against 319 g/day in 2014-15 and a global average of 394 g/day [1][3]. Average bovine productivity increased from 1,648 to 2,251 kg per animal per year over the decade [1]. Five states, Uttar Pradesh, Rajasthan, Madhya Pradesh, Gujarat and Maharashtra, account for 54.09% of output, and production grew fastest in exotic and crossbred cattle (4.97%) compared with indigenous cattle (3.51%) and buffaloes (2.45%) [3]. Egg production reached 149.11 billion (per capita 106 eggs per year, up from 62 in 2014-15), and meat production 10.50 million tonnes, of which poultry contributes about half [3].

Table 4. Livestock and fisheries indicators, 2024-25

Indicator	Value
Milk production	247.87 million tonnes (+3.58%); 485 g/day per capita
Egg production	149.11 billion; 106 eggs per capita per year
Meat production	10.50 million tonnes (poultry 5.18 million tonnes)
Wool production	34.57 million kg
Fish production	197.75 lakh tonnes
Seafood exports (2025-26)	About USD 8.46 billion
Livestock product exports	₹66,249 crore

Sources: BAHS 2025 [3]; PIB Factsheet (Aug 2026) [1].

The "2.0" agenda is less about adding volume than about raising productivity per animal and per hectare of water, improving genetics and nutrition, strengthening disease control and traceability, expanding cold chains and processing, and managing environmental externalities such as methane emissions and effluents. With a large share of milk produced by smallholders, the quality of cooperative and producer-company institutions will determine how much of the value reaches producers. In fisheries, the shift from capture to sustainable aquaculture and mariculture, supported by credit access (4.82 lakh Fisheries Kisan Credit Cards sanctioned out of 6.83 lakh applications [1]), offers a further growth avenue.

Animal health and feed security are further priorities. Productivity gains from improved genetics re realised only when animals are well fed, protected from endemic diseases and housed and milked hygienically. Fodder availability, a persistent constraint, can be improved through high-yielding forage varieties, crop-residue processing and community fodder banks. For smallholders, access to veterinary services, credit for animal purchase and assured milk procurement are equally important. The differing growth rates of crops (3.5%) and livestock (7.1%) over the decade [2] suggest that integrated crop-livestock-fish systems, which stabilise household income against crop failure, deserve greater emphasis in research and extension.

5. From Fields to Founders: Catalysing Agri-Innovation and the Start-up Revolution

A vibrant start-up ecosystem can shorten the distance between laboratory and field. The AgriSURE Fund, launched in September 2024, is a ₹750 crore Category II alternative investment fund, with ₹250 crore each from the Centre and NABARD and the balance from banks, insurers and private investors, to provide equity and debt to agritech and rural start-ups; the launch was accompanied by the Krishi Nivesh portal for agri-investment information [9]. At the time of launch, India was reported to have more than a thousand agritech start-ups applying IoT, AI and machine learning [9].

Start-ups do not operate in isolation. Over 10,000 Farmer Producer Organisations have been registered [1], and 79,630 Primary Agricultural Credit Societies have been sanctioned for computerisation, of which 63,707 had been onboarded on the common ERP platform by August 2026 [1]. These institutions are potential aggregators, customers and delivery partners for agri-enterprises. The share of processed foods in agricultural exports increased from 13.7% in 2014-15 to 20.4% in 2024-25 [1], pointing to the scale of the value-addition opportunity.

Priority opportunity areas include precision input management and drones, bio-inputs, post-harvest and cold-chain solutions, millet and nutri-cereal value chains, farm machinery for small holdings, and data services built on AgriStack. The principal constraints are long gestation periods, thin rural markets and limited patient capital. Publicly funded research institutions can help by licensing technologies on transparent terms, hosting incubators, sharing data and field-testing sites, and by recognising entrepreneurship as a legitimate research outcome.

A workable research-to-enterprise pathway has four links: discovery in public laboratories, validation through multi-location field trials, licensing or incubation into a venture, and commercial scale-up supported by early customers such as FPOs, cooperatives and agribusiness firms. Weak links include limited validation funds and the absence of reliable adoption data. Outcome-linked procurement by public programmes, shared testing facilities and mentoring from experienced agribusiness professionals would help young founders cross the stage between prototype and market.

6. Prosperity for the Plough: Securing Farmer Incomes in a New Agricultural Order

The most recent all-India household-level income estimate in the public domain is the NSS 77th Round Situation Assessment Survey (agricultural year 2018-19), which reported an average monthly income of ₹10,218 per agricultural household against ₹6,426 in 2012-13, a nominal increase of about 59% [10]. Later rounds of such a survey would be valuable for judging the impact of recent policy; until then, income conclusions should be drawn cautiously.

The policy architecture of income support has expanded considerably. The budget of the Department of Agriculture and Farmers Welfare rose from ₹27,663 crore in 2013-14 to ₹1,40,528.78 crore in 2026-27 [1]. PM-KISAN has transferred over ₹4.47 lakh crore through 23 instalments; the 23rd instalment alone reached over 9.49 crore farmers with about ₹18,984 crore [1]. Some 7.28 crore Kisan Credit Card accounts are operational, with ₹10.08 lakh crore outstanding, and PMFBY claims of ₹1.96 lakh crore had been disbursed up to December 2025 [1]. The value of procurement at minimum support prices rose from ₹7.41 lakh crore (2004-14) to ₹26.32 lakh crore (2014-26, up to February 2026) [1].

Table 5. Farmer income support and market access

Instrument	Latest reported position
Average monthly income per agricultural household	₹10,218 (2018-19) vs ₹6,426 (2012-13)
PM-KISAN	Over ₹4.47 lakh crore through 23 instalments
Kisan Credit Card	7.28 crore operational accounts; ₹10.08 lakh crore outstanding
PMFBY claims disbursed	₹1.96 lakh crore (up to Dec 2025)
MSP procurement value	₹7.41 lakh crore (2004-14) vs ₹26.32 lakh crore (2014-26)
MSP 2026-27 (₹/quintal)	Wheat 2,585; paddy (Grade A) 2,461
Farmer Producer Organisations	10,000 registered (July 2026)

Sources: [1], [10].

Income security in a new agricultural order will depend less on any single support and more on the combination of lower costs, stable yields under climate stress, diversification into livestock, fisheries and horticulture (which accounts for nearly one-third of agricultural GVA

[2]), better price discovery, and access to processing and export markets. Agricultural exports of USD 54.70 billion in 2025-26 show the market potential, but benefits will reach smallholders only if aggregation and quality systems are in place.

Three further points qualify the picture. First, budgetary support has grown about five-fold since 2013-14 (₹27,663 crore to ₹1,40,528.78 crore) [1], so the efficiency and targeting of expenditure now matter as much as its size; digital beneficiary identification can help. Second, price support and procurement are concentrated in a few crops and regions, whereas income gains in rain-fed and hilly areas depend on diversification and local value chains. Third, risk is rising with climate variability, and insurance and credit must be delivered quickly and transparently, particularly to tenant and marginal farmers who face the greatest barriers to documentation.

7. Nourishing a Nation: Safeguarding Food and Nutritional Security for Bharat

India's foodgrain output was a record 357.7 million tonnes in 2024-25, more than 25 million tonnes above the previous year [2]. Horticulture output reached 362 million tonnes, exceeding foodgrains, and is estimated at 377.78 million tonnes in 2025-26 [1][2]. India is the largest producer of dry onion, with about a quarter of global output, and ranks second in fruits, vegetables and potatoes [2]. Table 6 shows the crop-wise position from the Third Advance Estimates for 2024-25.

Table 6. Crop production, 2024-25 (Third Advance Estimates)

Crop group	Production
Total foodgrain	353.96 million tonnes (later estimate: 357.7 million tonnes)
Rice / Wheat	149.07 / 117.51 million tonnes
Maize	42.28 million tonnes
Shree Anna (millets)	18.02 million tonnes
Pulses	25.24 million tonnes
Oilseeds	42.61 million tonnes
Sugarcane / Cotton	450.12 million tonnes / 30.69 million bales (170 kg)

Sources: Ministry of Agriculture and Farmers Welfare, Third Advance Estimates 2024-25 [5]; Economic Survey 2025-26 [2].

Access to food is protected through the National Food Security Act, which covers about 81.35 crore persons; free foodgrain under PMGKAY has been extended to December 2028 with an outlay of ₹11.80 lakh crore, reaching 78.9 crore beneficiaries in October 2025 [11]. Rice fortification, approved until December 2028 at ₹17,082 crore, extends micronutrient delivery across all districts [11]. Procurement is substantial: 813.88 lakh tonnes of paddy from 1.15 crore farmers in KMS 2024-25 and 300.35 lakh tonnes of wheat from 25.13 lakh farmers in RMS 2025-26 [11].

Calorie sufficiency has, however, not fully translated into nutritional adequacy. NFHS-5 (2019-21) reported 35.5% of children under five as stunted and 32.1% as underweight [12]. Closing this gap requires dietary diversification toward pulses, oilseeds, fruits, vegetables, milk, eggs and fish, and a stronger role for biofortified varieties, a feature of the 109 varieties released in 2024 [6]. Millets are a natural ally: production of Shree Anna was 18.02 million tonnes from 12.86 million hectares in 2024-25, and exports reached 1.21 lakh tonnes worth ₹500.81 crore in 2024-25 [13]. Scaling millet consumption will depend on processing technology, public procurement and consumer acceptance rather than production alone.

Production diversity needs correction on both ends of the plate. Pulses (25.24 million tonnes) and oilseeds (42.61 million tonnes) in 2024-25 [5] remain below what a protein- and fat-secure diet would ideally draw on domestically, and dependence on imports for edible oils and some pulses continues; higher-yielding varieties, expansion in rice-fallows and better price signals are therefore strategic as well as nutritional priorities. Horticulture, which accounts for nearly one-third of agricultural GVA [2], supplies micronutrients but loses a significant share of its output after harvest, so cold chains and primary processing are nutrition interventions as much as economic ones. Finally, climate variability threatens the stability of the cereal base itself, making heat- and drought-tolerant wheat and rice central to long-term food security.

8. One Table, One Future: Building an Inclusive Agri-Ecosystem for Farmers, Youth and Consumers

An inclusive ecosystem means that the benefits of technology and markets reach the smallest farm, the youngest entrepreneur and the poorest consumer. Several elements point in this direction. Farmer IDs and the Farmers' Registry can link land, crop and benefit records so that entitlements reach the right person; BharatVistaar's multilingual advisory has already addressed over 72 lakh queries [1]. Young people are being drawn into agriculture through STRY training, Krishi Sakhi roles in crop surveys and start-up financing [4][8][9]. For consumers, the One Nation One Ration Card system recorded 191 crore portability transactions up to October 2025, with ration cards fully digitised and ePoS automation at 99.6% of fair price shops [11].

Inclusion also carries risks that deserve explicit attention: digital exclusion of farmers without connectivity or literacy, tenant farmers whose cultivation is not captured in land records, data privacy and consent in AgriStack, and unequal access of women to land, credit and training. The sources reviewed for this chapter do not give consolidated gender-disaggregated indicators, and building such indicators would be a valuable addition to national monitoring. Farmer organisations and cooperatives, as the 10,000 FPOs and the computerised PACS network show, can act as trusted intermediaries between individual farmers and digital or market systems [1].

For the youth, agriculture must become an aspirational career rather than a fallback. This calls for access to land through leasing, credit and mentoring for first-generation entrepreneurs, clear pathways from agricultural education to enterprise, and recognition of new roles such as drone operators, data collectors, soil-testing technicians and custom-hiring service providers. For consumers, inclusion means safe, affordable and nutritious food; this requires traceability, quality standards and fair retail margins alongside the public distribution system.

9. Linking the Seven Themes: A Systems View

The seven convention themes are interdependent rather than parallel. Digital infrastructure (Theme 1) enables targeted extension, credit and insurance (Theme 5); education (Theme 2) supplies the people who run start-ups (Theme 4) and livestock and fisheries enterprises (Theme 3); nutritional security (Theme 6) depends on diversified production from all of these; and inclusion (Theme 7) is the test of whether the whole system works for the smallest farmer, the young entrepreneur and the consumer. Table 7 maps each theme to its evidence base, priority action and principal actors.

Table 7. The seven themes: evidence, priority action and key actors

Theme	Evidence anchor	Priority action	Key actors
1. Roots to Routers	10.31 crore Farmer IDs; 648-district digital crop survey; NMNF 10.32 lakh ha	Validate traditional practices; ensure interoperable, consent-based, multilingual digital tools	ICAR, MoA&FW, states, FPOs
2. Cultivating Minds	113 institutes; 74 universities; 731 KVKs	Modernise curricula; track graduate and training outcomes; strengthen internships	ICAR, SAUs, KVKs
3. White and Blue 2.0	Milk 247.87 MT; fish 197.75 lakh t; livestock GVA +195%	Raise per-animal productivity; fodder, health and cold-chain; sustainable aquaculture	DAHD, cooperatives, ICAR
4. Fields to Founders	AgriSURE ₹750 crore; 10,000 FPOs	Research-to-enterprise pathway; patient capital; outcome-linked procurement	Incubators, NABARD, industry
5. Prosperity for the Plough	PM-KISAN ₹4.47 lakh crore; 7.28 crore KCC accounts	Diversify income; targeted support; faster insurance and credit	MoA&FW, banks, states
6. Nourishing a Nation	Foodgrain 357.7 MT; NFSA 81.35 crore; child stunting 35.5%	Diversify diets; pulses, oilseeds, millets; biofortification; post-harvest loss reduction	DFPD, ICAR, ICDS
7. One Table, One Future	ONORC 191 crore transactions; Krishi Sakhis; FPOs	Close digital, gender and tenancy gaps; youth careers; consumer safety	States, FPOs, civil society

Sources: compiled from [1]-[13].

10. Sustainability Imperatives and a Research Agenda

The evidence reviewed above supports a cautious optimism, tempered by several priorities for research and policy:

- **Resource-efficient intensification.** Raising yields and incomes while reducing water, fertiliser and energy use per unit of output, supported by soil profile mapping and decision support systems.
- **Climate resilience.** Continued development of heat-, drought-, salinity- and flood-tolerant varieties and breeds, with timely seed delivery to farmers.
- **Evidence for natural and regenerative practices.** Long-term, multi-location trials with transparent protocols, so that recommendations rest on data rather than advocacy.
- **Responsible data governance.** Consent, security and interoperability standards for AgriStack, together with grievance redress for farmers.
- **Measurement.** A regular, comparable national survey of farm household income, expenditure, debt and nutrition, supplementing production statistics.
- **Human capital and equity.** Curricula and extension suited to the digital era, and deliberate attention to women, tenants and smallholders in less-endowed regions.

11. Conclusion

New Indian Agriculture is defined by a shift from output to outcomes. The first decade of record harvests has delivered food security at national scale; the next must deliver incomes, nutrition and sustainability together. The Tradi-Tech approach, which tests and scales

traditional wisdom through digital infrastructure, ICAR-led research and enterprise, provides a coherent framework. The seven themes of the 10th National AgriVision Convention, from roots to routers to an inclusive table, together describe the components of this transformation, and platforms such as AgriVision play a valuable role in bringing scientists, students, entrepreneurs, policymakers and farmers into the same conversation.

I extend my warm congratulations and best wishes to the organisers of the 10th National AgriVision Convention for creating such a forum, and to the agricultural students of Bharat, on whose curiosity, skill and commitment the future of Indian agriculture rests. May your work keep our agriculture rooted in tradition, guided by science and directed to the prosperity of every farm family.

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SPACE GARDEN: FROM SEED TO SEED TO FEED FOR A GROWING POPULATION

A New Frontier for Global Food Security in an Era of Population Growth, Land Scarcity and Climate Change

A World Perspective on Future Food Systems, Space Agriculture, Seed Science and Sustainable Human Survival

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ABSTRACT

The rapid growth of the global population, declining per-capita availability of cultivable land, climate change, soil degradation, freshwater scarcity and increasing competition for natural resources are creating unprecedented challenges for global food security. Although agricultural science has substantially increased crop productivity during the past century, conventional agriculture remains dependent on suitable land, favourable climatic conditions, freshwater and biological resources that are increasingly under pressure. These challenges are particularly significant for densely populated countries with limited agricultural land and for regions experiencing environmental degradation and climatic instability. In this context, the concept of a "Space Garden: From Seed to Seed" offers an innovative scientific vision for expanding the frontiers of food production. A Space Garden is envisaged as a controlled, resource-efficient and regenerative agricultural ecosystem capable of supporting the complete crop life cycle, from seed germination and vegetative growth to flowering, pollination, seed maturation and the production of viable seeds for subsequent generations. Recent achievements in China's Tiangong space station, including the cultivation of fresh vegetables and the development of crop life-cycle experiments, together with international research by the Food and Agriculture Organization (FAO), the International Atomic Energy Agency (IAEA) and space agencies, demonstrate the growing scientific importance of space agriculture.

This article examines the scientific foundations, technological requirements, potential applications and limitations of Seed-to-Seed Space Gardens. It explores the integration of plant breeding, seed science, controlled-environment agriculture, hydroponics, aeroponics, artificial intelligence, robotics, renewable energy and resource recycling. It proposes that Space Gardens should complement, rather than replace, conventional agriculture, while contributing to food security, climate resilience, urban and remote food production, and the preparation of humanity for long-duration space exploration.

Keywords: Global food security, Space Garden, Seed to Seed, space agriculture, plant breeding, seed technology, controlled-environment agriculture, vertical farming, climate resilience, sustainable food systems.

1. Introduction: Feeding a Growing World through a New Agricultural Vision

Human civilisation has always been closely connected with the ability to produce, preserve and distribute food. From the earliest agricultural settlements to modern industrial societies, food production has shaped population growth, economic development, international relations and human survival. Agriculture is not merely an economic activity; it is the biological foundation of civilisation.

Today, humanity faces a fundamental question: How will the world feed its growing population when cultivable land, freshwater, fertile soils and favourable climatic conditions are increasingly constrained?

The United Nations' population projections indicate that the global population could approach 10 billion by 2050. This growth, accompanied by rapid urbanisation, changing dietary preferences and rising demand for nutritious food, will place additional pressure on agricultural production and food distribution systems. The challenge is not simply to produce more grain, but to provide a balanced, affordable, safe and sustainable diet to people across different regions and income groups.

For thousands of years, agriculture has depended primarily on land, sunlight, soil, water and seasonal climatic conditions. This relationship has supported diverse agricultural systems, from irrigated rice cultivation in Asia to wheat production in temperate regions and millet-based farming in semi-arid environments. The achievements of agriculture reflect the extraordinary adaptability of plants and the accumulated knowledge of farming communities.

However, the geographical distribution of agricultural resources is highly uneven. Some countries possess extensive cultivable land relative to their populations, while others have large populations concentrated in relatively small agricultural areas. High population density, urbanisation, limited arable land, water scarcity and competing demands for land make food security particularly challenging in many regions.

The issue is not that the Earth has suddenly become incapable of supporting human life. Rather, the challenge is to manage the planet's productive resources more efficiently, equitably and sustainably while preparing for future demographic and environmental pressures.

The Food and Agriculture Organization (FAO) and the International Institute for Applied Systems Analysis (IIASA) have developed global agro-ecological assessments examining land suitability, soils, terrain, climate and crop-production potential. These assessments demonstrate that agricultural potential depends not simply on the total area of land, but also on its ecological characteristics, competing uses, infrastructure and management.

A new agricultural vision is therefore required—one that combines conventional farming with protected cultivation, vertical farming, precision agriculture, urban food production, advanced seed science and controlled-environment systems.

One particularly forward-looking concept is the Space Garden: From Seed to Seed.

A Space Garden is a scientifically managed agricultural ecosystem designed to grow plants under controlled conditions, potentially in space habitats and, through adapted technologies, in resource-constrained environments on Earth. Its defining objective is not merely to grow edible leaves or harvest a crop once. It is to establish a regenerative production system capable of completing the entire plant life cycle, producing viable seeds and initiating the next generation.

The concept connects two major challenges facing humanity: feeding people on an increasingly crowded planet and developing sustainable food-production systems for future space exploration.

A Space Garden is not a replacement for the world's farms, forests, grasslands, oceans or farming communities. It is a complementary scientific frontier that may extend agricultural production into environments where conventional cultivation is difficult, expensive or impossible.

The central proposition of this article is that global food security in the coming decades will depend on a combination of agricultural productivity, ecological conservation, scientific innovation, equitable food distribution and new methods of food production. Space Gardens offer an opportunity to integrate these dimensions into a long-term strategy for human survival and prosperity.

2. The Global Food Security Challenge: Population, Land and Natural Resources

2.1 Population growth and rising food demand

Population growth is one of the major factors influencing the future of global agriculture. An increase in population leads to greater demand for cereals, pulses, fruits, vegetables, edible oils, milk, meat and other food products. Rising incomes and urbanisation are also changing consumption patterns and increasing demand for diversified, nutrient-rich diets.

Food security must therefore be evaluated in terms of nutritional quality as well as total food production. A population may have access to sufficient staple grains but still experience deficiencies in proteins, vitamins, minerals and other essential nutrients. Future agricultural systems must produce a wider range of nutritious foods rather than concentrating exclusively on increasing cereal output.

Agricultural production has increased considerably through improved crop varieties, irrigation, fertilisers, mechanisation, plant protection and scientific farm management. Nevertheless, continued expansion of conventional production faces environmental and economic constraints.

FAO's assessment of world agriculture identifies three principal sources of growth in crop production: expansion of cultivated land, increased cropping intensity and improvement in crop yields. Further production growth in many regions will need to rely increasingly on productivity improvements rather than unrestricted expansion of agricultural land.

Future food systems must consequently pursue two complementary objectives:

- Increase the productivity and nutritional output of existing agricultural land.
- Develop additional production systems that reduce dependence on extensive cultivable land and conventional growing seasons.

The second objective provides the scientific foundation for investigating Space Gardens and other controlled-environment production systems.

2.2 Unequal distribution of cultivable land

- Land scarcity is not uniform across the world. Some regions have considerable land resources but limited water, infrastructure, investment or agricultural technology. Other regions possess advanced technology and financial resources but have limited cultivable land relative to their populations.

- South Asia, for example, faces considerable pressure on agricultural land because of high population density, intensive cultivation and competing demands from housing, transportation, industry and urban development.
- Historical FAO assessments reported a decline in global arable land availability per person, from approximately 0.38 hectares in 1970 to 0.23 hectares in 2000, with a projection of 0.15 hectares by 2050. These are historical figures and projections, not verified measurements of present-day availability, but they illustrate the long-term demographic pressure on agricultural land.
- The relevant question is not whether every country should produce all its food within its borders. International trade, regional cooperation and agricultural specialisation will remain important. Instead, the question is how countries with restricted agricultural resources can diversify their food-production capacity and reduce vulnerability to disruptions.
- For land-constrained countries and densely populated cities, vertical farming, rooftop gardens, hydroponics, aeroponics and protected cultivation may provide supplementary sources of fresh produce. These systems can use buildings, rooftops, converted warehouses and other spaces unsuitable for conventional field agriculture.
- A Space Garden extends this principle by investigating whether crops can be grown and regenerated within compact, engineered environments where land and water are tightly controlled.

2.3 Climate change and agricultural instability

- Climate change presents an additional challenge to food security. Changes in temperature, rainfall, extreme weather events and irrigation-water availability can affect crop growth, flowering, pollination, seed formation and final productivity.
- Drought, flooding, heat stress, salinity and emerging pests and diseases can reduce agricultural output and destabilise rural livelihoods. Even where average production remains adequate, repeated extreme events can create severe local and regional shortages.
- Conventional agriculture is closely connected with its surrounding environment. A crop exposed to prolonged heat or unexpected rainfall may experience stress at critical stages of development. The reproductive stages of many crops are particularly sensitive to temperature and water stress.
- Space Gardens and controlled-environment agriculture offer a different production model. By regulating temperature, humidity, light, nutrients and water, they may reduce exposure to certain external climatic risks.
- However, climate control requires energy, infrastructure, technical expertise and reliable equipment. An enclosed growing system is not automatically sustainable or economically viable. Its environmental benefits depend on how efficiently it uses electricity, water, materials and nutrients.
- The future challenge is therefore to design systems that are both biologically productive and environmentally responsible.

2.4 Food security is more than food production

- Food security has four interconnected dimensions: availability, access, utilisation and stability.
- Availability concerns whether sufficient food is produced or supplied. Access relates to whether individuals can obtain food economically and physically. Utilisation

concerns dietary quality, food safety and the body's ability to benefit from nutrients. Stability requires that these conditions persist over time.

- A country may produce sufficient food nationally while vulnerable households remain food insecure because of poverty, conflict, weak distribution systems or high food prices.
- Consequently, Space Gardens cannot independently solve global hunger. They cannot replace effective agricultural policies, rural development, functioning food markets, social protection or international cooperation.
- Their potential contribution lies in strengthening food availability and supply stability in particular settings, especially for fresh vegetables, nutrient-rich crops, isolated settlements and environments with severe resource constraints.
- The central objective must remain a food system in which scientific innovation benefits farmers, consumers and communities rather than creating an isolated technological alternative accessible only to wealthy populations.

3. Space Garden: From Experimental Plant Growth to Seed-to-Seed Agriculture

3.1 China's Tiangong Space Garden: A milestone in orbital cultivation

- The development of Space Gardens is no longer merely a theoretical proposition. China's Tiangong space station provides an important example of the progress being made in orbital plant cultivation.
- As described in the supplied account of the Shenzhou-17 mission, astronauts harvested fresh vegetables grown in the station's Space Garden. The cultivation activities involved the Shenzhou-16 and Shenzhou-17 crews, who jointly nurtured the plants, harvested and tasted the produce, and prepared for subsequent crop cultivation.
- This achievement illustrates the practical value of growing fresh food during human spaceflight. It also demonstrates the importance of continuity between successive astronaut crews in maintaining biological experiments and collecting scientific data.
- Growing crops approximately 400 kilometres above Earth presents challenges that do not occur in ordinary terrestrial gardens.
- In microgravity, the movement of water and air around plant roots is altered. Water does not drain naturally under gravity, and root-zone aeration and moisture distribution require engineered solutions. Without appropriate management, roots may experience either inadequate water supply or excessive moisture.
- Natural sunlight is also unavailable inside the enclosed station growing compartment in the same manner as in an open field. Artificial lighting must therefore supply the required photosynthetically active radiation and appropriate light spectrum.
- According to the supplied account, the Tiangong cultivation system uses specialised breathable growing substrates, capillary water-supply arrangements, customised LED lighting and controlled-release fertiliser technology. These components help maintain the root environment and provide conditions for plant growth.
- The reported development of crop life-cycle cultivation, including the preparation of new planting cycles, is particularly relevant to the Seed-to-Seed concept.
- The broader significance lies in the transition from isolated plant-growth experiments towards a more systematic approach to space horticulture. The ability to grow successive crops, maintain plant health and investigate seed production is an important step towards understanding how agricultural systems might support longer-duration missions.
- It is important, however, to distinguish the cultivation of fresh vegetables from the achievement of complete food self-sufficiency. A Space Garden producing vegetables

can supplement astronauts' diets, but it does not necessarily produce the full caloric, protein and nutritional requirements of a crew. Complete independence would require a much wider range of crops, reliable seed regeneration, food processing and comprehensive resource recycling.

- Nevertheless, China's reported achievements demonstrate how controlled-environment agriculture can be adapted to an exceptionally constrained growing environment and provide valuable research opportunities for future space agriculture.

3.2 The meaning of a Seed-to-Seed Space Garden

A Space Garden may be defined as a controlled, regenerative plant-production ecosystem designed to complete the entire crop life cycle under engineered environmental conditions, including environments beyond Earth.

It integrates plant physiology, genetics, breeding, seed technology, controlled-environment agriculture, environmental engineering, microbiology, robotics and digital monitoring.

The defining feature is the principle of "Seed to Seed." A crop is initiated from a viable seed, grown through its vegetative and reproductive stages, harvested for food and seed, and regenerated through the next planting cycle.

A system that produces only leafy vegetables or edible biomass represents an important step towards space agriculture, but it does not necessarily establish a complete regenerative seed-production system.

A full Seed-to-Seed Space Garden must address:

1. Seed storage, viability and germination under controlled conditions.
2. Root establishment, nutrient acquisition and vegetative growth.
3. Flowering, pollen development, pollination and fertilisation.
4. Fruit, pod or grain development and seed maturation.
5. Harvesting, seed extraction, drying, storage and viability testing.
6. Replanting and successful completion of subsequent generations.

This distinction is fundamental because seeds represent the biological continuity of agriculture. A system capable of producing viable seeds can potentially reduce dependence on repeated seed supplies from Earth, although it would still require energy, nutrients, maintenance, genetic-resource management and periodic replacement of other supplies.

The Space Garden concept thus moves beyond the idea of growing food in a spacecraft. It considers the establishment of a regenerative agricultural ecosystem.

3.3 From terrestrial gardens to orbital agriculture

- On Earth, greenhouse cultivation, hydroponics, aeroponics and vertical farming have demonstrated that plants can grow without conventional field soil when their essential requirements are supplied in suitable forms.
- In space, the challenge is more demanding. Plants must grow in microgravity or other reduced-gravity environments, where water distribution, root-zone aeration, gas exchange, nutrient transport and plant orientation differ from those under terrestrial conditions.
- NASA has conducted plant-growth investigations aboard the International Space Station, including the Veggie system and the Advanced Plant Habitat. These programmes examine crop growth, plant responses to the space environment and technologies needed for future missions.

- The research is relevant to both space exploration and Earth agriculture. Technologies developed to manage water, nutrients, light and plant health in confined environments may also support agricultural production in deserts, urban buildings, remote research stations and regions with limited agricultural infrastructure.
- Nevertheless, the transfer of space technology to Earth must be evaluated scientifically. A technique developed for a spacecraft may require modification to become affordable and practical for farmers.
- The Space Garden should therefore be understood as a broad research and development framework rather than a single piece of equipment or a fully established commercial technology.

4. The Seed-to-Seed Principle: The Biological Foundation of Space Food Security

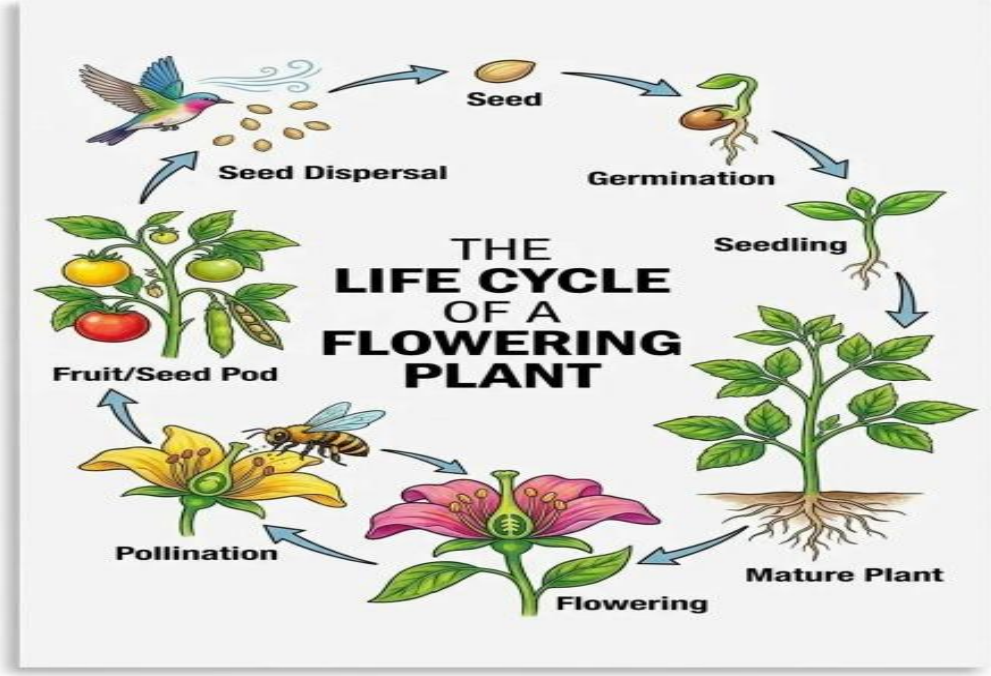
4.1 Why seed production must be central

- Seeds are the most fundamental input in agriculture. They contain the embryo, stored food reserves and genetic information required to establish a new plant generation. Seed quality influences germination, crop establishment, uniformity, productivity and the reliability of agricultural production.
- In conventional agriculture, farmers obtain seeds through farm-saved stocks, public-sector breeding programmes, seed corporations, cooperatives and private seed companies. These systems depend on a functioning network of breeding, multiplication, processing, testing, storage and distribution.
- In a space-based agricultural system, repeated transportation of seeds from Earth could be costly and logistically difficult. The capacity to regenerate seeds within a habitat would therefore have considerable scientific and operational value.
- A Seed-to-Seed Space Garden would establish a biological cycle in which a selected crop variety is planted, produces edible biomass and viable seeds, and supplies planting material for the next crop cycle.
- The concept also creates opportunities for developing specialised crop varieties adapted to enclosed environments.
- NASA's research on space-crop selection identifies important breeding considerations, including plant growth and development, physiology, nutritional composition, sensory acceptability and postharvest characteristics. Staple-crop production, food processing and integration with spacecraft systems are also necessary for greater food independence during long-duration missions.
- For plant breeders and seed technologists, this creates a new research frontier: developing varieties not merely for conventional fields, but for specific combinations of environmental conditions, growth systems and human nutritional requirements.

4.2 The complete crop life cycle

A Seed-to-Seed Space Garden must be designed around the biological requirements of the crop rather than around the engineering system alone.

The Seed-to-Seed Cycle



Seed → Germination → Vegetative growth → flowering → Fertilisation → Seed maturation → Harvest and storage → Next generation.

1. Seed selection and storage: Select genetically appropriate, healthy, viable seeds and establish controlled storage conditions.
2. Germination and establishment: Supply water, oxygen, temperature and suitable physical support for uniform emergence.
3. Vegetative development: Manage light, nutrients, humidity, root-zone conditions and plant architecture.
4. Reproductive development: Induce appropriate flowering, support pollination and ensure successful fertilisation.
5. Seed development and maturity: Maintain conditions for embryo development, seed filling, maturation and acquisition of desiccation tolerance where applicable.
6. Harvest, testing and regeneration: Harvest food and seeds, evaluate seed quality, preserve genetic identity and plant the next generation.

Every stage must be scientifically validated. A plant may grow well vegetative under artificial illumination but fail to flower or produce viable seeds because the light spectrum, photoperiod, temperature or reproductive environment is unsuitable.

Similarly, seed formation does not automatically guarantee high germination, genetic purity or long-term storability.

Seed quality assessment must include germination percentage, vigour, moisture content, physical purity, health and, where appropriate, genetic identity. Seed longevity must be evaluated under the intended storage temperature, humidity and atmospheric conditions.

In space, these considerations become particularly important because seeds may experience radiation, altered gravity, vibration during transport and fluctuations in environmental conditions.

A viable seed reserve, supported by controlled multiplication and quality assurance, would provide resilience against crop failure and supply interruptions.

5. Space Breeding: Developing Crops for Future Generations

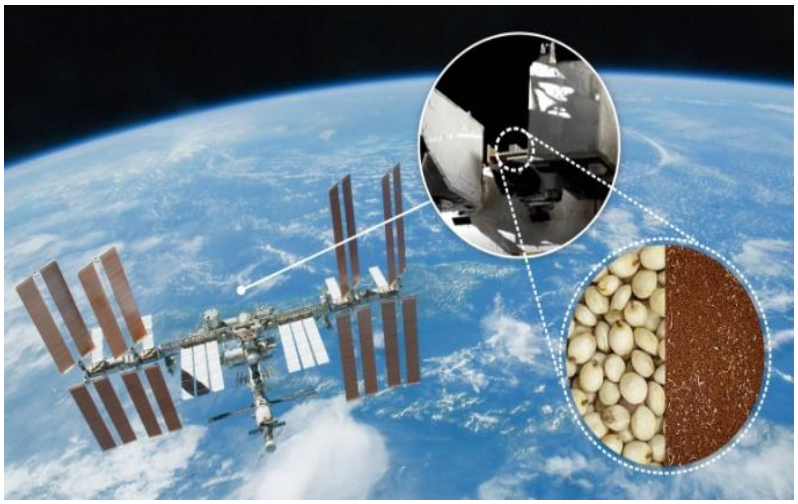
5.1 China's space rice and the development of new crop varieties

- China's space-breeding programme provides another important example of the connection between space research, plant breeding and food security.
- According to the report published on 14 July 2021, China harvested its first batch of "space rice" from seeds that had travelled aboard the Chang'e-5 lunar mission in November 2020. Approximately 40 grams of rice seeds accompanied the lunar probe. Following their return, the seeds were planted and the resulting crop harvested for further evaluation.
- The report emphasised that additional testing and successive plantings would be required before identifying varieties suitable for wider agricultural production. It also described China's longstanding space-breeding activities, which began in 1987, and the development of numerous space-bred crop varieties, including cotton and tomatoes.
- The reported expansion of space-bred crop cultivation in China illustrates the country's interest in combining space research with agricultural innovation and seed-sector development.
- The scientific principle underlying space breeding is the possibility that exposure to cosmic radiation and other spaceflight conditions may induce genetic variation. Some resulting variations may contain useful traits, but many may be neutral or undesirable.
- A space-exposed seed is therefore not automatically an improved seed. Its offspring must be grown, evaluated and selected through successive generations. Promising materials must undergo appropriate agronomic, genetic, nutritional and safety assessments before consideration for commercial cultivation.
- This distinction is essential to the scientific credibility of space agriculture. Space exposure provides a potential source of genetic variation; conventional breeding principles and rigorous testing remain necessary to identify useful crop improvements.
- The experience of China demonstrates that space-related crop improvement can form part of a wider national programme involving seed research, food security and agricultural development. It also highlights the need for sustained investment in plant breeding, seed multiplication and evaluation.

5.2 The FAO/IAEA initiative: Cosmic crops for a warming world

- An important international initiative linking space research with global food security is the joint programme of the Food and Agriculture Organization and the International Atomic Energy Agency.
- On 17 April 2023, FAO and IAEA reported the return of seeds that had spent approximately five months aboard the International Space Station. The project involved Arabidopsis and sorghum seeds launched from NASA's Wallops Flight Facility on 7 November 2022.
- The seeds returned aboard the SpaceX CRS-27 cargo spacecraft and were scheduled for analysis at the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture in Seibersdorf, Austria.
- The experiment was designed to investigate the combined effects of cosmic radiation, microgravity and extreme temperatures on plant genetics and biology. Scientists planned to compare space-exposed seeds with laboratory-irradiated and other control materials.

- Arabidopsis was selected because it is easy to cultivate, produces numerous seeds and has an extensive scientific research database. Sorghum was selected because it is a nutrient-rich cereal with established adaptation to arid environments and relevance to climate-resilient agriculture.



- The research programme aimed to investigate traits associated with tolerance to drought, salinity and heat, as well as other potentially useful genetic changes. DNA sequencing and comparative plant analysis were included to help distinguish the effects of different exposure conditions.
- The significance of this initiative lies in its attempt to connect space biology with the practical requirements of agricultural adaptation.
- Climate change is progressing rapidly, and crops must increasingly cope with environmental conditions different from those under which existing varieties were developed. Mutation breeding, genomic analysis and conventional selection provide complementary approaches for expanding the genetic resources available to plant breeders.
- Space-based experiments may contribute additional information about plant responses to extreme environments. However, whether exposure in space provides advantages over established terrestrial mutation-breeding techniques must be determined through comparative experiments.
- The FAO/IAEA initiative therefore represents a research pathway, not proof that space-exposed seeds will necessarily produce higher yields or climate-resilient varieties.
- Its wider relevance is the international recognition that plants genetic improvement is an important component of future food security.

5.3 Plant breeding for space environments

- Conventional plant breeding has developed crop varieties for diverse agro-climatic regions, including drought-prone areas, high-altitude environments, saline soils, short growing seasons and disease-affected regions.
- Space agriculture requires an additional set of selection criteria.
- Space-adapted varieties should ideally possess:
- Compact plant architecture and efficient use of growing volume.
- Short or manageable life cycles and predictable flowering.
- High edible biomass and nutritional value relative to growth time and resource inputs.
- Efficient root systems and nutrient uptake under controlled root-zone conditions.
- Reliable pollination, fertilisation and seed production.

- Resistance to important diseases and physiological disorders.
- Acceptable flavour, texture, colour and storage characteristics.
- Stable genetic performance across repeated generations.
- The breeding objective should not be simply maximum yield per plant. It should consider nutritional yield per unit of water, energy, growing area, time and other inputs.
- A compact crop with a shorter life cycle and reliable seed production may be more useful in a confined habitat than a large plant with high total biomass but excessive space requirements.
- Similarly, a variety that produces edible leaves quickly may be suitable for fresh-food supplementation, whereas a cereal or pulse capable of producing a complete reproductive generation would be needed for longer-term food autonomy.
- Breeding strategies may include conventional hybridisation, pedigree selection, mutation breeding, genomic selection, marker-assisted selection and other validated biotechnological approaches.
- The objective is to combine desirable genetic variation with rigorous phenotypic evaluation under the target environment.

5.4 The contribution of plant breeders and seed technologists

- The future Space Garden will depend not only on engineering but also on the science of seed production.
- Plant breeders must identify germplasm capable of completing the crop life cycle under specific environmental conditions. Seed technologists must develop appropriate methods for seed processing, drying, storage, viability testing and regeneration.
- The development of a reliable Seed-to-Seed system requires research into:
    1. Seed germination and vigour under altered gravity and controlled moisture conditions.
    2. Pollen viability, flowering behaviour and pollination requirements.
    3. Fertilisation, embryo development and seed maturation.
    4. Genetic stability and the inheritance of desirable traits across generations.
    5. Seed dormancy, longevity and storage under restricted environmental conditions.
    6. Nutritional quality and the safe use of harvested food.
- This research should be multidisciplinary, combining genetics and plant breeding, seed science, plant physiology, microbiology, agricultural engineering, nutrition and space biology.
- For India, agricultural universities and seed research institutions could begin by screening crop varieties in terrestrial controlled environments. Promising materials could then be evaluated through collaboration with space research institutions and specialised experimental facilities.
- The long-term objective should be the development of crop varieties and seed-production protocols that support both space agriculture and practical applications in protected cultivation and resource-constrained environments on Earth.

6. Technology Architecture of a Space Garden

The successful operation of a Space Garden requires the integration of biological and engineering systems. Plant growth cannot be separated from the management of light, water, nutrients, temperature, atmospheric composition, energy and waste.

6.1 Controlled-environment agriculture and artificial lighting

- Controlled-environment agriculture involves growing crops under managed environmental conditions, often within greenhouses, indoor farms or other protected

structures. Its principal advantage is the ability to regulate factors that otherwise fluctuate with weather and seasons.

- A Space Garden would use sensors and control systems to monitor and adjust light intensity, spectrum, photoperiod, temperature, humidity, carbon dioxide concentration, air circulation, water availability, nutrient composition and root-zone oxygen.
- Crop-specific environmental conditions are essential because different species and developmental stages have different requirements.
- The Tiangong cultivation system described earlier illustrates the importance of artificial lighting and controlled water supply in space. Customised LED systems can provide selected light spectra and photoperiods suited to plant photosynthesis and development.
- On Earth, greenhouses using natural sunlight and supplementary lighting may reduce energy requirements compared with fully enclosed farms. In space, artificial lighting and engineered environmental control may be necessary because natural sunlight is intermittent or unavailable within the growing compartment.
- The design must therefore balance crop productivity against the energy required to maintain the environment.

6.2 Hydroponics and aeroponics

- Hydroponics and aeroponics are two potential cultivation methods for Space Gardens.
- Hydroponics involves growing plants with their roots supplied by a nutrient solution, either directly or through an inert support medium. It permits precise management of nutrient concentrations, water supply and root-zone conditions.
- Aeroponics suspends roots in an enclosed chamber and delivers water and nutrients through a fine mist or other controlled delivery mechanism. It can reduce the amount of liquid water held in the growing system, but requires reliable pumps, nozzles, monitoring and backup systems.
- Both techniques offer advantages for compact growing environments. Neither is automatically free from disease, nutrient imbalances or equipment failures.
- In microgravity, the movement of water and gas differs from that under Earth's gravity. Systems must therefore be designed to maintain root aeration, distribute nutrients uniformly and prevent uncontrolled movement of liquids.
- The selection between hydroponics, aeroponics and other growing media should depend on the crop, habitat, reliability requirements and resource availability.

6.3 Artificial intelligence, sensors and robotics

- Artificial intelligence and digital agriculture can improve the management of complex growing environments.
- Sensors can measure temperature, humidity, light, pH, electrical conductivity, dissolved oxygen and other environmental variables. Cameras and image-analysis systems can monitor plant size, leaf colour, canopy development, flowering and visible stress symptoms.
- Machine-learning systems may assist with irrigation scheduling, nutrient management, disease detection, crop-growth prediction and early identification of equipment failures.
- Robotics may support seed placement, transplanting, pruning, pollination, harvesting and seed collection.
- For space habitats, automation is particularly important because crew time is limited and continuous manual management is impractical.
- However, automated decisions must remain transparent, reliable and subject to human oversight. Biological systems are complex, and AI predictions must be validated against actual crop performance.

- A practical Space Garden should include redundant sensors, manual controls, backup power and safe operating procedures. A single software or pump failure should not result in the loss of an entire crop cycle.

6.4 Water, nutrients and waste recycling

- Water is a critical resource in both terrestrial and space agriculture. A regenerative Space Garden must recover and reuse water wherever technically and hygienically feasible.
- Potential sources include recovered humidity, treated wastewater and water extracted from suitable local resources in future planetary habitats. Each source requires appropriate treatment, monitoring and quality assurance.
- Plant nutrients must also be supplied continuously. Nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and essential micronutrients must remain available in suitable concentrations and chemical forms.
- Organic residues, unused biomass and other waste streams may potentially be processed through biological or physicochemical systems to recover water and nutrients.
- Yet recycling does not eliminate the need for nutrient inputs or system maintenance. Some nutrients will be lost through harvesting, leakage, accumulation, chemical precipitation or other processes.
- Biological recycling also creates challenges involving pathogens, toxic compounds, nutrient imbalance and contamination. Waste-processing systems must be designed to protect crop health and food safety.
- A successful Space Garden would therefore operate as a carefully managed, partially or progressively closed-loop system rather than assume that all resources can be recycled indefinitely without losses.

7. What Should We Grow in a Space Garden?

- The choice of crops will determine whether a Space Garden functions primarily as a source of fresh vegetables, a seed-production facility or a substantial component of a future food system.
- A balanced crop portfolio should include leafy vegetables, fruiting vegetables, pulses, cereals, oilseeds and selected nutrient-dense crops. However, not every crop is equally suitable for every growing environment.

Table1. Potential crops and their functions in a Seed-to-Seed Space Garden

Crop group	Examples	Potential contribution
Leafy vegetables	Lettuce, spinach, amaranth	Fresh vegetables, vitamins, minerals and short production cycles
Fruiting vegetables	Tomato, pepper, dwarf cucumber	Dietary diversity and fresh produce
Pulses	Mung bean, cowpea, dwarf soybean	Protein, dietary fibre, seed production and potential nitrogen fixation
Cereals	Dwarf wheat, rice, sorghum	Carbohydrates, staple-food research and seed regeneration
Millets	Foxtail millet, finger millet	Nutrient-dense grains and research into compact, resilient crops
Oilseeds	Soybean and selected oilseed crops	Protein and oil, subject to processing and resource requirements

- Leafy vegetables are likely to remain important during the early development of space horticulture because they can provide fresh food without requiring the entire reproductive cycle to be completed for every harvest.
- Nevertheless, a long-term Seed-to-Seed system must go beyond leafy vegetables.
- Cereal and pulse crops are essential because they supply substantial proportions of dietary energy and protein in human diets. Developing varieties that complete their life cycles under controlled conditions would represent an important step towards greater food independence.
- Soybean deserves particular attention because of its protein and oil content, its importance in global agriculture and the availability of extensive genetic resources. However, soybean is not automatically suitable for every confined environment; plant height, canopy development, flowering behaviour, pollination, nutrient requirements and seed yield would need to be considered in breeding programmes.
- Similarly, millets and sorghum may offer valuable research opportunities because of their established adaptation to water-limited environments. Their terrestrial drought tolerance, however, does not by itself establish their suitability for microgravity or artificial-light cultivation.
- The central principle is crop diversification. A system depending on a single species would remain vulnerable to disease, nutritional deficiencies, genetic uniformity and environmental failures.
- Future Space Gardens should therefore maintain carefully selected crop portfolios, supported by diverse seed stocks and systematic evaluation of nutritional and agronomic performance.

8. Space Garden as a Supplementary Food Security System on Earth

- The greatest near-term relevance of the Space Garden concept may be its application to terrestrial agriculture.
- The technologies required for space agriculture—controlled environments, efficient water delivery, crop monitoring, compact plant architecture and resource recycling—can also address specific limitations of conventional food production.

8.1 Vertical farming and urban food production



- Urban populations often depend on food transported over long distances from agricultural regions. This creates logistical costs and potential vulnerabilities during extreme weather, transport disruptions or supply-chain interruptions.
- Vertical farms and rooftop greenhouses can produce selected crops close to consumers. By stacking growing surfaces, they increase production per unit of building footprint and can provide consistent supplies of certain fresh vegetables.
- NASA's account of controlled-environment agriculture describes how research into resource management for spaceflight contributed to the development of terrestrial indoor farming approaches. Such systems can reduce water use in particular

applications, although actual performance depends on crop, equipment, energy and operating conditions.

- The benefits must be considered alongside electricity consumption, construction costs, cooling requirements and the economic value of the crops produced.
- Indoor cultivation of leafy vegetables may be more practical than growing low-value bulk commodities such as wheat or rice in energy-intensive buildings.
- For this reason, vertical farming should complement field agriculture rather than displace it indiscriminately.
- The Space Garden framework can guide urban agriculture towards higher resource efficiency, year-round production, seed multiplication and research into compact crop varieties.

8.2 Agriculture in deserts and water-scarce regions

- Desert agriculture faces severe constraints involving water availability, high temperatures, salinity and soil quality.
- Protected cultivation, hydroponics and controlled-environment systems can reduce exposure to some of these constraints. Where water is scarce, carefully designed recirculating systems may improve water-use efficiency relative to particular conventional irrigation systems.
- The approach may be especially relevant to remote communities, research stations, arid settlements and locations where importing fresh vegetables is expensive.
- However, controlled environments do not eliminate the need for energy or water. Cooling in hot climates can be particularly demanding, and desalination or water treatment may add considerable costs.
- A viable desert Space Garden would need to combine renewable energy, efficient cooling, water recovery, appropriate crop selection and locally available technical support.

8.3 Food production in disaster-prone and isolated regions

- Disasters, conflicts and transportation failures can interrupt food supplies to islands, mountainous settlements, polar research stations and other isolated locations.
- Compact, protected growing facilities could provide a supplementary supply of fresh vegetables in such settings.
- For example, a modular growing unit could be deployed to a remote settlement and operated with locally available energy and treated water. Where the system also produces viable seeds, it could reduce the frequency of external seed deliveries.
- Nevertheless, such units would require spare parts, trained operators, disease control, food-safety procedures and contingency arrangements.
- Their contribution would be to improve the resilience of local food supply, not to replace emergency food stocks, regional agriculture or humanitarian assistance.

8.4 Sustainable agriculture and planetary boundaries

- The environmental sustainability of food production is central to its long-term viability.
- A research study available through NASA's Technical Reports Server examined the relationship between global agriculture and four planetary boundaries: biosphere integrity, land-system change, freshwater use and nitrogen flows. It's modelling indicated that changes in production patterns, water and nutrient management, cropland distribution, food waste and dietary practices could expand the population supportable within the boundaries examined.
- This finding is important because it demonstrates that technological expansion alone is not the only route to food security.

- Better management of existing agricultural land, conservation of ecosystems, reduced food loss, balanced diets and more efficient resource use must accompany new production technologies.
- Space Gardens can contribute to this transformation by demonstrating how food production may be organised around measured resource inputs, closed-loop processes and crop-specific environmental control.
- But the same sustainability standards must apply to Space Gardens themselves. A facility that consumes excessive fossil-fuel electricity or depends on resource-intensive materials may simply transfer environmental pressure from farmland to energy and industrial systems.
- The objective should be a measurable reduction in total environmental impact, not merely an increase in production per square metre.

9. Challenges and Limitations: From Scientific Possibility to Practical Reality

The Space Garden concept offers considerable research opportunities, but its successful implementation will depend on resolving major scientific, engineering, economic and social challenges.

9.1 Energy requirements and economic feasibility

- Artificial lighting, environmental control, water circulation, air filtration and cooling require energy. In a spacecraft, energy is limited; on Earth, electricity costs can determine whether indoor farming is commercially viable.
- A Space Garden producing high-value fresh vegetables may be economically feasible under certain conditions, while one intended to produce all the staple calories required by a large population would face much greater resource demands.
- The energy required per unit of edible food must therefore be measured alongside water use, crop yield, nutritional output and capital costs.
- Research should prioritise efficient light-emitting diodes, solar energy integration, passive cooling where possible, crop-specific lighting schedules and low-energy environmental control.
- The economic objective should be to identify applications where controlled-environment production offers demonstrable benefits over conventional alternatives.

9.2 Microgravity and reproductive biology

- Plant development in microgravity presents fundamental biological questions. Gravity influences root orientation, water distribution, plant architecture and various aspects of growth and development.
- Although plants can grow in spaceflight environments, completing a reliable Seed-to-Seed cycle under microgravity remains a more demanding objective.
- Pollination, fertilisation, seed maturation and the long-term stability of crop reproduction require further investigation for different species.
- Future experiments should evaluate the entire reproductive cycle rather than focus exclusively on vegetative growth or edible biomass.
- Research in simulated reduced-gravity environments can help identify mechanisms and test equipment, but terrestrial simulations cannot fully reproduce every feature of actual spaceflight.

9.3 Food safety, plant health and biological stability

- An enclosed growing environment can reduce exposure to some external pests and contaminants, but it may also allow certain pathogens to spread rapidly if they enter the system.
- Waterborne pathogens, root diseases, microbial contamination and nutrient imbalances can threaten the entire crop population.

- A Space Garden must incorporate clean seed, sanitation, quarantine, disease monitoring, safe water treatment and appropriate microbial management.
- Food safety is especially important when recycled water, organic residues or recovered nutrients are used.
- The system must also maintain nutritional quality and ensure that harvested products are suitable for human consumption.

9.4 Genetic diversity and dependence on technology

- A completely controlled agricultural environment can create a false impression that biological uncertainty has been eliminated.
- In reality, genetic uniformity, crop diseases, equipment failures and unexpected physiological responses remain possible.
- The loss of a particular variety or failure of a seed-generation cycle could interrupt production. Dependence on specialised electronic equipment, proprietary software or imported components may introduce additional vulnerabilities.
- A resilient Space Garden should maintain genetically diverse seed reserves, backup systems, alternative cultivation methods and the capacity to recover from crop failures.
- It should also preserve access to publicly available germplasm and avoid excessive dependence on a narrow range of proprietary varieties.

9.5 Social equity and technological accessibility

- Advanced agricultural technology must serve people across different economic circumstances.
- If Space Gardens become available only to wealthy cities, commercial enterprises or space agencies, their direct contribution to global food security will remain limited.
- Research should therefore include affordable modular systems, open technical standards, public-sector research partnerships and training programmes for agricultural communities.
- The participation of smallholder farmers, women, rural entrepreneurs and young agricultural graduates will be important in translating scientific advances into practical benefits.
- The central test of any food-production technology should be its contribution to reliable nutrition, environmental sustainability and equitable access—not simply its technical sophistication.

10. A Global Roadmap for Developing Seed-to-Seed Space Gardens

The transition from experimental plant growth to dependable regenerative agriculture requires a phased international research programme.

Proposed research and development roadmap

An illustrative framework. Stages and timelines should be established through scientific feasibility studies and international collaboration.

Phase I

Terrestrial controlled-environment research: Establish crop-specific protocols for hydroponics, aeroponics, artificial lighting, water recycling and seed production. Identify promising varieties and evaluate complete crop life cycles under Earth-based conditions.

Phase II

Spaceflight validation and biological research: Evaluate selected crops in microgravity and other relevant spaceflight conditions. Investigate plant physiology, reproductive development, seed quality and environmental-control requirements.

Phase III

Integrated regenerative garden systems: Combine food production, seed multiplication, environmental control, water recovery, nutrient recycling and automation into integrated experimental facilities.

Phase IV

Demonstration and wider terrestrial applications: Establish pilot facilities for remote communities, urban agriculture, research stations and other suitable locations. Evaluate costs, food safety, resource efficiency and accessibility.

10.1 International cooperation

- The development of Space Gardens will require cooperation among agricultural universities, space agencies, international organisations, seed industries and technology developers.
- FAO and the International Atomic Energy Agency have already demonstrated the value of international collaboration in plant breeding and research involving seeds exposed to space conditions. NASA's space-crop programme provides another important foundation for research into plant growth, crop selection and bioregenerative life-support systems.
- A future international research network could establish common protocols for evaluating crop performance, seed quality, food safety, environmental efficiency and genetic stability.
- International cooperation should also support the exchange of scientific knowledge and plant genetic resources under applicable legal frameworks, while respecting national regulations and the rights of farming communities.
- The objective would be to develop a shared scientific foundation for regenerative agriculture in extreme environments.

10.2 India's opportunity in Space Garden research

- India has a substantial scientific foundation for contributing to this emerging field through agricultural universities, seed research institutions, biotechnology programmes and space research.
- The country's experience in crop improvement, seed multiplication, protected cultivation and agricultural extension provides a basis for investigating crop varieties suitable for compact, resource-efficient production.
- Particular research priorities could include soybean, sorghum, millets, pulses, leafy vegetables and selected horticultural crops.
- India's diverse agro-climatic conditions also offer opportunities to test controlled-environment systems under hot, humid, dry and water-limited conditions.
- Agricultural universities could establish interdisciplinary Space Garden research units that bring together genetics and plant breeding, seed science, plant physiology, agricultural engineering, biotechnology and food science.
- Such centres could conduct terrestrial experiments first, followed by collaboration with relevant space research institutions for specialised experiments.

A national research initiative could focus on the following objectives:

1. Developing crop varieties for compact, low-resource cultivation.
2. Establishing Seed-to-Seed protocols for selected food crops.
3. Developing affordable hydroponic and aeroponic systems.
4. Evaluating renewable energy and water-recycling technologies.
5. Training students and young researchers in space agriculture and controlled-environment crop production.

6. Translating validated technologies into protected cultivation and urban agriculture.

The emphasis should be on scientifically validated research, practical affordability and applications that benefit India's food system.

11. Conclusion: From the Soil of Earth to the Gardens of Space

- Humanity is entering an era in which food security must be understood beyond the traditional boundaries of agricultural land. Population growth, uneven distribution of cultivable resources, climate change, water scarcity and environmental degradation demand a more diversified and scientifically advanced approach to food production.
- Conventional agriculture will remain the foundation of global food security. The world's farmers, fertile soils, agricultural biodiversity, freshwater resources and established food systems will continue to provide the principal sources of human nutrition. Protecting these resources, improving crop productivity, conserving biodiversity, reducing food loss and ensuring equitable food distribution must remain immediate priorities.
- At the same time, scientific progress makes it possible to investigate agricultural production in environments where conventional farming cannot operate effectively.
- The concept of a Space Garden: From Seed to Seed represents an important step in this direction. It brings together plant breeding, seed technology, controlled-environment agriculture, artificial intelligence, water and nutrient recycling, and space biology within a regenerative agricultural framework.
- The reported achievements of China's Tiangong space station, including the harvesting of fresh vegetables and the development of successive crop-growing experiments, demonstrate the practical relevance of orbital horticulture. China's space-breeding activities and the FAO/IAEA cosmic-crops initiative further illustrate how space research can contribute to investigations into plant genetics, crop improvement and climate resilience.
- These developments do not establish that space agriculture can independently feed the world's population. Rather, they provide a scientific foundation for investigating new agricultural possibilities and developing technologies with potential applications both in space and on Earth.
- The defining vision of a Seed-to-Seed Space Garden is the development of a system capable of producing food while preserving the biological continuity of agriculture through successive generations of viable seeds. Achieving this objective requires reliable seed production, appropriate crop varieties, reproductive success, resource recycling, food safety and rigorous evaluation of economic and environmental performance.
- The greatest contribution of this concept may ultimately extend beyond space exploration. Research into compact crop architecture, efficient resource use, controlled environments and automated seed production could contribute to urban agriculture, remote food-production systems, protected cultivation and agricultural resilience on Earth.
- Nevertheless, the scientific and economic limitations are substantial. Space Gardens are not yet a demonstrated, universally scalable substitute for conventional agriculture or a complete solution to global hunger. Their future value will depend on rigorous experimentation, practical engineering, affordability, energy efficiency and the successful completion of full crop life cycles.
- The pathway towards future food security must therefore combine the strengths of traditional agriculture with the opportunities of emerging science. The objective is not

to abandon the soil, but to expand humanity's ability to produce food wherever it can be done sustainably and safely.

- For agricultural scientists, plant breeders and seed technologists, this emerging field offers an opportunity to redefine the relationship between seeds, agriculture and human survival. For governments and research institutions, it presents a reason to invest in interdisciplinary research and international cooperation. For young scientists, it opens a frontier in which agriculture, biotechnology, engineering and space science converge.
- The ultimate vision is a world in which agriculture is not limited exclusively by the availability of fertile land, where seeds can be regenerated in carefully managed environments, and where scientific innovation supports the nutritional security of people on Earth and future human settlements beyond it.
- From Seed to Seed, from Earth to Space, and from Agricultural Knowledge to Sustainable Human Survival—Space Gardens may become one of the defining research frontiers of future food security.

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TradiTech: Reimagining Indian Agriculture Traditional Wisdom, Modern Innovation and the Transformation of Uttar Pradesh

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ABSTRACT

Indian agriculture is undergoing rapid transformation under the combined influence of climate variability, groundwater depletion, resource degradation, rising input costs, shrinking farm sizes, market uncertainty and technological advancement. This paper proposes **"TradiTech"** as an integrated framework that combines traditional agricultural knowledge with modern science, digital technologies and institutional innovation. The framework recognizes farmers accumulated ecological knowledge as a valuable resource while emphasizing its systematic documentation, scientific validation and contextual adaptation. Uttar Pradesh provides a significant context for developing and testing the TradiTech approach because of its diverse agro-climatic regions, extensive agricultural base and large population of small and marginal farmers. Traditional practices such as crop diversification, intercropping, local seed selection, organic resource recycling, soil conservation and community-based water management can complement modern agricultural technologies. These technologies include remote sensing, precision agriculture, artificial intelligence, geospatial technologies, improved crop varieties, micro-irrigation, digital advisory systems and digital market platforms. The paper examines opportunities for integrating traditional knowledge with contemporary agricultural innovations across different agro-climatic and farming systems of Uttar Pradesh. It particularly highlights the role of the Uttar Pradesh Council of Agricultural Research (UPCAR) in research coordination, technology assessment, capacity building, institutional collaboration, climate resilient agriculture, technology dissemination and entrepreneurship development. The proposed TradiTech transformation pathway links traditional knowledge, documentation, scientific validation, technology integration, field demonstration, capacity building, institutional adoption, value addition, market linkage and entrepreneurship**.** The approach promotes a participatory knowledge system in which farmers, researchers, extension agencies, institutions, start-ups and industry jointly contribute to innovation and scaling. TradiTech therefore represents neither a return to traditional agriculture nor an uncritical adoption of modern technologies, but a process of scientific validation, contextual adaptation and technological enhancement of locally relevant knowledge. The paper concludes that Uttar Pradesh can serve as an important testing ground for scalable TradiTech models that promote climate-smart, resource-efficient, economically viable and farmer-centered agricultural transformation, contributing ultimately to improved farm resilience, livelihoods and farmers' prosperity.

Introduction

Walk through a village in Uttar Pradesh at dawn and it is possible to observe two generations of agricultural knowledge operating within the same landscape. An experienced farmer may assess soil moisture by touching the soil, observing its colour and texture, and interpreting local weather conditions based on years of experience. Nearby, a younger farmer may consult a smartphone-based weather advisory, satellite-derived information or a digital crop-management application before making the same decision.

These approaches need not be viewed as competing systems of knowledge. They represent different ways of responding to the same fundamental agricultural question: how can farmers produce food reliably in an environment characterized by uncertainty**?**

This meeting point between inherited agricultural knowledge and contemporary science provides the conceptual foundation for TradiTech. In this paper, TradiTech refers to the deliberate and evidence-based integration of traditional agricultural wisdom with modern scientific, technological and digital innovation. It does not imply that every traditional practice is automatically appropriate, nor does it suggest that modern technology should be rejected. Instead, it proposes that locally accumulated knowledge should be identified, scientifically evaluated and, where appropriate, strengthened through modern technology. Traditional agricultural systems have developed through generations of observation, experimentation and adaptation. Practices related to crop rotation, mixed cropping, local seed selection, water harvesting, organic nutrient management and biological pest management often reflect an intimate understanding of local ecological conditions. Modern agriculture, meanwhile, has generated powerful tools for measurement, prediction, mechanisation, genetic improvement, resource-use efficiency and market connectivity.

The central proposition of TradiTech is therefore integration rather than substitution. Farmers' traditional knowledge can provide contextual intelligence, while modern science can provide measurement, validation and predictive capability. Digital technologies can provide speed and scale, while local institutions and community networks can provide trust and social legitimacy.

This convergence is particularly important in Uttar Pradesh. The state occupies a central position in India's agricultural economy, with extensive production of cereals, sugarcane, potato, pulses, oilseeds, horticultural crops and livestock products. At the same time, agriculture faces challenges associated with small and fragmented holdings, pressure on groundwater, increasing production costs, climate variability, changing labour availability and uneven access to technology. The objective of this paper is therefore to examine how a TradiTech approach could contribute to the transformation of agriculture in Uttar Pradesh. The paper focuses on five questions:

1. What forms of traditional agricultural knowledge remain relevant to contemporary agriculture?
2. Which modern technologies can complement this knowledge?
3. How can TradiTech approaches be adapted to different agro-climatic regions of Uttar Pradesh?
4. What is the current role of UPCAR in activities that align with this approach?
5. What institutional and policy framework is required to scale TradiTech?

1. Conceptualizing TradiTech

Term TradiTech is used here to describe a structured relationship between two knowledge systems:

Traditional agricultural knowledge + Scientific validation + Modern technology + Institutional support = TradiTech transformation

The concept rests on four principles

1.1- Traditional knowledge is a resource, not an obstacle

Traditional agricultural knowledge should not automatically be classified as outdated. Many practices developed in response to specific combinations of soil, rainfall, temperature, biodiversity and resource constraints. Their relevance, however, must be assessed scientifically rather than assumed.

1.2- Technology should strengthen local decision-making

Technology should support farmers rather than replace their judgement.

Weather forecasts, soil diagnostics, satellite imagery, artificial intelligence and digital advisories can improve the information available to farmers while leaving the final decision within the local farming context.

1.3 - Context matters

A technology that is successful in one agro-climatic region may not be equally suitable elsewhere. TradiTech therefore requires location-specific models rather than a single technology package for the entire state

1.4- Innovation must be inclusive

A technology-driven agricultural transformation can widen inequalities if it reaches only large or digitally connected farmers. TradiTech must therefore incorporate women farmers, smallholders, tenant cultivators, marginal farmers and communities with limited digital access

2. Agricultural Wisdom in Uttar Pradesh

2.1-Seed Selection and Crop Diversity

Farmers traditionally selected and conserved seed not solely for yield potential but also for adaptation to local conditions. Characteristics such as tolerance to drought, temporary waterlogging, pests, disease and variable rainfall could be important determinants of seed choice.

Community-level seed exchange and maintenance of locally adapted varieties also provided a mechanism for spreading production risk. In a variable climate, genetic diversity can function as a form of biological insurance. Modern crop improvement can complement this approach by identifying useful traits within traditional germplasm and combining them with improved breeding programmes. The objective should not be to eliminate local genetic resources but to conserve, characterize and utilize them strategically.

2.2- Mix Cropping and Intercropping

Mixed cropping and intercropping have long been used to distribute production risk and make better use of land, sunlight, nutrients and moisture. Cereal-legume combinations can also contribute to soil fertility through biological nitrogen fixation. From a TradiTech perspective, these systems can be enhanced through modern agronomic research, crop modelling, improved varieties, precision nutrient management and digital advisory services.

2.3- Traditional Water Management

Water management provides perhaps the strongest example of the TradiTech concept. Village ponds, tanks, small check dams, field bunds and other water-harvesting structures historically played important roles in storing rainfall and supporting agriculture during dry periods. In Bundelkhand and other water-stressed regions, the restoration of traditional water structures can be combined with modern watershed mapping, GIS, remote sensing, hydrological modelling and groundwater monitoring. The objective is not simply to restore historical infrastructure but to make it more effective using modern scientific knowledge

2.4- Soil as a Living System

Traditional farming systems frequently relied on farmyard manure, crop residues, green manures, composting and crop rotations to maintain soil productivity. Modern soil science has provided a more detailed understanding of soil organic matter, microbial activity, nutrient cycling and soil structure. This creates a natural convergence between traditional resource recycling and modern soil-health management

2.5- Indigenous Approaches to Pest Management

Traditional farmers have used locally available materials and ecological

practices to manage pests. Neem-based preparations, crop diversity, crop rotation and habitat management are examples of approaches that can reduce pest pressure. However, traditional pest-control practices should be subjected to scientific validation regarding efficacy, dosage, safety and environmental impact before large-scale recommendation.

3. The Modern Agricultural Technology Landscape:

The second component of TradiTech is the rapidly expanding technological ecosystem surrounding Indian agriculture

3.1- Precision Agriculture and Remote Sensing

Satellite imagery, remote sensing, GIS and drones can provide information on crop condition, vegetation health, water stress and spatial variability. Such information can transform local observations into more systematic decision-support tools. A farmer who traditionally observes clouds, soil moisture and crop appearance can potentially combine these observations with weather forecasts and remote-sensing information.

3.2- Soil Diagnostics and Digital Soil Information

Soil testing and Soil Health Card-based recommendations provide scientific information on nutrient status and fertiliser requirements. Digital soil mapping and geospatial technologies can further improve the spatial understanding of soil variability. The future opportunity lies in combining laboratory-based diagnostics with farmers' field-level observations.

3.3- Micro-Irrigation

Drip and sprinkler irrigation can improve water-use efficiency by delivering water more directly to the crop root zone. Their impact, however, depends on crop choice, irrigation scheduling, maintenance, affordability and local water availability. The TradiTech approach therefore combines modern micro-irrigation with traditional water harvesting, groundwater recharge and crop diversification.

3.4- Farm Mechanization for Smallholders

Small and fragmented holdings create challenges for conventional farm mechanisation. Custom Hiring Centres can provide access to tractors, implements, harvesters and other machinery without requiring every farmer to purchase equipment individually. This model is particularly relevant for smallholders and can also reduce physical drudgery associated with agricultural operations

3.5- Improved Varieties and Biotechnology

Modern breeding has generated varieties with improved tolerance to heat, drought, disease and other stresses. Such varieties can complement traditional seed systems if they are appropriately adapted to local agro-ecological conditions. The preservation and characterization of local genetic resources should proceed alongside modern crop improvement.

3.6- Digital Markets and Financial Services

Digital platforms can improve access to price information, markets, financial services and institutional credit. Platforms such as eNAM, digital payments and agricultural financial technologies have the potential to reduce information asymmetry. However, digital inclusion requires appropriate infrastructure, literacy, trust and institutional support.

3.7- Artificial Intelligence and Digital Advisory

Artificial intelligence can support crop diagnosis, weather-based decision-making, pest identification and personalized advisory services. Voice-based and vernacular-language systems are particularly important for farmers who may have limited literacy or limited familiarity with text-heavy applications. AI should be

regarded as a decision-support tool rather than a replacement for farmers, extension personnel or agricultural scientists

4- Uttar Pradesh as a TradiTech Laboratory

Uttar Pradesh is particularly suitable for a TradiTech approach because of its diversity of agro-climatic conditions and farming systems. The state includes water-stressed areas such as Bundelkhand, intensive sugarcane systems in western Uttar Pradesh, rice-based systems in eastern districts, and diverse horticultural, livestock and mixed farming systems across the state

Table.1-Major Agricultural Challenges and TradiTech Opportunities in Uttar Pradesh

Dimension	Major Challenge	TradiTech Opportunity
Farm size	Small and fragmented holdings	Custom hiring, FPO-based services and shared machinery
Water	Groundwater stress and variable rainfall	Traditional water harvesting + GIS + micro-irrigation
Soil	Nutrient imbalance and declining soil quality	Traditional organic resource recycling + soil diagnostics
Climate	Heat, drought, erratic rainfall and extreme events	Traditional diversification + climate-resilient varieties + weather advisories
Seeds	Genetic erosion and dependence on external seed	Community seed systems + modern characterization and breeding
Markets	Price volatility and weak bargaining power	FPOs + digital markets + value addition
Labour	Rising labour costs and drudgery	Small-scale mechanisation and custom hiring
Digital access	Unequal access to technology	Voice-based, vernacular and community-based advisory
Knowledge	Weak connection between local and scientific knowledge	Participatory research and farmer-led validation

5- Region- Specific TradiTech Opportunities

5.1- Bundelkhand Reviving Water Memory through Modern Tool

Bundelkhand represents one of the clearest contexts for combining traditional knowledge with modern technology. The region has experienced recurrent drought and water stress, making water conservation central to agricultural resilience.

The restoration of traditional ponds and water-harvesting structures can be strengthened through GIS-based watershed planning, satellite imagery, hydrological assessment, groundwater monitoring and scientific water budgeting. The TradiTech model for Bundelkhand should therefore combine:

Traditional water harvesting → watershed science → GIS mapping → groundwater recharge → efficient irrigation → diversified cropping.

Recent work involving UPCAR and ICRISAT on climate-resilient and regenerative agriculture further demonstrates the relevance of this direction. ICRISAT reported a 2026 training programme supported by UPCAR that focused on regenerative farming, climate resilience, soil health, natural-resource conservation and sustainable development.

5.2- Western Uttar Pradesh: Precision Agriculture in Intensive Cropping Systems

Western Uttar Pradesh has highly productive agricultural systems, particularly sugarcane-based systems. At the same time, intensive irrigation and water-intensive crops create resource-management challenges.

A TradiTech approach can combine:

- drip irrigation;
- precision irrigation scheduling;
- soil and water diagnostics;
- crop diversification;
- appropriate intercropping;
- improved varieties; and
- digital advisory services.

The goal is to increase productivity and profitability without increasing pressure on groundwater resources.

5.3- Eastern Uttar Pradesh: Smallholders, FPOs and Digital Inclusion

Eastern Uttar Pradesh is characterized by high population density and numerous small and marginal farms. Farmer Producer Organizations can provide collective access to inputs, machinery, processing facilities, finance and markets. The combination of FPOs with digital platforms creates an opportunity to integrate traditional community-based decision-making with modern market intelligence.

5.4- Role of UPCAR in TradiTech Transformation

The Uttar Pradesh Council of Agricultural Research (UPCAR) is currently playing an important role in promoting and coordinating various programmes and projects related to agricultural research, technology development, technology assessment, capacity building, and dissemination of agricultural technologies across the state. The Council is engaged in reviewing and monitoring research projects being implemented by agricultural universities and research institutions, assessing the progress of Centres of Excellence and Revolving Fund Projects, and facilitating the wider dissemination and adoption of technologies developed through these initiatives.

In the context of the TradiTech concept, several important dimensions of UPCAR's ongoing work are already aligned with the integration of traditional agricultural knowledge and modern technologies. Through collaboration with ICRISAT, UPCAR is promoting work in areas such as water resource management, climate-resilient agriculture, precision farming, Artificial Intelligence, and data-driven agricultural decision-making. Similarly, initiatives related to the Millet Revival Programme, capacity building of Farmer Producer Organizations **(FPOs)**, millet processing and value addition, and agricultural entrepreneurship represent significant efforts to connect traditional and locally important agricultural resources with modern processing, enterprise development, and market systems.

UPCAR is also promoting initiatives such as the Agricultural Incubation Centre/UPCAR-SEED to encourage agriculture-based startups and innovations. In addition, capacity building in areas such as advanced geospatial technologies, digital soil mapping, carbon accounting, and AI/ML is being promoted. Work related to biochar, value addition, and climate-smart agriculture further contributes to the efficient utilization of natural resources and enhancement of farmers' income.

Thus, UPCAR's current activities can be viewed within the TradiTech framework as a continuous chain of "Research → Validation → Technology Integration → Capacity **Building → Demonstration → Dissemination → Adoption → Entrepreneurship."** The next step is to bring these diverse initiatives together under a common **TradiTech framework** and develop region-specific models for different agro-climatic zones of Uttar

Pradesh. Such an approach can integrate farmers' traditional knowledge and local agricultural practices with modern science, digital technologies, and market systems, thereby contributing to a more **climate-smart, resource-efficient, innovative, and farmer-centric transformation of agriculture in Uttar Pradesh**

5.5- TradiTech and Climate Change

Climate change provides perhaps the strongest justification for a deliberate TradiTech strategy. Agriculture in Uttar Pradesh is increasingly exposed to:

- heat stress;
- irregular rainfall;
- delayed or early monsoon conditions;
- extreme rainfall events;
- prolonged dry spells;
- water scarcity;
- groundwater depletion; and
- changing pest and disease dynamics.

Traditional farming systems contain several mechanisms for managing uncertainty, including diversification, local seed selection, water conservation and mixed cropping. However, climate change is occurring at a pace and scale that may exceed the capacity of traditional trial-and-error adaptation alone.

Modern climate modelling, seasonal forecasting, early warning systems, stress-tolerant varieties, remote sensing and digital advisory can therefore provide the additional predictive capacity required.

The resulting principle is Traditional resilience + modern prediction + scientific validation = climate-smart TradiTech agriculture.

6- Human and Social Dimensions

Technology alone cannot guarantee agricultural transformation

6.1- Digital Divide

Digital agriculture can unintentionally exclude farmers who lack smartphones, connectivity, digital literacy or financial resources.

Technology design should therefore include:

- voice-based advisories;
- local-language services;
- community digital centres;
- FPO-based digital facilitation;
- KVK-mediated support; and
- offline or low-bandwidth solutions

6.2- Women farmers

Women play major roles in seed selection, livestock management, crop processing, kitchen gardens and post-harvest activities. However, they may remain underrepresented in land records, formal credit systems and agricultural training.

A successful TradiTech strategy should explicitly recognize women as knowledge holders, technology users, entrepreneurs and decision-makers.

6.3- Trust and Adaption

Farmers do not adopt technologies simply because they are technically advanced. Adoption depends on evidence, affordability, usability, perceived risk and trust.

Demonstration plots, farmer-to-farmer learning, KVKs, FPOs and participatory research can therefore be as important as digital platforms.

7 - Key Challenges to TradiTech Adoption

Several challenges must be addressed before TradiTech can become a large-scale agricultural transformation strategy.

7.1- Lack of Systematic Documentation

Much traditional agricultural knowledge remains undocumented and is transmitted orally. There is a risk of losing valuable knowledge as older generations leave farming.

7.2 –Scientific Validation

Traditional practices should not be promoted merely because they are traditional. Their agronomic, economic and environmental performance needs systematic evaluation.

7.3- Fragmentation of Initiatives

Research projects, extension programmes, digital platforms, FPO initiatives and entrepreneurship programmes may operate independently. A common framework is needed to connect these activities.

7.4- Affordability

Precision technologies, irrigation systems, machinery and digital services may require initial investment. Collective ownership and service-based models can help overcome this barrier.

7.5- Institutional Coordination

TradiTech requires coordination among agricultural universities, ICAR institutes, UPCAR, government departments, KVKs, FPOs, private technology providers and farmers.

8- TradiTech Roadmap for Uttar Pradesh

The proposed TradiTech Roadmap for Uttar Pradesh provides a structured framework for integrating traditional agricultural knowledge with modern science, digital technologies, institutional support, and market-oriented innovation. The roadmap focuses on eight key priorities: systematic documentation of traditional agricultural knowledge; scientific validation of indigenous practices; development of agro-climatic zone-specific TradiTech models; creation of a multilingual digital TradiTech platform; strengthening FPOs as technology and enterprise platforms; using KVKs for field-level validation and demonstration; developing agricultural incubation ecosystems; and establishing a measurable TradiTech monitoring framework**.**

The approach emphasizes that Uttar Pradesh should not adopt a uniform technological package but should develop region-specific solutions based on local agro-climatic conditions, farmer knowledge, and resource availability. FPOs and KVKs can serve as critical institutional bridges between farmers, research institutions, technologies, and markets, while incubation centres can convert traditional resources and farmer innovations into viable enterprises.

Overall, the roadmap seeks to transform traditional knowledge into scientifically validated**,** technologically enhanced, economically viable, and climate-resilient agricultural solutions**.** Its success should be assessed not merely through technology adoption but through tangible outcomes such as increased farm income, improved water and input-use efficiency, better soil health, greater crop diversity, enhanced climate resilience, women's participation, employment generation, and value addition**.**

9- Proposed Institutional Framework

TradiTech institutional framework envisions UPCAR as a state-level coordinating platform connecting agricultural universities, ICAR institutions, KVKs, research stations, FPOs, farmers, women farmers, start-ups, agri-tech companies, industry, and markets. This integrated ecosystem would facilitate the movement of knowledge, technologies, innovations, and feedback across the entire agricultural value chain.

Unlike the conventional one-way "Laboratory → Extension → Farmer" approach, the TradiTech framework promotes a two-way and participatory knowledge system in which farmer knowledge interacts continuously with scientific research, technology development, field validation, and farmer feedback. This approach can help combine **traditional wisdom** with modern science and technology, making agricultural innovation more locally relevant, adaptive, scalable, and farmer-centric.

10- TradiTech Transformation Chain

The TradiTech Transformation Chain provides a systematic pathway for converting traditional agricultural knowledge into scientifically validated, technologically integrated, and market-oriented solutions**.** It begins with documenting traditional knowledge and proceeds through scientific validation, technology integration, field demonstration, capacity building, and institutional adoption. The process is further strengthened through value addition, market linkages, entrepreneurship, and scaling.

The ultimate objective is to translate local knowledge and innovations into higher farmer incomes, improved resource-use efficiency, and greater climate resilience**.** Thus, TradiTech represents a fundamental shift from the conventional technology-transfer approach to an integrated knowledge-based approach, where traditional wisdom and modern science jointly contribute to agricultural innovation and sustainable rural development.

The central argument of this paper is not that traditional agriculture should replace modern agriculture. Nor is it that modern technologies should be imposed upon traditional farming systems.

The more productive question is: Which elements of traditional knowledge remain useful, which can be scientifically validated, and how can modern technologies make them more effective, scalable and economically viable?

For example, traditional water harvesting may be enhanced through satellite-based watershed mapping. Traditional crop diversification may be supported by improved varieties and market intelligence. Local seed systems can be connected with modern germplasm characterization. Traditional organic resource recycling can be strengthened through soil testing and nutrient management. Farmer knowledge of weather patterns can be complemented by modern forecasting and early-warning systems.

This approach also has an important institutional implication. Agricultural research should not operate as a one-way process in which scientists generate technologies and farmers merely receive them.

Farmers should increasingly participate in defining research problems, evaluating technologies and providing feedback.

UPCAR's current research coordination, institutional partnerships, climate-resilient agriculture initiatives, millet promotion, capacity-building programmes and technology dissemination activities provide several building blocks for such an approach. The 2026 Uttar Pradesh Agricultural Science Congress, for example, brought together research and policy stakeholders around themes including climate-smart agriculture, natural farming, soil health, mechanization, value addition and farmer income, reflecting a broad innovation-oriented agricultural agenda.

The opportunity now is to connect such activities through a common conceptual framework rather than treating them as isolated programmes.

11- Police Implications

A state-level TradiTech policy framework should consider the following priorities:

1. Recognition of traditional knowledge as a potential source of agricultural innovation.

2. Scientific validation before large-scale promotion.
3. Agro-climatic customization of technology packages.
4. Strengthening of KVKs and FPOs as local knowledge and technology intermediaries.
5. Inclusive digital agriculture with special attention to women and smallholders.
6. Water-centred agricultural planning in groundwater-stressed regions.
7. Support for traditional crops and value chains, particularly millets and locally adapted crops.
8. Institutional convergence among UPCAR, agricultural universities, ICAR institutions, government departments and private-sector innovators.
9. Integration of digital and traditional knowledge systems
10. Promotion of agricultural entrepreneurship and incubation.

12- Conclusion

Indian agriculture does not have to choose between tradition and technology. The more promising pathway is to build a system in which each strengthens the other.

Traditional farmers have accumulated generations of knowledge about soil, water, seed, biodiversity, crop combinations and local climatic conditions. Modern science provides tools for measurement, prediction, genetic improvement, resource-use efficiency and technological scaling. Digital technologies provide unprecedented opportunities to connect information, institutions and markets.

TradiTech is therefore best understood not as a return to the past, but as a strategy for carrying the most useful elements of the past into the future through scientific validation and technological enhancement

Uttar Pradesh is particularly well positioned to pursue this approach. Its diverse agro-climatic regions, large smallholder population, extensive agricultural research network and growing ecosystem of digital and institutional innovation make it an important testing ground for integrated agricultural transformation.

The next step should be to connect these activities within a coherent TradiTech framework for Uttar Pradesh. Such a framework could help transform traditional knowledge into scientifically validated solutions, modern technologies into locally relevant tools, and research outputs into farmer-centred innovations.

Ultimately, the objective is not simply technological modernization. It is the creation of an agricultural system that is productive, climate-resilient, resource-efficient, knowledge-intensive, economically viable and socially inclusive.

If Uttar Pradesh can demonstrate such a model at scale, it could provide an important pathway not only for the transformation of agriculture within the state but also for other regions of India facing the same challenge: how to combine the wisdom accumulated over centuries with the scientific and technological capabilities required for an uncertain future.

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ONE TABLE, ONE FUTURE

Building an Inclusive Agri-Ecosystem for Farmers, Youth and Consumers

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ABSTRACT

Indian farmers have never grown more. Yet the people who grow our food still earn little, many young people see farming as something to leave behind, and consumers know less and less about where their food comes from. This article argues that these three problems are really one problem: the farmer, the young innovator and the consumer work in separate worlds. Drawing on recent official data and three Indian examples (Amul, Sahyadri Farms and DeHaat), it explores what an inclusive agri-ecosystem could look like. It follows how farmers can move from producing to creating value, how youth can find real opportunity in agri-services, processing and technology, and how consumer demand can guide change on the farm. It then proposes a simple model, "One Table – One Future", in which farmers, youth and consumers sit at the centre, supported by FPOs, startups, industry, universities, finance and government. The article closes with a practical agenda for each group.

Keywords: inclusive agri-ecosystem; farmer producer organisations; agripreneurship; rural youth; consumer demand; value network; digital agriculture; policy convergence

1. Introduction: One Table, One Future

Picture a mustard farmer in Uttar Pradesh on a March morning, watching his crop go onto a trolley. By the time that mustard turns up in a kitchen in Bengaluru as bottled oil, it will have passed through a trader, a processor, a brand, a transporter and an online platform, and it will have been chosen by a buyer who cares about purity. Half a dozen people have touched it. Yet the farmer, the young entrepreneur, the startup and the buyer have rarely sat in the same room.

That is the quiet problem of our agriculture. We talk about the farmer who produces, the youth who innovates, the entrepreneur who adds value, the market that connects, the consumer who demands and the institution that enables, as though they belong to different stories. They belong to one. When they work apart, farmers grow what the market does not want, startups build tools that farmers cannot afford, and consumers pay more for food they cannot trace.

My argument in this article is simple. The next chapter of Indian agriculture will depend less on how much we grow and more on how well we are connected. What we need is one table, with a seat for everyone who has a stake in what ends up on the plate.

2. Indian Agriculture at a Turning Point

First, the good news. The Economic Survey 2025–26 reports that agriculture and allied sectors have grown at about 4.4 per cent a year on average over the last five years, with horticulture, roughly a third of agricultural GVA, doing particularly well. Food grain production reached a record 3,577.3 lakh tonnes in 2024–25. By any production measure, the farmer has delivered. The harder question is what that abundance has meant for the farmer's own pocket. Three facts help us answer it.

The first is size. According to the Agriculture Census 2015–16, 86.1 per cent of operational holdings are small or marginal, under two hectares, and more than half of these

farmers live in just five states: Uttar Pradesh, Bihar, Madhya Pradesh, Maharashtra and Andhra Pradesh. The average holding shrank to 1.08 hectares in 2015–16 from 1.15 hectares five years earlier. A farmer with a plot this small has very little to bargain with.

The second is income. The NSS Situation Assessment Survey found that an average agricultural household earned ₹10,218 a month in 2018–19, up from ₹6,426 in 2012–13, which works out to about 16 per cent growth in real terms. For marginal farmers the figure was lower, around ₹9,099. I should be honest that this is the latest national round I could verify, and it is now several years old. A fresh round would tell us a good deal.

The third is dependence. Agriculture accounted for about 42.4 per cent of total employment in the second quarter of FY26, according to PLFS, while the sector itself grew 3.1 per cent in FY26. A very large share of our workforce shares a much smaller share of national income.

Meanwhile, the plate is changing. In 2023–24, food took up roughly 47 per cent of rural and 40 per cent of urban household spending, and within food, beverages, refreshments and processed items had the largest share (11.09 per cent in urban India). More and more of what Indians eat is packaged, branded and processed, so more of the value is now created after the produce leaves the farm.

Table 1: Key trends shaping Indian agriculture

Trend	Evidence	Source and year
Steady sector growth	~4.4% average annual growth over five years; horticulture ~33% of agri GVA	Economic Survey 2025–26 (PIB, Jan 2026)
Record output	3,577.3 lakh tonnes foodgrain	Economic Survey 2025–26 (2024–25 data)
Small holdings dominate	86.1% of holdings below 2 ha	Agriculture Census 2015–16
Modest farm incomes	₹10,218/month average; ₹9,099 for marginal farmers	NSS 77th round, 2018–19
Labour concentration	Agriculture ~42.4% of employment	PLFS, Q2 FY26 (via Economic Survey 2025–26)
Shifting food demand	Processed food and beverages the largest food-spend share	HCES 2023–24 (MoSPI)

Put together, the picture is clear enough. Growing food is no longer our main constraint. Reaching buyers, adding value and earning trust are.

3. The Farmer: From Producer to Value-Creator

A farmer who doubles his harvest but sells it to the same buyer at the same price has not doubled his income. Every farmer knows this, even if our statistics sometimes forget it. Yield matters, but so do market access, quality, value addition and, above all, bargaining power.

The most promising answer so far has been to organise. The Central Sector Scheme for 10,000 FPOs began in February 2020 with an outlay of ₹6,865 crore, and the 10,000th FPO was registered at Khagaria in Bihar in early 2025. Each FPO can receive ₹18 lakh for management costs, an equity grant of up to ₹15 lakh, and a credit guarantee of up to ₹2 crore. By 1 January 2026, 56.32 lakh farmers had been mobilised, including 21.96 lakh women, and 1,175 FPOs were entirely women-led.

Digital markets have widened the doorway too. By March 2026, e-NAM linked 1,656 mandis and had registered over 1.80 crore farmers and 4,724 FPOs, with cumulative trade of ₹4.84 lakh crore since 2016. A word of caution, though. Registration is not the same as regular trading, and one PIB-based analysis notes that only about 23 per cent of APMC mandis are integrated. e-NAM is a promising channel, not yet a complete market.

So, what does "creating value" mean on an actual farm? It begins with grading and pooling produce, moves on to storing it so that the farmer need not sell in distress, then to processing or packing it, then to branding it with certified quality and traceability, and finally to selling it directly to institutions, retailers or consumers. At each step a little more of the consumer's rupee finds its way back to the village.

4. The Youth: From Job Seekers to Agripreneurs

Ask a village youngster whether he wants to farm, and you will often get a polite smile. He has seen the hard work and the uncertain returns, and he is looking for a way out. But a lot of the new opportunity in agriculture has little to do with the plough. It lies in services, data, logistics, processing and markets, and it needs exactly the skills our young people already have.

Table 2: Emerging opportunities for youth across the agricultural value chain

Segment	Examples of enterprise	Enabling support
Pre-production	Seed and input enterprises, soil testing, nursery and tissue-culture units	RKVY agribusiness incubators; AIF
Production services	Drone spraying, custom hiring and mechanisation services, precision-farming advisory	Incubators, KVKs, startup funds
Post-harvest	Cold chains, grading, packhouses, agri-logistics	Agriculture Infrastructure Fund
Processing	Micro food-processing units, ODOP products	PMFME
Markets	Agri e-commerce, B2B aggregation, export services	e-NAM, ONDC, APEDA

Segment	Examples of enterprise	Enabling support
Digital and finance	Farm advisory apps, AI tools, rural fintech and insurance	Digital Agriculture Mission, startup grants
Experience economy	Agri-tourism, natural and organic farming enterprises	State schemes, FPO linkages

The government has started building the pipeline. Under the RKVY programme for innovation and agri-entrepreneurship, 2,096 agri-startups were supported between FY2019–20 and 2025–26, with ₹168.14 crore in grants released through knowledge partners and agribusiness incubators, and over 6,000 startups trained. Seed-stage support goes up to ₹25 lakh. Set against the size of rural India these numbers are small, and that tells us both how far we have come and how far we still have to go.

Money alone will not close the gap. What young people often lack is the bridge between a degree and a business: practical skills, a mentor, a first customer, and the trust of farmers who have seen many promises come and go. The most successful young agripreneurs tend to be translators. They understand the field and the spreadsheet equally well.

5. The Consumer: The Missing Partner in Agriculture

We usually draw the consumer at the far end of the value chain, as the person who simply pays at the end. I think it is more useful to see the consumer as the place where the signals begin. Today's buyers ask questions that their parents rarely did. Is it safe? Where was it grown? Is it nutritious? Can I trust this label? Convenience, local identity, natural and organic claims, and transparent supply chains all shape what sells. The growing share of packaged and processed food in household spending, which we saw earlier, points the same way: people want quality assurance and convenience, and they are willing to pay for it.

This suggests a simple idea. **Consumer demand can become a signal for farm-level transformation.** If buyers reward residue-tested vegetables, growers will change how they spray. If buyers value regional varieties, farmers will keep growing them. And if a brand can show a customer the very farm behind the pack, the farmer earns a premium for trust that no mandi auction can offer.

I should add a limit here. Evidence on how much Indian consumers will actually pay extra for traceability or organic claims is mixed, and I have not cited a national survey on it. That is a good question for our universities to take up.

6. Technology: The Bridge Across the Ecosystem

Technology is the connective tissue of this ecosystem. It is not the table itself. The government is laying down digital public infrastructure for agriculture. The Digital Agriculture Mission, approved on 2 September 2024 with an outlay of ₹2,817 crore, aims to create 11 crore Farmer IDs by 2026–27, and over 10.31 crore had been created by 3 August 2026. In Rabi 2025–26 the Digital Crop Survey covered 648 districts and more than 31.3 crore plots. When a verified farmer identity is linked to land and crop records, credit, insurance and benefit payments can reach people faster.

On the farm, satellite imagery, drones, mobile advisories, AI-based crop and market intelligence, digital payments and farm-management apps can all bring down the cost of information. For consumers, a QR code can link a pack to its origin, and blockchain may help in specific cases where it genuinely adds value.

But a table with missing chairs is not inclusive, so four cautions need equal attention. Connectivity, smartphones and local-language interfaces are still uneven, which is the digital divide. Precision tools must be priced for a one-hectare farm, most often through shared services rather than individual purchase. Farmers need trusted people nearby, such as FPO staff, extension workers and local young entrepreneurs, to help them use new tools with confidence. And farmers should know who uses their data and share in the benefits when it creates value. Technology works when it strengthens relationships. It fails when it tries to replace them.

7. FPOs, Startups and Agribusiness: Building the Missing Links

Between millions of scattered small farms and a few organized buyers, there is a wide gap, and it takes institutions to fill it. FPOs bring scale. Startups bring technology and speed. Established agribusinesses bring capital and market reach. Cooperatives bring trust and a democratic form of ownership. Banks and NABARD bring credit. Three Indian examples show what this looks like in practice.

Case 1: Amul, a cooperative that became a national brand

Marginal milk producers, each selling a litre or two a day, once depended on traders for their income. Amul's answer was a three-tier cooperative in which village societies, district unions and a state federation together collect, process and market milk under one brand. The Gujarat Cooperative Milk Marketing Federation (GCMMF) reported a turnover of about ₹59,500 crore in 2023–24, with 36 lakh farmers across 18,600 villages. It has also stated that almost 80 paise of every rupee a consumer pays for milk and milk products goes to the producer. The lesson is plain: when farmers own the downstream business, value stays in the village.

Case 2: Sahyadri Farms, a farmer-owned company in horticulture

Grape growers around Nashik struggled with export rejections and unreliable middlemen. In 2010, about 100 farmers formed a producer company with shared quality standards, post-harvest facilities and processing capacity. By 2022–23 Sahyadri had crossed ₹1,000 crore in turnover, working with 24,500 farmers on 40,000 acres and processing 2.7 lakh tonnes. A January 2026 report puts turnover for FY25 at ₹1,954.7 crore, with exports to 42 countries. The lesson is that collective governance and professional management allow smallholders to compete globally. These later figures are company-reported and carried in the press, so they should be confirmed with the company before print.

Case 3: DeHaat, a youth-founded agritech startup from Bihar

Smallholders in eastern India found it hard to get good inputs, reliable advice and a fair market for their produce. DeHaat built a technology platform and paired it with local micro-entrepreneurs who act as the human face for farmers in the village. A 2021 interview with its founder reported over 1,300 such entrepreneurs serving more than 360,000 farmers across Bihar, Uttar Pradesh, Jharkhand and Odisha. The company has since claimed larger numbers, so the current figure should come from its own disclosures. The lesson is that technology works best when a trusted person on the ground delivers it.

8. Universities and Research Institutions: From Knowledge to Enterprise

Our agricultural universities and ICAR institutes hold much of the country's agricultural knowledge. Too much of it still stays in journals and on shelves. The path that matters runs from laboratory to field, from field to startup, from startup to market, and from market to consumer.

Incubators are one of the best bridges we have. The RKVY programme works through knowledge partners and 24 agribusiness incubators, most of them based in agricultural institutions. Extension services and Krishi Vigyan Kendras carry knowledge to the village, and they could do more by co-developing products with FPOs, licensing technologies to young entrepreneurs and letting farmers' feedback shape research priorities.

A university that counts only its publications sits at a different table from the farmer. One that also counts the enterprises it has helped found, the farmers it has served and the technologies that have been adopted is sitting at the same one.

9. Policy and Institutional Ecosystem: Convergence Is the Point

India has no shortage of schemes. What we need is for them to work together, and it helps to follow a single FPO through the system to see how that could happen. The FPO first registers under the 10,000 FPO scheme and receives management support, an equity grant and a credit guarantee. It then turns to the Agriculture Infrastructure Fund, which had sanctioned ₹80,224 crore for 1,50,431 projects by 26 January 2026, to finance a cold room or a grading unit. Next, through PMFME, which had sanctioned 1,62,744 credit-linked loans by 31 October 2025, groups of FPOs and cooperatives can claim up to 50 per cent support for branding and marketing. The FPO then lists its produce on e-NAM, links with Farmer ID-based services and sells through digital marketplaces. Along the way a local incubator can help with technology and market intelligence. Each of these programmes is useful on its own. Together they create a pathway from aggregation to a brand. The trouble is practical: separate portals, different eligibility rules and uneven state capacity. Real convergence means a single window for facilitation, shared data standards through Farmer IDs, and hands-on help from FPO promoters and incubators who know their way through the maze.

10. From "Value Chain" to "Value Network"

The old picture of agriculture was a line: farmer, trader, processor, retailer, consumer. Each link took its margin, and information rarely travelled back up the line. The picture that is emerging looks more like a network:

Farmer ↔ FPO ↔ Youth/Agripreneur ↔ Startup ↔ Processor ↔ Digital Platform ↔ Consumer

In a network, information moves both ways. Price signals reach the farm, and quality data reaches the buyer. This can bring several gains. Value is shared more fairly because ownership and pricing are more transparent. Prices are discovered among many buyers and sellers, not dictated by one. New ideas appear wherever different actors meet. Local services create jobs. A shock at one point can be absorbed by others, which makes the whole system more resilient. And consumers trust food more when the chain behind it can be explained.

11. The "One Table" Model

Putting these ideas together, I propose a simple model, **One Table – One Future: The Inclusive Agri-Ecosystem Model**. Imagine a round table with three main seats, ringed by the enablers who keep it standing.

Table 1: The Inclusive Agri-Ecosystem Model

FARMERS	YOUTH	CONSUMERS
Produce · Sustainability · Knowledge · Resources	Innovation · Skills · Entrepreneurship · Technology	Demand · Quality · Trust · Market signals

Around the table: Government · FPOs · Startups · Industry · Academia · Finance · Technology · Extension. Everyone at this table gives something and gets something back. Farmers bring produce, stewardship of the land and local knowledge, and gain stable markets and a larger share of the value. Young people bring energy, digital fluency and enterprise, and gain livelihoods and leadership in a growing sector. Consumers bring demand and a call for quality, and gain safer, more traceable food. Around them, government supplies infrastructure, rules and risk-sharing, and gains stronger rural incomes and food security. FPOs and cooperatives supply aggregation and trust, and gain scale. Startups and industry supply technology, capital and reach, and gain reliable supply. Universities and extension services supply research, training and incubation, and gain relevance. Finance supplies credit and insurance, and gains a well-organised set of clients.

Table 3: Farmer–Youth–Consumer ecosystem: challenges and opportunities

Stakeholder	Main challenge	Opportunity
Farmers	Small holdings, weak bargaining power, price risk	Collective marketing, value addition, direct sales
Youth	Low perceived status of agriculture, skills mismatch, access to capital	Agri-services, agritech, processing, logistics
Consumers	Limited traceability and quality assurance	Transparent, branded, locally linked supply
Institutions	Fragmented schemes, weak last-mile delivery	Convergence, incubation, shared platforms

12. From Vision to Action

For farmers: join and actively shape your FPO, grade, store and process before you sell, grow for a specific market rather than only for the mandi, and build your digital and financial skills.

For youth: treat agri-services as serious businesses, look for incubation and mentoring early, and build local enterprises that farmers can see and trust.

For consumers: ask where your food comes from, reward verified quality, support local and sustainable producers, and remember that a fair price for the farmer is part of food security.

For institutions: link universities, industry and FPOs through joint projects, expand incubation, improve market infrastructure, and make finance and technology reachable for small enterprises.

For government: bring schemes together through single-window support, invest in storage, logistics and markets, reduce transaction costs, back innovation, and keep digital access open to all.

13. Conclusion: One Table, One Future

Indian agriculture will not be rebuilt by farmers alone, or by policymakers, scientists, startups or consumers alone. Each hold one piece of the answer, and none can finish the puzzle without the others. The farmer who knows the soil needs the young innovator who understands data. The innovator needs the processor who understands the market. The processor needs the consumer who values trust. And all of them need institutions that bring people together instead of competing with one another.

When farmers have a stronger voice, young people have real opportunities, consumers have greater trust and institutions pull in the same direction, agriculture becomes more than a sector. It becomes an ecosystem of shared prosperity. There is room at the table. The work of building it starts with pulling up the chairs.

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Modelling And Forecasting of Area, Production and Yield of Pigeon Pea (Arhar) In India and Madhya Pradesh Using Box-Jenkins Arima Time Series Models

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ABSTRACT

Pigeon pea (*Cajanus cajan*), commonly referred to as Arhar or Tur, is the second largest pulse crop in India and an important source of protein for the vegetarian population of the country. Accurate estimates of its extent, output and production are needed for price stabilisation, buffer-stock policies and import-export policies. The present study developed and projected the area, production and yield of Arhar for India and Madhya Pradesh (MP), one of the leading producing states of India for last seventy-five years (1950-51 to 2024-25) using annual time-series data from India Stat. All six series were treated using the Box-Jenkins methodology known as Autoregressive Integrated Moving Average (ARIMA). The Augmented Dickey-Fuller (ADF) test was used to check the stationarity of each series, and first differencing (d = 1) was applied to non-stationary series, and d = 0 was used to a stationary series. Each stationary series was examined using the autocorrelation function (ACF) and the partial autocorrelation function (PACF) to establish a plausible range of autoregressive (p) and moving-average (q) orders and a systematic grid of models was estimated for each series within the range of plausible autoregressive (p) and moving-average (q) orders, with the best-fitting model selected by a composite ranking system using the minimum Akaike Information Criterion (AIC) and Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE) and Mean Percentage Error (MPE) computed on a 5-year hold-out sample (2020-21 to 2024-25). The selected specifications comprised ARIMA (1,1,2) for India's area, ARIMA (0,1,2) for its production, ARIMA (0,1,5) for its yield, ARIMA (0,1,5) for MP's area, ARIMA (1,0,5) for MP's production, and ARIMA (0,1,4) for MP's yield. It is projected that India's area and production and yield will stabilize around the 2024-25 levels by 2029-30, indicating a matured, low growth trend in the years ahead (area compound annual growth rate (CAGR) 0.93%, production CAGR 1.01% and yield CAGR 0.08% between 1950-51 and 2024-25). Madhya Pradesh, on the other hand, had a clear structural decline, with a peak area of approximately 690 thousand hectares in 2016-17 and a projected area of 151 thousand hectares in 2024-25, its forecasts were directionally confirmed as weak, but with high level of uncertainty (MAPE of 47% for area and 91% for production), reflecting the limits of univariate extrapolation across a structural break. Finally, the study outlines policy suggestions for the revival of Arhar cultivation in Madhya Pradesh and suggests the use of intervention-aware or hybrid models as an improvement over the ARIMA model for future studies.

Keywords: Arhar; Pigeon pea; ARIMA; Time series forecasting; Augmented Dickey-Fuller test; ACF-PACF; Madhya Pradesh; Box-Jenkins methodology.

Introduction

Pulses have a special relevance in Indian agriculture because it is the main protein source for the large vegetarian population, it is a nitrogen fixing crop and is grown by mainly small and marginal farmers with rain fed agriculture. Pigeon pea (*Cajanus cajan* L.) or Arhar/tur is the second largest pulse crop after chickpea in terms of area and production in India. Pigeon pea is the main producer and consumer of the world, accounting to most of the global production and it plays an important role in food and nutritional security of the country as there is always demand-supply mismatch for pulses

resulting in sharp price volatility and import dependence sometimes. Madhya Pradesh (MP) has always been one of the top Arhar producing states in India accounting for significant contribution in Arhar basket in the country. During the last two decades, however, the State has seen a significant decline in the acreage of Arhar grown which is likely due to the competition with more profitable crops like soybean and wheat, change in cropping pattern, price risk, market risk and localized incidence of disease or pest. Identifying the nature of this contraction, whether temporary or permanent and the likely trajectory of area, production and yield in the short-term is pertinent to state agricultural planning, procurement policy and farmer advisory services.

Time-series forecasting can offer a data-driven and objective estimate of the near-term evolution of an agricultural aggregate without forcing the selection of a structural model for the agro-economic forces driving the aggregate. The Box-Jenkins Autoregressive Integrated Moving Average (ARIMA) method (Box and Jenkins, 1976) is the most popular time-series technique used for forecasting univariate crop-statistics in the Indian agricultural-statistics literature as it is flexible, has a well-developed diagnostic apparatus and can handle non-stationary trending series by differencing. The ARIMA model has been applied successfully in forecasting the area, production and yield of crops in India, such as sugarcane (Vishwajith et al., 2016) [9], wheat, rice and food grains in general (Ahmar et al., 2023) and pigeon pea (Wankhade et al., 2010; Vishwajith et al., 2018; Dash et al., 2022).In the present study, a long annual time series of the area, production and yield of Arhar (1950-51 to 2024-25) is used for modeling and forecasting the same, for India as a whole and for Madhya Pradesh, by literature. The specific objectives of the study were then: (i) To examine the stationarity properties of the six constituent series using Augmented Dickey-Fuller (ADF) test and determine the appropriate order of differencing; (ii) To identify a plausible autoregressive and moving-average order (p, d, q) for each series through inspection of the autocorrelation function (ACF) and partial autocorrelation function (PACF); (iii) To estimate a systematic grid of ARIMA models ranging from ARIMA(0,d,1) to ARIMA(1,d,5) for each series, and find the best-fitting model using minimum AIC along with out-of-sample RMSE, MAE, MAPE and MPE; and (iv) To make point forecasts for each series to 2029-30 and discuss their implications, including the limitations imposed where a series has experienced a structural break.

Material and Methods

The data were secondary, collected from IndiaStat from the period 1950-51 to 2024-25 (seventy-five crop years). For the purpose of stationarity testing, model identification and forecast evaluation, each series was further split into an estimation sample (1950-51 to 2019-20) and a five-year hold-out sample (2020-21 to 2024-25).

Stationarity testing

The Box-Jenkins ARIMA methodology requires the working series to be weakly stationary, that were possess a constant mean, a constant variance and an autocovariance structure dependent only on lag rather than on time. Because agricultural area, production and yield series typically display secular trends, the stationarity of each series was formally examined using the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) based on the regression shown below, with the null hypothesis H0: $\gamma = 0$ (series contains a unit root, i.e. is non-stationary) tested against H1: $\gamma < 0$ (series is stationary), the lag length of the augmentation term being chosen by minimising the Akaike Information Criterion (Akaike, 1974); (Supriya *et al.,* 2023)

$$\Delta y_t = \alpha + \gamma y_{t-1} + \Sigma \delta_i \Delta y_{t-i} + \varepsilon_t \quad \text{..... (1)}$$

Where Δy_t is the first difference of the series, y_{t-1} is the one-period lag, and ε_t is a white-noise error term. Where the ADF test failed to reject the null hypothesis at level, the series was first-differenced once ($\Delta y_t = y_t - y_{t-1}$) and the ADF test was reapplied to the

differenced series, the differencing order d being accordingly set to 1. Where the ADF test rejected the null hypothesis at level, the series was treated as stationery and d was set to 0.

Model identification: ACF and PACF

Once each series had been rendered stationary, its autocorrelation function (ACF) and partial autocorrelation function (PACF) were computed and plotted to twelve lags, together with the approximate 95% confidence band ($\pm 1.96/\sqrt{n}$), so as to identify plausible autoregressive (AR) and moving-average (MA) orders in the classical Box-Jenkins tradition: an abrupt cut-off in the PACF after lag p combined with a gradually decaying ACF indicated an AR(p) process, whereas the converse pattern, an ACF cutting off after lag q with a decaying PACF, indicated an MA(q) process. These plots were used to guide, and cross-check, the systematic grid search described below.

The ARIMA (p, d, q) model

An ARIMA (p, d, q) model expresses the d-th difference of a series, $wt = \Delta^d yt$, as a linear combination of its own past values (the autoregressive component of order p) and past forecast errors (the moving-average component of order q):

$$wt = c + \varphi 1 wt-1 + \varphi 2 wt-2 + \ldots + \varphi p wt-p + et + \theta 1 et-1 + \theta 2 et-2 + \ldots + \theta q et-q \quad \ldots\ldots\ldots (2)$$

where φi denotes the autoregressive coefficients, θj the moving-average coefficients, c a constant retained only for the stationary-at-level (d = 0) case, and et a white-noise error term. Model parameters were estimated by minimising the conditional sum of squared one-step-ahead errors (the Conditional Sum of Squares, CSS, estimator), a standard and numerically robust alternative to exact maximum likelihood for Box-Jenkins models.

Model selection: grid search and forecast-accuracy criteria

A systematic grid of ARIMA models spanning ARIMA (0, d,1) through ARIMA (1, d,5), that is $p \in \{0,1\}$ and $q \in \{1,2,3,4,5\}$, at the differencing order d established for each series, was estimated, yielding ten candidate models per series and sixty models in total across the six series. Each candidate was evaluated using, first, the Akaike Information Criterion [1]:

$$AIC = n \cdot ln(\hat{\sigma}^2) + 2k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where $\hat{\sigma}^2$ is the estimated residual variance and k the number of estimated parameters; and, second, four out-of-sample forecast-accuracy statistics computed on the five-year hold-out sample (2020-21 to 2024-25), with each model estimated on data through 2019-20 and used to forecast the withheld years:

$$RMSE = \sqrt{[(1/h)\,\Sigma(Yt - \hat{Y}t)^2]} \qquad MAE = (1/h)\,\Sigma|Yt - \hat{Y}t| \quad \ldots\ldots\ldots (4)$$

$$MAPE = (100/h)\,\Sigma|Yt - \hat{Y}t| / Yt \qquad MPE = (100/h)\,\Sigma(Yt - \hat{Y}t) / Yt \quad \ldots\ldots\ldots (5)$$

Where, Yt denotes the actual value and $\hat{Y}t$ the forecast value in hold-out year t, and h = 5 is the hold-out horizon. Because the model minimising in-sample AIC does not always minimise out-of-sample forecast error, a higher-order specification being prone to overfitting the training residuals, the best-fitting model for each series was chosen as the candidate with the lowest composite rank-sum across all five criteria (AIC, RMSE, MAE, MAPE and |MPE|, each ranked in ascending order across the ten candidates) rather than by AIC alone.

Forecast horizon

The selected the best ARIMA(p,d,q) specification for each series through the hold-out procedure described above, each model was re-estimated on the full 1950-51 to 2024-25 sample and used to generate point forecasts for the five crop years 2025-26 to 2029-30. All computations, including ADF testing, ACF/PACF estimation, CSS-based ARIMA estimation and forecasting, were carried out in Python (Google Colab).

Results and Discussion

Growth and variability in area, production and yield

Table 1 presents the descriptive statistics of the six series over 1950-51 to 2024-25, together with the compound annual growth rate (CAGR).

Table 1. Descriptive statistics of Arhar area, production and yield in India and Madhya Pradesh, 1950-51 to 2024-25 (area in '000 ha, production in '000 tonnes, yield in kg/ha)

Particulars	Mean	Std. Dev.	Min	Max	CV (%)	CAGR (%/yr)
India						
Area	3221.8	732.1	2181.0	5338.0	22.7%	+0.93%
Production	2346.8	744.8	1130.0	4873.0	31.7%	+1.01%
Yield	722.8	93.0	448.0	967.0	12.9%	+0.08%
Madhya Pradesh						
Area	412.3	107.1	151.0	690.0	26.0%	-0.95%
Production	325.2	129.7	125.0	839.0	39.9%	-1.02%
Yield	790.5	191.2	263.0	1323.0	24.2%	-0.07%

Note: CV = coefficient of variation; CAGR = compound annual growth rate.

During the last seven and a half decades, India's area of arhar and its production increased by 0.93% and 1.01% per annum, respectively; while yield remained almost unchanged (CAGR 0.08% per annum), the growth in arhar production over the past seven and a half decades was mainly due to area expansion. The CAGRs for area, production and yield in Madhya Pradesh were negative (−0.95%, −1.02% and −0.07% per annum respectively) and were significantly higher for all series in Madhya Pradesh than the corresponding series in India (coefficient of variance), indicating high volatility. MP's area and production experienced a clear boom with the peak values of about 690 thousand hectares and 839 thousand tonnes, respectively, between 2016-17 and 2018-19 which was followed by a significant decline to the lowest values ever recorded by 2024-25. This mismatch between the national, mature trend of a regional approach and the highly uncertain trend of the national structural approach is what drives the modelling approach that is carried out on a series basis below.

Stationarity of the series

Table 2 reports the ADF test statistics at level and, where applicable, at first difference.

Table 2. Augmented Dickey-Fuller unit-root test and order of differencing (d)

Series	ADF stat. (level)	5% crit. value	Decision @ level	ADF stat. (1st diff.)	d
India					
Area	0.795	-2.906	Non-stationary	-5.961	1
Production	1.266	-2.906	Non-stationary	-6.034	1
Yield	-2.026	-2.906	Non-stationary	-7.240	1

Series	ADF stat. (level)	5% crit. value	Decision @ level	ADF stat. (1st diff.)	d
India					
Madhya Pradesh					
Area	-1.787	-2.906	Non-stationary	-5.302	1
Production	-3.323	-2.906	Stationary	—	0
Yield	-2.496	-2.906	Non-stationary	-5.442	1

Five of the six series area, production and yield of India and area and yield of Madhya Pradesh failed to reject the null hypothesis of a unit root at level (the ADF statistic exceeded the 5% critical value of approximately −2.90 in each instance) and were therefore first-differenced (d = 1); the ADF test on the differenced series comfortably rejected the unit-root null in every case (statistics ranging between −5.30 and −7.24, well below the 1% critical value), confirming that a single round of differencing sufficed to induce stationarity. On other hand production of Madhya Pradesh rejected the unit-root null at level (ADF statistic of −3.32, below the 5% critical value of −2.91) and was accordingly modelled at d = 0, that is, as a stationary though highly volatile series fluctuating around a long-run mean.The ACF and PACF of the stationary transform of each series (first-differenced for all series except MP Production, examined at level) were inspected next. For most series, the ACF exhibited a sharp negative spike at lag 1, typical of a differenced trending series, with subsequent autocorrelations remaining largely within the 95% confidence band, while the PACF displayed a more gradual, damping pattern across several lags a signature consistent with a low-order mixed ARMA structure rather than a pure AR or pure MA process. This pattern motivated reliance on the systematic grid search (ARIMA(0,d,1) to ARIMA(1,d,5)) rather than on a single visually identified order, since several combinations of low AR and MA order appeared plausible from visual inspection alone.

Model identification and forecasts

This sub-section presents, for each of the six series, the ARIMA(0,d,1) to ARIMA(1,d,5) grid-search results, the selected best-fit model with its estimated equation, and the resulting forecast to 2029-30.

India: Arhar area

Table 3. Best model selection under arhar area in India

ARIMA (p,d,q)	AIC	RMSE	MAE	MAPE (%)	MPE (%)
(1,1,2)	740.44	342.41	324.80	7.45	-2.79
(0,1,2)	738.56	344.30	325.36	7.48	-2.94
(0,1,1)	746.56	344.65	325.58	7.48	-2.97
(0,1,3)	729.20	372.42	338.12	7.90	-4.79
(1,1,1)	748.56	344.73	325.62	7.48	-2.97
(1,1,5)	701.05	563.15	534.70	12.36	-5.59
(0,1,5)	703.11	578.72	491.93	11.66	-9.15
(0,1,4)	714.62	593.89	486.28	11.59	-10.88

ARIMA (p,d,q)	AIC	RMSE	MAE	MAPE (%)	MPE (%)
(1,1,4)	715.99	631.53	549.89	12.96	-11.13
(1,1,3)	721.66	728.08	569.10	13.63	-13.63

Note: Best model was arranged accordingly in descending order

The composite ranking across AIC, RMSE, MAE, MAPE and MPE identified ARIMA (1,1,2) as the best-fitting specification in India arhar area (AIC = 740.44; hold-out RMSE = 342.41; MAE = 324.80; MAPE = 7.45%; MPE = -2.79%). The fitted model, re-estimated on the full 1950-51 to 2024-25 sample, was:

$$\Delta Yt = -0.576\Delta Yt-1 + 0.131et-1 - 0.357et-2 + et$$

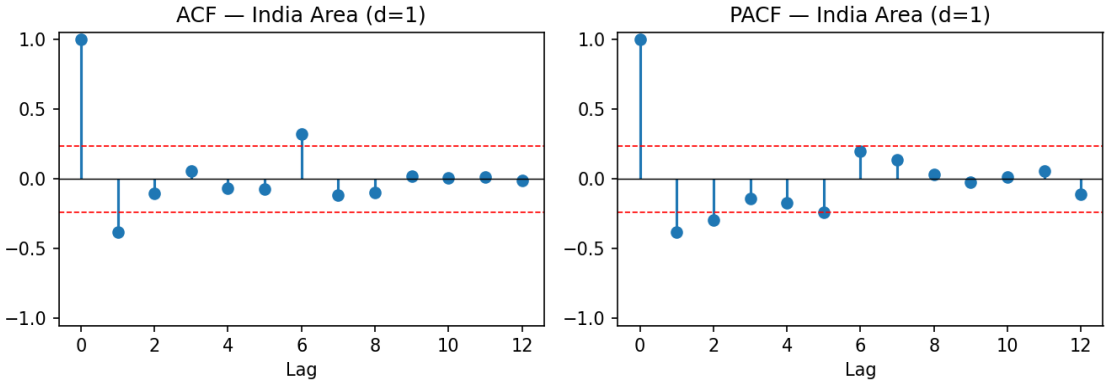


Figure 1(a). ACF and PACF of the stationary transform (d = 1) of India Arhar area, with 95% confidence band.

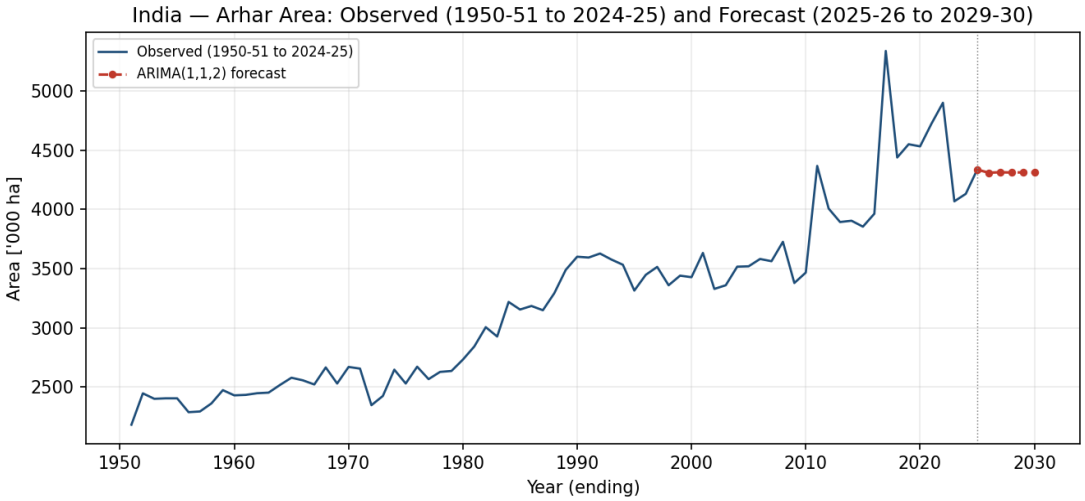


Figure 1(b). Observed (1950-51 to 2024-25) and ARIMA (1,1,2) point forecast (2025-26 to 2029-30) of arhar area in India

India's Arhar area is forecast to remain broadly stable, moving from 4,336 thousand hectares in 2024-25 to a range of 4,309–4,313 thousand hectares over 2025-26 to 2029-30, essentially a plateau close to the current level and consistent with an area series that, after decades of expansion, has entered a mature phase.

India: Arhar production

Table 4. Best model selection under arhar production in India

ARIMA (p,d,q)	AIC	RMSE	MAE	MAPE (%)	MPE (%)
(0,1,2)	808.60	418.95	386.66	10.10	-0.07

(0,1,1)	817.70	419.15	378.76	9.82	0.61
(1,1,1)	819.64	419.47	382.02	9.93	0.37
(1,1,4)	783.85	654.58	522.50	15.12	-14.90
(0,1,4)	781.88	655.88	525.58	15.20	-14.88
(1,1,3)	792.60	654.22	525.67	15.19	-14.77
(1,1,2)	807.39	631.26	534.83	15.26	-12.59
(0,1,5)	772.91	710.64	589.05	16.91	-15.62
(1,1,5)	759.72	901.81	738.74	21.25	-21.25
(0,1,3)	792.15	1047.07	903.84	25.67	-25.67

Note: Best model was arranged accordingly in descending order

The composite ranking across AIC, RMSE, MAE, MAPE and MPE identified ARIMA (0,1,2) as the best-fitting specification for India: Arhar production (AIC = 808.60; hold-out RMSE = 418.95; MAE = 386.66; MAPE = 10.10%; MPE = -0.07%). The fitted model, re-estimated on the full 1950-51 to 2024-25 sample, was:

$$\Delta Yt = -0.610et-1 - 0.042et-2 + et$$

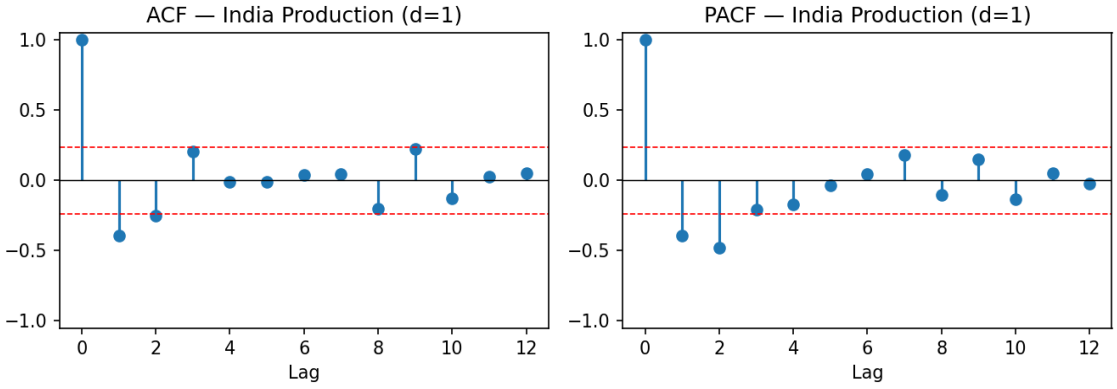


Figure 2(a). ACF and PACF of the stationary transform (d = 1) of India Arhar production, with 95% confidence band.

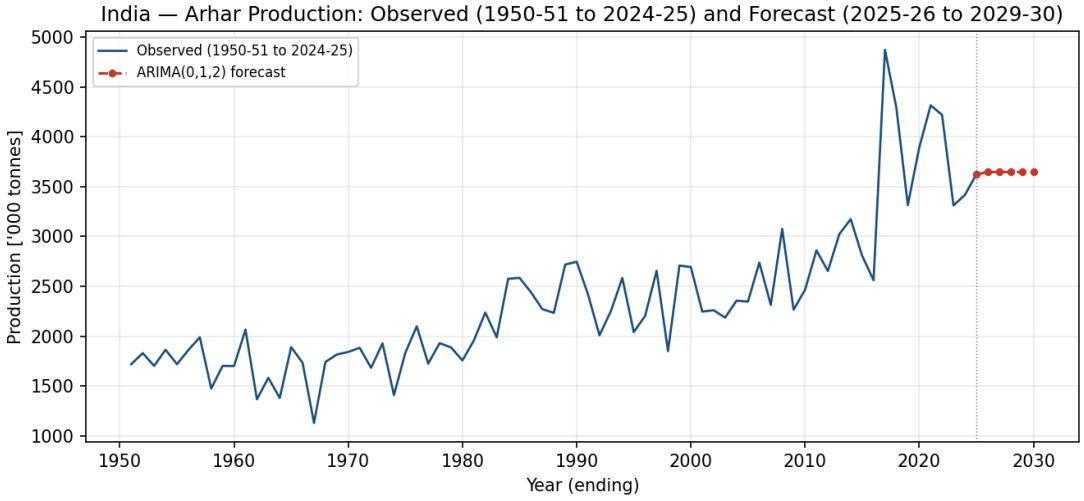


Figure 2(b). Observed (1950-51 to 2024-25) and ARIMA (0,1,2) point forecast (2025-26 to 2029-30) of arhar production in India

Arhar production in India would forecast to settle around 3,646–3,647 thousand tonnes across the forecast horizon, a modest adjustment from the 2024-25 level of 3,624 thousand tonnes and well below the historical peak of 4,873 thousand tonnes recorded in 2016-17, reflecting the model's expectation of continued year-to-year weather-driven fluctuation around a broadly flat trend rather than a repetition of the exceptional 2016-17 harvest.

India: Arhar yield

Table 5. Best model selection under arhar yield in India

ARIMA (p,d,q)	AIC	RMSE	MAE	MAPE (%)	MPE (%)
(0,1,5)	587.78	25.09	22.04	2.58	-0.61
(1,1,5)	589.29	25.45	22.84	2.67	-0.50
(0,1,4)	594.03	40.14	31.29	3.58	2.71
(1,1,3)	601.61	35.99	33.51	3.93	-0.75
(0,1,3)	599.85	38.06	34.98	4.11	-1.40
(1,1,4)	594.07	63.77	58.79	6.83	6.83
(1,1,1)	617.38	69.69	59.19	6.80	6.80
(1,1,2)	611.23	71.80	61.31	7.05	7.05
(0,1,1)	615.53	75.12	66.30	7.64	7.64
(0,1,2)	609.24	78.86	69.88	8.06	8.06

Note: Best model were arranged accordingly in descending order

The composite ranking across AIC, RMSE, MAE, MAPE and MPE identified ARIMA(0,1,5) as the best-fitting specification for India: Arhar yield (AIC = 587.78; hold-out RMSE = 25.09; MAE = 22.04; MAPE = 2.58%; MPE = -0.61%). The fitted model, re-estimated on the full 1950-51 to 2024-25 sample, was:

$$\Delta Yt = -0.872et-1 - 0.028et-2 + 0.282et-3 + 0.077et-4 - 0.153et-5 + et$$

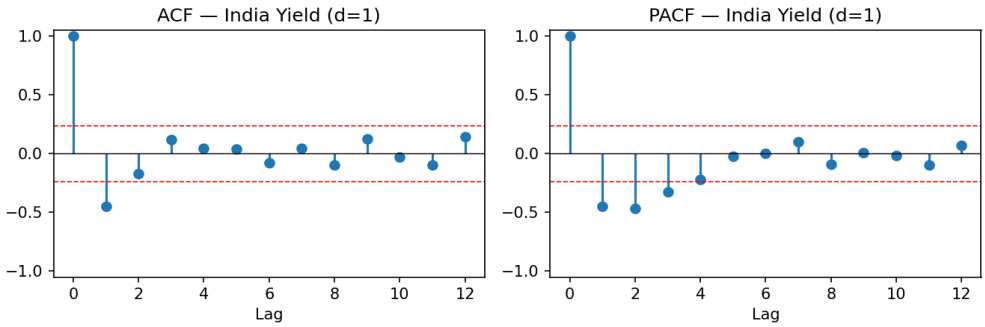


Figure 3(a). ACF and PACF of the stationary transform (d = 1) of India Arhar yield, with 95% confidence band.

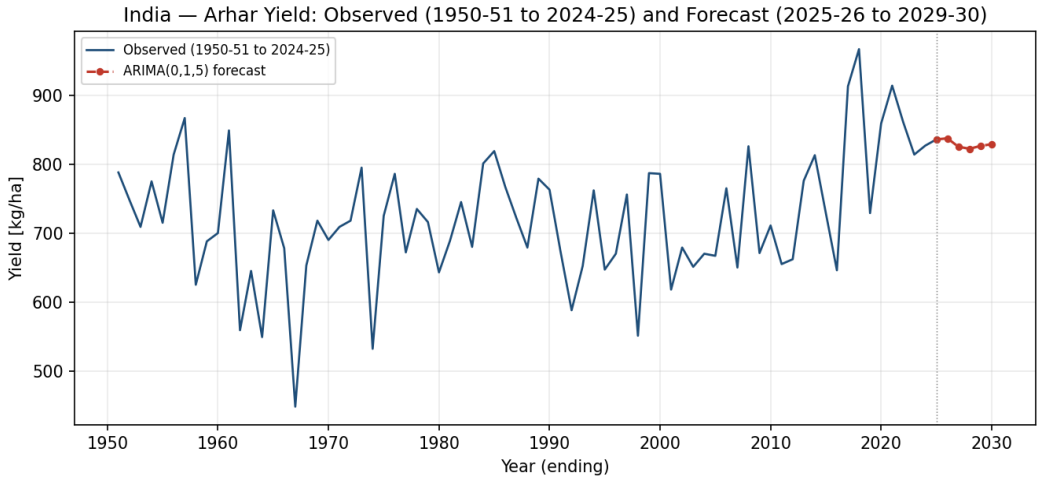


Figure 3(b). Observed India Arhar yield (1950-51 to 2024-25) and ARIMA(0,1,5) point forecast (2025-26 to 2029-30).

India's Arhar yield is forecast to hover within a narrow band of approximately 822–838 kg/hectare through 2029-30, close to but somewhat above its long-run mean of 723 kg/hectare, consistent with gradual, incremental productivity gains rather than an abrupt change.

Madhya Pradesh: Arhar area

Table 6. Best model selection under arhar yield in Madhya Pradesh

ARIMA (p,d,q)	AIC	RMSE	MAE	MAPE (%)	MPE (%)
(0,1,5)	518.23	102.36	90.85	47.08	-19.30
(0,1,1)	567.74	77.19	70.19	42.45	-42.45
(1,1,5)	519.40	140.50	103.72	65.23	58.92
(0,1,4)	532.87	159.55	110.75	53.15	-53.15
(1,1,1)	562.58	108.26	102.59	60.61	-60.61
(1,1,4)	522.98	216.12	188.17	114.22	-105.99
(0,1,3)	538.76	229.34	227.84	130.30	-130.30
(1,1,3)	545.87	243.20	241.43	138.32	-138.32
(0,1,2)	550.68	251.83	250.27	143.19	-143.19
(1,1,2)	552.68	252.60	251.05	143.63	-143.63

The composite ranking across AIC, RMSE, MAE, MAPE and MPE identified ARIMA (0,1,5) as the best-fitting specification for Madhya Pradesh: Arhar area (AIC = 518.23; hold-out RMSE = 102.36; MAE = 90.85; MAPE = 47.08%; MPE = -19.30%). The fitted model, re-estimated on the full 1950-51 to 2024-25 sample, was:

$$\Delta Y_t = +0.094e_{t-1} - 0.224e_{t-2} + 0.192e_{t-3} - 0.113e_{t-4} + 0.452e_{t-5} + e_t$$

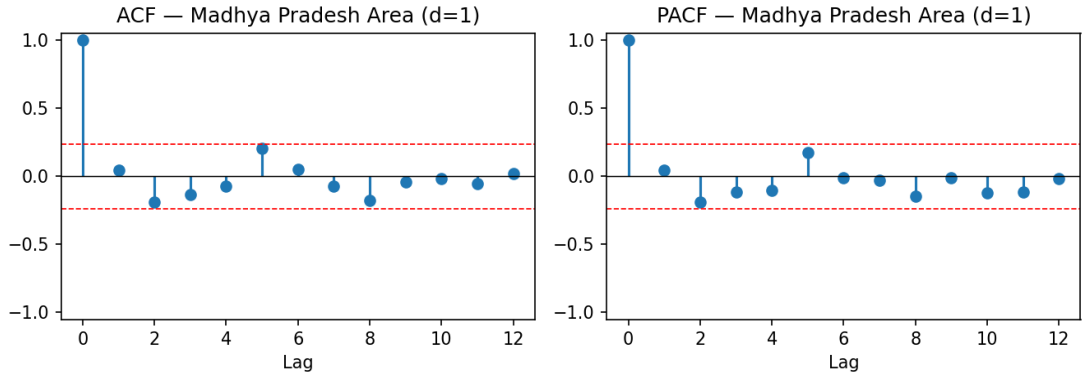


Figure 4(a). ACF and PACF of the stationary transform (d = 1) of Madhya Pradesh Arhar area, with 95% confidence band.

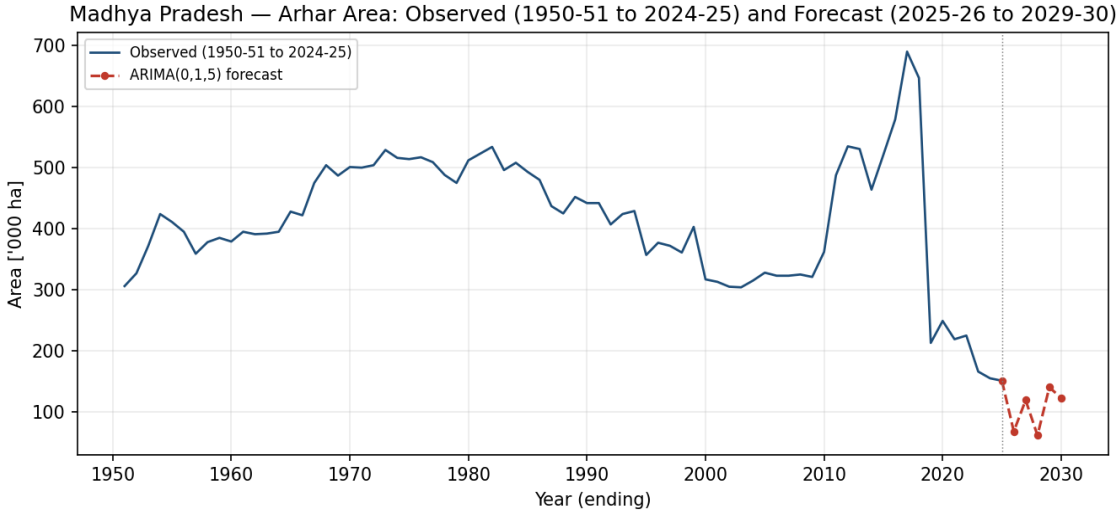


Figure 4(b). Observed (1950-51 to 2024-25) and ARIMA (0,1,5) point forecast (2025-26 to 2029-30) under arahar area of Madhya Pradesh

The area forecast of Madhya Pradesh is highly variable, ranging from about 62 to 140 thousand hectares for 2025-26 to 2029-30. The fact that all forecast values are well below the already depressed 2024-25 figure of 151 thousand hectares, which reinforces the message of area contraction, also provides a useful clue: the large range in forecasts suggests that the state has not reached a new and lower level, but continues on a downward trend, as implied by a low-order univariate ARIMA model estimated on a series that has recently experienced a dramatic structural drop (from 690 thousand hectares in 2016-17 to 151 thousand hectares in 2024-25). This forecast should thus be viewed as a suggestion or an indication of the continued weakness of direction and magnitude, not as a point forecast.

Madhya Pradesh: Arhar production

Table 7. Best model selection under arhar production in Madhya Pradesh

ARIMA (p,d,q)	AIC	RMSE	MAE	MAPE (%)	MPE (%)
(1,0,5)	622.58	154.94	125.84	91.44	-91.44
(0,0,5)	620.62	157.22	132.19	93.36	-93.36
(0,0,3)	635.12	159.73	130.88	98.45	-93.91
(1,0,2)	646.36	153.22	139.20	99.71	-94.88
(0,0,4)	628.60	168.93	133.37	102.01	-99.85

ARIMA (p,d,q)	AIC	RMSE	MAE	MAPE (%)	MPE (%)
(1,0,3)	620.26	160.39	154.56	104.62	-104.62
(1,0,4)	613.12	180.29	143.90	109.09	-106.50
(1,0,1)	652.90	163.08	147.03	105.70	-105.70
(0,0,2)	646.44	175.46	170.01	115.85	-101.84
(0,0,1)	657.03	178.41	171.89	117.80	-117.80

The composite ranking across AIC, RMSE, MAE, MAPE and MPE identified ARIMA (1,0,5) as the best-fitting specification for Madhya Pradesh: Arhar production (AIC = 622.58; hold-out RMSE = 154.94; MAE = 125.84; MAPE = 91.44%; MPE = -91.44%). The fitted model, re-estimated on the full 1950-51 to 2024-25 sample, was:

$$Yt = 253.940 + 0.211Yt-1 + 0.314et-1 + 0.262et-2 + 0.305et-3 + 0.112et-4 + 0.209et-5 + et$$

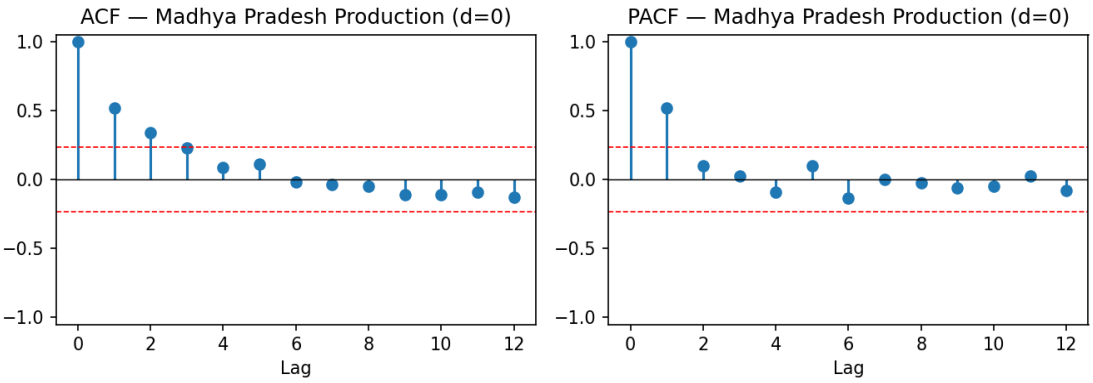


Figure 5(a). ACF and PACF of the stationary transform (d = 0) of Madhya Pradesh Arhar production, with 95% confidence band.

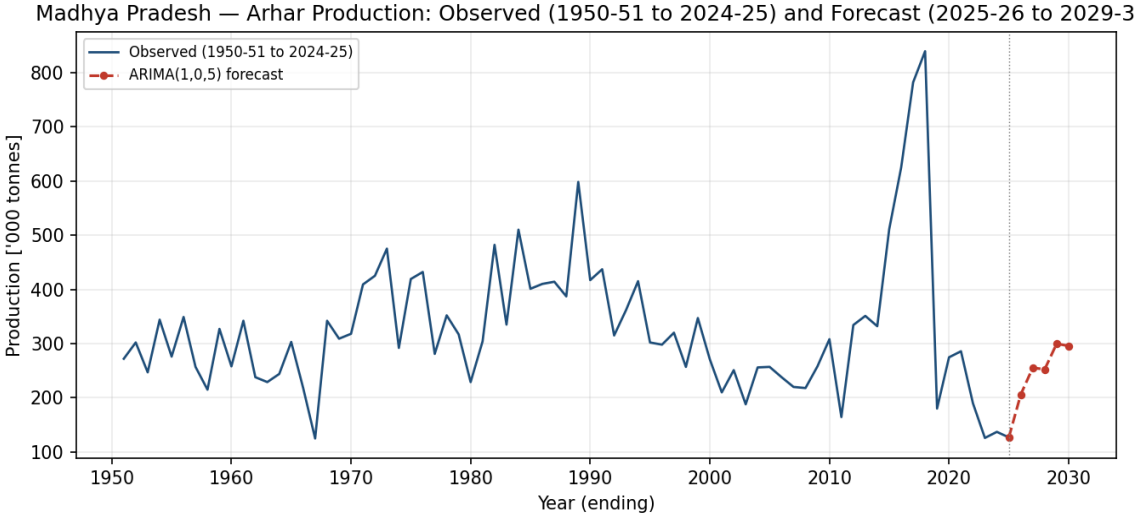


Figure 5(b). Observed Madhya Pradesh Arhar production (1950-51 to 2024-25) and ARIMA (1,0,5) point forecast (2025-26 to 2029-30).

Madhya Pradesh's Arhar production, modelled as a stationary, mean-reverting series, is forecast to recover somewhat from its 2024-25 trough of 127 thousand tonnes towards 206–305 thousand tonnes by 2029-30, gravitating back towards its long-run historical mean of 325 thousand tonnes. Given the extremely high hold-out MAPE (91%) obtained

for this series, this projected recovery should be regarded as indicative of the model's mean-reversion property rather than as a confident quantitative estimate.

Madhya Pradesh: Arhar yield

Table 8. Best model selection under arhar yield in Madhya Pradesh

ARIMA (p,d,q)	AIC	RMSE	MAE	MAPE (%)	MPE (%)
(0,1,4)	674.30	174.53	110.23	10.38	1.89
(0,1,5)	668.78	176.42	115.34	11.01	0.47
(1,1,5)	667.95	187.62	122.37	11.41	5.24
(1,1,4)	676.12	181.71	121.07	11.61	2.33
(0,1,3)	684.96	224.65	216.87	23.69	-14.40
(1,1,2)	694.17	226.86	222.61	24.77	-16.83
(0,1,1)	702.43	227.41	223.25	24.86	-16.99
(1,1,1)	703.81	230.16	225.81	25.09	-16.92
(1,1,3)	686.05	230.31	224.00	25.47	-19.16
(0,1,2)	692.88	230.60	226.63	25.27	-17.41

The composite ranking across AIC, RMSE, MAE, MAPE and MPE identified ARIMA (0,1,4) as the best-fitting specification for Arhar yield in Madhya Pradesh (AIC = 674.30; hold-out RMSE = 174.53; MAE = 110.23; MAPE = 10.38%; MPE = 1.89%). The fitted model, re-estimated on the full 1950-51 to 2024-25 sample, was:

$$\Delta Yt = -0.643et-1 - 0.117et-2 + 0.182et-3 - 0.306et-4 + et$$

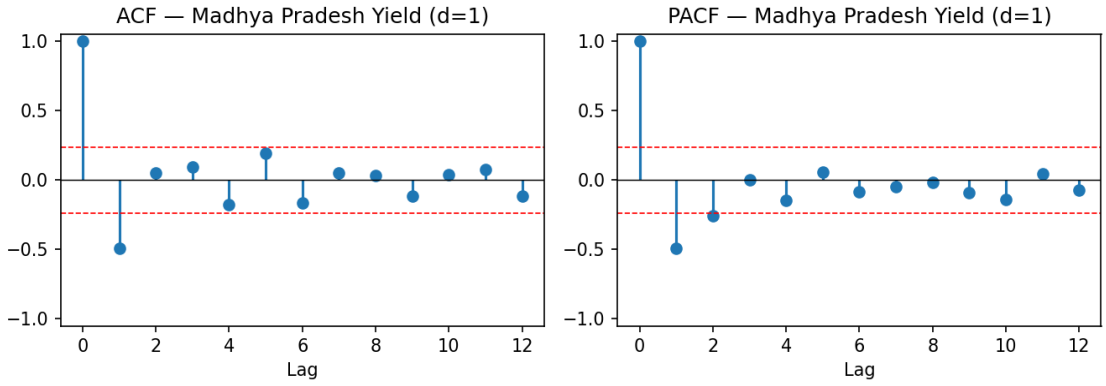


Figure 6(a). ACF and PACF of the stationary transform (d = 1) of Madhya Pradesh Arhar yield, with 95% confidence band.

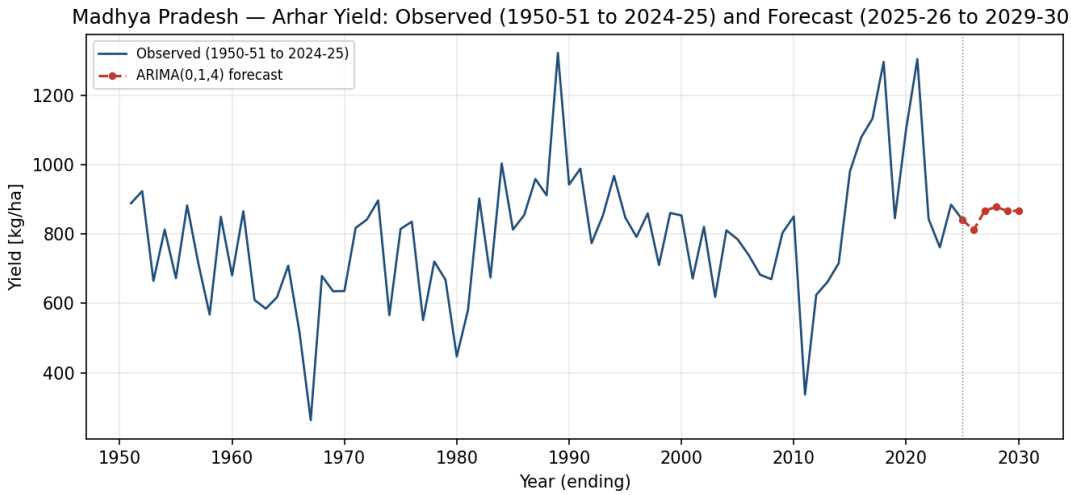


Figure 6(b). Observed (1950-51 to 2024-25) and ARIMA (0,1,4) point forecast (2025-26 to 2029-30) under arhar yield of Madhya Pradesh

Madhya Pradesh's Arhar yield is forecast to rise mildly from 842 kg/hectare in 2024-25 to a range of 812–879 kg/hectare over the forecast horizon, broadly consistent with its long-run mean of 791 kg/hectare and suggesting that, notwithstanding the collapse in area and production, per-hectare productivity on the remaining cultivated area is not deteriorating and may even be improving slightly, plausibly because cultivation is retreating towards more favourable, higher-yielding tracts.

Forecast and model adequacy

Table 9 consolidates the selected best-fit ARIMA order and its hold-out forecast-accuracy statistics for all six series, and Table 10 presents the consolidated point forecasts to 2029-30.

Table 9. Selected best-fit ARIMA model and hold-out (2020-21 to 2024-25) forecast-accuracy statistics, by series

Series	Best order	AIC	RMSE	MAE	MAPE	MPE
India						
Area	(1,1,2)	740.44	342.41	324.80	7.45%	-2.79%
Production	(0,1,2)	808.60	418.95	386.66	10.10%	-0.07%
Yield	(0,1,5)	587.78	25.09	22.04	2.58%	-0.61%
Madhya Pradesh						
Area	(0,1,5)	518.23	102.36	90.85	47.08%	-19.30%
Production	(1,0,5)	622.58	154.94	125.84	91.44%	-91.44%
Yield	(0,1,4)	674.30	174.53	110.23	10.38%	1.89%

Table 10. Point forecasts of Arhar area, production and yield, India and Madhya Pradesh, 2025-26 to 2029-30

Series	2025-26	2026-27	2027-28	2028-29	2029-30
India					
Area ['000 ha]	4309.6	4313.4	4311.2	4312.5	4311.8
Production ['000 tonnes]	3646.3	3646.9	3646.9	3646.9	3646.9
Yield [kg/ha]	837.5	825.2	822.4	826.5	829.0
Madhya Pradesh					
Area ['000 ha]	67.9	119.1	61.6	140.3	122.8
Production ['000 tonnes]	206.3	255.3	252.5	299.8	295.7
Yield [kg/ha]	811.6	867.4	878.7	867.1	867.1

Reported by MAPE, the India-level models performed well to very well (2.6% for yield, 7.5% for area and 10.1% for production, all comfortably within the conventional 'good forecast' range of below 10–20% used in the agricultural-statistics forecasting literature), whereas the Madhya Pradesh models performed markedly worse, particularly for area (47.1%) and production (91.4%). This asymmetry does not reflect a modelling artefact but rather a direct consequence of the underlying data: India's aggregate series are smoothed through averaging across many states and dominated by a gentle, persistent trend, whereas Madhya Pradesh's series had undergone a sharp, recent structural break (a boom followed by collapse in area and production after 2016-17) that a linear, constant-parameter ARIMA model, which implicitly assumes a stable estimated autocovariance structure over the sample, could not fully anticipate once that break fell within the hold-out window used for evaluation.

Discussion

The outcome conveys two separate yet complementary stories. First, at the national level, the Arhar economy seems to have reached a mature, low-growth state: Area and production have doubled nearly over the period 1950-51 to 2024-25, and are expected to remain similar to the current level by 2029-30; yield, on the other hand, has grown by only a small margin over the full seventy-five-year record period, and is projected to rise somewhat. Overall, this study is in line with the broader research and policy on Indian pulses which has consistently called for a shift in policy and research focus from expanding crop areas to improving productivity with technology development, such as new varieties, new farming practices, irrigation, and integrated pest management, in order to narrow India's structural pulses demand-supply gap (Vishwajith et al., 2018).More strikingly, the Arhar area and production in Madhya Pradesh went down to their lowest ever level in 2024-25, while the yield was relatively stable, indicating that the reduction is due to the farmers' decisions of how much area to allocate to Arhar compared to other crops rather than any deterioration in agronomic productivity per se (probably due to relative profitability vis-à-vis other crops like soybean and likely due to a decade of price and weather shocks). This contraction is also a structural break in the data series, and the India-level ARIMA forecasts indicate broadly stable yield along with continued weakness in area and production, but have significantly higher uncertainty relative to the India-level forecasts, including a higher MAPE when forecasting out-of-sample values. This is a widely recognised drawback of the Box-Jenkins methodology: a linear, constant-parameter model fitted on a full sample that includes a structural break will undershoot or overshoot the period around the break, as it would be unable to distinguish, just using a univariate series, between a real structural break and a large transient shock.

The results have two practical implications. Further extension of the total area in India may be better directed into policies aimed at demand management, such as buffer stock and price support, and policies aimed at yield improvement programmes, with the identified plateauing trend here. In the case of Madhya Pradesh, the steep fall in the area requires special attention to the relative agro-economic drivers behind this decrease; these factors range from relative crop profitability to the effectiveness of the minimum support prices, the procurement infrastructure, climatic and pest conditions, etc., and a policy and extension response should be based on the specific diagnostics of the state, as opposed to just taking a national average and applying it.Methodologically, the results also show a general lesson that model-selection criteria that promote in-sample fit (e.g., AIC alone) can lead to more flexible, higher-order models that may not necessarily perform well out-of-sample, especially for short, volatile series. One practical way to mitigate this bias is to make use of the composite ranking method that is used here, which combines AIC with out-of-sample RMSE, MAE, MAPE and MPE; however, as the results for Madhya Pradesh illustrate, no linear ARIMA model can completely replace structural or intervention-aware modelling once a series has actually experienced a regime shift.

CONCLUSION

Box–Jenkins ARIMA approach was used to model and forecast the area, production and yield of pigeon pea (Arhar) in India and Madhya Pradesh with the help of annual data for the period 1950–51 to 2024–25. Based on the results, the pigeon pea production in India is expected to be fairly stable during the forecast period till 2029–30 with area, production and yield having only marginal fluctuations from the recent trend. It indicates that there is a need for more productivity improvement in order to increase future production of pigeon pea at national level to meet the demand. The area and production of pigeon pea have, however, experienced significant reduction in the recent past in Madhya Pradesh as compared to Bihar. The out of sample forecast errors of relatively high magnitude for Madhya Pradesh, especially for area and production, also indicate that a conventional ARIMA model may not be very effective when structural changes occur in the production system. Hence, all the forecasts are only a suggestive baseline data for short term agricultural planning and the Madhya Pradesh estimates should be treated with care. Structural breaks and exogenous variables should be included in future studies by using intervention-based ARIMA/ARIMAX, regime-switching and hybrid ARIMA–machine-learning models and a systematic study of the underlying economic, climatic and technological factors that caused the reduction in the cultivation of pigeon peas in the State of Minas Gerais. These methods would help to make predictions more accurate and support more effective formulation of policies and long-term planning of pigeon peas.

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Five A for a Sustainable future: Nature based solutions for Ecosystem Conservation

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ABSTRACT

Nature-Based Solutions (NBSs) are integrated and sustainable approaches for conservation of biodiversity, soil health, ecosystem and climate resilience. These approaches are particularly important in the North Eastern Region of India due to its rich biodiversity and diverse traditional farming systems but there are limitations related to soil degradation, waterlogging, biodiversity loss, and climate variability. The present paper highlights the potential of the 5A approach-Agriculture, Apiculture, Aquaculture, Agroforestry, and Animal-based farming-as a nature-oriented strategy and tool for sustainable agriculture, conservation of resource and enhancement of rural livelihood with reference to initiatives undertaken by Central Agricultural University (CAU), Imphal, Manipur. The agricultural component promotes crop diversification, intercropping, composting, vermicomposting, green manuring and recycling of farm residues to improve soil organic matter, nutrient cycling, and water retention. Apiculture improves crop pollination and productivity as well as generates income, while aquaculture utilizes water resources productively. Agroforestry component contributes to biodiversity conservation by the process of erosion control, carbon sequestration and livelihood diversification. Animal-based farming (dairy and duckery) also complements other components through nutrient recycling and consumption of farm by-products, thereby strengthening integrated farming systems and reducing dependence on external inputs. A practical model of this approach is demonstrated at the Central Farm, Lamphelpat, Imphal, where CAU implemented an integrated farming model on previously underutilized, waterlogged land by integrating crop cultivation, aquaculture, apiculture, agroforestry, dairy, and duckery. The potential of the 5A approach to improve farm profitability, resource-use efficiency, biodiversity conservation and ecosystem resilience is highlighted for wider adoption, scientific research, indigenous knowledge, institutional collaboration and region-specific interventions to sustain agricultural development and livelihood security in the North Eastern Region.

Keywords: Ecosystem, 5A approach, Nature-based solutions, integrated farming system, soil health

Introduction

The International Union for Conservation of Nature (IUCN) suggested five categories of NBS as part of its conceptual framework, based on the ecosystem-based methodologies used. (i) restorative (ecological restoration, forest landscape restoration, and ecological engineering (ii) subject-specific (ecosystem-based adaptation and mitigation, ecosystem-based disaster risk reduction, climate sequestration services); (iii) infrastructure (natural infrastructure and grey infrastructure); (iv) management (integrated coastal management, integrated water resource management); and (v) protective (area-based conservation approaches, which include area management and other successful area-based conservation measures) (Cohen-Shacham *et al*., 2019).

India, particularly the North Eastern Region of India, which is among the biodiversity hotspots on the planet, is susceptible to anthropogenic and natural disruptions that risk the deterioration in the regional ecosystem. Focusing on NBSs in the Indian context needs to be expedited due to multiple factors such as:

1. wide scale degradation of the environment recently due to increasing population and rapid urbanization,

2. exceeding dependence of input-intensive agricultural production across agro-climatic zones in India leading to plausible exploitation of natural resources, and
3. frequent climate change led natural disasters like flood, drought etc.

North-East India is characterized by diverse agro-climatic and geographical situations. The region has remained economically backward, though there is ample potential for development due to the presence of abundant natural resources. Valleys are rich in organic matter but on a steep slope; because of the continuous removal of topsoil, organic matter status is poor to medium. The region is a hot spot of biodiversity. The aquatic bodies of the region harbour a rich diversity of ichthyo-fauna, 274 fish species belonging to 114 genera under 37 families and 10 orders constitute about 34% of the total freshwater fish species of the country.

In NER of India, 'Slash and Burn' form of agriculture known as 'jhuming' is prevalent in an area of about 0.88 million hectares (mha). Other predominant indigenous farming systems of the region are Zaboo farming in Nagaland, a pond-based farming system in Tripura, Assam and Manipur, Apatani rice-based farming system in Arunachal Pradesh and terrace rice



cultivation or wet rice cultivation in Sikkim and Nagaland. All these farming practices are organic by default and farmers use farmyard manure, green manure, composts and indigenous means of pest control for crop and vegetable production.

Rationale for adopting NBSs in Agriculture

It is increasingly becoming evident that sustainable alternative nature-based solutions that drive the agricultural production systems need to be adopted by the farming community to be prepared to address multiple challenges in the field of agriculture. Adaptation of NBSs in the field of agriculture can potentially benefit the Indian farming community in diverse ways, such as:

1. ensuring synergistic environmental conservation with economic growth of the farming communities and indigenous people,
2. addressing the issue of loss of agro-biodiversity caused due to agricultural intensification, and
3. Conservation of traditional nature-friendly land use systems developed with accumulated wisdom and insights with sound scientific rationale over many generations.

5A approach as Nature based solutions (NBSs)

"5A approach" comprises of Agriculture, Apiculture, Aquaculture, Agro-forestry and Animal Based Farming. The components of the 5A approach have been in practice among the farmers either in isolation or in combination with two to three components, using all five components on a single farm is very rare owing to diverse factors. It aims to explore the impact of this

approach in addressing issues related to natural resource conservation, potential ecosystem services that can be achieved, the biodiversity outcomes offered by the 5A approach and how it ensures health-promoting diet diversity for consumers.

1. Agriculture

NBSs in agriculture are purported to be efficient options to reverse the adverse environmental impacts caused due to modern high-input agriculture practices. Traditional agricultural practices also embody the centuries-old wisdom and beliefs of farmers who have been working with the environment for aeons with no external inputs, monetary resources, or scientific expertise. These farming techniques are inherently self-sufficient and coherent with the NBSs in agriculture. The constituent practices of Agriculture can be divided in the following three major categories:

1. Nutrient Management: This focuses on maintaining and enhancing soil fertility using natural methods. Key techniques include crop rotation, intercropping, and the use of green manure, compost, bio-inputs and other organic matter. The goal is to ensure healthy soil that can support crop growth without the need for synthetic fertilizers.

2. Pest and Weed Management: This involves using biological control methods and natural pest control techniques instead of synthetic pesticides. This includes using beneficial insects, trap crops, and other natural methods to manage pest populations and prevent damage to crops. Weed management focuses on preventing weed growth and using natural methods like mulching and crop rotation to control weeds.

3. Diversification and Resource Recycling: This involves diversifying farming activities to enhance resource utilization and reduce risk. This can include integrating livestock, agroforestry, and other farming practices. It also involves recycling farm waste, such as crop residues and animal manure, to enrich the soil and reduce waste. It is necessary to maintain proper co-ordination between natural assets and resources like soil, organic matter, biotic life and water for plant nutrient supply management for production at higher level.

Soil Health: A Foundation of Sustainable Agriculture

Soil health refers to the biological, chemical, and physical integrity of the soil. A healthy soil can support plant growth, maintain environmental quality, and promote plant, animal, and human health. Soil health is essential for long-term agricultural productivity and ecological balance.

Nature based farming directly supports and enhances soil health through several mechanisms:

Natural inputs like *Jeevamrut* promote the growth of beneficial microbes, decompose organic matter, more availability of nutrients to plants, preserves soil structure, improves water retention, reduces erosion and soil pollution.

Students research on characterization of jeevamrit on different days of decomposition revealed that Jeevamrit attains its peak nutritional and microbiological quality on the eighth day of fermentation, recording the maximum total N, P, K and micronutrient (Zn, Fe, Cu and Mn) content as well as the maximum bacteria, fungi and actinomycetes population, coinciding with a mildly acidic reaction of pH 5.1, before declining on further ageing up to Day 16. Application of 8 days old jeevamrit @ 750 litre ha^{-1} produced the maximum protein content in grain with 13.18% increase over absolute control. Thus, established that jeevamrit fermented for 8 days and applied at 750 litre ha^{-1} is the most effective combination for enhancing available soil nutrients, microbial population, growth parameters, yield parameters, nutrient concentration and their uptake by stover and grain and grain quality of chickpea grown in the acid soil of Manipur. 8 days old jeevamrit formulation @ 750 litre ha^{-1} can be recommended as a viable natural farming bio input for improving soil health and chickpea (variety- GNG 2299) productivity in acid soil of Manipur, in line with the growing emphasis on sustainable, chemical-free crop production.

In an experiment studied by Sarangthem *and Salam* (2005), "Recycling of farm and other plant residue as manure on French Bean (*Phaseolus vulguris*) as test crop", the farm waste is enriched

with micro-organisms (*Aspergillus niger*, *Trichoderma virid*, *Azatobacter*) and Vermicast (*Eudrilus eugeniae*). The composting raw material- paddy straw, grass weeds and fresh cowdung consists of 31.94 per cent carbon, 0.972 per cent nitrogen, 0.156 per cent total phosphate; 1.38 per cent nitrogen, 0.5 per cent P_2O_5, 0.68 percent K_2O; 31.94 per cent carbon, 0.15 per cent nitrogen, 0.1 per cent P_2O_5, and 0.05 per cent K_2O respectively. In a similar pot experiment entitled "Recycling of urban waste as manures on French bean as test crop" was conducted on french bean by Sarangthem and Salam (2008), where the urban waste was also enriched with micro-organisms (*Aspergillus niger*, *Trichoduma Viride*, *Azotobacter*) and Vermiculture (*Endrillus sp.)* The application of decomposed urban waste with total nitrogen 0.58%, 1.9% available phosphorus 0.45%-0.67% and available potash 1.4%-1.8% increased the yield of French bean to 228 gm/pot from 53 gm/pot of the control. The response on growth and yield of french bean (228g/ pot) was recorded higher in the decomposed manure enrich with vermiculture. Significantly highest ball yield of cabbage (17.89tha^{-1}) was recorded in treatment of vermicompost @3t ha^{-1} with Azospirillum which was closely followed with Vermicompost @ 2 t ha^{-1} plus Azospirillum in an investigation entitled "Cabbage productivity, nutrient uptake and soil fertility as affected by organic and bio sources" done by Sarangthem *et al.* 2011. Overall yield increased from treatment of vermicompost and FYM with Azospirillum (17.89, 13.98 t ha^{-1}) compared to single application of Azospirillum, vermicompost and FYM (7.73, 10.25, 10.32 t ha^{-1}) respectively. The increased cabbage yield in the treatment was attributed to the beneficial effect of combined use of organic manure with biosource (Azospirillum), which enhanced the nutrient availability.

2. Animal-based Farming

Animal-based Farming is a traditional and sustainable agricultural method that integrates the cultivation of crops with the rearing of livestock. Crop-livestock-based farming offers both environmental and economic sustainability. It provides farmers with multiple sources of income—from crop sales, dairy products, and even compost or bio-fertilizer production—thus reducing dependency on single crop yields. It also minimizes expenditure on chemical fertilizers, pesticides, and animal feed, since most resources are sourced from within the farm. This self-sufficiency improves the resilience of small and marginal farmers, especially in times of market volatility or climate stress. Ultimately, this integrated system supports food security, preserves natural resources, and promotes a more regenerative form of agriculture that aligns with nature rather than working against it. Animal based farming creates a resilient, regenerative, and eco-friendly agricultural system. It enhances productivity through natural processes rather than synthetic inputs, ensuring food security and sustainability for future generations.

3. Aquaculture

Aquaculture, in the context of farming, refers to the integration of fish farming with ecologically sustainable and chemical-free practices that align with the principles of natural or organic agriculture. Unlike conventional aquaculture, which often relies on synthetic feeds, antibiotics, and intensive systems, natural based aquaculture emphasizes harmony with nature, biodiversity, and minimal external inputs.

Case studies on fish-based IFS in North East India

Different scientists have conducted research on the importance of fish-based IFS in North East India. The farming system is beneficial in increasing farm income, creating employment opportunities and improving soil health. The system is useful in minimizing risk, encouraging biodiversity, reducing pesticide use and improving the ecosystem as a whole. Rautaray et al., 2013 revealed that rice-fish integrated farming system during the period from 2002-03 to 2006-07 as a whole generated Rs 47810/ha in deficit rainfall year 2006-07 to Rs 92828/ha in flash flood affected year 2004 with a mean of Rs 68962/ha. This is high compared to generation of Rs 12496/ha from traditional practice of growing high yielding rice variety in Sali season (Rautaray et al, 2005). Rice accounted 41% of the gross income followed by fish (34%), and horticulture (25%). The fishery component had higher income generation potential as the area allocated for

this component was only 17% (10% for pond and 7% for trench). Rice accounted 60% of the area but generated only 41% of the gross income. The mean rice equivalent yield for the period from 2002-03 to 2006-07 was 11.5 t/ha, which is higher than sole rice cropping 3 to 4 t/ha and double rice cropping 7 to 8 t/ha. Income is again expected to increase in the subsequent years from the produce of coconut, areca nut, and teak crops.

4. Agroforestry

Integrating agroforestry with conservation agriculture practices such as minimum tillage and crop rotation further boosts soil health, water retention, and carbon sequestration, demonstrating promising results for smallholder farmers in India.

Horticulture Research Farm, CAU, Andro, Imphal: Agri-horti-silvi-pastoral system which is the combination of agricultural crops, horticultural crops, multipurpose trees and shrubs are major components in Horticulture Research Farm, CAU, Andro. There is immense scope for the integration of fisheries under integrated agroforestry farming system. Further, the development of horticultural land use system with mixed horticultural crops including fruits and vegetables grown under optimum management conditions can be more remunerative on long term basis with least gestation cycle from Horticulture Research Farm, CAU, Andro. While utilizing the steep slopes, bunds, contour terraces and grassed waterways are major soil and water conservation measures required for proper land development. The different horticultural land use system at different elevation and selection of crops depends upon the altitude, soil and climatic condition/ local preferences and marketability.



View of HRF, CAU, Andro

i) **High hills**: 800-890m above MSL (Temperate fruit crops like low chilling apple and pear)
ii) **Mid hills**: Below 840-860m (Subtropical fruit crops like mandarin, sweet orange, litchi, pineapple, amla and vegetable like, sweet potato, tapioca)
iii) **Foot hills**: 740-820m above MSL. Foothill areas of hills (Tropical fruit like mango, papaya, guava, banana, papaya, amla, jackfruit, treebean, dragon fruit and vegetable like, king chilli, water melon and cole crops and agriculture crops like soyabean, groundnut etc.).

Thus, different components of agro-forestry system under Agri-horti-silvi-pastoral system from Horticulture Research Farm, CAU, Andro play an important role in the soil conservation as well as income generation for the livelihood for the people of Manipur.

5. Apiculture

Apiculture, or beekeeping, is an essential component of NBSs that significantly contributes to the ecological balance and productivity of agricultural systems. Natural pollinator improved crop quality and quantity without relying on artificial methods, making apiculture an integral part of sustainable farming practices. A sustainable, integrated approach between apiculture and agri-horticulture is essential to ensure mutual benefits and secure food, nutrition, and economic security.

Scientific Beekeeping: AICRP on Honey Bees and Pollinators, COA, CAU, Imphal: 1108 beneficiaries from different districts of Manipur have started scientific beekeeping of Apis *cerana himalaya* with a significant increase in the knowledge regarding various aspects of beekeeping. CAU recommended technology of bee hive design of ISI A-type is being adopted by 402 beekeepers from all districts of Manipur, with highest percentage of adoption from Ukhrul district 47.06%. Superior strains of Apis cerana himalaya from these beekeepers were identified for future breeding programme. One beneficiary has established the production unit

of quality bee hives recommended by AICRP (HB&P), COA, CAU, Imphal (M. Modhu Furniture, Yairipok Yambem deals in manufacturing modern wooden bee hive). Thotmaya, Beekeeper from Ukhrul trained in scientific beekeeping from CAU, Imphal deals in manufacturing beekeeping equipments under the name T. Thotmaya Beekeeping Centre. Two startups on honey production marketed under the names Shirui Wild Honey (Ukhrul) and Tampha Lairembi Mashaigol Khoihee (Wangoo) after gaining knowledge and skill of honey processing and marketing from the training programme imparted through the project. United Horticulture & Beekeeping Cooperative Society, Wangoo Laipham, Kakching district-initiated sales of honey, honey comb, beeswax candle acquiring the value addition skill from the training programme



Scientific Beekeeping at CAU, Imphal

5A Concept adopted at Central Farm, Lamphelpat, Imphal, Manipur

Over the last five years, the Central Farm at Lamphelpat, Imphal (24°49'15.8"N 93°54'03.4"E) has been redeveloped (Figure 2). The 14-hectare plot of land is part of the Imphal Valley's catchment basin, which experiences severe flooding and subsequent water logging after the rainy season. Due to waterlogging, the area was primarily useless before the concept's execution. It was made up of several eutrophicated ponds that had been exposed to aquatic weeds, leaving them unsuitable for aquaculture. Representative satellite imagery from Google Earth as of June 1st, 2021, clearly substantiates the situation of the land patch. The Central Agricultural University Team took on the task of turning this idle land area using the 5A approach.

Central Farm's comparative development based on the 5A approach, aquaculture play the central pillar of the concept. The natural ponds were cleaned and excavated. The marshy mud excavated was used to reclaim the farm area and to change the topography to cultivate it for crop planting (Agriculture). Because the area is organic by default, no chemical fertilizers were used to cultivate the crops. Crops included cereals such as black rice, annual vegetables, spices, and plantation crops such as papaya and banana, ensure optimal pollination, "Apiculture" was used judiciously.

To make the farm self-sufficient in terms of farm inputs such as manure, an "Animal-based model" was built in the form of a Dairy unit and a Duckery unit. Agroforestry has recently received attention, with plantations of Tree Bean, Oil Palm, and Dragon Fruit.



Aerial view of CAU Central Farm



5A Model: Natural Farming Model developed at CAU, Central Farm







Layout of the Farm Developed based on the 5A Approach

Table 01: Plant/Animal Species grown/reared at the Central Farm as per the 5A Approach

Categories	**Crops/Animal Species**
Cereal Crops	*Zea mays* (Maize), *Oryza sativa* (Paddy)
Floriculture Crops	*Chrysanthemum* sp, *Gladiolus* sp, *Nelumbo nucifera* (Lotus)
Fodder Crops	*Bajra-Napier, Oat, Sorghum*
Fruit yielding crops	*Moringa oleifera* (Drum stick), *Ananas comosus* (Pineapple), *Carica papaya* (Papaya), *Psidium guajava* (Guava), *Citrus sp* (Lemon), *Mangifera indica* (Mango), *Selenicereus undatus* (Dragon fruit)
Medicinal and Aromatic Plants	*Ocimum sanctum* (Tulsi), *Azhadiracta indica* (Neem)
Pulses and Oilseeds	*Glycine max* (Soybean), *Cicer arietinum* (Chickpea), *Arachis hypogea* (Ground nut), *Brassica juncea* (Mustard)
Spices	*Zingiber offcianale* (Ginger), *Curcuma longa* (Turmeric)
Tuber crops	*Cassava*
Vegetables	*Lagenaria siceraira* (Bottle gourd), Cabbage, Cauliflower,
Indigenous underutilized edible plants	*Pshophocarpus tetragonolobus (Winged Bean), Neptunia oleracea (Water mimosa), Ipomea aquatic (Water spinach), Parkia roxburghii (Tree Bean), Black rice, Syngonium podophyllum (Arrow head, King Chilli*
Animals	*Indigenous cows*
Aquaculture	*Ngton (Local Fish), Pengba, Silver carp, Grass Carp, Sareng (Local Fish)*

Economic impact assessment of the IFS unit in Central Farm, Central Agricultural University, Lamphelpat, Imphal West, Manipur (Area=30 Acres)

Table 02: Economic Assessment of IFS of Central Farm, CAU, Imphal

Economic Metric / Year	2021-22	2022-23	2023-24	2024-25
Total Cost of Cultivation	43704	40617	38130	35300
Gross Return	96549	115434	122875	126140
Net Return	52845	74817	84745	90840
Benefit-Cost Ratio	1.20	1.84	2.22	2.57

Conclusion

Nature-Based Solutions (NBSs) offer a comprehensive and sustainable approach to agriculture by integrating diverse practices such as the 5A approach-Agriculture, Apiculture, Aquaculture, Agroforestry, and Animal-based farming. These systems enhance soil health, conserve biodiversity, and promote ecosystem services while reducing reliance on chemical inputs. By restoring natural nutrient cycles, improving water retention, and supporting pollination, NBSs help maintain resilient and productive agroecosystems. This holistic integration is especially crucial in biodiversity hotspots like India's North Eastern Region, where environmental degradation threatens traditional farming and ecological balance.

Furthermore, agroforestry and apiculture play vital roles in strengthening food security and farmer livelihoods by providing diversified income sources and fostering climate resilience. Animal-based farming and nature-based aquaculture complement these efforts by promoting sustainable resource use and ecological harmony. Together, these nature-inspired practices contribute to long-term socio-economic benefits, environmental sustainability, and climate change mitigation. Embracing NBSs is essential for building regenerative agriculture systems that ensure the health of the planet and the prosperity of farming communities.

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Edible Coatings for Horticultural Crops: A Sustainable Approach to Safeguarding Food and Nutritional Security of Bharat

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ABSTRACT

Horticultural crops are vital sources of essential vitamins, minerals, antioxidants, and bioactive compounds; however, significant post-harvest losses reduce their availability, nutritional value, and economic returns. Edible coating technology offers a promising, sustainable solution to address these challenges. Biodegradable coatings based on natural polymers such as chitosan, alginate, starch, cellulose, proteins, and plant-derived compounds can form protective barriers that reduce moisture loss, respiration, oxidation, ripening, and microbial spoilage. Incorporation of natural antioxidants, essential oils, plant extracts, and nano-enabled ingredients can further enhance coating performance and nutritional preservation. By extending shelf life and maintaining quality, edible coatings can increase the effective availability of fruits and vegetables without requiring additional production resources, thereby contributing directly to food and nutritional security. The technology also has potential to reduce dependence on synthetic preservatives and conventional plastic packaging, supporting environmentally sustainable and circular food systems. Development of low-cost, locally adaptable coating formulations can particularly benefit small and marginal farmers, farmer-producer organisations, and rural enterprises by reducing post-harvest losses and enhancing value realization. Integrating edible coatings with cold-chain infrastructure, smart packaging, and advanced quality-monitoring technologies can further strengthen India's post-harvest management system. Thus, edible coating technology represents a practical and sustainable intervention for **reducing food loss, preserving nutritional quality, enhancing farmer income, and safeguarding the food and nutritional security of Bharat**.

Keywords: Edible coating, horticultural crops, post-harvest loss, nutritional security, food security, sustainable preservation, Bharat.

1. Introduction

Horticulture forms the backbone of agricultural diversity and nutritional security in Bharat (India). Fruits, vegetables, and commercial horticultural commodities supply vital micronutrients—including ascorbic acid, carotenoids, polyphenols, dietary fiber, and essential minerals—necessary to combat hidden hunger and chronic malnutrition across urban and rural demographics. India stands as one of the world's leading producers of fresh fruits and vegetables; however, a substantial portion of this harvest fails to reach consumers in an edible or nutritious state.

Post-harvest losses (PHL) in Indian horticulture are estimated between 15% and 30% annually, driven by physiological degradation, rapid respiration, transpiration, mechanical damage, and microbial decay. These losses represent not only a reduction in physical food volume but also a severe wastage of land, water, energy, and labor resources invested during pre-harvest cultivation. Furthermore, post-harvest deterioration severely diminishes farmer income, destabilizes market prices, and restricts regional and international export opportunities.

Traditional post-harvest preservation relies heavily on synthetic chemical fungicides, cold storage, and non-biodegradable petroleum-based plastic packaging. While synthetic

preservatives present environmental toxicity and food safety concerns regarding chemical residues, single-use plastic packaging exacerbates municipal waste management crises. Low-temperature storage, though effective, remains resource-intensive and often inaccessible to resource-constrained small and marginal farmers due to supply chain disruptions and intermittent power grids in rural sectors.

Edible coatings have emerged as an eco-friendly, non-toxic, and economically feasible post-harvest intervention. Applied directly onto the surface of fruits and vegetables by dipping, spraying, or brushing, these thin layers of edible biopolymers function as semi-permeable barriers to gases (O2 and CO2) and water vapor. When functionalized with natural bioactive additives, essential oils, or nano-structures, edible coatings actively inhibit pathogen proliferation and retard enzymatic browning. This review critically synthesizes the functional materials, mechanisms of action, active additive integrations, socio-economic impacts on smallholders, and future integration paths for edible coating technologies within Bharat's post-harvest ecosystems.

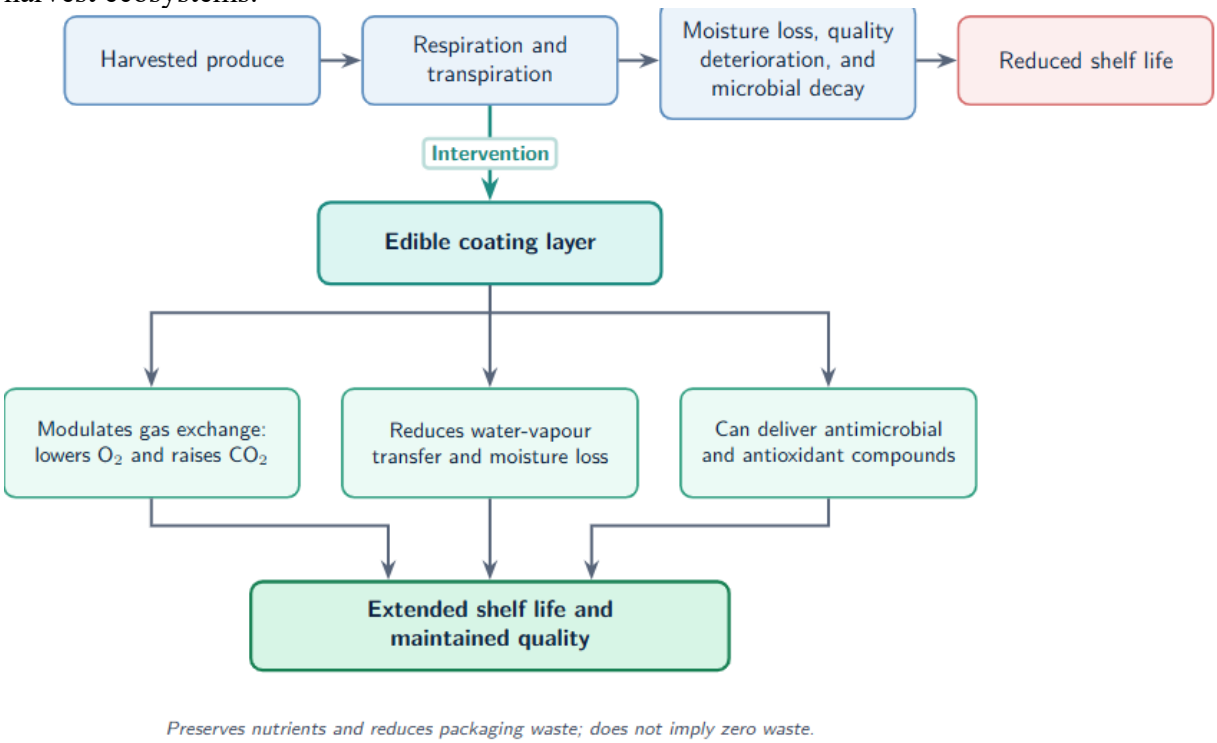


Fig.1. Edible coating can enhance the shelf life

2. Classification and Functional Properties of Edible Coating Materials

Edible coatings are formulated from naturally derived hydrocolloids, lipids, or multi-component composite mixtures. The selection of the structural polymer matrix determines the mechanical strength, gas permeability, and moisture barrier properties of the coating layer.

Table 1. Classification of edible coating

Biopolymer Category	Specific Materials	Primary Functional Advantage	Key Limitations
Polysaccharides	Chitosan, Sodium Alginate, Starch, Pectin, Cellulose derivatives	Excellent O2 and CO2 barrier; high structural integrity; intrinsic antimicrobial activity (Chitosan).	Poor water vapor barrier due to hydrophilic nature; requires plasticizers.
Proteins	Whey Protein Isolate, Zein (Corn),	Superior mechanical strength; strong gas	High water solubility; potential allergenicity

	Soy Protein, Gelatin, Casein	barrier at low relative humidity.	(e.g., soy, gluten, dairy).
Lipids & Waxes	Beeswax, Carnauba Wax, Shellac, Fatty Acids	Outstanding water vapor barrier; reduces transpiration and fruit shrinkage.	Opaque/waxy appearance; poor gas barrier; prone to cracking and anaerobic fermentation if applied thick.
Composites	Polysaccharide-Lipid, Protein-Lipid, Multi-layer Polyelectrolytes	Synergistic combination of moisture control (lipids) and mechanical strength/gas barrier (hydrocolloids).	Complex formulation process; potential phase separation during drying.

2.1 Polysaccharide-Based Coatings

Polysaccharides represent the most widely researched matrix materials due to their abundance, non-toxicity, and film-forming capabilities.

- **Chitosan:** Derived from deacetylated chitin, chitosan exhibits inherent broad-spectrum antimicrobial activity against fungi (*Botrytis cinerea*, *Penicillium digitatum*) and bacteria. It forms a transparent film that restricts oxygen diffusion, thereby suppressing respiration rates in climacteric fruits such as mango, papaya, and banana.
- **Alginate & Pectin:** Polyuronides extracted from brown algae and citrus peels, respectively, form rigid, ionically cross-linked gels in the presence of divalent cations (Ca2+). Calcium alginate coatings maintain cell wall structure by retarding pectin solubilization, thereby preserving tissue firmness.
- **Starch & Cellulose Derivatives:** Native and modified starches (cassava, potato, corn) and cellulose ethers (carboxymethyl cellulose [CMC], hydroxypropyl methylcellulose [HPMC]) yield clear, odorless films that effectively restrict gas exchange.

2.2 Protein-Based Coatings

Proteins contain 20 different amino acids, enabling diverse functional linkages (hydrophobic, hydrogen, disulfide bonds). Corn zein, wheat gluten, whey protein isolate (WPI), and gelatin form cohesive, flexible coatings with high oxygen barrier properties. However, their hydrophilic nature demands conjugation with hydrophobic lipids to prevent moisture absorption under high humidity conditions.

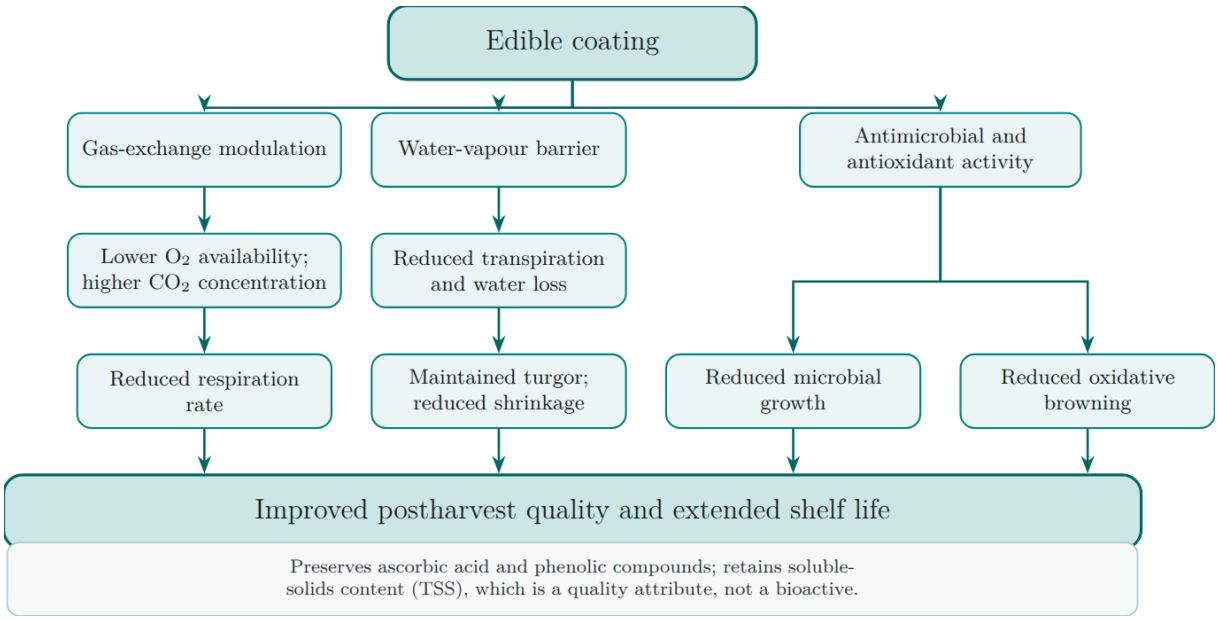


Fig. 2. Properties of edible coating

2.3 Lipid and Wax-Based Coatings

Lipids (carnauba wax, beeswax, candelilla wax, shellac, and mono/diglycerides) lack coherent film-forming properties independently but excel at retarding transpiration. Waxes are extensively utilized on citrus, apples, and stone fruits to restore natural wax removed during washing, impart high surface gloss, and prevent desiccation.

3. Functional Active Additives & Nano-Enabled Formulations

To convert passive physical barriers into active preservation systems, functional agents are encapsulated within the polymer matrix.

3.1 Essential Oils and Botanical Extracts

Natural plant extracts serve as sustainable alternatives to synthetic chemical fungicides:

- **Essential Oils (EOs):** Hydrophobic volatile compounds derived from thyme, oregano, clove, lemongrass, and cinnamon contain active phenols (carvacrol, thymol, eugenol). Incorporating EOs (0.1–1.0%v/v) into edible coatings disrupts microbial cell membranes, causing electrolyte leakage and cell death.
- **Botanical Extracts:** Extracts from indigenous plants such as Neem (*Azadirachta indica*), Aloe vera gel, green tea, and turmeric (*Curcuma longa*) provide potent antioxidant capacity. Polyphenolic compounds in these extracts scavenge reactive oxygen species (ROS), protecting horticultural produce from oxidative degradation and enzymatic browning.

3.2 Nano-Enabled Formulations

Nanotechnology enhances the mechanical, thermal, and barrier efficiency of edible coatings:

- **Nano-Emulsions:** Encapsulating hydrophobic essential oils within sub-micron droplet structures (20–200 nm) improves their solubility, thermodynamic stability, optical clarity, and sustained release kinetics without negatively impacting the sensory profile of the fruit.
- **Polymer Nanocomposites:** Reinforcing biopolymer matrices with nano-clays, cellulose nanocrystals (CNCs), or zinc oxide nanoparticles (ZnO-NPs) creates a tortuous path for diffusing gas molecules, drastically lowering water vapor and oxygen permeability while adding structural strength.

4. Mechanisms of Action in Quality Preservation

Edible coatings protect horticultural produce through interconnected physiological, biochemical, and microbiological pathways.

4.1 Gas Exchange Modulation & Respiration Suppression

Fresh produce continues respiration post-harvest, consuming internal sugars and organic acids according to the net reaction:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Heat}$$

Edible coatings act as semi-permeable membranes, creating a modified internal atmosphere (MIA) within the tissue by restricting O2 influx and retarding CO2 efflux. The reduced internal O2 concentration depresses the activity of key respiratory enzymes (such as cytochrome c oxidase), delaying peak respiration in climacteric fruits (e.g., mango, guava, tomato) and slowing down ethylene production (C2H4).

4.2 Moisture Barrier & Transpiration Control

Transpiration involves the movement of water vapor from internal fruit tissues to the external environment through stomata, lenticels, and micro-cracks. Moisture loss beyond 5–10% causes visible wilting, shriveling, loss of crispness, and direct economic weight loss. Hydrophobic lipid constituents or tightly cross-linked biopolymer networks lower the water vapor transmission rate (WVTR), maintaining turgor pressure and cell wall integrity.

4.3 Preservation of Bioactive Compounds and Nutritional Value

Post-harvest oxidative stress rapidly degrades vital nutrients, particularly L-ascorbic acid (Vitamin C), anthocyanins, carotenoids, and soluble phenolics. Edible coatings slow down nutrient breakdown by:

1. Minimizing exposure to atmospheric oxygen, thereby reducing the direct oxidation of ascorbic acid by ascorbic acid oxidase.
2. Maintaining total soluble solids (TSS) and titratable acidity (TA) balance by retarding the metabolic conversion of organic acids into sugars during prolonged storage.

4.4 Inhibition of Microbial Spoilage and Enzymatic Browning

Enzymatic browning occurs when polyphenol oxidase (PPO) and peroxidase (POD) catalyze the oxidation of endogenous mono- and diphenols into o-quinones, which subsequently polymerize into brown melanin pigments. Edible coatings act as physical barriers to external oxygen, inhibiting PPO activity. Concurrently, incorporated natural antimicrobials suppress the growth of post-harvest pathogens including *Colletotrichum gloeosporioides* (anthracnose), *Rhizopus stolonifer*, and *Aspergillus niger*.

5. Socio-Economic Impact and Sustainable Implementation in Bharat

The practical deployment of edible coating technology holds profound socio-economic and environmental implications for India's agricultural ecosystem.

5.1 Low-Cost Formulations for Smallholder Farmers and FPOs

Over 85% of agricultural landholdings in Bharat belong to small and marginal farmers. Complex industrial preservation systems are financially out of reach for this demographic. Edible coating formulations synthesized from locally available, low-cost agricultural by-products—such as fruit processing waste (citrus peel pectin, mango kernel starch), crop residues, and native gums (guar gum, gum arabic)—offer affordable solutions. Farmer Producer Organisations (FPOs) and rural self-help groups (SHGs) can adopt simple dip-coating or low-pressure spray setups at village-level primary processing centers, enhancing value addition right at the farm gate.

5.2 Synergistic Integration with Cold Chain and Smart Packaging

Edible coatings do not replace cold chains; rather, they act as an operational buffer.

- **Thermal Shock Protection:** Coated produce tolerates short-term temperature spikes during transport or market display significantly better than uncoated produce.
- **Smart Packaging Integration:** Combining edible coatings with Internet-of-Things (IoT) environmental sensors, optical colorimetric indicators, and smart storage units enable real-time tracking of fruit ripeness, microbial decay, and ambient humidity during transit.

5.3 Reduction of Plastic Waste and Advancement of Circular Bioeconomy

Conventional food packaging relies heavily on expanded polystyrene trays and polyethylene stretch films. Transitioning to biodegradable, bio-based edible coatings support a circular bio-economy. By utilizing agricultural residues as biopolymer feedstocks, this technology reduces municipal plastic waste while minimizing the environmental footprint of post-harvest supply chains.

6. Current Challenges, Regulatory Aspects, and Future Directions

Despite significant research, broad commercial scale-up of edible coatings in Bharat faces several technological and regulatory hurdles.

6.1 Technological and Scale-up Challenges

- **Coating Uniformity:** Achieving uniform coating thickness across irregular, hydrophobic fruit cuticles remains difficult. High viscosity can lead to uneven, thick layers that cause anaerobic fermentation and off-flavor development.
- **Drying Efficiency:** Industrial adoption requires rapid, energy-efficient drying systems (e.g., forced air, infrared drying) that fit into existing high-throughput washing and sorting lines.

6.2 Regulatory Frameworks and Food Safety

Edible coatings are consumed alongside the host commodity and must strictly comply with food safety standards set by the Food Safety and Standards Authority of India (FSSAI) and Codex Alimentarius.

- Ingredients must hold Generally Recognized as Safe (GRAS) status.
- Clear labeling is required if coatings contain potential allergens (e.g., soy proteins, casein, shellac) or animal-derived constituents (gelatin), which is particularly important for Bharat's vegetarian demographic.

6.3 Future R&D Priorities

- **Advanced Encapsulation Systems:** Developing stimulus-responsive nano-carriers (pH, humidity, or temperature-triggered release) for active ingredients.
- **Genomic and Metabolomic Profiling:** Studying the transcriptomic response of coated fruit tissues to optimize gas-barrier formulations for specific cultivars.
- **Indigenous Biomass Valorization:** Standardizing extraction protocols for underutilized regional biopolymers (e.g., jackfruit seed starch, *Moringa oleifera* gum, herbal mucilages).

7. Conclusion

Edible coating technology offers an eco-friendly, scalable, and effective solution to address post-harvest losses in Bharat's horticultural sector. By acting as semi-permeable physical barriers and active delivery systems for natural antimicrobials and antioxidants, these bio-based coatings preserve firmness, retain vital nutrients, and extend shelf life without relying on synthetic chemicals or single-use plastics. Extending the shelf life of fresh produce increases effective food availability without requiring additional land, water, or energy inputs. When tailored for rural deployment through FPOs and integrated with cold chain networks and smart monitoring tools, edible coatings can reduce post-harvest losses, boost rural income, and help safeguard the food and nutritional security of Bharat.

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Potential of North-East India for Plant Genetic Resources

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1. Introduction

North-East India is one of the most important regions of the country from the perspective of plant genetic resources (PGR). The eight states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura are characterised by highly diverse topography, climate, soils and ecosystems. The region lies at the interface of the Eastern Himalayas and the Indo-Burma region, two of the world's recognised biodiversity hotspots, and this position has contributed to exceptionally high biological and agricultural diversity. Tropical forests, subtropical vegetation, temperate ecosystems, wetlands, river islands and high-altitude habitats occur within a relatively small geographic area, providing favourable conditions for the evolution and maintenance of many different plant genetic resources.

Plant genetic resources include landraces, modern cultivars, wild and weedy relatives, primitive cultivars and other plant materials that carry useful genetic variation. They are the raw material on which all crop improvement depends. A breeder who wishes to develop a variety tolerant of flooding, resistant to a new race of a pathogen or richer in a particular nutrient can only succeed if a gene for that trait exists somewhere within the available germplasm. The wider and better conserved the gene pool, the greater the chance of finding it. North-East India is particularly valuable in this respect because its traditional farming communities have conserved many locally adapted varieties over generations. Farmers in the hills and valleys of the region have maintained rice, millets, pulses, vegetables, tubers, spices and fruits under agro-ecological conditions that are very different from those of the irrigated plains where modern agriculture is concentrated. The region is therefore important not only for biodiversity conservation but also for future crop improvement, food and nutritional security, climate resilience and sustainable agriculture. The ICAR-National Bureau of Plant Genetic Resources (NBPGR) has identified the North-East as an important area for exploration and collection of crop diversity, including rice, chilli, citrus landraces from Nagaland and other traditional crops (Roy et al., 2024).

2. Geographic, Climatic and Phytogeographic Setting

The North-Eastern Region covers roughly 2.6 lakh km^2, about 8% of the geographical area of India, yet it contains a disproportionately large share of the country's plant diversity. Estimates vary between sources, but the region is commonly reported to hold about half of India's flowering plant species. Several features of its geography explain this concentration of diversity.

Altitudinal range: Elevation rises from the Brahmaputra and Barak floodplains, which lie close to sea level, to the snow-capped peaks of Sikkim, where Kangchenjunga exceeds 8,500 metres. Within short horizontal distances, vegetation changes from tropical evergreen and semi-evergreen forest through subtropical and temperate forest to alpine meadow. Each altitudinal belt supports its own crops, wild relatives and associated species.

Rainfall and climate: The region includes some of the wettest places on Earth in the Khasi Hills of Meghalaya, where annual rainfall exceeds 11,000 millimetres, as well as drier rain-shadow pockets. Humid subtropical conditions prevail over much of the plains and foothills, while the higher ranges experience cold temperate and alpine conditions. This climatic mosaic favours the evolution of populations adapted to waterlogging, heavy rain, cold, acidic soils and seasonal drought.

Biogeographic position: North-East India is a meeting point of the Indian, Indo-Malayan, Indo-Chinese and Sino-Himalayan floras. Plant lineages from these different regions overlap here, and many species reach the limit of their distribution within the region. Vavilov's classic work on the centres of origin of cultivated plants placed Assam and Burma within the Indian centre, and the region remains central to discussions on the origin and early diversification of rice, citrus, tea, banana and several spices.

Soils and landforms: Alluvial soils of the river valleys, red and lateritic soils of the plateau and foothills, and acidic, humus-rich hill soils form a wide range of edaphic niches. Wetlands, river islands (such as the char areas of the Brahmaputra) and further habitats where distinctive flood-adapted rice and vegetables are grown.

The cultural landscape adds to this natural diversity. The region is home to a large number of ethnic communities speaking many languages, each with its own food preferences and farming practices. Because food culture shapes which seeds farmers keep, this human diversity has been an important driver of crop diversity. Together, the physical, biological and cultural features of the region make it one of the richest repositories of agricultural biodiversity in the country.

3. Rich Agro-Biodiversity of North-East India

The varied ecological conditions of North-East India have resulted in significant diversity of cultivated and wild plants. The region contains rich diversity of cereals, pulses, vegetables, fruits, spices, medicinal plants, bamboo, orchids and other economically important species. Habitats range from subtropical rainforests to alpine environments, supporting a wide range of plant taxa. An institutional overview of the region highlights its noticeable diversity of bamboos, orchids, rhododendrons, zingibers, medicinal and aromatic plants, as well as numerous agricultural landraces (Koku et al., 2020).

Traditional agricultural systems have played a major role in maintaining this diversity. Farmers have selected varieties according to local environmental conditions, taste, cooking quality, cultural preferences and resistance to environmental stresses. As a result, many landraces possess valuable characteristics that may not be present in modern high-yielding varieties. Landraces are not static relics. They are dynamic populations that continue to evolve under farmer selection, natural selection and gene flow from neighbouring fields and wild relatives, and this continuing evolution is itself an asset for adaptation to changing conditions.

The table below summarises the main groups of plant genetic resources found in the region and the kinds of material they offer to breeders and users.

Crop group	Examples from the region	Value for crop Improvement
Cereals	Rice landraces (upland, lowland, glutinous, aromatic, deep-water types), foxtail millet, finger millet, maize landraces, Job's tears	Stress tolerance, grain quality, aroma, nutrition
Pulses and oilseeds	Rice bean, cowpea, black gram, soybean landraces, perilla, rapeseed-mustard	Nutritional quality, adaptation to marginal land
Tuber crops	Colocasia (taro), Dioscorea (yam), sweet potato, Alocasia	Food security, climate resilience
Fruits	Citrus, banana, pineapple, jackfruit, guava, tree tomato, wild edible fruits	Fruit quality, disease and pest resistance
Vegetables and spices	Chilli (including King Chilli), ginger, turmeric, large cardamom, brinjal and cucurbit landraces	Pungency, pigment content, market and nutritional value
Plantation and economic crops	Tea, bamboo, cane, rubber	Quality, adaptation, new products

Medicinal, aromatic and ornamental plants	Curcuma, Zingiber, Piper, orchids, rhododendrons	Pharmaceutical, aromatic and horticultural uses

Beyond these domesticated crops, a very large number of wild edible plants, including leafy vegetables, shoots, tubers, flowers and fruits collected from forests and fallows, form part of the daily diet of many communities. These species are rarely included in formal statistics, but they represent an important and largely unstudied component of the region's genetic resources.

Several products of the region have also gained recognition under India's Geographical Indications framework, which reflects the link between local genetic resources, local environment and local knowledge. Examples include Joha aromatic rice and Karbi Anglong ginger from Assam, Chak-hao black rice from Manipur, Lakadong turmeric from Meghalaya, and Naga King Chilli. Such recognition shows how genetic diversity can be translated into livelihood opportunities for farming communities.

4. Rice Genetic Resources

Rice is arguably the most important crop for studying the genetic-resource potential of North-East India. It is the staple food of almost every community in the region and is cultivated under diverse conditions, including uplands, lowlands, terraces, jhum systems and deep-water environments. The region is considered a major hotspot of rice diversity and is regarded by many workers as part of the probable area of origin of Asian rice (Umakanth et al., 2017). It possesses numerous traditional cultivars, landraces and wild relatives.

4.1 Extent of diversity

Durai et al. (2015) reported that approximately 10,000 indigenous rice cultivars are associated with North-East India. These materials exhibit variation in adaptability, grain quality, aroma, nutritional properties and resistance to biotic and abiotic stresses. Earlier collection efforts had already resulted in thousands of rice germplasm accessions from the northeastern hill region, demonstrating the enormous reservoir of rice diversity present there.

In Assam, farmers traditionally recognise distinct rice seasons and ecosystems, each with its own set of varieties: autumn rice (ahu) grown on uplands, winter rice (sali) in rain-fed lowlands, deep-water rice (bao) in flood-prone areas, and summer rice (boro) in winter-spring irrigated or low-lying fields. In the hill states, jhum and terraced rice systems add further diversity, including cold-tolerant types for high altitudes.

4.2 Special-quality rice

The region is well known for rice with distinctive grain quality, many of which are tied to cultural identity and festival foods.

- **Aromatic rice**, such as Joha in Assam, valued for fragrance and cooking quality.
- **Glutinous or sticky rice**, widely grown and consumed in Assam, Arunachal Pradesh, Nagaland and Manipur for festival foods, rice beer and snacks.
- **Pigmented rice**, such as the black rice Chak-hao of Manipur, which contains anthocyanin pigments and attracts interest for its nutritional properties.
- **Ready-to-eat rice**, such as the Komal saul types of Assam, which can be softened by soaking in water without cooking.
- **Deep-water and flood-tolerant rice**, adapted to the Brahmaputra floodplain, which can elongate with rising water.

These attributes are rarely found together in the modern improved varieties, and each represents a trait that breeders could transfer into high-yielding backgrounds.

4.3 Wild relatives

The wild relatives of rice, including *Oryza rufipogon* and *Oryza nivara*, grow in wetlands, ditches and field margins in the region. Natural hybridisation between wild and cultivated populations has probably contributed to the diversity of the cultivated gene pool.

Because wild rice have often evolved in the presence of intense pest and disease pressure, they are potential donors of resistance genes that have been lost from cultivated rice during domestication and intensive selection.

4.4 Molecular evidence

Molecular studies have further confirmed the genetic richness of northeastern rice. Roy et al. (2024) Identified substantial genetic differentiation among aromatic and quality rice landraces from Assam, Manipur, Mizoram, Nagaland and Sikkim. Their study demonstrated the future use of these landraces for rice improvement, particularly for grain quality and adaptation. A related study of rice landraces in Nagaland also explored associations between ethnolinguistic groups and the genetic diversity of the rice they maintain, which underlines the point that cultural and genetic diversity are closely linked (Roy et al., 2024). Where a community's seed-keeping practices follow cultural lines, conserving the culture is part of conserving the genes.

5. Other Cereals, Millets, Pulses and Tuber Crops

Although rice dominates the farming systems of the region, many other field crops contribute to genetic diversity. These crops are often grown in small plots, home gardens and jhum fields, and they are mostly maintained by women farmers through informal seed exchange.

Millets and minor cereals: Finger millet, foxtail millet, sorghum and Job's tears (*Coix lacryma-jobi*) are traditionally grown in the hills, often as part of mixed cropping with rice, maize and vegetables. Buckwheat is grown in the higher altitudes of Arunachal Pradesh, Sikkim and Meghalaya. These crops tolerate poor soils and moisture stress, and they are rich in minerals and dietary fibre. With growing interest in nutri-cereals, the millet landraces of the region may become important sources of nutritional and climatic adaptation traits.

Maize: Local maize landraces, including types with different kernel colours and textures, are widely cultivated in the hills of Arunachal Pradesh, Nagaland, Manipur and Meghalaya. They show variation in maturity, grain colour, protein content and adaptation to acidic soils.

Pulses and legumes: The region maintains many landraces of rice bean (*Vigna umbellata*), cowpea, black gram, French bean, pigeon pea and local soybean forms, which are used as pulses, vegetables and fermented foods. Fermented soybean products are an important part of local cuisines in several states. Rice bean, which is grown in the hills of the region and other parts of South-East Asia, is a nutritionally rich but still underutilised legume, and it is a promising source of traits for pulse improvement in marginal environments.

Oilseeds: Rapeseed-mustard, sesame and perilla (*Perilla frutescens*) are grown in the region. Perilla seeds and leaves are used in traditional foods and are of interest because of their oil quality.

Root and tuber crops: Colocasia (taro), *Dioscorea* (yams), sweet potato, tapioca and several aroids are grown in home gardens and jhum fields. The region holds a wide range of local types, including those with different corm sizes, colours and culinary qualities. Tuber crops are a dependable food source in times of scarcity, and they are efficient converters of land and labour into calories on marginal soils. Wild yams and related species growing in forests also form part of the gene pool.

Mixed cropping systems: In jhum and homestead systems, farmers commonly grow many crop species together in the same plot, sometimes dozens of different crops in a single season. These systems not only conserve a wide range of crop species but also maintain intraspecific diversity, since farmers often keep several varieties of the same crop for different uses, soils and planting times. This stratification reduces risk and provides a continuous supply of food through the year.

Because these crops have received far less research attention than rice, wheat or maize, much of their diversity remains uncharacterised. Systematic collection, evaluation and documentation of these materials is a priority.

6. Source of Biotic and Abiotic Stress Resistance

One of the greatest potentials of North-East Indian plant genetic resources is their ability to contribute genes for resistance and tolerance to environmental stresses. Farmers have traditionally maintained varieties under conditions involving flooding, soil acidity, low temperature, moisture stress, poor soils and disease pressure. Over many generations, both natural and farmer selection have favoured plants that survive and yield under these conditions, so the landraces now carry adaptive gene combinations that are difficult to create through modern breeding alone.

6.1 Blast resistance in rice landraces

Rice landraces are particularly valuable for this purpose. Umakanth et al. (2017) evaluated 232 rice landraces from North-East India for resistance to rice blast, caused by the fungus *Magnaporthe oryzae*, at two blast hotspots, one in Hyderabad and one in Manipur, over two consecutive seasons. The landraces were also profiled using markers for 12 major blast-resistance genes. The study identified 84 resistant landraces possessing one or more known resistance genes, either singly or in combination. It also found seven resistant landraces that did not possess any of the tested genes, indicating the possibility of discovering novel resistance sources.

The authors went further and developed a core set of 33 landraces, built from molecular data, blast screening results and agro-morphological traits, which is intended to represent the diversity of the whole collection in a manageable number of lines. They also reported marker-trait associations for blast resistance and yield-related traits. A core set of this type is practically useful because breeders can test a few dozen lines rather than hundreds, and conservationists can prioritise material for safe duplication.

Blast is one of the most destructive diseases of rice, and the pathogen population changes rapidly, so resistance genes introduced into a variety can break down within a few years. A continuing supply of new and diverse resistance sources is therefore essential, and landraces that have co-evolved with the pathogen over long periods are one of the best places to look.

6.2 Other stress traits

Beyond blast, the genetic resources of the region are expected to contain useful variation for many other constraints:

- **Submergence and flood tolerance** in lowland and deep-water rice of the Brahmaputra and Barak valleys, where seasonal flooding is a recurrent hazard.
- **Cold tolerance** in rice grown at high altitude in Arunachal Pradesh, Sikkim, Nagaland and Manipur.
- **Tolerance of acid soils and low phosphorus**, which are widespread constraints in the hill regions.
- **Drought and moisture-stress tolerance** in upland jhum rice and millets.
- **Resistance to other diseases and pests**, including bacterial blight, brown spot, sheath blight and insect pests, which has been less systematically explored than blast resistance.
- **Tolerance of heat and nutrient-poor conditions** in fruit and vegetable crops grown under low-input systems.

Such genetic resources can be incorporated into breeding programmes to develop varieties better adapted to changing climatic conditions and emerging pest and disease pressures. The practical route usually runs through systematic phenotyping, marker-assisted introgression and, increasingly, genomic selection and gene discovery, all of which depend on first having well-characterised germplasm in hand.

7. Citrus and Horticultural Genetic Resources

7.1 Citrus

North-East India is an important reservoir of citrus diversity and is widely regarded as part of the centre of origin of the genus. Wild, semi-wild and cultivated citrus forms occur throughout the region. Hazarika (2012) reported considerable diversity of Citrus species, landraces and probable hybrids, many of which occur outside intensive commercial cultivation. The region's environmental conditions favour the maintenance of substantial citrus diversity.

Earlier surveys reported 17 species, 52 cultivars and seven probable natural hybrids from the region, and a later compilation raised the count to 23 species along with one subspecies and 68 varieties (see the karyological study of North-East Citrus species in Comparative Cytogenetics and the sources cited therein). Wild and endangered species such as *Citrus indica*, *C. macroptera*, *C. latipes*, *C. ichangensis* and *C. assamensis* persist in natural habitats, and the south and west hills of Meghalaya are reported to hold the greatest diversity of mandarin, pummelo, lemon and lime. The Khasi mandarin is the best-known commercial type of the region, and the Assam lemon is another locally important selection. Studies of citron (*C. medica*) populations in the Eastern Himalayan foothills have also revealed high genetic variation among natural populations, along with signs of decline in the wild stock.

This diversity has considerable potential for developing improved citrus varieties with desirable fruit characteristics and resistance to pests, diseases and environmental stresses. Wild species are also valuable as rootstocks, for their tolerance of soil and water stress, and as sources of traits such as cold hardiness and disease resistance. However, genetic erosion caused by changing land-use patterns and replacement of traditional crops with commercial crops threatens several citrus genetic resources. Deforestation, shifting cultivation with short fallow periods and farmer preference for more remunerative crops have all been identified as drivers of this loss (Hazarika, 2012).

The response has included in situ and ex situ measures. A citrus gene sanctuary was established in the Nokrek Biosphere Reserve in Meghalaya to protect wild populations in their native habitat, and the national gene bank system has been building a cryopreserved base collection of Indian citrus germplasm, in addition to field gene banks.

7.2 Other fruit and horticultural crops

Apart from citrus, North-East India possesses diversity in banana, pineapple, chilli, ginger, turmeric, tree tomato and numerous indigenous vegetables and fruits. These crops have potential for improving nutritional security and developing new horticultural enterprises.

- **Banana:** Wild *Musa* species and a wide range of local banana types grow in the region, along with related genera such as *Ensete*. Wild banana populations are potential sources of resistance to diseases such as Fusarium wilt and leaf spot, which threaten commercial cultivation worldwide.
- **Pineapple:** Traditional pineapple types, such as the Queen pineapples of Tripura and the Kew types grown in Meghalaya and Assam, are well adapted to hill conditions and have good processing and table qualities.
- **Chilli:** The Naga King Chilli, or Bhut Jolokia, is among the pungent chillies in the world and has received GI recognition. The region also holds numerous other local chilli types of differing pungency, colour and aroma.
- **Ginger and turmeric:** Local types such as Lakadong turmeric of Meghalaya, known for its high curcumin content, and many ginger landraces are important for both domestic use and trade.
- **Large cardamom:** Large cardamom (*Amomum subulatum*) is a major spice crop of Sikkim and parts of Arunachal Pradesh, and its local types are adapted to shaded, cool and humid hill conditions.

- **Other fruits:** Jackfruit, guava, passion fruit, kiwi, plum, pear, tree tomato and many wild edible fruits are grown or collected, and several of them show wide variation in fruit size, taste and ripening season.
- **Vegetables:** Local brinjal, cucurbits, leafy vegetables, beans, gourds and Solanum species form an essential part of home gardens and often possess unusual flavour or colour traits.

The horticultural genetic resources are particularly valuable because the crops are high-value and often vegetatively propagated, so a single superior clone can be multiplied and made available to farmers quickly. At the same time, vegetatively propagated material is vulnerable to loss, since it must be kept alive in the field year after year.

8. Medicinal, Aromatic and Underutilized Plants

8.1 Medicinal and aromatic plants

The region is exceptionally rich in medicinal and aromatic plants. Many indigenous communities traditionally use local plants for food, medicine and cultural purposes, and every state has its own healing traditions based on local flora. Species belonging to genera such as *Curcuma*, *Zingiber* and *Piper* have considerable economic and medicinal importance. The Zingiberaceae in particular are well represented, with many wilds and cultivated gingers, turmerics and related genera found from the foothills to the temperate zone.

The region's plant wealth also includes species of high value to the pharmaceutical, perfumery and cosmetic industries, such as agarwood-yielding *Aquilaria* species, various species of *Dioscorea*, *Taxus* (yew) in the Eastern Himalaya, *Swertia*, *Paris* and several aromatic grasses and herbs. Many of these are collected from the wild, and over-harvesting, habitat loss and unregulated trade have placed some of them under pressure. Scientific cultivation, domestication and certification of these species can reduce pressure on wild populations and provide income to local communities.

Ornamental plants form another high-value group. The region is rich in orchids, rhododendrons, primulas, begonias and other ornamentals, and these have substantial potential for floriculture, horticulture and eco-tourism. Bamboos are another characteristic feature of the region, with many species used for food, construction, handicrafts and industry.

8.2 Underutilized crops and wild edible plants

Underutilized crops and wild edible plants are also important components of the region's genetic resources. Millets, tuber crops, traditional vegetables, pulses and wild food plants may contain valuable nutritional and stress-adaptation traits. Greater research on these crops could contribute to dietary diversification and climate-resilient agriculture.

These species are often described as neglected, but in local contexts they are neither unknown nor unimportant. They are valued for taste, cultural significance, ability to grow without inputs and availability during lean periods. Examples include:

- Leafy vegetables and shoots gathered from forests, fallows and field margins, including bamboo shoots, which are consumed fresh and fermented.
- Wild fruits such as local species of *Docynia*, *Elaeagnus*, *Garcinia*, *Prunus* and *Rubus*, which are valued for flavour and as sources of vitamins and antioxidants.
- Minor millets, buckwheat and Job's tears, which are rich in minerals and grown with very few external inputs.
- Edible flowers, tubers and mushrooms that are traditionally collected and eaten seasonally.

The nutritional importance of such crops has been recognised increasingly in recent years, since they can supply micronutrients that are often lacking in diets based largely on polished rice. They also offer a route for developing new products, such as value-added foods, herbal formulations and natural colourants, from traditional resources.

However, the lack of systematic documentation, characterisation and seed supply systems restricts their use. Priority actions include collecting and cataloguing these species, evaluating them for nutritional and agronomic traits, and creating market linkages so that conservation is matched by livelihood benefits.

9. Crop Wild Relatives

Crop wild relatives (CWR) are wild species that are closely related to cultivated crops and can exchange genes with them, either naturally or through breeding. They have evolved without human management and have been exposed to a wide range of pests, diseases and climatic pressures. As a result, they carry genes for tolerance and resistance that are often absent from cultivated varieties. Examples from around the world include the use of wild relatives to introduce disease resistance into rice, tomato, potato and wheat, and North-East India offers a particularly rich set of such material.

The main groups of crop wild relatives found in the region include the following.

Crop	**Wild relatives and related species in the region**	**Possible use**
Rice	*Oryza rufipogon*, *O. nivara* and other wild rices of wetlands and field margins	Resistance to pests and diseases, stress tolerance, yield-enhancing alleles
Citrus	*Citrus indica*, *C. macroptera*, *C. latipes*, *C. ichangensis*, *C. assamensis*	Disease and cold tolerance, rootstock traits, fruit quality
Banana	Wild *Musa* species such as *M. balbisiana* and *M. acuminata*, and *Ensete*	Resistance to wilt and leaf diseases, drought tolerance
Tea	Wild and semi-wild *Camellia* species of the forests of Assam, Arunachal Pradesh and neighbouring areas	Quality, disease resistance, adaptation
Ginger family	Wild *Curcuma*, *Zingiber* and *Hedychium* species	Pigments, essential oils, disease resistance
Legumes and vegetables	Wild *Vigna*, *Solanum*, *Cucumis*, *Momordica* and *Abelmoschus* species	Disease resistance, nutritional traits
Sugarcane and bamboo	Wild *Saccharum* species and diverse bamboos	Stress tolerance, biomass, fibre properties

Wild relatives are often found in habitats that are shrinking quickly. Many occur in forests, wetlands, grasslands and field margins that are cleared, drained or converted to other land uses. Others are lost through hybridisation with cultivated forms, or through competition with invasive weeds such as *Mikania micrantha*, *Chromolaena odorata* and *Ageratina adenophora*, which have spread widely across the region.

As compared with cultivated crops, CWR remain poorly collected and poorly represented in gene banks, and their distributions and population sizes are often not well known. A gap analysis, which compares the geographic distribution of known populations against the material already held in collections, is a useful starting point for planning surveys. Conservation can combine protected areas and community-managed forests, which keep wild populations in situ, with targeted collection of seed or vegetative material for ex situ storage.

The use of wild relatives in breeding has become more practical with modern techniques, such as embryo rescue, marker-assisted backcrossing and genomic tools that can pinpoint useful alleles and reduce the negative effects of linked genes. Establishing pre-breeding programmes that bridge the gap between wild material and breeders' lines would help translate the potential of the region's CWR into actual crop varieties.

10. Indigenous Knowledge and Traditional Agriculture

An important but sometimes overlooked component of plant genetic resources is traditional knowledge. Indigenous and rural communities of North-East India have

accumulated knowledge about seed selection, crop cultivation, medicinal plants, wild foods and natural-resource management. This knowledge is passed on orally across generations and is embedded in language, ritual, festivals and everyday practice. It tells the community which variety suits which soil, how to read the seasons, how to store seed, and which wild plant treats which ailment.

Traditional farming practices have helped maintain locally adapted crop varieties over generations. Farmers often select seed based on traits such as maturity, grain quality, resistance, taste and suitability to particular soils. Therefore, conservation of plant genetic resources should involve local communities rather than relying exclusively on institutional gene banks.

10.1 Seed systems and the role of women

In most communities, seed is selected, stored and exchanged through informal networks of kin, neighbours and village markets. Seeds are commonly saved from the best plants or panicles, dried and stored in granaries, baskets, bamboo containers or above the hearth. Women play a central role in this process, being responsible for seed selection, storage and the management of home gardens, and they frequently hold detailed knowledge of the characteristics of dozens of varieties. Any conservation programme that overlooks women's knowledge and decision-making is likely to be less effective.

10.2 Shifting cultivation as a diversity-conserving system

Shifting cultivation, locally known as jhum, is often criticised for its environmental impact when fallow periods become short. In its traditional form, however, it is a complex system in which many crops are planted together in the same field and the land is left fallow for long enough to recover. This system maintains a high degree of crop and varietal diversity, and farmers use different varieties for different positions on the slope, different uses and different planting times. The challenge is to improve livelihoods and land productivity without losing the diversity that these systems conserve.

10.3 Cultural and ethnolinguistic links

Crop varieties are closely tied to food habits, rituals, festivals and social identity. Particular rices are reserved for ceremonies, brewing or gifting, and particular plants have ritual or sacred status. Sacred groves, which are patches of forest protected on religious grounds in several states, shelter many wild species and serve as informal in situ conservation sites. The reported association between ethnolinguistic groups and rice diversity in Nagaland (Roy et al., 2024) is one illustration of how cultural boundaries can shape the pattern of crop genetic diversity on the ground.

10.4 Documentation and protection

The knowledge held by communities is under threat as younger people migrate, languages shift and customary practices change. Documentation through community biodiversity registers, participatory characterisation and seed festivals can help to record and revitalise it. At the same time, documentation must be carried out with the consent of communities and with clear arrangements for benefit sharing, so that traditional knowledge is not exploited without recognition or reward. These issues are taken up again in the section on policy and legal frameworks.

11. Institutional Efforts in Exploration, Collection and Conservation

A network of national and regional institutions is involved in exploring, collecting, conserving and using the plant genetic resources of the region. The ICAR-National Bureau of Plant Genetic Resources (NBPGR) is the nodal agency for the management of plant genetic resources in India, responsible for plant exploration and collection, quarantine, characterisation, documentation and long-term conservation. Its National Genebank in New Delhi holds a large collection of seed and other germplasm under long-term storage conditions, and its cryopreservation facilities allow the storage of vegetatively propagated and recalcitrant-seeded species. The Bureau also maintains a regional station in Shillong, Meghalaya, which

serves as a base for exploration and short- and medium-term conservation of material from the North-East.

Other institutions contribute in different ways:

- **ICAR Research Complex for the North-Eastern Hill Region (Umiam, Meghalaya)** and its regional centres, which carry out evaluation and improvement of crops adapted to hill agriculture.
- **State agricultural universities and the Central Agricultural University (Imphal)**, which maintain germplasm collections, conduct breeding and run training programmes for farmers.
- **Specialised research centres**, such as the National Research Centre for Orchids in Sikkim and the tea research stations of Assam, which hold field collections of high-value crops.
- **The Botanical Survey of India and universities of the region**, which document wild flora and conduct taxonomic and ecological studies.
- **State biodiversity boards and non-governmental organisations**, which support community registers, seed fairs and local seed banks.

The record of work so far shows that exploration in the region has paid off. Collection missions have brought in thousands of rice accessions from the northeastern hill region, and NBPGR collection efforts have targeted rice landraces from Nagaland and other traditional crops (Roy et al., 2024). Subsequent evaluation of this material, such as the screening of 232 landraces for blast resistance (Umakanth et al., 2017), shows how collected germplasm can be turned into usable information for breeders.

Despite these efforts, important gaps remain.

1. **Incomplete coverage.** Remote areas, especially in Arunachal Pradesh, Nagaland and Mizoram, are still under-explored, and many minor crops and wild relatives are poorly represented in collections.
2. **Limited characterisation.** A large part of the stored material has been evaluated only for a few morphological traits. Detailed phenotyping and molecular characterisation lag behind collection.
3. **Duplication and safety.** Not all collected material is safely duplicated in long-term storage, and field gene banks are vulnerable to disease, flooding and neglect.
4. **Weak links to users.** Breeders and farmers often lack easy access to information about what is held in collections and how to obtain it.
5. **Documentation of passport data.** Passport information, including the collection site and the name of the community that conserved the variety, is sometimes incomplete, which limits the value of the accession and complicates benefit sharing.

Closing these gaps requires sustained funding, trained staff, better coordination among institutions and the active involvement of local communities.

12. Threats and Conservation Strategies

12.1 Threats

Despite its enormous potential, North-East India's plant genetic resources face threats from deforestation, habitat destruction, changing land-use patterns, modernization of agriculture, replacement of landraces, climate change and genetic erosion. Citrus genetic resources, for example, have been reported to face genetic erosion due to changing farmer preferences and increasing cultivation of introduced cash crops (Hazarika, 2012).

The main pressures can be grouped as follows.

- **Replacement of landraces.** Improved and hybrid varieties, promoted for higher yield, steadily displace traditional varieties. Once farmers stop growing a landrace, its seed is usually lost within a few seasons.

- **Changes in land use.** Expansion of monoculture plantations, settled cultivation in place of jhum, road and dam construction, urbanisation and mining reduce the area available to traditional crops and wild relatives.
- **Shortening of jhum cycles.** Growing population pressure has reduced fallow periods in many areas, leading to soil degradation and the loss of the crop mixtures that characterise traditional systems.
- **Climate change and extreme events.** Altered rainfall patterns, more intense floods, landslides and warming can wipe out local populations, and can push crops and wild species out of their present ranges.
- **Invasive alien species.** Fast-spreading weeds crowd out native vegetation, including wild relatives and medicinal plants.
- **Over-harvesting of wild resources.** Unregulated collection of valuable medicinal plants, orchids and wild fruits can deplete natural populations.
- **Loss of knowledge and changing food habits.** Out-migration of youth, the shift to purchased and polished-rice-based diets and the decline of seed-saving customs weaken the social basis of conservation.

12.2 Complementary conservation approaches

Both in situ and ex situ conservation are therefore necessary. In situ conservation maintains genetic diversity within natural ecosystems and traditional farming systems, whereas ex situ conservation involves seed banks, field gene banks, botanical gardens and tissue-culture facilities. Each approach has strengths and limits, and they work best together.

Approach	Methods	Main strengths	Main limits
In situ (natural habitats)	Protected areas, biosphere reserves, gene sanctuaries, sacred groves, community-conserved areas	Keeps species evolving with their environment; protects wild relatives and associated species	Hard to guarantee over the long term; vulnerable to land-use change and climate shifts
On-farm (traditional systems)	Farmers' continued cultivation of landraces, community seed banks, seed fairs, incentives for custodians	Maintains adaptation and local knowledge; keeps crops in use	Depends on livelihood incentives and market access
Ex situ seed storage	Long-term gene bank storage of orthodox seeds	Compact, safe and accessible for breeders	Stops evolution; unsuitable for recalcitrant or vegetatively propagated species
Field gene banks and botanical gardens	Living collections of fruit trees, spices, bamboos, tubers	Allows evaluation and direct use	Costly, vulnerable to pests, disease and weather
In vitro and cryopreservation	Tissue culture, shoot-tip and embryo storage in liquid nitrogen	Suits clonal and recalcitrant species; long-term and space-efficient	Technically demanding, needs protocols for each species

12.3 Characterisation and use

Systematic collection should be followed by morphological, biochemical and molecular characterization. Modern tools such as DNA markers, genomics, geographic information systems and digital databases can help identify useful genes and accelerate their incorporation

into breeding programmes. Characterisation turns a collection from a store of seed into a working resource, because breeders can only use what they can find and trust. Core and mini-core collections, like the 33-landrace core set derived from the blast study (Umakanth et al., 2017), are one practical way to make large collections accessible.

Digital tools can also help in targeting conservation. Distribution models, remote sensing and geographic information systems can identify gaps in current collections, locate priority areas for exploration, and anticipate how climate change may affect species ranges. Open databases that link passport data, characterisation data and images allow users to search for materials with desired traits.

13. Policy and Legal Framework

The use and conservation of plant genetic resources are governed by an international and national framework, and knowledge of this framework is essential for anyone working with germplasm from the North-East. The main instruments are summarised below.

Instrument	Main relevance to plant genetic resources
Convention on Biological Diversity (1992)	Recognises national sovereignty over biological resources; sets objectives of conservation, sustainable use and fair and equitable sharing of benefits
Nagoya Protocol (2010)	Provides a legal framework for access to genetic resources and benefit sharing; India is a party
International Treaty on Plant Genetic Resources for Food and Agriculture (2001)	Establishes a multilateral system of access and benefit sharing for a list of major food and forage crops, and recognises farmers' rights
Biological Diversity Act, 2002	Regulates access to biological resources and associated knowledge in India; creates the National Biodiversity Authority, State Biodiversity Boards and local Biodiversity Management Committees
Protection of Plant Varieties and Farmers' Rights Act, 2001	Provides for protection of new plant varieties, recognises the rights of farmers who conserve and improve varieties, and provides for registration of farmers' varieties
Geographical Indications of Goods Act, 1999	Protects products whose qualities are linked to their place of origin, such as Joha rice and Lakadong turmeric

Several features of this framework matter particularly for North-East India.

Farmers' rights. The Protection of Plant Varieties and Farmers' Rights Act allows farmers to save, use, sow, exchange and share farm-saved seed, and it provides for recognition and reward of communities that have conserved genetic resources. Registration of farmers' varieties and community claims can give formal recognition to local custodians of landraces, though the process is demanding and requires documentation that many communities need help to prepare.

Access and benefit sharing. Under the Biological Diversity Act, foreign entities and non-resident persons require approval to access biological resources of India, and commercial use triggers benefit-sharing obligations. Local Biodiversity Management Committees are expected to prepare People's Biodiversity Registers that document local biological resources and knowledge. The Act was amended in 2023, and researchers should check the current provisions before planning collaborative work.

Customary governance. In much of the region, land and forest resources are held and managed by communities under customary law and special constitutional arrangements, such as those for Nagaland under Article 371A and for autonomous district councils under the Sixth Schedule. This means that conservation initiatives are most likely to succeed when they work through traditional institutions such as village councils.

Protecting local identity. Geographical Indication registration can protect distinctive local products from misuse and support better prices for farmers. Experience shows that protection

works best when it is accompanied by quality control, collective organisation and marketing support.

Policy gaps persist. Procedures for registration are complex, awareness among farmers is limited, and coordination between agencies responsible for agriculture, forests, environment and tribal affairs is often weak. Simplified procedures, local-language outreach and regional facilitation centres would help communities benefit from the rights that the law already provides.

14. Future Prospects

The future potential of North-East India's plant genetic resources is enormous. Priority should be given to the following actions.

- Systematic exploration and collection of unexplored germplasm.
- Conservation of traditional landraces through community seed banks.
- Molecular characterization of important crop germplasm.
- Identification of genes for disease resistance and climate adaptation.
- Greater utilization of underutilized crops and wild relatives.
- Conservation of medicinal and aromatic plants.
- Documentation and protection of indigenous knowledge.
- Participatory conservation involving farmers and indigenous communities.
- Development of value-added products from traditional crops.
- Stronger collaboration between NBPGR, agricultural universities, research institutes and local communities.

Several of these priorities deserve elaboration.

Exploration and gap-filling. Collection should be planned using gap analysis so that effort goes to areas, crops and wild relatives that are poorly represented, and missions should include community members as partners. Collection should record detailed passport data, including the name of the community and the local name and use of each variety.

Community seed banks and on-farm management. Community seed banks allow villages to hold, multiply and exchange their own seed. They work best when they are run by local institutions, linked to a formal gene bank for safety duplication, and supported by seed fairs, small grants and recognition of farmer custodians. Women's groups are natural leaders for this work.

Genomics and trait discovery. Falling sequencing costs make it feasible to characterise large collections at the DNA level. Genome-wide association studies, as already applied to blast resistance in 232 landraces (Umakanth et al., 2017), can link markers to traits such as flood tolerance, cold tolerance, grain quality and nutrient content, and can guide marker-assisted introgression into elite varieties.

Pre-breeding and participatory plant breeding. Pre-breeding bridges the gap between wild or unadapted material and breeders' lines. Participatory approaches, in which farmers help select among segregating populations, can produce varieties that suit local conditions and tastes and that farmers are more likely to adopt.

Climate-resilient and nutritious crops. Stress-tolerant landraces, millets, pulses and tubers can strengthen food systems against climate shocks and add dietary diversity. Linking them with nutrition programmes, school meals and local markets can create demand that rewards farmers for keeping them.

Value chains and livelihoods. Value addition through processing, branding, geographical indications, organic certification and tourism can turn genetic resources into income. The experience of Sikkim, which has moved its agriculture to organic production, shows how a regional identity can be built around traditional crops and farming methods.

Capacity, data and collaboration. Trained taxonomists, breeders, molecular biologists and social scientists are needed in the region. Integrated databases, interoperable with national

systems, should make characterisation data and passport data openly available to researchers. Stronger collaboration between NBPGR, agricultural universities, research institutes, state departments and local communities, under clear access and benefit-sharing arrangements, will help ensure that the benefits of research reach those who conserved the resources.

15. Conclusion

North-East India is a major reservoir of plant genetic resources and has exceptional potential for agricultural development, crop improvement, biodiversity conservation and climate resilience. Its diverse rice landraces, citrus germplasm, horticultural crops, medicinal plants, underutilized species and crop wild relatives provide valuable genetic material for future breeding programmes. Scientific studies have already demonstrated the genetic diversity and stress-resistance potential of northeastern germplasm, as shown by the identification of blast-resistant landraces and the genetic differentiation of aromatic and quality rice. However, rapid environmental and socioeconomic changes are creating serious risks of genetic erosion. Replacement of landraces, land-use change, shortening of jhum cycles, invasive species, climate change and the loss of traditional knowledge all threaten the resource base. Therefore, conservation must combine on-farm/in situ approaches with ex situ gene-bank conservation, while ensuring active participation of local communities. Proper characterization and utilization of these resources, supported by an enabling policy environment and fair benefit sharing, can make North-East India an important contributor to India's future food, nutritional and agricultural security. The region's farmers have conserved this wealth over generations. The task for science and policy is to ensure that it is documented, protected and put to use, in partnership with those farmers, before it is lost.

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Theme 01-Prosperity for the Plough Securing Farmer Incomes in a New Agricultural Order

Influence of Farmyard manure and Vermi compost on the growth and yield of turnip (Brassica rapa L.)

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INTRODUCTION:

Turnip (2n=20) (Brassica rapa L, syn. Brassica campestris variety, rapa) is a quick growing root vegetable and one of the most important members of the family Cruciferae. Turnip was grown under organic treatments (FYM + vermicompost) had higher nutritional content (vitamin C and minerals) and longer shelf life than those grown with chemical inputs (Patidar and Mali, 2020). Integrated use of FYM and vermicompost with or without chemical fertilizers results in better growth and higher yields than when used alone. This also helps in maintaining soil health and reducing dependency on chemical fertilizers in sustainable agriculture systems (Sharma and Verma ,2021).

METHODOLOGY:

The experiment was performed during winter season of 2024-2025 at Agricultural Research Farm, Raja Balwant Singh College, Bichpuri, Agra. The field experiment was carried out with 10 treatments and 3 replications laid out in Randomized Block Design consisting treatment combinations as T0: Absolute Control, T1: RDF(60:40:50 kg/ha) + FYM (25 tonnes/ha), T2 : RDF (75%) + FYM (25%) , T3 : RDF (50%) +FYM (50%) , T4 : RDF (25%)+ FYM (75%) , T5 : RDF (75%)+V.C (25%), T6 : RDF (50%) + V.C (50%) ,T7 : RDF (25%)+V.C (75%) ,T8 : FYM (50%)+ V.C (50%) ,T9 : FYM (25%) + V.C (75%) and N:P:K fertilizers were applied as per treatments keeping the recommended doses 60 kg N, 40 kg P2O5 and 50 kg K2O respectively through Urea, DAP and MOP.

RESULT & DISCUSSION:

Table 1. Plant height, Number of leaves and total yield of roots (q/ha) as influenced by different treatments at successive stages

Treatment	Plant height (cm)		No. of leaves per plant		Total yield of roots (q ha-1)
	30 DAS	60 DAS	45 DAS	60 DAS	At Harvest
T_0	10.50	26.15	8.12	11.94	280.29
T_1	19.78	42.73	10.76	16.29	652.77
T_2	19.75	42.52	10.65	16.26	580.52
T_3	18.19	38.95	9.68	15.40	396.15
T_4	16.29	34.77	8.38	14.3	337.56
T_5	18.63	41.61	9.98	15.98	447.15
T_6	18.23	40.65	9.76	15.94	425.06
T_7	17.79	37.46	8.51	15.28	336.17
T_8	15.65	34.40	8.26	14.28	312.60
T_9	17.27	37.26	8.42	14.63	361.10

SEm±	0.66	2.55	0.37	0.51	11.13
CD at 5%	1.97	7.58	1.10	1.52	33.07

In above findings, the highest plant height was observed in treatment T1, at both 30 and 60 days after sowing (DAS), 19.78 cm at 30 DAS and 42.73 cm at 60 DAS respectively. This was closely followed by the T2 treatment and T0 recorded the lowest plant height at both successive stages (10.50 cm at 30 DAS and 26.15 cm at 60 DAS). T1 treatment also yielded the highest number of leaves, of 10.76 at 30 DAS and 16.29 at 60 DAS. The T2 treatment was the second most effective in this regard, while the T0 treatment resulted in the lowest leaf count. In terms of root yield, T1 produced the highest root yield at 652.77 quintals per hectare (q ha^{-1}). The second highest yield from T2 (580.52 q ha^{-1}) and T5 (447.15 q ha^{-1}), whereas the T0 treatment produced the lowest yield at 280.29 q ha^{-1}. This (T1) treatment recorded the maximum growth parameters and ultimately, the highest fresh root yield (q ha^{-1}).

CONCLUSION:

From the above research findings, it was concluded that among all the treatment combinations, the application of RDF and FYM proved to be the most superior. Specifically, the treatment involving the application of FYM at (25 t ha^{-1}) combined with 100% (60:40:50 kg/ha) of the recommended Dose of Fertilizers (RDF) resulted in the most significant treatment combination. Besides from the root yield, it also produced turnip with better growth. This (T1) treatment recorded the maximum plant height, number of leaves, root diameter, root length, and ultimately, the highest fresh root yield (t ha^{-1}). having same observations and results by Yadav et al. (2021), Sharma et al. (2022) and M. Kiran (2023). This also improves the physical condition and water holding capacity of soil and nutrients as well as it reduces economic pressure on farmers.

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Applications of genome editing in vegetable crops

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ABSTRACT

Vegetable crops are essential sources of vitamins, minerals, dietary fibre, and bioactive compounds, but their productivity and quality are increasingly threatened by biotic and abiotic stresses. Conventional breeding and earlier genome-editing technologies have limitations in developing improved cultivars rapidly and precisely. The CRISPR/Cas9 system has emerged as a powerful tool for targeted genome modification, enabling the development of vegetable crops with desirable agronomic, nutritional, and quality traits. This review highlights the applications of CRISPR/Cas9-mediated genome editing in major vegetable crops, including tomato, cucumber, watermelon, eggplant, lettuce, cabbage, and other leafy vegetables. Reported applications include improvement of fruit size and yield, stress tolerance, disease resistance, flowering behaviour, fruit ripening, nutritional quality, and reduction of enzymatic browning. The technology has also facilitated functional genomics and the development of novel genetic variations for crop improvement. Despite these advances, challenges such as off-target mutations, efficient delivery of editing components, genotype-dependent transformation, plant regeneration, and the complex genetic control of quantitative traits remain. Continued advances in genome-editing tools and transformation systems could accelerate the development of high-yielding, nutritious, and stress-resilient vegetable cultivars, contributing to sustainable agriculture and global food security.

Keywords: CRISPR/Cas 9, Genome editing, Vegetable improvement

Introduction

The world population is estimated to increase by 10 billion in the next three decades, thereby the demand for food crops is likely to increase by 25–70% (Hunter *et al*., 2017). Contemporary agriculture will eventually face enormous challenges to produce crops having high yield and better quality which require few inputs (Tilman *et al*., 2011). Vegetable crops act as protective foods that provide essential nutrients in the human diet due to their richness in vitamins, minerals, dietary fiber and phytochemicals preventing oxidative stress and reducing risk of chronic problems like diabetes, cancer and cardiovascular diseases. However, vegetables, like all other crops, are generally sensitive to biotic and abiotic stresses, and thus, disease, high temperature, and limited water supply are major limiting factors in vegetable productivity. These problems are likely to prevail due to climate change. For tackling with this problem researchers are striving to improve vegetable varieties in terms of yield and yield stability, nutritional value, and biotic and abiotic stress tolerance by classical breeding and by using plant molecular breeding technologies.

There have been a number of major advances in molecular biological methods over the last few decades. The discovery of sequence-specific nucleases (SSNs) and the development of the clustered regulatory interspaced short palindromic repeats (CRISPR)/CRISPR-associated protein (Cas) system have enabled programmable gene editing at the DNA level to generate vegetables with altered functions and desired traits (Nunez de Caceres Gonzalez and De la Mora Franco, 2020). Advanced molecular biological methods using SSNs, such as zinc-finger nucleases (ZFNs) and transcription activator like effector nucleases (TALENs), and CRISPR-Cas system have made it possible for plant researchers to conduct targeted gene/genome engineering precisely and efficiently. These techniques generate double-strand breaks (DSBs) at specific DNA sites and, via the endogenous DNA repair system, induce insertions or

deletions of nucleotides by non-homologous end joining (NHEJ), or cause gene replacements by homologous recombination (HR) thereby resulting in loss-of-function or gain-of-function of target genes. The various CRISPR-Cas systems have been revealed to be powerful tools for gene/ genome editing, and numerous genome-edited plants have been created by these gene-/genome-editing technologies (Gao, 2014). The use of first-generation technologies like ZFNs and TALENs has been limited due to their adverse mutagenic outcome, low editing efficiency, time-consuming process and labor-intensive selection and screening process (Jaganathan *et al*., 2018). The second-generation genome editing technology i. e. CRISPR/ Cas9 is easier to design, and execute and more cost-effective. The use of CRISPR/Cas9 in vegetable crops has substantially expanded gene editing technology and made it possible to create novel genotypes with desired phenotypic features and altered genomic functions at the base pair level.

Applications of clustered regularly interspaced short palindromic repeats/CRISPR-associated protein9 in vegetable crops

Genome editing, in particular using CRISPR-Cas9 systems, has been extensively applied to various crops. In most cases, it has been used for complete knockout by specific indel mutations to identify the function of the target genes or produce crops with desired traits. As vegetables are susceptible to various abiotic and biotic stresses which reduce optimum production, which highlights the significance of developing resistant/tolerant cultivars. Additionally, in vegetable crops, various quality traits including flavor and nutritional profile, plant architecture, and shelf life can be improved. Various gene editing systems have good potential to improve the quality and yield of vegetables among which CRISPR/Cas is very popular. The major applications of CRISPR/Cas9 in vegetable crops is being discussed below.

Tomato- Tomato (*Solanum lycopersicum* L.), owing to the readily available genomic resources and its global economic importance, is the representative vegetable crop where CRISPR-Cas9 approaches have been tested for crop improvement. In this species, the first report on CRISPR-Cas9-mediated genome editing was in 2014, targeting the SIAGAMOUS-LIKE 6 (SIAGL6) gene responsible for leaf development (Brooks *et al.,* 2014). The CRISPR-Cas9 system was also applied to induce targeted mutations in an exon and an untranslated region (UTR) of RIPENING INHIBITOR (RIN) gene, which encodes a MADS-domain transcription factor regulating tomato fruit ripening (Ito *et al.,* 2015). The mutant showed an incomplete ripening phenotype, indicating the importance of functional roles and potential applications of RIN in tomato fruit. Moreover, tomato plants with CRISPR-Cas9-mediated slmapk3 (*Solanum lycopersicum* mitogen-activated protein kinase 3) mutation exhibited enhanced tolerance to heat stress: They showed less severe wilting, milder membrane damage with lower reactive oxygen species (ROS) contents, and presented higher levels of both activity and transcript abundance of antioxidant enzymes under the heat stress condition (Yu *et al*., 2019). In 2019, Tomlinson *et al*. reported the first use of CRISPR technology to create a dominant dwarf mutation, PROD by modifying the tomato PROCERA gene that encodes a DELLA protein, a key negative regulator of gibberellin. regulation of a coding sequence provides a more refined method for creating phenotypic diversity for enhancing crop breeding (Wolter and Puchta, 2018). Indeed, multiplexed CRISPR-Cas9 mutagenesis in the *SlCLV3* promoter region created a series of cis-regulatory alleles, resulting in a range of changes from the transcriptional level of SlCLV3 to phenotypes in fruit size, flower morphology, and locule number. Hence, this approach offers the possibility of more efficient breeding by fine-tuning the expression of genes associated with improved yield and crop quality (Rodríguez-Leal *et al.,* 2017). The capacity to simultaneously target multiple genes for editing facilitated an experiment to perform some major steps in "redomestication" of tomato. Through CRISPR-Cas9-mediated disruption of six independent genes in wild tomato (*Solanum pimpinellifolium*), fruit size and

fruit number in mutated wild tomato were increased three- and ten-fold, respectively (Zsögön *et al*., 2018). Of note, the "redomesticated" tomato with improved fruit and agronomic traits retained the increased tolerance to salt stress and disease (Li *et al*., 2018). Besides these approaches aiming at phenotypic changes, CRISPR-Cas9 became a routine technology for functional genomics, including validation of candidate genes identified in genome-wide association studies (Alonge *et al*., 2020).

Cucumber- Cucumber (*Cucumis sativus* L.), belonging to the Cucurbitaceae family, is also an economically important vegetable that is cultivated in nearly all countries within both temperate and tropical zones. The first application of CRISPR-Cas9 in cucumber was for conferring broad viral resistance through knockout of eukaryotic translation initiation factor 4E (eIF4E) gene (Chandrasekaran *et al*., 2016). Gynoecious inbred lines in cucumber have great importance due to their higher production yield and the lower labor cost required for crossing. Hu *et al*. (2017) generated Cswip1 mutants by CRISPR-Cas9 tools, targeting the WPP trp/ pro/pro domain Interacting Protein1 (*CsWIP1*) gene, which encodes a zinc-finger transcription factor. Cswip1 T0 mutants exhibited gynoecious phenotype bearing only female flowers, implying that the gene is involved in inhibition of cucumber carpel development.

Watermelon- Watermelon (*Citrullus lanatus*), which belongs to the Cucurbitaceae family, is a rich source of citrulline, vitamins, and lycopene. CRISPR-Cas9-mediated mutations in the phytoene desaturase (*ClPDS*) gene, encoding a key enzyme of carotenoid synthesis, caused the expected albino phenotype in watermelon plants (Tian *et al.,* 2017). The CRISPR-Cas9-mediated base editing system was also utilized to achieve single-nucleotide conversion at the acetolactate synthase (*ClALS*) gene in watermelon (Tian *et al*., 2018). In addition, the CRISPR-Cas9 system was used to generate the knockout mutation of the phytosulfokine1 (*ClPSK1*) gene responsible for the infection by *Fusarium oxysporum* f. sp. *niveum* (FON). The loss-of-function mutation of *ClPSK1* rendered watermelon seedlings more resistant to infection by FON (Zhang *et al.,* 2020b). Recently, it was reported that the ClWIP1, a homologue of CsWIP1 and CmWIP1 in cucumber and melon, respectively, acts as the gynoecious (*gy*) gene in watermelon (Martin *et al*., 2009). The ClWIP1 is specifically expressed in carpel primordia in male floral buds and also linked to the abortion of carpel primordia in early floral development. Artificial gynoecious watermelon lines have been generated using the CRISPR-Cas9 system targeting the ClWIP1 (Zhang *et al*., 2020a).

Eggplant- Eggplant (*Solanum melongena* L.) ranks fifth among vegetables in terms of total global production, with 52.3 million tons produced in 2017 (Alam and Salimullah, 2021). Three polyphenol oxidase genes (PPOs; SmelPPO4, SmelPPO5, and SmelPPO6) showing the highest transcript levels in the fruit after cutting were regarded to be associated with enzymatic browning of eggplants, and CRISPR-Cas9-based mutagenesis has been applied to knockout three target PPO genes simultaneously aiming to reduce fruit flesh browning (Maioli *et al*., 2020).

Leafy Vegetables- Lettuce Leafy vegetables have also been edited for trait improvement through CRISPR-Cas applications. In particular, a DNA-free genome-editing approach has been applied in lettuce and cabbage via Cas9- and Cpf1-RNPs delivery into protoplasts. Woo *et al*. (2015) succeeded in delivering CRISPR-Cas9 RNPs into lettuce protoplasts by PEG-mediated transfection and, subsequently, regenerated plants with intended mutations from the protoplasts. Recently, it has been suggested that electroporation is more efficient in RNP delivery to protoplasts than PEG-mediated transfection in cabbage based on the results of phytoene desaturase1 (PDS1) sgRNA delivery, which may be due to lower chemical toxicity (Lee *et al*., 2020). Like other vegetables, the CRISPR-Cas9-based gene knockout or

knockdown was applied to PDS genes in chicory (*Cichorium intybus* L.; Bernard *et al*., 2019), Chinese kale (*Brassica oleracea* var. *alboglabra*), and cabbage (*Brassica oleracea* var. *capitata*; Lee *et al*., 2020), and PDS mutants were detected by their albino phenotype. CRISPR-Cas9 was also used to induce mutations in the carotenoid isomerase gene (*BoaCRTISO*) of Chinese kale (Sun *et al*., 2020). Jeong *et al*. (2019) succeeded in generating the early flowering Chinese cabbage (*Brassica rapa* spp. *pekinensis*) by the CRISPR-Cas9- mediated knockout in FLOWERING LOCUS C (*BraFLC*) genes homologous to *Arabidopsis* FLC, which encodes a MADS domain protein that plays a central role in repressing flowering.

Challenges and future prospects of clustered regularly interspaced short palindromic repeats/CRISPR-associated protein-9 genome editing

The CRISPR/Cas9 system is the latest cutting-edge technology that augments crop improvement by generating high-yielding, better quality, and resistant crop plants to biotic and abiotic stresses crops in Niazian *et al.,* 2017a short span of time. The NHEJ-mediated gene repair creates precise alterations to knock out or change the function of a particular. target gene(s) which plays an important role in crop-trait-specific applications, but still there exist many challenges which must be overcome. Foremost is the selection of genes that are to be targeted for mutations and the types of mutation to avoid off-target gene editing. Moreover, it is difficult to carry out genome editing in the target organisms without genome sequencing. Editing a single gene does not result in desired phenotypic changes, because significant agronomic factors are quantitative. To add desired mutant alleles, effective CRISPR-Cas-mediated target site-specific insertion, deletion, and chromosomal recombination procedures can be applied. Once a gene has been identified, the second major challenge is to deliver CRISPR-Cas gene-editing agents into plant cells and the procedure to regenerate the putative edited plants. Actually, it is quite challenging to create a universal and effective genetic transformation and regeneration system for vegetable crops. In addition to this, for successful genetic transformation of vegetable crops editing efficiency is to be considered, which is further influenced by various factors, such as the number of sgRNA and GC amount; the expression levels of sgRNA and Cas9; and the secondary structure of the paired sgRNA and target sequence. (Hu *et al*., 2019). Since genome editing in vegetable crops has such huge potential, we expect that strategies will be formulated to overcome these challenges in the near future.

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The New Agricultural Order: Pathways to Higher, Stable and Resilient Farmer Incomes

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ABSTRACT

Agriculture is entering a new agricultural order where the goal must move beyond producing more to earning more, earning consistently, and building resilience. Climate change, rising input costs, market volatility, resource constraints, technological disruption and changing consumer demand are reshaping the economics of farming and placing farmer income security at the centre of agricultural development. This paper examines an integrated income-centric framework based on diversification, digitalisation, collective action, value addition and risk management. Diversification into horticulture, dairy, livestock and other high-value activities can create multiple income streams, while artificial intelligence, precision farming, remote sensing and digital advisory services can improve productivity and resource-use efficiency. Farmer Producer Organisations, better market linkages, storage, processing and direct value chain participation can strengthen farmers' bargaining power and increase their share of consumer value. Crop insurance, institutional credit and climate-smart practices can further reduce exposure to production and market risks. The paper argues that the success of the new agricultural order should be judged not only by yield and output, but by the level, stability and resilience of farmer income. A coordinated approach integrating technology, markets, institutions and policy is therefore essential to make farming profitable, climate-resilient, inclusive and future-ready, ensuring that prosperity truly reaches the plough.

Keywords: Agricultural Transformation, Climate Resilience, Digital Agriculture, Crop Diversification, Value Addition, Market Linkages, Risk Management, Artificial Intelligence

Influence of Integrated Nutrient and Irrigation Management on Growth, Water Productivity, And Sustainable Yield of Chickpea (*Cicer Arietinum* L.)

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ABSTRACT

The present investigation entitled *"Influence of Integrated Nutrient and Irrigation Management on Growth, Water Productivity, and Sustainable Yield of Chickpea (Cicer arietinum L.)"* was undertaken to optimize nutrient combinations and critical-stage irrigation scheduling for enhancing crop productivity and resource-use efficiency in the Malwa agro-climatic region. The field experiment was laid out in a Split Plot Design (or Randomized Block Design) with three replications, evaluating varying irrigation regimes (such as branching and pod development stages) along with graded levels of inorganic fertilizers, organic amendments, and bio-inoculants (*Rhizobium* and PSB). The results revealed that the application of integrated nutrient management combined with scheduled critical irrigations significantly enhanced vegetative growth parameters, dry matter accumulation, and nodulation compared to rainfed and control treatments. Yield attributing characters, including the number of pods per plant, 100-seed weight, and total seed yield, demonstrated marked improvement under optimal moisture and balanced nutrition. Furthermore, this management practice substantially improved water-use efficiency (WUE), nutrient availability in the soil, and net economic returns, without compromising soil biological health. The study indicates that coupling targeted critical-stage irrigation with integrated plant nutrition is an effective agronomic strategy to achieve sustainable chickpea yield and maximize resource-use efficiency under semi-arid conditions.

Keywords: Biofertilizers, Chickpea, Growth attributes, Irrigation scheduling, Nutrient management, Sustainable yield, Water-use efficiency

Evaluating On-Farm Water Productivity, Irrigation Performance, and Management Strategies Across Canal and Groundwater Commands in the Middle Gangetic Plain, India

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ABSTRACT

Irrigation optimization water use is crucial for maintaining agricultural sustainability amid rising cross-sectoral resource competition. This study presents a diagnostic evaluation of farm-level water productivity, hydraulic performance, and operational management strategies across canal and groundwater commands in India's Middle Gangetic Plain. Utilizing primary datasets from 40 farming households alongside precise field-scale hydraulic, pedological, and crop-water measurements across seven intensively monitored plots during the 2020–21 season, the research quantifies systemic operational dynamics. System discharge was mapped via volumetric and Parshall flume frameworks, while adequacy and field capacity parameters were determined through pre- and post-irrigation soil moisture profiles. Conveyance and application efficiencies, irrigation water-use efficiency (IWUE), and total water productivity were evaluated against crop water requirements modelled via CROPWAT 8.0. The metrics reveal distinct structural inefficiencies across delivery modes. Conveyance losses varied significantly, spanning 1.92–3.37, 1.62–2.86, and 0.63–1.07 L s^{-1} per 100 m in earthen, lined, and piped systems, respectively, yielding peak delivery efficiencies of up to 95.37% in pipes compared to a low of 77.37% in earthen channels. Field application efficiencies ranged broadly from 54.40% to 77.31%. Systemic source variations heavily influenced output; mean IWUE for paddy stood at 0.82, 0.99, and 0.96 kg m^{-3} under canal, diesel-tubewell, and electric-tubewell configurations, respectively, while corresponding wheat values were 0.87, 1.21, and 1.25 kg m^{-3}. Overall water productivity spanned 0.43–0.49 kg m^{-3} for paddy and 0.84–1.24 kg m^{-3} for wheat. The post-irrigation moisture levels exceeding field capacity confirmed widespread over-application. Notably, regression diagnostics indicated that the irrigation source alone does not account for all performance variances, pointing to broader socio-technical influences. Thus, the findings showed a critical need to transition away from rigid delivery regimes toward soil-moisture-driven scheduling and modernized conveyance infrastructures to elevate water productivity without driving unsustainable groundwater dependency.

Keywords: Water productivity; Irrigation water-use efficiency; Conveyance efficiency; Field application efficiency; Canal irrigation; Groundwater irrigation

Evaluation of Farming Practices for Sustainable Soybean Productivity under Mid-Hill Conditions of Himachal Pradesh

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ABSTRACT

A field experiment was conducted at Research Farm of Department of Agronomy, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishwavidyalaya, Palampur during *Kharif* (rainy) season of 2025 to study the effect of different farming practices on growth and yield of soyabean. The field experiment was laid out in Randomized Block Design (RBD) with seven treatments replicated thrice. The different farming practices were evaluated to assess their effect on the growth and productivity of soybean under the agro-climatic conditions of Palampur. The treatments included farmers' farming practices, farmers' natural farming practices, organic farming practices, natural farming practices, inorganic farming practices and absolute control. The results showed that the highest plant height and dry matter accumulation were recorded with the organic farming practices including seed treatment with *Rhizobium &* PSB @200 g/10 kg of seeds and vermicompost @7.5 t/ha and vermiwash @10% at 15, 30 and 45 DAS. The highest seed yield and biological yield were also recorded in the same treatment of organic farming. The improved crop growth under this treatment resulted in better overall productivity of soybean. The lowest values of plant height, dry matter accumulation, seed yield and biological yield were recorded in absolute control. The study indicated that organic farming practices have good potential for improving the growth and productivity of soybean and promoting sustainable crop production under the mid-hill conditions of Himachal Pradesh. Such practices can contribute towards productive and resilient farming systems, with potential relevance for improving the sustainability of farm-based agricultural production.

Keywords: Organic, Inorganic, Natural, Integrated, Soybean

Molecular evaluation of markers contributing towards drought tolerance in soybean [*Glycine max* (L.) Merrill]

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ABSTRACT

The present investigation entitled "Molecular evaluation of markers contributing towards drought tolerance in soybean [*Glycine max* (L.) Merrill]" was conducted at the State Level Biotechnology Centre, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, during *summer 2026*. The study aimed to evaluate diverse soybean genotypes and segregating populations using molecular markers linked with drought tolerance, along with field phenotyping under restricted irrigation. The experimental material comprised nine parental genotypes, including six drought-tolerant or delayed-wilting lines, one drought-sensitive genotype, and two high-yielding advanced lines, together with 92 segregants from eleven biparental crosses belonging to F4 to F7 generations. Drought stress was imposed by providing only two irrigations, at sowing and 15 days after sowing. Morpho-physiological traits such as canopy temperature, chlorophyll content, normalized difference vegetation index, relative leaf water content, days to 50% flowering, days to maturity, hundred-seed weight, and yield per plant were recorded. Molecular characterization was carried out using ten gene-specific primers and eleven SSR markers. Phenotypic screening revealed wide genetic variation and transgressive segregation for important drought-related traits. EC 333901, TGX 709 50E, EC 602288, JS 2212 and JS 2216 were identified as drought-tolerant or delayed-wilting genotypes, whereas NRC 37 was drought-sensitive. The cross KDS 1201 × EC 333901 showed superior performance for relative leaf water content, chlorophyll content, and yield per plant under stress. All gene-specific markers and SSR markers exhibited useful polymorphism. LEA_2, TIP_1, IAA9_1, IAA9_2, BARCSOYSSR_14_0050 and BARCSOYSSR_19_1324 were highly informative and showed putative associations with favourable physiological traits. The study identified promising marker–trait associations and useful segregants for validation and marker-assisted breeding of drought-resilient soybean cultivars.

Keywords: Canopy temperature; Drought tolerance; Marker-assisted selection; Molecular markers; Relative leaf water content; Soybean

Molecular Approaches for treatment of Red Rot Disease in Sugarcane and Development of New Varieties

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ABSTRACT

Sugarcane crop is the backbone of Indian agriculture economy. Red Rot Disease is a destructive fungal disease caused by *Colletotrichum falcatum* species in India, which causes loss of sugar content, thinning & red brownish spots on inner side of stem, and paling of leaves and gives out foul smell which causes immense economic loss. Upon research, it was found that PKS1 and SCD1 are key enzymes found as intermediate in CMR1 gene biosynthesis responsible for DHN-melanin which creates mechanical turgor pressure results damaging the stem cuticle, helping fungus to feast on sucrose content and outgrowth in population. This melanin obstructs oxidative defense mechanism of plants against it. Therefore, with help of molecular technique- Bacterium-meditated transformation to integrate CfBIR1 gene which inhibits anti-apoptotic system synthesis in fungal genome with combination of HIGS method for reducing the expression of CMR1gene systhesis, in sugarcane polyploid genome will trigger apoptosis and decrease fungal infestation and creates a transformed variety resistant to red rot disease.

Keywords: CMR1-colletotrichum melanin regulation1; CfBIR1: baculoviral IAP repeats; HIGS: Host induced gene silencing; resistant variety; PKS1-polyketide synthase; Red Rot; SCD1-sytalone; dehydratase1

From Yield to Prosperity: Transforming Agronomic Practices for Higher and Resilient Farmer Incomes

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ABSTRACT

Indian agriculture is increasingly challenged by rising input costs, climate variability, declining resource-use efficiency and unstable market returns. Although improving crop productivity remains important, higher yield alone does not necessarily translate into higher and stable farm income. The present concept focuses on shifting the agricultural approach from yield-centric production towards income-oriented, resource-efficient and climate-resilient farming systems. Improved agronomic practices such as conservation agriculture, precision nutrient management, efficient water management, crop diversification, integrated nutrient management, improved crop establishment methods and appropriate use of digital and mechanization technologies can reduce production costs while maintaining or improving productivity. Integration of pulses, millets, oilseeds and other suitable crops into existing production systems can further improve resource utilization, nutritional security and income stability. Efficient use of nitrogen and other inputs, site-specific management and recycling of farm resources can enhance nutrient-use efficiency and reduce unnecessary expenditure. At the same time, better access to markets, value addition, storage, collective marketing and farmer-producer organizations is essential for converting farm output into improved economic returns. The proposed approach therefore emphasizes a holistic pathway in which productivity, profitability, resource conservation and resilience are considered together. Such an integrated strategy can help small and marginal farmers reduce production risks, improve the efficiency of scarce resources and build more stable sources of income. The approach is also relevant beyond India, particularly in regions facing climate stress, resource degradation and increasing pressure to produce more food with fewer resources. Transforming agronomic practices from a purely production-oriented model to a farmer-income-oriented model can contribute substantially to sustainable agricultural development, livelihood security and resilient food systems.

Keywords: Agronomic practices, Climate resilience, Conservation agriculture, Crop diversification, Farmer income, Resource-use efficiency, Sustainable farming

Role Of Integrated Nutrient Management in Sustainable Crop Production: A Review

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ABSTRACT

The present review entitled "Role of Integrated Nutrient Management in Sustainable Crop Production" was undertaken to understand the importance of balanced and efficient nutrient management for improving crop productivity, soil health and long-term sustainability of agricultural production. Integrated Nutrient Management (INM) involves the combined and efficient use of chemical fertilizers, organic manures, biofertilizers, crop residues and other locally available nutrient resources. The excessive and imbalanced use of chemical fertilizers may adversely affect soil properties, nutrient-use efficiency and environmental sustainability. Integration of organic and inorganic nutrient sources can improve nutrient availability, soil organic matter, microbial activity and overall soil fertility. Biofertilizers such as Rhizobium, Azotobacter, Azospirillum and phosphate-solubilizing microorganisms can further contribute to nutrient availability and sustainable crop production. Proper soil testing, balanced fertilization and site-specific nutrient management are important components of an effective INM strategy. The approach can also help reduce unnecessary input costs and improve the efficient utilization of available nutrients. Therefore, adoption of integrated nutrient management practices, along with improved agronomic practices and farmer awareness, can play an important role in maintaining soil health and achieving sustainable agricultural production.

Keywords: Biofertilizers, Crop Production, Fertilizers, Integrated Nutrient Management, Soil Health, Sustainable Agriculture

BIOCHAR AMENDMENTS AND SOIL RESTORATION

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ABSTRACT

Soil degradation is a major problem affecting Indian agriculture. Most agricultural soils have lost organic matter, microbial activity, water retention capacity, and essential nutrients, leading to poor crop yields and reduced farmer income. Biochar offers a practical and sustainable solution to this problem. Biochar is a carbon-rich material produced by heating agricultural waste and crop residues in the absence of oxygen. When biochar is added to degraded soils, it improves multiple soil properties that directly benefit crop growth and productivity. Biochar works in several important ways. First, its porous structure acts like a sponge, holding water and nutrients in the soil longer, reducing water loss and nutrient leaching. This is especially beneficial during dry seasons and in rainfed farming areas. Second, biochar creates favorable habitats for beneficial soil microorganisms and mycorrhizal fungi. These microorganisms help break down organic matter and make nutrients available to plant roots. Third, biochar increases soil organic carbon content, which improves soil structure and stability. Strong soil structure prevents erosion and improves water infiltration. When biochar is combined with compost or manure, its benefits are significantly enhanced. Research demonstrates that biochar-amended soils show 20–25% improvement in crop yields, better soil structure, and increased microbial activity. Additionally, biochar stores carbon in soil for hundreds of years, helping reduce atmospheric carbon dioxide and supporting India's climate change mitigation goals. Biochar is cost-effective and can be produced locally from agricultural waste available in every farming region without requiring expensive technology or chemicals. This makes it especially suitable for smallholder and marginal farmers who form the backbone of Indian agriculture. Adopting biochar-based soil management represents an effective, practical, and sustainable approach for restoring degraded soils, improving crop productivity, and promoting environmental sustainability in Indian agriculture.

Keywords: Agricultural productivity; Biochar; Carbon sequestration; Soil health; Soil restoration; Sustainable agriculture.

Farm-Share- A Community-Owned Agriculture Model for Farmer Prosperity and Urban Food Security

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ABSTRACT

India's agricultural value chain remains burdened by two persistent gaps: farmers' dependence on high-interest credit and multi-layered intermediaries that erode their income, and urban consumers' growing demand for transparent, organic, traceable food. This concept proposes Farm-Share, a crowdfunding-and-participation platform that directly bridges these two ends of the supply chain by combining equity-based farm financing, urban participatory farming, and direct-to-consumer marketing. Under this model, urban investors fund a farmer's input costs (seeds, fertilizer, labor) for a season in exchange for a proportional share of the harvest — either as produce or profit — replacing debt-based lending with risk-shared equity. Investors can choose a passive tier (financial contribution only) or an active tier, where they periodically visit the farm to participate in sowing, weeding, or harvesting their own share, building trust and emotional investment in the food they consume. This physical engagement also opens a secondary revenue stream through agri-tourism, including farm stays and organic farming workshops. Critically, these urban participants become the platform's direct marketing channel: as verified buyers and firsthand witnesses to farming practices, they eliminate the need for mandis, commission agents, and retail markups. Farmers capture retail-equivalent prices instead of wholesale rates, while consumers access fresher, traceable produce at lower cost than premium organic retail. Digital tools — WhatsApp coordination groups, subscription-based ordering, and farm-progress updates — sustain the relationship between harvests. By uniting farmer income security, urban food security, and an inclusive agri-ecosystem into a single participatory model, Farm-Share offers a scalable, trust-driven alternative to India's traditional agricultural supply chain, particularly suited to peri-urban farming clusters near major cities.

Keywords: Agri-tourism; Community supported agriculture; Direct-to-consumer marketing; Equity-based crowdfunding; Farmer income security; Urban food security

Precision Breeding of Dragon Fruit for High Yield & Climate Resilience: Adopting Integrative Genomics and Genomics Editing Practices.

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ABSTRACT

Dragon fruit (Hylocereus spp.) is an emerging high-value horticultural crop in India, but its expansion is constrained by dependence on introduced planting material, limited systematic breeding, variable productivity, and vulnerability to environmental and biotic stress. Conventional hybridization can generate useful variation; however, the long juvenile phase and complex inheritance of important quantitative traits make the identification of superior genotypes relatively slow. This study proposes an integrated precision-breeding framework combining interspecific hybridization, molecular characterization, and targeted genome editing for the development of improved dragon fruit genotypes suited to Indian agro-climatic conditions. The proposed approach will begin with the characterization of genetically diverse Hylocereus accessions based on yield, fruit quantity, phenology, and tolerance to heat, drought, and diseases. Superior and generally complementary parents will subsequently be selected for controlled hybridization. Progenies will be evaluated using morphological, biochemical, and molecular markers to identify genomic regions associated with yield, stress tolerance, and fruit-quality traits. Transcriptomic and comparative genomic analyses will then be used to prioritize candidate genes or regulatory regions controlling the selected traits.

Keywords: systematic breeding; juvenile phase; superior genotype; agro-climatic conditions; integrated precision – breeding; Transcriptomic.

Off-Season Vegetable Production: Unlocking Counter-Cyclical Price Premiums Under Protected Cultivation

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ABSTRACT

Off-season vegetable production under protected cultivation offers a strategic approach to improving farm profitability by aligning production cycles with periods of limited market supply and higher consumer demand. Conventional vegetable production is often concentrated during favourable seasons, resulting in seasonal gluts, depressed prices, and reduced returns to growers. Protected structures such as polyhouses, naturally ventilated polyhouses, shade nets, and low tunnels enable growers to manipulate the crop environment by regulating temperature, humidity, light, and moisture, thereby facilitating production beyond the normal growing season. This approach can create counter-cyclical price advantages by allowing high-value vegetables to reach markets when open-field supplies are limited. Crops such as tomato, capsicum, cucumber, chilli, leafy vegetables, and selected cucurbits have considerable potential for off-season production, particularly when supported by suitable cultivars, precision irrigation, fertigation, and integrated pest management. However, profitability depends on initial investment, energy and input costs, market access, crop selection, price volatility, and efficient management of protected structures. Therefore, integrating protected cultivation with market-oriented crop planning, staggered production, post-harvest handling, and reliable market intelligence can improve economic returns and resource-use efficiency. Off-season vegetable production thus represents an important opportunity for diversification, income enhancement, and more stable vegetable supply while supporting sustainable and commercially viable horticultural production.

Keywords: Protected cultivation; off-season vegetables; counter-cyclical prices; market premium; polyhouse; profitability; precision production

Optimizing Row Spacing and Nitrogen Fertilization for Enhanced Growth, Yield and Nitrogen Use Efficiency in Mustard (*Brassica juncea* L.) in Arid Regions

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ABSTRACT

A field experiment was conducted during *Rabi* 2024-25 at CAZRI, Jodhpur, Rajasthan, to evaluate the effect of row spacing and nitrogen fertilization on growth, yield, nitrogen use efficiency, and economics of mustard (*Brassica juncea* L.) under arid conditions. The experiment was laid out in a split-plot design with three row spacings (30, 45 and 60 cm) and four nitrogen levels (0, 40, 80 and 120 kg N ha^{-1}). The results showed that 45 cm row spacing combined with higher nitrogen levels significantly improved growth, yield attributes, seed yield, oil yield and nutrient uptake. The highest seed yield (26.3 q ha^{-1}), net return (₹1,11,395 ha^{-1}) and B:C ratio (2.99) were recorded with 45 cm spacing and 120 kg N ha^{-1}. However, nitrogen-use efficiency was highest at 40 kg N ha^{-1}, while the economic optimum nitrogen dose was estimated at 100.23 kg N ha^{-1}. Thus, 45 cm row spacing with about 100–120 kg N ha^{-1} was found suitable for improving mustard productivity and profitability under arid conditions.

Keywords: Arid conditions, Brassica juncea, economic optimum dose, mustard, nitrogen levels, nitrogen use efficiency, row spacing

Productivity and profitability of a rice-mustard cropping system under different nutrient-management strategies in lateritic West Bengal

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ABASTRACT

Rice-mustard is an important cropping system in eastern India, particularly in areas where limited irrigation restricts the cultivation of water demanding crops during the rabi season. However, maintaining its productivity and profitability requires a nutrient management strategy that can provide adequate crop nutrition without imposing an excessive production cost. Therefore, a field experiment was conducted during 2023-24 and 2024-25 in the lateritic zone of West Bengal to assess the effects of different nutrient management strategies on system production, system productivity and economic returns of a rice-mustard cropping system. The experiment was laid out in a randomized block design with three replications and seven treatments: farmers' practice (T_1), recommended dose of fertilizers (T_2), integrated nutrient management (T_3), natural farming (T_4), 75% organic nutrients with natural concoctions (T_5), 50% organic nutrients with natural concoctions (T_6) and organic farming (T_7). System production was expressed as rice-equivalent yield. Integrated nutrient management (T_3) recorded the highest rice equivalent yield of 6.57 and 7.25 t ha^{-1} during 2023-24 and 2024-25, respectively, with a pooled value of 6.91 t ha^{-1}. Correspondingly, T_3 registered the highest system productivity of 18.00 and 19.86 kg ha^{-1} day^{-1} during the respective years and a pooled productivity of 18.93 kg ha^{-1} day^{-1}. The improvement under integrated nutrient management was associated with the complementary supply of immediately available nutrients from mineral fertilizers and the gradual release of nutrients from organic sources. Despite producing a comparatively lower pooled rice equivalent yield of 5.51 t ha^{-1}, natural farming (T_4) proved to be the most economically efficient treatment. It recorded the lowest pooled cultivation cost of ₹82,012 ha^{-1} and the highest pooled net return of ₹93,980 ha^{-1}, along with the maximum benefit-cost ratio of 2.14. The findings demonstrated that integrated nutrient management was the most suitable strategy for maximizing system production and daily productivity. In contrast, natural farming offered greater profitability per rupee invested because of its reduced dependence on purchased inputs. Thus, nutrient management practices may be selected according to whether the production objective is higher system output or greater economic efficiency.

Keywords: Integrated nutrient management; natural farming; profitability; rice-mustard system; rice-equivalent yield; system productivity.

Impact Of Climate Change on Insect Pest Population

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ABSTRACT

Climate change is one of the biggest threats to sustainable agriculture and food security. Changes in temperature, rainfall patterns, increasing atmospheric carbon dioxide (CO_2) and droughts and extreme weather events have a large impact on the populations, distribution and behaviour of insect pests. Temperature is one of the most important factors controlling insect development, reproduction and survival. Increased temperatures can shorten insect life cycles, increase the number of generations and enhance pest population expansion and geographic range. But, the answer varies between insect species and climatic zones. Elevated CO_2 can change crop quality and plant defence mechanisms, which may influence insect feeding, growth and population density. These effects are particularly important in C_3 crops such as wheat and rice. Similarly, irregular rainfall, drought and excessive precipitation can either suppress or enhance pest populations depending on the pest–crop relationship and environmental conditions. Climate-driven changes may further facilitate the establishment and spread of invasive insect pests, increase pest outbreaks and disturb the ecological balance between pests and their natural enemies. Changes in temperature can create a gap between pests and biological control agents, potentially reducing the effectiveness of natural enemies. Therefore, climate-resilient crop protection requires continuous monitoring of pest populations and climatic conditions, improved forecasting and modelling, and adaptive integrated pest management (IPM). Combining biological control, need-based pest management and climate-based prediction can strengthen agricultural resilience and reduce future crop losses. Developing climate-smart pest management strategies will be essential for protecting crop productivity, farmer livelihoods and long-term food security.

Keywords: Climate change, Insect pest dynamics, Global warming, Pest outbreaks

Constraints to Resilience: Securing Livelihoods in Betel Leaf Cultivation in Purba Medinipur of West Bengal

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ABSTRACT

Betel leaf (*Piper betle* L.) cultivation, locally known as "boroj" farming, is a high-value but labour-intensive enterprise that supports the livelihoods of thousands of farmers in the coastal belt of Purba Medinipur district, West Bengal. Despite its economic importance, betel vine growers face a wide range of technological, production, and marketing constraints that threaten the sustainability of this traditional farming system. The present study, based on a sample of farmers cultivating three major varieties Bangla, Chandrokona Kalo, and Mitha used Garrett's Ranking Technique to identify and prioritize the key constraints faced across these categories. The findings reveal that labour intensiveness and lack of knowledge about disease-pest management were the most critical technological constraints, largely due to weak research-extension linkages and limited access to biofertilizers. Among production constraints, the absence of crop insurance emerged as the single most severe issue, since betel vine despite heavy investment in boroj structures remains excluded from national crop insurance schemes, leaving growers highly vulnerable to natural disasters like cyclones and unpredictable weather. Scarcity of skilled labour and adverse climatic conditions further compounded production risks, particularly in the coastal, disaster-prone zones. On the marketing front, high price fluctuation and non-availability of storage facilities were identified as the most pressing constraints, forcing farmers to sell at distress prices due to the perishable nature of betel leaves and lack of temporary storage infrastructure. These findings underscore the urgent need for targeted interventions including extension of crop insurance coverage, strengthening of research-extension linkages, development of cold storage/temporary storage facilities, and improved market information systems to transform vulnerability into resilience and secure sustainable livelihoods for betel vine farming communities.

Keywords: Betel vine; Constraints; Crop insurance; Garrett's Ranking; Marketing efficiency; Sustainable livelihood.

Impact of training cum workshop for different agrarian stakeholders and their position role in Natural Farming in East Singhbhum district of Jharkhand

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ABSTRACT

Natural farming has emerged as a sustainable and eco-friendly approach to agriculture, particularly beneficial for small and marginal farmers in rural regions of India. In East Singhbhum, a training-cum-workshop program was organized with the primary objective of empowering women in agriculture and enhancing the knowledge and participation of different agrarian stakeholders in natural farming practices. The workshop included women farmers, self-help groups (SHGs), local extension workers, rural youth, progressive farmers, and community leaders. The program focused on creating awareness regarding the principles of natural farming, preparation and use of organic inputs, soil health management, crop diversification, integrated pest management, and low-cost sustainable agricultural practices. Special emphasis was given to the active participation and leadership role of women in decision-making, farm management, and income-generating activities. Interactive sessions, field demonstrations, group discussions, and practical exposure visits helped participants gain hands-on experience and confidence in adopting natural farming techniques. The training significantly improved the understanding of stakeholders regarding environmentally sustainable agriculture and reduced dependence on chemical fertilizers and pesticides. Women participants demonstrated increased confidence, leadership skills, and willingness to adopt natural farming as a livelihood option. The workshop also strengthened collaboration among farmers, local institutions, and extension agencies, thereby promoting collective learning and community-based agricultural development. The study highlights that capacity-building initiatives through training and workshops play an important role in transforming the attitudes and practices of agrarian stakeholders toward sustainable agriculture. Empowering women through such programs not only enhances agricultural productivity and household income but also contributes to social inclusion, food security, and rural development. Therefore, regular training programs, institutional support, and policy interventions are essential for scaling up natural farming practices and ensuring long-term sustainability.

Keywords: Natural Farming, Sustainable Agriculture, Sustainability, Women, Rural Development

Genetic characterization evaluation of soybean genotypes for agronomic and quality traits

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ABSTRACT

The present study entitled "Genetic characterization evaluation of soybean genotypes for agronomic and quality traits" was undertaken to evaluate and characterize diverse soybean genotypes for key agronomic performance and nutritional quality parameters. A randomized complete block design (RCBD) with three replications was applied for the evaluation of the selected genotypes at the experimental field. The primary data were collected through field observations on days to flowering, days to maturity, plant height, pod number, and seed yield per plant. Quality traits, including oil and protein content, were analyzed using standard laboratory procedures during the agricultural year 2024-25. Secondary data related to historical weather patterns and standard varietal benchmarks were obtained from institutional records. From the investigation, significant genetic variability was observed among the soybean genotypes for most of the studied traits. The top three agronomic traits showing high genetic advance coupled with high heritability were seed yield per plant, number of pods per plant, and plant height. The top three quality challenges observed during the evaluation were maintaining high protein stability across environments, oil content fluctuations, and seed longevity during storage. Major suggestions to leverage these findings include the selection of elite genotypes for future hybridization programs, integration of marker-assisted selection for rapid trait introgressions, and multi-location trials to confirm environmental stability.

Keywords: Agronomic traits, Genotypes, Heritability, Quality traits, Soybean, Variability

Screening of wheat (*Triticum aestivum* L.) genotypes for heat tolerance at the grain filling stage using stress tolerance indices

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ABSTRACT

Heat is a major stress that severely affects wheat productivity. This study assessed the effect of heat stress during the grain-filling stage to screen heat-tolerant wheat genotypes. Six stress tolerance indices were calculated for grain yield, and the percent decline in other important traits was measured. A set of 150 wheat genotypes along with four local checks was evaluated in two separate experiments, one under normal (timely sown) and one under heat stress (late sown) conditions, laid out in an augmented block design at the research farm of the Department of Genetics and Plant Breeding, Sardar Vallabhbhai Patel University of Agriculture and Technology (SVPUA&T), Meerut (U.P.), during the rabi seasons of 2023 and 2024. Percent decline calculations showed a significant reduction in trait performance under heat stress compared to the normal environment, with grain yield/plant, biological yield/plant and grain weight/spike declining by 57.15%, 53.66% and 47.73%, respectively, indicating these were the traits most affected by heat stress. To identify susceptible and tolerant genotypes for grain yield under heat stress, six stress tolerance indices were calculated: heat susceptibility index (HSI), mean productivity (MP), tolerance (TOL), stress tolerance index (STI), trait stability index (TSI) and trait index (TI). Under normal conditions, grain yield showed significant positive correlation with MP (0.822**), STI (0.568**), TSI (0.316**), HSI (0.314**) and TI (0.188*), and a non-significant correlation with TOL (0.084). Under stress, grain yield correlated significantly and positively with TI (1.000**), STI (0.907**) and MP (0.713**), non-significantly with TOL (0.129), and significantly negatively with HSI (-0.860**) and TSI (-0.808**). Based on this correlation analysis, four indices (HSI, MP, STI and TI) were selected for identifying heat-tolerant genotypes. Nine genotypes (G51, G64, G71, G114, G119, G134, G139, G148 and G150) were heat tolerant, while twelve genotypes (G1, G3, G7, G27, G38, G40, G77, G107, G120, G127, G131 and G136) were highly heat susceptible. G77 was the most heat-sensitive genotype, whereas G119 and G139 gave high yields under heat stress, making them suitable for late-sown conditions and recommendable for heat-stressed environments. These genotypes may also be used in breeding programs aimed at developing heat-tolerant wheat varieties.

Keywords: Grain yield; Heat stress; Heat tolerance; Late sowing; Stress tolerance indices; Wheat

To Evaluate the different genotypes of tomato for the morphological characters under protected and open field condition

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ABSTRACT

The present investigation, entitled "Molecular Characterization and Evaluation of Genotypes for Morphological and Qualitative Traits of Tomato (*Solanum lycopersicum* L.) under Protected and Open Field Condition", was undertaken to assess the extent of genetic variability, heritability, among fifty-two tomato genotypes. The experiment was conducted at the Horticulture Research Centre, SVPUAT, Meerut during the Zaid season of 2024 and 2025, in a Randomized Block Design with three replications across four environments, viz., E1 (Year 1 Protected), E2 (Year 1 Open), E3 (Year 2 Protected) and E4 (Year 2 Open). Observations were recorded on twenty-eight morphological, yield and quality related characters, including days to first flowering, days to 50 per cent flowering, days to first fruit set, days to first fruit ripening, days to first picking, number of flower clusters per plant, number of flowers per cluster, number of primary branches, plant height, internodal length, node number at first flower, number of fruits per cluster, number of fruits per plant, fruit length, fruit width, average fruit weight, fruit shape index, 100-seed weight, number of seeds per fruit, number of locules per fruit, pericarp thickness, diameter of stalk scar, fruit firmness, total soluble solids, fruit yield per plant, fruit yield per plot and fruit yield per hectare. Analysis of variance revealed highly significant differences among the 52 genotypes for all 28 characters across all four environments, confirming the presence of substantial genetic variability. High GCV and PCV, together with high heritability and high genetic advance as per cent of mean, were recorded for diameter of stalk scar, number of primary branches, number of flower clusters per plant, plant height and fruit shape index, indicating the predominance of additive gene action and scope for improvement through direct selection for these traits. divergence among the genotypes studied, which can be effectively exploited through direct selection and hybridization for the genetic improvement of tomato under both protected and open field conditions.

Key words: Tomato; Genetic variability; Heritability; Mahalanobis D^2; High yield; Protected and open conditions.

Create new transparent wall between farmers and government with help of agriculture students

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ABSTRACT

At first, when you read the title, you might think this is going to be a political statement but the next line is actually more important. I believe one of the biggest problems in Indian agriculture is the lack of transparency between the government, farmers, and the people working on the ground. We have many schemes, subsidies and other forms of support, but the real question is: how much of it actually reaches the farmer, and how effectively? As agriculture students, I think we have a responsibility to question this and try to improve it with our knowledge. Take one simple example: the sale of fake and poor-quality pesticides and herbicides. There are also chemicals that are restricted or misused, which can harm the environment, human health and, ultimately, the farmer's own pocket. Some people may say, "This is impossible to change." And honestly, I understand why. There are strong local networks, agro-centres, credit relationships and other systems that farmers have depended on for years. We can't simply remove them overnight. But I don't think the answer is to accept the system as it is. I believe we need to start building a new system — slowly, practically and with the farmer at the centre And I'm not talking about changing Indian agriculture in 5 years. I think real change may take 20 years or more. But if we start today, we can build an Indian agriculture system where farmers get better information, use safer and more effective inputs, earn better incomes, and consumers get more nutritious food this is one of the biggest opportunities I see for the future of Indian agriculture. I have many more ideas around this, but I'd rather discuss those face-to-face.

Keywords: Transparency, Farmer Income, Safe Inputs, Agri Knowledge, Sustainable Agriculture

Multivariate Genetic Diversity and Key Trait Associations in Soybean (Glycine *max* L) Genotypes Through Principal Component Analysis in Manipur

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ABSTRACT

The present investigation, entitled "Multivariate Genetic Diversity and Key Trait Associations in Soyabean (*Glycine max* L) Genotypes Through Principal Component Analysis in Manipur" was carried out under experimental field of CAU research farm, Andro, Imphal East with three replications using the Randomized Block Design (RBD) pattern to assess, genetic diversity carried of 23 diverse soyabean genotypes during kharif season of 2025. According to Principal Component Analysis, of the fifteen, only four principal components (PCs) exceeded 1.00 and explained about 76.42% of the variability among the traits studied for each genotype. PC1 and PC2 showed maximum variability, whereas PC4 showed minimum variability among the genotypes for the traits under study. PC1 showed a positive effect towards nodes per plant and pods per plant, while PC2 showed a positive effect on yield per hectare and row yield. The fourth principal component was more related to plant height. The third and fourth principal components was more related to yield per plant. These findings revealed that PC1, PC2, PC5, and PC6 were linked to a variety of morphological and physiological traits in soyabean, and that these traits can be used to identify different genotypes that could be used in soyabean hybridization programmes. The result of the present study could be exploited in the planning and execution of future breeding programmes in soyabean.

MULCHING AS A TECHNIQUE FOR SOIL MOISTURE CONSERVATION

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ABSTRACT

Soil moisture is one of the most important factors influencing crop growth, particularly in rainfed and water-limited agricultural systems. Mulching is a simple and effective soil management technique in which the soil surface is covered with organic or inorganic materials to reduce moisture loss and improve the soil microenvironment. By creating a protective layer over the soil, mulch reduces direct evaporation, moderates soil temperature, improves water infiltration, and helps maintain more stable soil moisture conditions. Organic mulches such as crop residues, straw, dry leaves, compost and grasses gradually decompose and also contribute organic matter and nutrients to the soil. Inorganic mulches such as plastic films can provide effective control of evaporation and weeds, although their environmental impacts and disposal requirements need consideration. The effectiveness of mulching depends on mulch type, thickness, soil condition, crop, climate and method of application. Properly selected and managed mulch can improve water-use efficiency, support better root growth, reduce weed competition and enhance crop productivity. Therefore, mulching is an important component of climate-smart and resource-conserving agriculture, especially where water availability is limited. Its integration with other moisture-conservation practices can further improve the efficient use of rainfall and irrigation water.

Keywords: Mulching, Soil moisture conservation, Evaporation, Water-use efficiency, Organic mulch, Plastic mulch, Rainfed agriculture.

Compatibility Study of Herbicide Application and Nitrogen Sources on Weed Suppression and Wheat Yield

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ABSTRACT

Weed infestation and nitrogen management are among the major constraints limiting wheat productivity. Effective weed suppression coupled with judicious nitrogen management is therefore essential for achieving higher crop yields and improving resource-use efficiency. Since post-emergence herbicide application often coincides with nitrogen fertilization, the compatibility of herbicides with different nitrogen sources assumes considerable importance for integrated crop management. Studies on herbicide–nitrogen interactions have demonstrated that the post-emergence application of clodinafop + metsulfuron (60 + 4 g ha^{-1}) provides effective control of both grassy and broad-leaved weeds, thereby reducing crop–weed competition and improving crop growth and productivity. Its integration with nano urea further improved weed management and crop performance, as reflected by reduced weed density and higher weed control efficiency. Similarly, metsulfuron (4 g ha^{-1}), when applied in combination with either nano urea or prilled urea, exhibited satisfactory weed suppression and supported efficient nitrogen utilization. The combination of mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) also provided effective weed control; however, its initial phytotoxic effects necessitated further evaluation of compatible herbicide–nitrogen combinations. Subsequently, carfentrazone + metsulfuron (20 + 4 g ha^{-1}) was evaluated as an alternative and effectively controlled weeds with minimal crop injury. However, its integration with nano urea or prilled urea resulted in comparatively poorer weed suppression and consequently lower grain and straw yields, possibly owing to greater crop–weed competition. Among the evaluated combinations, clodinafop + metsulfuron (60 + 4 g ha^{-1}) integrated with nano urea resulted in superior crop productivity, which may be attributed to effective weed suppression, improved nutrient availability and uptake, and enhanced crop growth. These findings indicate that appropriate integration of selective post-emergence herbicides with suitable nitrogen sources, particularly nano urea, can provide a promising strategy for simultaneous weed management and improved nitrogen-use efficiency in wheat. In view of the increasing need to manage weeds effectively while optimizing nitrogen use and sustaining wheat productivity, the integration of herbicides with nano urea and prilled urea may offer a practical and resource-efficient approach for farmers. Therefore, the present study was undertaken to evaluate the compatibility of different post-emergence herbicides with nitrogen sources and their effects on weed dynamics, crop growth, productivity, and nitrogen-use efficiency in wheat under field conditions.

Keywords: Weed density, weed control efficiency (WCE), Crop–weed competition, Weed suppression, post-emergence herbicides, Herbicide compatibility

Study of genetic variability, heritability and genetic advance in various genotypes of bottle gourd [*Lagenaria siceraria* (Molina) Standl.]

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ABSTRACT

The present research experiment was carried out at the Research Farm of Department of Vegetable Science, CCS Haryana Agricultural University, Hisar during the *Rainy Season* 2024. The experiment was laid out in randomized complete block design (RCBD) with three replications. Twenty-eight hybrids with eight parents were evaluated for various quantitative and quality traits. Analysis of variance revealed significant differences among genotypes for all the traits. The estimates of phenotypic coefficient of variance were slightly higher than the corresponding genotypic coefficient of variance for all the characters studied indicating the little influence of environment in the expression of these traits. The highest phenotypic and genotypic coefficients of variation were observed for seed yield per fruit (43.80 and 43.61) followed by number of seeds per fruit (43.58 and 43.17) and titrable acidity (42.92 and 40.47). High heritability coupled with high genetic advance was recorded for titrable acidity (99.58 and 95.67), seed yield per fruit (99.15 and 89.46) and days to first fruit harvest (99.00 and 70.20) indicating that the heritability is most likely due to additive gene effects and thus the chances of fixing by selection are more.

Keywords: Genetic variability; genotypes; genetic advance; heritability; *Lagenaria siceraria*

Evaluation of test cross hybrids derived from a two-line hybrid breeding system employing promising TGMS lines in rice (*Oryza sativa* L.)

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ABSTRACT

Rice (*Oryza sativa* L.) is one of the most important food crops globally, and exploitation of heterosis through hybrid rice technology offers considerable scope for enhancing productivity. The present investigation was conducted during Kharif 2025 at the Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, to evaluate test cross hybrids developed through a two-line hybrid breeding system using promising TGMS lines. The experimental material comprised **22 test cross hybrids** along with three standard check varieties, namely NDR-359, Pusa 1121 and PR126. The experimental material was evaluated in a Randomized Block Design with three replications for agronomic, yield and grain quality traits. Significant variability was observed among the test cross hybrids for the traits studied, indicating the presence of substantial genetic variation that could be exploited for hybrid selection. Among the hybrids, **PB_2(RB) × NTG-1102** exhibited the earliest flowering and recorded the highest number of effective tillers per plant. **Haryana Basmati sel-8 × MTUGLP3** recorded the highest grain yield per plant along with the highest 1000-grain weight, indicating its superior performance for important yield-contributing traits. **Haryana Basmati sel-3(M) × MUTG108 (F)** produced the highest number of grains per panicle, while **Lal Basmati × PCMS3A** exhibited superior cooking quality. Analysis of variance revealed significant differences among the test cross hybrids, confirming considerable genetic variability for selection. Grain yield per plant showed positive association with effective tillers per plant, number of grains per panicle, panicle length and 1000-grain weight, suggesting the importance of these traits in improving grain yield. Standard heterosis analysis further identified several promising hybrids exhibiting desirable heterotic performance for grain yield and its component traits. The identified superior test cross hybrids, particularly those showing high grain yield and desirable yield attributes, may serve as promising material for further evaluation and utilization in hybrid rice breeding programmes.

Keywords: grain quality; grain yield; heterosis; rice; test cross hybrids; two-line hybrid system

Direct-seeded rice: A resource-efficient approach for enhancing farm profitability and securing farmer incomes

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ABSTRACT

Rice production is facing increasing challenges due to rising cultivation costs, labour scarcity, declining water availability and the need for sustainable resource management. Direct-seeded rice (DSR) has emerged as an important alternative to conventional transplanted rice because it eliminates nursery raising and manual transplanting operations and offers opportunities for saving labour, water and production costs. The present study was undertaken to evaluate the performance of direct-seeded rice with emphasis on crop productivity, resource-use efficiency and economic returns, with the broader objective of identifying a profitable and sustainable rice establishment technology for farmers. Different DSR management practices were evaluated for their effects on crop establishment, growth, yield attributes and grain yield. Economic parameters including cost of cultivation, gross returns, net returns and benefit–cost ratio were also assessed to determine the economic feasibility of the production system. The study demonstrated that appropriate DSR management can improve the efficiency of major production resources while maintaining satisfactory crop productivity. The reduction in labour requirement associated with the elimination of transplanting operations provides an important economic advantage, particularly under conditions of increasing labour costs and limited availability of farm labour. Improved water-use efficiency and reduced operational expenditure further contribute to the economic viability of the system. The findings highlight that successful adoption of DSR depends on timely crop establishment, effective weed management and appropriate agronomic practices. Overall, DSR represents a promising resource-efficient production approach capable of reducing cultivation costs and improving farm-level profitability. Its integration with suitable agronomic and water-management practices can contribute to sustainable rice production while supporting the broader goal of strengthening farmer income security and resilience in a changing agricultural production environment.

Keywords: Direct-seeded rice; Farm profitability; Farmer income; Resource efficiency; Sustainable agriculture; Water management

BIOCHAR AMENDMENTS AND SOIL RESTORATION

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ABSTRACT

Soil degradation is a major problem affecting Indian agriculture. Most agricultural soils have lost organic matter, microbial activity, water retention capacity, and essential nutrients, leading to poor crop yields and reduced farmer income. Biochar offers a practical and sustainable solution to this problem. Biochar is a carbon-rich material produced by heating agricultural waste and crop residues in the absence of oxygen. When biochar is added to degraded soils, it improves multiple soil properties that directly benefit crop growth and productivity. Biochar works in several important ways. First, its porous structure acts like a sponge, holding water and nutrients in the soil longer, reducing water loss and nutrient leaching. This is especially beneficial during dry seasons and in rainfed farming areas. Second, biochar creates favorable habitats for beneficial soil microorganisms and mycorrhizal fungi. These microorganisms help break down organic matter and make nutrients available to plant roots. Third, biochar increases soil organic carbon content, which improves soil structure and stability. Strong soil structure prevents erosion and improves water infiltration. When biochar is combined with compost or manure, its benefits are significantly enhanced. Research demonstrates that biochar-amended soils show 20–25% improvement in crop yields, better soil structure, and increased microbial activity. Additionally, biochar stores carbon in soil for hundreds of years, helping reduce atmospheric carbon dioxide and supporting India's climate change mitigation goals. Biochar is cost-effective and can be produced locally from agricultural waste available in every farming region without requiring expensive technology or chemicals. This makes it especially suitable for smallholder and marginal farmers who form the backbone of Indian agriculture. Adopting biochar-based soil management represents an effective, practical, and sustainable approach for restoring degraded soils, improving crop productivity, and promoting environmental sustainability in Indian agriculture.

Keywords: Agricultural productivity; Biochar; Carbon sequestration; Soil health; Soil restoration; Sustainable agriculture.

TRADITION MEETS CLIMATE-SMART AGRICULTURE: BUILDING RESILIENT FARMING SYSTEMS IN INDIA

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ABSTRACT

Indian agriculture has historically evolved through locally adapted knowledge systems that enabled farming communities to respond to variations in climate, soil, water availability, and ecological conditions. Practices such as crop diversification, mixed and intercropping, indigenous seed conservation, organic nutrient management, traditional water harvesting, agroforestry, and crop–livestock integration have contributed to the resilience of farming systems across diverse agroecological regions. In the context of climate change, these traditional approaches offer valuable foundations for developing more resilient and sustainable agriculture. At the same time, advances in climate-smart agriculture, including precision farming, remote sensing, artificial intelligence, weather-based advisories, digital platforms, improved crop varieties, efficient irrigation, and sensor-based farm management, provide new opportunities to strengthen farmers' capacity to manage climate-related risks. The convergence of these two knowledge systems can create a context-specific approach in which technology complements rather than replaces indigenous agricultural wisdom. This paper proposes a Tradition–Technology–Resilience framework for Indian agriculture, focusing on the integration of traditional ecological knowledge with modern scientific and digital innovations to support efficient resource utilization, soil health, biodiversity conservation, climate-risk management, and sustainable farm productivity. For instance, traditional water-conservation practices can be enhanced through geospatial technologies, indigenous crop diversity can be supported through digital seed documentation and conservation systems, and locally developed climate-adaptation practices can be strengthened through weather forecasting and digital advisory services. The approach emphasizes that climate-smart agriculture should remain farmer-centric, locally adaptable, economically viable, and ecologically sustainable, supported by collaboration among farmers, researchers, extension institutions, start-ups, Farmer Producer Organizations, and local communities. Reconnecting traditional agricultural wisdom with contemporary science and technology can therefore provide a pathway toward resilient farming systems capable of addressing climate uncertainty while preserving India's rich agricultural heritage. The future of Indian agriculture may lie not in choosing between tradition and technology, but in thoughtfully integrating both to create locally rooted, scientifically informed, and climate-resilient farming systems.

Keywords: Climate Resilience; Climate-Smart Agriculture; Indigenous Knowledge; Sustainable Agriculture; Traditional Practices

Sundarja Mango: Climate Resilience, Adaptive Potential and Superior Fruit Quality under Changing Environmental Conditions

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ABSTRACT

Climate change is emerging as a major challenge to mango production, with rising temperatures, erratic rainfall, altered seasonal patterns, water stress and increasing frequency of climatic extremes affecting flowering, fruit set, fruit development and quality. Finding and promoting climate-resilient mango cultivars with consistent performance and appealing fruit qualities has become more crucial in this shifting environment. The Sundarja mango is a promising cultivar with unique fruit quality characteristics and significant potential for environmental adaptability. In light of shifting environmental conditions, the current study summarises the body of knowledge about the agro-climatic adaptability, phenological behaviour, physiological responses, climate resistance, and fruit-quality traits of Sundarja mangos. The current research summarises known data on Sundarja mango's agro-climatic adaptation, phenological behaviour, physiological responses, climate resistance, and fruit-quality attributes in the context of changing environmental circumstances. The cultivar's potential sensitivity to temperature fluctuation, moisture stress, and other climate-related restrictions is highlighted, as well as its desired characteristics such as fruit appearance, pulp quality, flavour, sweetness, texture, and consumer preference. The review delves deeper into the significance of cultivar-specific traits and climate-smart orchard management in maintaining production and fruit quality under future climate scenarios. Understanding the adaptation capacity of Sundarja can contribute to the protection, use, and further promotion of climate-resilient mango germplasm. Integrating genetic potential with suitable water, nutrient, canopy and orchard management practices may provide a viable pathway towards resilient and sustainable mango production. Future research should focus on systematic multi-location evaluation of Sundarja under diverse agro-climatic conditions and on identifying physiological and biochemical traits associated with its resilience and fruit-quality stability.

Keywords: Sundarja mango, climate change, climate resilience, adaptive potential, fruit quality, abiotic stress, sustainable mango production

AGRICULTURAL WATER CRISIS IN INDIA

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ABSTRACT

This research on "Agricultural Water Crisis in India" was undertaken to study the growing water crisis in Indian agriculture and its impact on farmers. Agriculture is highly dependent on the availability and timely supply of water. However, increasing population, irregular rainfall, groundwater depletion, changing climatic conditions, inefficient irrigation practices, and competing demands from domestic and industrial sectors have intensified water-related problems in different parts of the country. The study aims to examine the major causes of agricultural water scarcity, its effects on crop production, farm income, and livelihood security of farmers, and the measures adopted by farmers to overcome these constraints. It was based on secondary information collected from government reports, agricultural publications, research papers, and relevant institutional sources. The study revealed that irregular and inadequate rainfall, declining groundwater levels, insufficient irrigation facilities, high dependence on monsoon rainfall, poor water-use efficiency, and inadequate water-storage facilities are among the major constraints faced by farmers. Small and marginal farmers were found to be particularly vulnerable because of their limited financial capacity to adopt efficient irrigation technologies and alternative sources of water. The agricultural water crisis adversely affects the timely sowing of crops, crop growth, productivity, cropping intensity, and farm profitability, thereby increasing the economic uncertainty faced by farming communities. The study further indicates that efficient irrigation systems such as drip and sprinkler irrigation, rainwater harvesting, farm ponds, watershed management, mulching, crop diversification, and adoption of drought-tolerant crop varieties can contribute significantly towards improving agricultural water security. Strengthening groundwater management, improving irrigation infrastructure, promoting water-saving technologies, and creating awareness among farmers are essential for sustainable agricultural development. The study suggests that coordinated efforts by farmers, government agencies, research institutions, and local communities are required to ensure economic utilization, conservation, and equitable distribution of agricultural water resources. Sustainable water management should therefore be considered an essential component of long-term food security and farmers' livelihood security in India.

Keywords: Agricultural water crisis; climate variability; groundwater depletion; irrigation efficiency; sustainable water management; water scarcity

Morphological Characterization of Gamma-Treated Lentil (*Lens culinaris* Medik.) Genotypes Based on DUS Descriptors

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ABSTRACT

Lentil (*Lens culinaris* Medik.) is an important cool-season pulse crop in which broadening of the genetic base is essential for developing productive and resilient cultivars. The present study assessed morphological variation in 30 gamma-treated lentil genotypes maintained under net-house conditions at Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur. Thirty genotypes were exposed to 250 Gy gamma radiation at Bhabha Atomic Research Centre (BARC), Trombay, Mumbai, and subsequently evaluated in a completely randomized design with three replications. Nine morphological descriptors recorded in the supplied dataset were considered, foliage colour, stem anthocyanin colouration, time of flowering, leaf pubescence, leaflet size, plant growth habit, flower colour, plant height and pod anthocyanin colouration. Marked variation was observed for foliage colour, stem anthocyanin, flower initiation, leaflet size, plant growth habit, flower colour, plant height and pod anthocyanin, whereas leaf pubescence was uniform. Medium foliage was recorded in 16 genotypes (53.33%), stem anthocyanin was present in 19 (63.33%), early flower initiation occurred in 22 (73.33%) and medium leaflet size occurred in 18 (60.00%). Semi-erect growth habit predominated (17 genotypes, 56.67%), followed by erect types (11, 36.67%). Violet flowers were recorded in 27 genotypes (90.00%), while 28 genotypes (93.33%) had medium plant height and 18 (60.00%) showed pod anthocyanin colouration. The observed phenotypic diversity provides useful material for subsequent selection and breeding.

Keywords: Induced mutation, gamma radiation, morphological characterization, DUS descriptors, genetic variability

Efficient Crop Selection Strategies for Rice (*Oryza sativa* L.) under Natural Farming: Combining Indigenous Varietal Selection with Marker-Assisted Selection and Omics

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ABSTRACT

Most modern rice varieties were bred and selected under heavy use of chemical fertiliser and pesticides. About 95% of the varieties grown in organic systems still come from these conventional programmes. As a result, they often do poorly under natural and organic farming, where the main limits on yield are the slow release of nitrogen from soil organic matter, low soil phosphorus, and competition from weeds. This review explains how selection can be made more efficient for natural farming by combining three things that are usually kept apart: the varietal selection skill of traditional farmers, the useful genes held in landraces, and modern molecular tools such as marker-assisted selection (MAS), QTL mapping, genome-wide association studies (GWAS) and genomic selection. A central point, supported by field studies in wheat and rice, is that selection works best when it is done in the same conditions where the variety will be grown: the best genotypes under chemical inputs are usually not the best under organic management. We review landrace genes such as Pup1/PSTOL1 for low-phosphorus soils and SUB1A for flooding, which were found in traditional varieties and moved into modern ones by MAS. We set out the traits that matter under natural farming, an integrated selection pipeline, and the yield evidence, including four meta-analyses of the organic-conventional yield gap. We do not claim that natural farming always yields more; we show that the gap is mainly caused by nitrogen supply and by varieties that were not selected for these conditions, and that both can be improved. We conclude that agroecological management and plant breeding work better together than apart.

Keywords: *Oryza sativa;* natural farming; organic breeding; direct selection; marker-assisted selection; genomic selection; landraces; participatory varietal selection; genotype × environment interaction.

Integrating Climate-Smart Technologies and Resource-Efficient Management for Sustainable Agricultural Intensification

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ABSTRACT

Sustainable agriculture represents a multidimensional paradigm for reconciling increasing global food demand with ecological integrity, resource conservation and long-term agroecosystem resilience. Contemporary agricultural intensification is increasingly constrained by soil degradation, declining water-use efficiency, climate variability, biodiversity loss and excessive dependence on synthetic agrochemical inputs. Addressing these challenges requires integration of climate-smart production systems with precision agriculture, biological inputs, conservation practices and circular resource management. Site-specific nutrient management, sensor-assisted crop monitoring, remote sensing, variable-rate input application and decision-support systems can optimize resource allocation while minimizing nutrient losses and environmental externalities. Conservation agriculture practices, including minimum or zero tillage, residue retention and diversified crop rotations, contribute to improved soil aggregation, carbon sequestration, microbial activity, and water-use efficiency. Furthermore, integrated nutrient management combining mineral fertilizers with compost, biofertilizers, crop residues and other organic amendments can enhance nutrient-use efficiency and maintain soil fertility. Biological approaches involving beneficial microorganisms, biostimulants and biocontrol agents provide opportunities to reduce dependence on chemical inputs while supporting plant growth and ecosystem functioning. Climate-resilient cultivars developed through conventional breeding, marker-assisted selection, genomic approaches and phenomics can further strengthen crop adaptation to drought, heat, salinity and emerging biotic stresses. Integration of digital agriculture, artificial intelligence, Internet of Things-enabled sensors, and geospatial technologies can facilitate real-time monitoring and predictive management of crop and soil conditions. Thus, sustainable agricultural intensification should be approached as a systems-level strategy integrating productivity, profitability, resource-use efficiency, biodiversity conservation, greenhouse-gas mitigation and socio-economic resilience. Such integrated frameworks are essential for developing productive and climate-resilient agroecosystems capable of sustaining food security without compromising the ecological resources required by future generations.

Keywords: Sustainable agriculture; Precision farming; Conservation agriculture; Soil health; Digital agriculture; Integrated nutrient management.

FROM MONOCROPPING TO DIVERSIFICATION: INTEGRATING TRADITIONAL CROPPING WISDOM WITH MODERN AGRICULTURAL TECHNOLOGIES FOR SUSTAINABLE INDIAN AGRICULTURE

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ABSTRACT

Indian agriculture has undergone significant changes in cropping patterns, with the expansion of monocropping and crop specialization driven by market incentives, input-intensive production systems, and changing consumption patterns. While such systems have contributed to agricultural productivity, they have also raised concerns related to soil degradation, declining agrobiodiversity, water stress, climate vulnerability, and farm-level economic risks. In this context, traditional Indian agricultural knowledge offers valuable insights into diversified farming systems based on crop rotation, intercropping, mixed cropping, indigenous crops, and locally adapted production practices. However, the integration of this knowledge with contemporary agricultural technologies remains relatively underexplored. This paper proposes a TradiTech framework that combines traditional cropping wisdom with modern agricultural technologies to promote sustainable crop diversification in India. Technologies such as remote sensing, geographic information systems, artificial intelligence-based crop advisories, digital weather forecasting, soil-health monitoring, and digital agricultural markets can support farmers in making informed decisions regarding crop selection and diversification. By integrating local knowledge with data-driven tools, farmers can potentially identify crops suited to changing climatic conditions, soil characteristics, water availability, and market opportunities. The paper conceptually examines how this integration can facilitate a transition from monocropping towards diversified and resilient cropping systems. Particular attention is given to the diversification of cereal-dominated systems towards pulses, oilseeds, millets, horticultural crops, and other locally suitable crops. The study argues that TradiTech should not be viewed as a replacement for traditional agricultural knowledge, but as a means of enhancing, validating, and scaling it. Such an approach can contribute to climate resilience, resource conservation, agrobiodiversity, and sustainable farm livelihoods while supporting the broader transformation of Indian agriculture.

Keywords: Crop Diversification, Cropping Pattern, Traditional Agricultural Knowledge, TradiTech, Climate Resilience, Sustainable Agriculture

Bioefficacy of prominent insecticides against *Helicoverpa armigera* (Hübner)

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ABSTARCT

One of the most significant biotic challenges that modern intensive agriculture faces is *Helicoverpa armigera* (Hübner), a polyphagus pest having capacity for seasonal migration and facultative diapause. Insecticide use has been the cornerstone of efforts to control this pest and nearly 30% of all insecticides used worldwide are used against it. In consequence, the insecticidal activity declined with time leads to development of resistance in the pest, it necessitates the search for new insecticides with novel mode of actions. Newer chemicals like Broflanilide which is a novel meta-diamide insecticide that is metabolized to desmethyl-broflanilide, that acts as a non-competitive resistant-to-dieldrin γ-aminobutyric acid receptor antagonist. It exhibits high larvicidal activity levels against various pests including lepidopteran, coleopteran insects. Among emerging insecticides, anthranilic diamides like Chlorantraniliprole, cyantraniliprole and tetraniliprole etc. are promising because of their efficacy against lepidopteran pests. These anthranilic diamides have a novel mode of action i.e.; they selectively bind to and activate insect ryanodine receptors which are non-voltage gated calcium channels in the muscle cells. In addition to directly killing the insects, insecticides may have sublethal effects. Sublethal exposure to these insecticides could result in reduced larval body mass, emergence ratio, adult longevity and egg hatching rate in both parental and offspring generations. During the past decade, insecticide possessing a variety of novel mode of actions have been launched or are under development. Broflanilide, Chlorantraniliprole, cyantraniliprole, cyclaniliprole, flubendimide and tetraniliprole, as effective, safe and environment friendly diamide insecticide, exhibit high bioactivity levels and excellent control performances against lepidopteran pests in particular.

Key words: *Helicoverpa armigera*, Diamides, Broflanilide, Chlorantraniliprole, Sublethal effects

Regenraterative Agriculture: Restoring Soil, Reducing Inputs and Rebuilding Farm Resilience

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ABSTRACT

Regenerative agriculture represents a holistic approach to farming that aims to restore soil health, improve ecosystem functioning, reduce dependence on external agricultural inputs, and strengthen the long-term resilience of farming systems. Soil degradation caused by intensive tillage, excessive use of synthetic fertilizers and pesticides, monocropping, erosion, and declining organic matter has adversely affected soil fertility, biodiversity, water retention, and crop productivity. Regenerative farming emphasizes the restoration of soil biological, physical, and chemical properties through practices such as reduced tillage, crop diversification, cover cropping, crop rotation, residue retention, compost and organic amendments, integrated nutrient management, agroforestry, and efficient water management. These practices promote soil organic matter accumulation, microbial activity, nutrient cycling, aggregate stability, and water-holding capacity while reducing soil erosion and nutrient losses. Improved soil health can also enhance nutrient-use efficiency and reduce farmers' reliance on synthetic fertilizers and other external inputs. Furthermore, regenerative practices contribute to carbon sequestration and biodiversity conservation, thereby supporting climate-change mitigation and adaptation. By improving the capacity of soils to retain water and nutrients, regenerative agriculture can help crops withstand drought, heat, and other environmental stresses, ultimately contributing to greater farm resilience and production stability. However, the effectiveness of regenerative practices depends on local soil conditions, climate, cropping systems, resource availability, and farmer knowledge. Successful adoption therefore requires location-specific strategies, scientific guidance, farmer capacity building, appropriate incentives, and long-term monitoring of soil and crop responses. Regenerative agriculture provides a promising pathway for transitioning from input-intensive production towards resilient and resource-efficient farming systems. Integrating soil restoration with sustainable crop and resource management can contribute significantly to maintaining productive soils, reducing environmental impacts, and ensuring the long-term sustainability of agriculture.

Keywords: Agroecology; Biodiversity; Carbon sequestration; Regenerative agriculture; Soil health; Sustainable farming

Micropropagation Of Annona Squamosa L. Using Nodal Explants

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ABSTRACT

Large-scale micropropagation has been successfully achieved in Annona squamosa L. from nodal explants. Several media with different hormones and culture conditions were tried in standardization of in vitro propagation of this plant. Effect of various surface sterilants in eliminating the contamination from the explants collected from the field has been worked out. Activated charcoal has a profound effect in preventing the polyphenol leaching in cultures. BAP, Kinetin, IAA, IBA and NAA were used either alone or in combination to induce shoot buds. Explants produced shoot buds in 7-14 days. Effect of hormones on rhizogenesis was studied. IBA was found to be more effective in root induction. True to type plantlets were obtained from the explants from elite trees. Present protocol is rapid, reproducible and less cumbersome over the conventional methods.

Key words: micropropagation, In Vitro, Annona Squamosa, Nodal Explants, Microbial Contamination, Rhizogenesis

Prosperity for the Plough: Reimagining Indian Agriculture through Sustainable Farm Income Enhancement, Market Integration and Farmer Empowerment

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ABSTRACT

Agriculture remains the backbone of rural livelihoods and an essential pillar of India's food and economic security. However, farmers continue to face challenges arising from rising input costs, climate variability, fragmented landholdings, market uncertainties, price fluctuations, post-harvest losses and limited access to remunerative markets. In this changing agricultural order, securing and enhancing farmers' income requires a shift from production-oriented agriculture towards a more diversified, market-linked and income-oriented agricultural system. This paper highlights the need for a comprehensive approach to farmer prosperity through sustainable intensification, diversification and improved value-chain integration. Crop diversification towards pulses, oilseeds, horticulture, livestock, dairy, fisheries and other allied enterprises can reduce production risks and create additional income opportunities. Strengthening Farmer Producer Organisations (FPOs), cooperatives, digital agricultural markets, storage, processing and direct market linkages can improve farmers' bargaining power and reduce dependence on intermediaries. Access to quality seed, balanced fertilization, efficient irrigation, mechanization, precision agriculture and climate-resilient technologies can further improve productivity and resource-use efficiency. Income security also depends on effective risk-management mechanisms, including crop insurance, institutional credit, weather advisories and timely access to agricultural information. Greater emphasis should be placed on value addition and agro-processing so that farmers participate not only in production but also in higher-value stages of the agricultural supply chain. Special attention is required for small and marginal farmers, women farmers and rural youth through skill development, entrepreneurship and collective action. The future of Indian agriculture therefore lies in combining productivity with profitability, sustainability with resilience, and technology with inclusiveness. A farmer-centred agricultural policy framework, supported by efficient institutions, infrastructure and markets, can transform farming from a subsistence activity into a viable and dignified enterprise. Prosperity for the plough ultimately means building an agricultural system in which higher productivity translates into stable, sustainable and equitable farm incomes.

Ploughing Prosperity: Cultivating Sustainable Farmer Incomes

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ABSTRACT

For a long time, the plough has stood as the symbol of Indian farming. But today the goal is not just to grow more. What really matters is whether the farmer ends up earning more from the same land. Input costs keep going up, the weather has become unpredictable, markets are unstable, landholdings are shrinking, and many farmers stick to just one or two crops. All of this has squeezed farm incomes. This abstract looks at how farming can move from being focused only on crops to being focused on income. The idea is to run the farm as a mix of different activities that support each other. Integrated Farming Systems, dairy and livestock, fisheries, horticulture, agroforestry, beekeeping, mushroom growing and similar side enterprises can bring in money from more than one source, and they also make better use of the resources already on the farm. Farmers can earn even more by processing their produce, adding value to it, storing it properly and selling directly to buyers. Joining Farmer Producer Organisations and using digital platforms can also help them keep a bigger share of what the final product sells for. So, the future of Indian agriculture is not only about growing more food. It is about finding several ways to raise what the farmer takes home. With diversification, new methods, smarter use of resources and better access to markets, the plough can once again become a sign of prosperity. "Ploughing prosperity" means creating many sources of income for farmers and opening up new opportunities for rural India.

Prosperity for the Plough: Securing Farmer Incomes in a New Agricultural Order

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ABSTRACT

Agriculture remains the backbone of India's rural economy, providing livelihoods, food security and employment to millions of farming households. However, increasing input costs, climate variability, fragmented landholdings, market fluctuations, post-harvest losses and limited value addition continue to affect farm profitability. "Prosperity for the Plough" represents a farmer-centric approach to building a new agricultural order in which higher and more stable farm incomes become the central objective of agricultural development. Securing farmer incomes requires a transition from production-oriented agriculture towards income-oriented, diversified and market-linked farming systems. Crop diversification, integrated farming systems, horticulture, livestock, dairy, fisheries and agroforestry can provide multiple income sources and reduce dependence on a single crop. Adoption of improved varieties, precision agriculture, efficient irrigation, soil-health management, mechanization and digital technologies can increase productivity while improving resource-use efficiency. Strong farmer institutions are equally important. Farmer Producer Organisations (FPOs), cooperatives and self-help groups can enable small and marginal farmers to aggregate produce, reduce input costs, improve bargaining power and access better markets. Post-harvest infrastructure such as storage, grading, processing, cold chains and transportation can reduce losses and increase the share of value received by producers. Greater emphasis on food processing and value addition can convert agricultural commodities into higher-value products and create rural employment. Digital agriculture can further strengthen farmers' decision-making through weather advisories, market information, digital payments, e-commerce and data-based farm management. At the same time, climate-resilient agriculture, efficient water management, sustainable soil practices and risk-management mechanisms are essential for protecting farm incomes against climate-related uncertainties. A new agricultural order must also provide greater opportunities for women and rural youth through entrepreneurship, skill development, agri-start-ups, custom hiring services, processing and allied enterprises. Coordinated efforts by farmers, research institutions, government agencies, private enterprises and financial institutions are necessary to create an enabling ecosystem. Thus, farmer prosperity should be measured not merely by production, but by sustainable income, resilience, value realization and quality of life. A farmer-centric agricultural transformation can strengthen rural economies, improve food and nutritional security, generate employment and contribute substantially to the vision of a prosperous and developed India.

Keywords: Farmer Income; Agricultural Transformation; FPOs; Crop Diversification; Value Addition; Digital Agriculture; Climate Resilience; Rural Entrepreneurship; Sustainable Agriculture; Farm Prosperity.

Smart Farming Technologies for Enhancing Crop Productivity and Farm Income

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ABSTRACT

Indian agriculture faces challenges of declining resource-use efficiency, rising input costs, climate variability, and the need to enhance farmers' income. Smart farming technologies offer opportunities to address these challenges through data-driven and site-specific agricultural management. This study aims to examine the role of smart farming technologies in improving crop productivity, input-use efficiency, resource conservation, and farm profitability, while identifying major constraints to their adoption. A systematic review and synthesis of relevant research literature, government reports, and published studies were undertaken to assess the applications of Artificial Intelligence (AI), Internet of Things (IoT), remote sensing, drones, Geographic Information Systems (GIS), precision irrigation, and digital decision-support tools in agriculture. The review indicates that smart technologies can improve crop monitoring, optimize irrigation and fertilizer application, facilitate early detection of pests and diseases, and support timely farm-level decision-making. These interventions have the potential to reduce input wastage, production costs, and environmental impacts while enhancing productivity and farm income. However, high initial investment, fragmented landholdings, inadequate digital infrastructure, limited technical knowledge, and poor accessibility remain significant adoption barriers. Integrating smart farming with farmer training, affordable technologies, improved digital infrastructure, and supportive agricultural policies can strengthen sustainable and profitable farming systems and contribute to the vision of a developed and self-reliant Bharat.

Keywords: Smart Farming, Precision Agriculture, Artificial Intelligence, IoT, Crop Productivity, Farm Income

Unravelling genetic basis of *Meloidogyne incognita* resistance in guava through SSR-Based diversity analysis

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ABSTRACT

Root-knot nematode (*Meloidogyne incognita*) is a major constraint to guava (*Psidium guajava* L.) production, causing root galling, impaired nutrient and water uptake, and yield losses. Identification of resistant and genetically diverse germplasm is essential for effective resistance breeding and integrated nematode management. In the present study, 25 guava genotypes were evaluated against *M. incognita* under screen-house conditions and characterized using simple sequence repeat (SSR) markers. The experiment was conducted in a completely randomized design with three replications using an inoculum load of 2 J2 g^{-1} soil. Significant variation ($p \leq 0.05$) was observed among genotypes for root galling, egg mass production, and root-knot index (RKI). Chinese Guava, Purtgal, H1, H3, Punjab Pink, and F1 Hybrid were resistant (RKI 1–2), whereas Arka Mridula, H2, H4, H5, and Lalit were moderately resistant (RKI 3). Ten genotypes were susceptible (RKI 4), while Hisar Safeda, Banarasi Surkha, Pant Prabhat, and L-49 were highly susceptible (RKI 5). L-49 recorded the highest galling (112.00 galls $root^{-1}$), whereas Pant Prabhat produced the maximum egg masses (132.00 $root^{-1}$). SSR profiling with 38 primer pairs generated 34 amplifiable loci, including 15 polymorphic markers, revealing 49 alleles (2–6 per locus; mean 3.26) with PIC values of 0.13–0.72. Guv 4-45 was the most informative marker (PIC = 0.72). MDS, PCoA, and UPGMA analyses revealed distinct patterns of genetic relatedness among the genotypes. The integration of phenotypic resistance screening and molecular diversity analysis identified promising resistant germplasm and provides a useful framework for parent selection and marker-assisted breeding for resistance to *M. incognita* in guava.

Keywords: Genetic diversity; Guava, host-plant resistance; *Meloidogyne incognita*; Root-knot index; SSR markers

Soil Organic Carbon: A Key Indicator of Soil Health, Fertility and Sustainable Agriculture

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ABSTRACT

Organic carbon is an important component of soil organic matter and plays a vital role in maintaining soil fertility, soil structure, water-holding capacity and nutrient availability. It is derived mainly from decomposed plant and animal residues, roots, microorganisms and other organic materials. Soil organic carbon improves aggregation, porosity and microbial activity, thereby supporting healthy plant growth. It also acts as an important reservoir of carbon in terrestrial ecosystems and contributes to carbon sequestration and climate-change mitigation. The level of organic carbon is influenced by climate, soil texture, vegetation, cropping system, tillage and the addition of organic manures. Practices such as farmyard manure, compost, crop-residue incorporation, green manuring, cover crops, mulching and reduced tillage can help maintain or increase soil organic carbon. Regular assessment of soil organic carbon is useful for evaluating soil health and developing sustainable nutrient-management strategies. Thus, maintaining adequate organic carbon is essential for sustainable agriculture, long-term soil productivity and environmental health.

Keywords: Organic Carbon; Soil Organic Matter; Soil Fertility; Soil Structure; Water-Holding Capacity

Post- Harvest Management of Fruits and Vegetables

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ABSTRACT

Fruits and vegetables are highly perishable commodities and undergo considerable quality deterioration after Harvest due to physiological, biochemical and microbial processes. Post-harvest management plays an important Role in reducing these losses and maintaining the quality, nutritional value and marketability of fresh produce. This research focuses on important post-harvest practices such as harvesting at the proper maturity stage, Grading, sorting, cleaning, packaging, pre-cooling, storage, transportation and marketing. Appropriate Temperature and relative humidity management can help slow respiration, moisture loss and microbial Deterioration. Modern approaches such as modified atmosphere packaging, edible coatings, cold-chain systems and non-chemical preservation methods are also being studied to extend shelf life and reduce post-harvest losses. Efficient post-harvest management can improve farmers' returns, reduce wastage and contribute to food and Nutritional security. The study highlights the need for suitable, affordable and sustainable post-harvest Technologies for reducing losses in fruits and vegetables. Keywords: fruits, management, packaging, post-harvest losses, shelf life, vegetables

Natural Farming: A Sustainable Approach for Improving Soil Health and Agricultural Productivity

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ABSTRACT

Natural farming is an eco-friendly and sustainable agricultural approach that emphasizes the use of locally available natural resources and minimizes dependence on synthetic fertilizers and pesticides. It focuses on maintaining soil health, enhancing biodiversity, improving nutrient cycling and reducing the cost of cultivation. Natural farming practices such as the use of farm-made bio-inputs, crop diversification, mulching, intercropping and efficient water management can contribute to the development of resilient agricultural systems. These practices may improve soil biological activity and soil structure while reducing the adverse environmental impacts associated with excessive use of chemical inputs. Natural farming also has the potential to lower input costs and improves the economic sustainability of small and marginal farmers. However, its successful adoption requires adequate knowledge, availability of quality bio-inputs, appropriate crop-specific practices and effective extension support. Therefore, promoting scientific awareness, farmer training and location-specific research is essential for wider adoption of natural farming. Overall, natural farming offers a promising pathway towards sustainable agriculture by integrating ecological, economic and social dimensions of agricultural production.

Keywords: Natural farming, sustainable agriculture, soil health, biodiversity, bio-inputs, input cost, farm Sustainable

RESPONSE OF RICE TO FLOODING STRESS AND PROSPECTS OF TRANSFERRING SUB 1 QTL THROUGH MARKER ASSISTED BACKCROSSING

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ABSTRACT

A submerged rice plant faces several problems ranging from inadequate growth to damage and death. For example, low light levels inhibit photosynthesis, slower gas exchange results in lower carbon dioxide intake for photosynthesis and lower oxygen intake for respiration, and gases trapped in the water, such as ethylene, promote plant elongation and chlorosis (yellowing or discoloration of the normally green parts of the plant), with a consequent loss of photosynthetic area. Therefore, it is important to study the mechanics that allow rice plants with the *Sub1* genes to tolerate submergence. The Indian variety FR13A can survive submergence because of some key physiological traits that emerge when the plant is underwater. FR13A maintains a higher carbohydrate supply in its shoots before submergence and does not greatly elongate, meaning it conserves energy that can then be used for survival. It also experiences slower carbohydrate depletion and higher rates of alcoholic fermentation as a way of providing energy for maintenance processes in the absence of oxygen underwater. And, when submerged, FR13A maintains higher chlorophyll levels—allowing relatively better photosynthesis during submergence and also after the water recedes to resume its growth and recovery—than intolerant varieties. As survival strategies, maintenance of higher carbohydrate levels before and during submergence and minimization of both elongation growth and chlorosis had the most striking effects. This resulted in an improved survival rate for submergence-intolerant varieties but not for submergence tolerant varieties such as FR13A. This suggested that *Sub1* reduces a plant's sensitivity to ethylene and therefore reduces elongation and chlorophyll degradation under submerged conditions. This increase the chance of survival in two ways. First, less energy is wasted on elongation. Second, the plant needs intact chlorophyll to generate more energy during submergence and to resume active growth during recovery from submergence.

Keywords: Rice, Flooding Stress, Submergence Tolerance, Sub1 Gene, QTL, Marker-Assisted Backcrossing, FR13A, Carbohydrate, Chlorophyll, Ethylene, Photosynthesis, Alcoholic Fermentation, Recovery.

Sustainable Nanofiber Coatings for Pomegranate Preservation: Integrating Biopolymers, Green Nanoparticles and Biocontrol Agents

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ABSTRACT

Pomegranate is a high-value fruit that suffers significant postharvest losses due to microbial decay, moisture loss, and physiological deterioration during storage and transportation. Conventional preservation methods based on synthetic waxes and chemical fungicides are increasingly restricted because of concerns regarding food safety, environmental sustainability, and international trade regulations. Consequently, there is growing interest in developing eco-friendly, biodegradable, and multifunctional preservation technologies. Electrospinning has emerged as an innovative non-thermal technique for producing ultrafine nanofiber coatings with high surface area, excellent gas permeability, and controlled release properties. This review summarizes recent advances in electrospun bioactive nanofiber coatings for postharvest preservation of pomegranate, with particular emphasis on biodegradable polymer matrices, green-synthesized antimicrobial nanoparticles, and beneficial microbial biocontrol agents. The synergistic integration of these components provides enhanced antimicrobial activity, improved moisture resistance, delayed physiological deterioration, and extended storage life while maintaining fruit quality and nutritional attributes. The review also discusses critical factors affecting coating performance, including polymer selection, electrospinning parameters, crosslinking strategies, and coating functionality. Furthermore, recent developments in sustainable material utilization, waste-derived biomaterials, active packaging, and scalable processing technologies are highlighted to demonstrate their potential for commercial implementation. Challenges associated with industrial-scale production, regulatory approval, food safety, and consumer acceptance are also examined. Overall, electrospun multifunctional bioactive coatings represent a promising next-generation approach for sustainable postharvest management of fresh fruits, offering an environmentally friendly alternative to conventional preservation methods while supporting reduced food losses, improved export quality, and enhanced value addition in horticultural supply chains.

Keywords: Electrospinning; Bioactive nanofibers; Pomegranate; Postharvest preservation; Sustainable edible coatings.

Synergistic Integration of Traditional Agricultural Practices and Modern Technologies for Climate Change Adaptation in Indian Agroecosystems

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ABSTRACT

Climate change, increasing rainfall variability, rising temperatures and declining soil and water quality pose significant challenges to the sustainability of Indian agroecosystems. Integrating traditional agricultural knowledge with modern technological innovations offers opportunities to strengthen climate adaptation while improving natural resource-use efficiency. Traditional practices, including crop diversification, mixed farming, rainwater harvesting, and agroforestry, provide locally adapted approaches to managing climatic and environmental uncertainties. Modern technologies, including remote sensing, precision irrigation, agrometeorological forecasting and digital decision-support systems, can complement these practices through improved monitoring and site-specific management. Quantitative evidence supports the environmental potential of such interventions. A meta-analysis by Kumara et al. (2023) reported 25.34% higher soil carbon sequestration in agroforestry systems than in non-agroforestry systems, although outcomes varied with previous land use, system configuration, and climatic conditions. Furthermore, a systematic review by Nivetha and Mohanraj (2026), covering 113 empirical studies of agricultural adaptation in India, identified agronomic adaptation strategies as prominent approaches while highlighting constraints associated with institutional support, climate information and adoption capacity. Despite this growing evidence base, the connections between traditional knowledge systems, technological interventions, and measurable adaptation outcomes require further integrated assessment across diverse Indian agroecological regions. This review aims to critically synthesise published scientific evidence on the complementarities between traditional agricultural practices and modern technologies, examine their contributions to climate change adaptation and environmental sustainability, and identify research and implementation gaps. Particular emphasis is placed on agroforestry, soil organic carbon conservation, water-use efficiency, crop diversification, biodiversity conservation, and the socioeconomic determinants of technology adoption. The review further considers the need for integrated assessment frameworks incorporating productivity, resource-use efficiency, carbon sequestration, greenhouse gas emissions and ecosystem functions. Synthesising these dimensions can help distinguish context-specific opportunities from implementation constraints and establish priorities for comparative field research. Integrating indigenous knowledge with scientifically validated technologies may provide a practical foundation for adaptive agricultural management, sustainable resource utilisation, and long-term food security in India.

Keywords: Agroforestry; Climate change adaptation; Indian agroecosystems; Natural resource management; Precision agriculture; Traditional knowledge

BajraBase: Pearl Millet Genomic Intelligence Platform from Raw sequence to real Biology

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ABSTRACT

Pearl millet [*Cenchrus americanus* (L.) Morrone] is the sixth most important cereal worldwide and a climate-resilient nutricereal for the semi-arid tropics of Asia and Africa. Several chromosome-scale assemblies are now available, yet the information needed to act on them remains scattered across separate files tied to different assemblies and identifier systems. Converting a candidate gene into a genome-editing experiment still requires moving data by hand between annotation portals, BLAST servers, guide designers and primer tools. We developed **BajraBase**, an integrated genomic intelligence platform built on the chromosome-scale SOSAT-C88-P10 reference. It unifies 40,689 high-confidence gene models with 188,285 Pfam, SMART and CDD domain records, 398,014 InterProScan signatures, Gene Ontology, KEGG and Reactome annotation, protein physicochemical properties, promoter scans for eight plant cis-regulatory elements, and 35,605 orthogroups linking three pearl millet genomes (14,229 strict 1:1:1 orthologs). Analytical modules include fourteen local BLAST databases, a pre-computed library of 777,397 SpCas9 guides annotated with exon, amino-acid position and protein-domain context, genome-wide off-target assessment, and a seven-mode PCR primer designer. Annotation inferred through orthology is stored separately and labelled, so direct and transferred evidence remain distinguishable. We demonstrate the platform with PgTGL1 (PgP10c0101G017608), a class-3 triacylglycerol lipase relevant to post-milling flour rancidity. From a single keyword search the workflow proceeds through domain architecture, paralog discovery, selection of a guide RNA cutting within the catalytic Lipase_3 domain with one perfect genomic site and no mismatched sites, and design of genotyping primers yielding amplicons of 750–876 bp — all within one session. BajraBase runs on a server or entirely offline as a self-contained package, suiting breeding programmes with limited connectivity. By linking annotation directly to editing design, it shortens the path from candidate gene to validated target in pearl millet improvement.

Keywords: pearl millet; genomic database; functional annotation; cross-genome orthology; CRISPR/Cas9 guide design; PCR primer design; flour rancidity

Assessment of Long-Term Trends, Post-Monsoon Fluctuations, and Groundwater Recovery in the Bundelkhand Region, India

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ABSTRACT

The hard-rock terrains of the Bundelkhand region in central India, variable hydrogeological conditions drive severe domestic and agricultural vulnerabilities, making groundwater management critical. This study presents a comprehensive evaluation of long-term post-monsoon water table dynamics, decadal shifts, interannual fluctuations, and seasonal groundwater recovery across 13 districts spanning the years 1996 to 2023. Utilizing rigorous statistical frameworks—including descriptive analytics, autocorrelation models, Mann–Kendall (MK) and Hamed–Rao Modified Mann–Kendall (MMK) tests, Sen's slope estimation, and standardized anomaly indices—the research quantifies critical hydrological behaviors. Seasonal recovery rates were isolated by mapping the definitive delta between corresponding pre- and post-monsoon groundwater tables. The results showed that mean post-monsoon depth varied geographically, ranging from a shallow 3.90 meters below ground level (m bgl) in Mahoba to a deeper 10.11 m bgl in Datia, with the highest relative volatility captured in Mahoba (CV = 37.74%). Long-term diagnostic trends revealed escalating groundwater depletion tendencies in 11 districts, led by a statistically significant drop in Chhatarpur (+0.072 m year^{-1}; p = 0.040), while Hamirpur and Lalitpur stood out with positive, decreasing-depth tendencies. Anomaly mappings further confirmed intense, period-specific shifts across the decadal timelines. Critically, while the regional mean seasonal groundwater recovery was calculated at 2.96 meters—peaking in Panna (3.93 m) and hitting its lowest point in Lalitpur (1.57 m)—the long-term viability of this recharge is under threat. The trend analysis revealed alarming, statistically significant declines in seasonal recovery across Banda, Jalaun, Jhansi, Lalitpur, and Damoh, with contraction rates ranging from −0.061 to −0.108 m year^{-1}. Ultimately, these distinct, localized hydrogeological responses emphasize that uniform policies are insufficient, providing a definitive, data-driven foundation for executing targeted, district-specific groundwater replenishment strategies across Bundelkhand.

Keywords: Groundwater level; Mann–Kendall test; Hamed–Rao Modified Mann–Kendall test; Sen's slope; Seasonal groundwater recovery; Bundelkhand

Conservation Agriculture for a Climate-Resilient Viksit Bharat: From Adoption to Transformation

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ABSTRACT

Indian agriculture must deliver food and nutritional security while confronting rising temperatures, erratic monsoons, water scarcity, soil degradation and pressure on farm profitability. These challenges make climate adaptation and mitigation central to the vision of Viksit Bharat and the transition towards a net-zero economy. Conservation agriculture (CA) offers a systems-based pathway where a set of technologies are aligned to sustain production while rebuilding the natural resource base. Global CA area reached approximately 205.4 million hectares (14.7% of global cropland) across 102 countries and 3.5 Mha in India in 2018–2019 (Kassam et al., 2021). This substantial global expansion highlights both the growing relevance of CA and the considerable scope for wider adoption in India. Conservation Agriculture rests on three mutually reinforcing principles: minimum or no mechanical soil disturbance; permanent soil cover through retained crop residues or cover crops; and diversified crop rotations, including legumes where locally suitable. In a South Asian meta-analysis covering 9,686 paired site–year comparisons, Jat et al. (2020) reported that CA practices, on average, increased grain yield by 4.6%, water-use efficiency by 14.6% and net economic return by 25.6%. Zero tillage combined with residue retention delivered a 5.8% yield advantage, 12.6% higher water-use efficiency, 25.9% higher net returns and a 12–33% reduction in global-warming potential. These results are highly relevant to India's cereal-based production regions. Pittelkow et al. (2015), analysing 5,463 paired observations across 48 crops and 63 countries, found that no-tillage alone reduced yields by 5.7% on average; its negative effects were minimised when residue retention and crop rotation were combined, with yield benefits emerging in rainfed dry climates. In sub-Saharan Africa, Corbeels et al. (2020) found only modest average yield gains, reinforcing that outcomes depend on climate, soil, crop, weed control and whether all three principles can be implemented. From these findings, the practical lesson is clear: promote complete, locally adapted CA systems, not zero tillage in isolation. CA can protect aggregates, reduce erosion, conserve soil moisture, support soil organic carbon and biological activity, and improve the soil's capacity to buffer drought and intense rainfall. In a 29-year study of cotton systems in the southeastern United States, Nouri et al. (2021) linked long-term no-tillage with greater soil structural stability, organic carbon, resilience and yield stability during climate extremes. Knapp and van der Heijden (2018) likewise found that no-tillage did not significantly alter temporal yield stability relative to conventional tillage. Such findings support CA as a risk-management strategy, while reminding us that resilience depends on management and local conditions. Su et al. (2021) further projected that climate-change effects on CA performance will vary geographically; for maize, the probability of yield gains was projected to improve across substantial areas of tropical production, including parts of India, but gains were not universal. For India, TradiTech-led transformation means combining farmers' knowledge of soils, residue use, mixed farming and locally adapted rotations with precision land levelling, residue-capable seeders, happy seeders, laser-guided implements, sensors, weather advisories, remote sensing and decision-support tools. Priorities should include affordable custom-hiring services for smallholders; reliable access to quality seed and suitable machinery; residue management that balances soil cover with livestock-feed needs; integrated weed and pest management; diversified rotations; and site-specific nutrient and water management. Demonstration clusters, farmer-led trials and extension support must show whole-system costs, labour and fuel savings, yields, soil indicators and profitability over multiple years. India should scale CA through agroecological targeting and measurable outcomes. Research and policy must: (i) establish long-term, multi-location trials and farmer-field monitoring; (ii) quantify soil-carbon change, greenhouse-gas emissions, water productivity and yield stability alongside yield and net returns; (iii) develop crop-

and region-specific packages, especially for rice–wheat, rice-fallow, maize-based, pulse-based, oilseed-based, and rainfed cropping systems; (iv) incentivize residue retention and ecosystem services; and (v) link carbon and climate finance to independently verified results. CA is not a sole adoption of balanced fertilization, effective weed control, suitable varieties or sound agronomy. Its promise lies in integrating these practices into a resilient production system. A climate-resilient Viksit Bharat requires more than increasing output: it requires producing reliably with less resource waste and lower environmental cost. Scaled intelligently, supported by evidence and enabled by appropriate technology, conservation agriculture can become a cornerstone of India's sustainable, profitable and climate-ready agri-food future.

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Theme Area: Nourishing a Nation: Safeguarding Food and Nutritional Security for Bharat

Integrated Management of Wheat Spot Blotch: A Pathway towards Sustainable Food and Nutritional Security in Bharat

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ABSTRACT

Wheat (Triticum aestivum L.) underpins India's food security, supplying dietary energy and nutrients to millions. Its productivity and grain quality, however, are increasingly threatened by spot blotch, caused by Bipolaris sorokiniana (Sacc.) Shoem. The disease is especially severe in the warm, humid environments of the eastern Indo-Gangetic plains, including the Eastern Plain Zone of Uttar Pradesh, where conditions favour rapid disease progression and premature foliar senescence. Several studies outline an integrated disease management (IDM) strategy for sustainable spot blotch suppression, combining host resistance, cultural practices, biological control and judicious fungicide use. Screening and deployment of resistant or moderately resistant genotypes form the foundation of an effective, environmentally sound programme, complemented by timely sowing, balanced nutrition, seed treatment, biocontrol agents and need-based fungicide application to limit disease severity and preserve photosynthetic leaf area. Integrating these components is expected to enhance management efficiency while reducing reliance on chemical inputs. Beyond protecting individual crops, effective spot blotch management sustains wheat productivity, minimizes avoidable yield losses and secures a stable supply of nutritious food. Location-specific, economically viable and environmentally sustainable IDM practices can strengthen the resilience of wheat production systems amid changing climatic conditions.

Keywords: *Bipolaris sorokiniana*; food security; integrated disease management; spot blotch; wheat

Geospatial Variability of Soil and Plant Micronutrient Status in Nutri-Gardens of Kangra Block and Their Contribution to Dietary RDA

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ABSTRACT

Micronutrients, though required in smaller quantities than macronutrients play an indispensable role in plant and human nutrition, yet their spatial distribution and soil-to-plant transfer in kitchen-garden systems remain poorly characterized. The present study was conducted across 100 Nutri-Gardens of Kangra block, Himachal Pradesh, to assess the geospatial variability of micronutrient status in soil and in the consumable parts of vegetables cultivated therein, and to evaluate their contribution to the recommended dietary allowance (RDA). A total of 100 soil and 100 plant samples were analysed. Soil samples were analysed for micronutrients (Fe, Mn, Cu, Zn) by DTPA extraction, B by 0.1 M salicylic acid extraction followed by the azomethine-H method, and Mo by ammonium oxalate extraction, with concentrations determined using atomic absorption spectrophotometer (AAS) (graphite furnace AAS for Mo). Plant samples were digested (di-acid/dry ashing) and analysed for Fe, Mn, Cu and Zn using AAS, B calorimetrically, and Mo using graphite furnace AAS. Thematic maps of spatial variability were generated using QGIS software. Soil micronutrients showed significant spatial variability, with molybdenum (CV = 82.13%) and boron (CV = 62.56%) recording the highest coefficients of variation, followed by zinc (38.69%), manganese (21.37%), iron (21.06%) and copper (14.00%). Among plant micronutrients, all six elements exhibited significant variability. Pearson's correlation revealed weak and statistically non-significant relationships between soil and plant micronutrient concentrations for all elements ($r = -0.15$ to 0.06, $p > 0.05$), indicating limited dependence of plant uptake on soil micronutrient availability alone. RDA comparison showed that no single vegetable could meet the full daily requirement across all micronutrients: iron contribution ranged from 10.93-75.21 per cent, manganese from 52.50-100 per cent, copper from 47.77-100 per cent, and zinc from only 3.41-23.3 per cent of RDA. These findings highlight spinach as a consistently strong micronutrient source and underscore the need for dietary diversification and targeted biofortification, particularly for zinc, to address micronutrient inadequacy through Nutri-Garden produce.

Keywords: Micronutrients; geospatial variability; Nutri-Garden, RDA; soil-plant relationship

Biofortification: An Agricultural Pathway to Combat Hidden Hunger in Bharat

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ABSTRACT

Micronutrient deficiencies remain an important challenge to nutritional well-being, even when sufficient quantities of staple foods are available. This condition, commonly described as "hidden hunger," highlights the need to improve not only the quantity but also the nutritional quality of food. Biofortification offers an agricultural approach in which the concentration or bioavailability of essential nutrients in food crops is enhanced through plant breeding, agronomic practices or modern biotechnological approaches. Nutrient-enriched varieties of staple crops can potentially reach large populations because they can be incorporated into existing food production and consumption systems. Biofortification targeting nutrients such as iron, zinc and provitamin. A can complement dietary diversification, supplementation and food fortification programmes. However, successful adoption depends on several factors, including farmer acceptance, seed availability, yield performance, nutrient bioavailability, consumer preference and effective integration with food and nutrition programmes. Greater collaboration between agricultural scientists, nutrition experts, breeders, policymakers, food industries and farming communities is therefore essential. Biofortification should not be viewed as a standalone solution to malnutrition but as one component of a broader nutrition-sensitive food system. Combining nutrient-dense crops with diversified diets, improved food access and nutrition awareness can strengthen efforts to address hidden hunger. Thus, placing nutrition at the centre of crop improvement can help transform agricultural production into a direct instrument for improving human health and nutritional security in Bharat.

Keywords: Biofortification; crop improvement; iron; hidden hunger; micronutrient deficiency; nutritional security; nutrition-sensitive agriculture; zinc

Harnessing India's Arid and Semi-Arid Fruits Biodiversity for Food and Nutritional Security

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ABSTRACT

India faces persistent challenges of food and nutritional insecurity, particularly in regions affected by climatic and resource constraints. According to the 2025 Global Hunger Index (GHI), India ranks 102nd among 123 countries, with a GHI score of 25.8, indicating a serious level of hunger and highlighting the need for strengthened approaches to food and nutritional security. In this context, India's rich diversity of arid and semi-arid fruit crops offers an important, yet underexploited, opportunity. Fruits such as ber, aonla, bael, karonda, ker, lasora, phalsa, pilu, tamarind and wood apple are naturally adapted to water scarcity, high temperature, salinity, poor soils and climatic variability. They are also valuable sources of vitamins, minerals, dietary fibre, phenolics, flavonoids and other bioactive compounds, contributing to dietary diversification and nutritional well-being. the present presentation focuses on strategies for conservation, characterization, genetic improvement, sustainable production, post-harvest management, value addition and promotion of these resilient fruit resources. Strengthening farmer training, SHGs, FPOs, entrepreneurship, processing and market linkages, along with institutional and government support, can enhance their utilization and economic value. harnessing arid and semi-arid fruit biodiversity can provide a triple benefit nutritional security, climate resilience and improved rural livelihoods while conserving valuable genetic resources for future generations. thus, integrating scientific improvement with value addition and effective promotion can help transform these resilient fruits into a strategic resource for a healthier, more nourished and food-secure India.

Keyword: Arid and semi-arid fruits; Climate resilience; Value addition; Fruit biodiversity; Nutritional security; Global Hunger Index; Rural livelihoods.

From Nutrient Management to Farmer Prosperity: Innovative Strategies for Enhancing Fodder Sorghum Productivity and Profitability

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ABSTRACT

Fodder productivity and profitability are important components of economically viable livestockbased farming systems. Adequate availability of quality fodder is essential for sustaining livestock production, while efficient nutrient management plays a key role in improving biomass production, fodder quality and economic returns from forage cultivation. Sorghum is an important forage crop owing to its high biomass-producing potential, adaptability and suitability for fodder production. However, the persistent gap between feed and forage demand and supply necessitates the adoption of improved crop and nutrient-management practices. Integrated nutrient management, involving balanced use of conventional fertilizers, micronutrients, nano-fertilizers and beneficial microbial products, may provide opportunities to enhance fodder productivity while improving the profitability of forage cultivation. In this context, the present study synthesizes the results of two agronomic trials conducted under the All India Coordinated Research Project on Forage Crops and Utilization to evaluate innovative nutrient-management strategies in fodder sorghum. The first trial, conducted during Kharif 2023– 2025, evaluated soil and foliar application of zinc sulphate and nano-zinc in summer fodder sorghum. The second trial, conducted during Kharif 2024–2025, evaluated nano-urea, nano-DAP, conventional urea and DAP foliar application, and bio-products in multicut fodder sorghum. In the zinc-management trial, soil application of $ZnSO_4$ at 8 kg ha^{-1} followed by foliar application of nano-Zn at 500 ppm (T10) recorded the highest pooled green fodder yield (455.37 q ha^{-1}), dry matter yield (100.09 q ha^{-1}), plant height (272.89 cm), gross return (₹113,844 ha^{-1}), net return (₹67,732 ha^{-1}) and benefit–cost ratio (2.47). The treatment also resulted in a progressive increase in soil Zn concentration, with 0.87 and 0.83 mg kg^{-1} recorded after harvest in the respective years. In the second trial, the integrated application of *Azospirillum* at 2 kg ha^{-1} + PSB at 2 kg ha^{-1}, combined with 75% of the recommended N and P and foliar application of urea and DAP at 2% (T10), recorded the highest pooled green fodder yield (420.56 q ha^{-1}), gross return (₹105,139 ha^{-1}), net return (₹66,191 ha^{-1}) and benefit–cost ratio (2.70). Overall, the findings demonstrate that integrated and treatment-specific nutrient-management strategies can substantially influence fodder productivity and economic returns. Thus, efficient and context-specific nutrient management can contribute not only to increased fodder availability but also to improved economic returns, strengthening the role of forage cultivation in supporting livestock-based livelihoods and farmer prosperity.

Key words: bio-products; fodder productivity; fodder sorghum; nutrient management; nano-zinc; zinc sulphate; nano-urea; nano- DAP; profitability; benefit ratio

Beyond Yield: Unlocking Nutritional Diversity in Tomato Landraces and Improved Genotypes for a Food-Secure Bharat

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is India's most widely consumed vegetable and a critical dietary source of lycopene, ascorbic acid, and antioxidants essential for combating micronutrient malnutrition. However, decades of breeding focused predominantly on yield, uniformity, and shelf-life have progressively narrowed the genetic base of commercial cultivars, often at the cost of nutritional and quality attributes retained in traditional farmer varieties and landraces. This review synthesizes recent findings on genetic variability and diversity for yield and quality traits across diverse tomato genotypes, including elite cultivars, hybrids, and farmer-conserved varieties. Reported estimates of genotypic and phenotypic coefficients of variation, broad-sense heritability, and genetic advance as percentage of mean reveal substantial variability for fruit yield, number of fruits per plant, total soluble solids, lycopene content, ascorbic acid, and titratable acidity, with quality traits frequently showing higher heritability coupled with high genetic advance, indicating additive gene action and strong scope for direct selection. Notably, several farmer varieties and landraces, despite lower yield potential, exhibit superior nutritional profiles compared to high-yielding elite genotypes, underscoring an inverse yield-quality relationship inadequately addressed in conventional breeding programs. The review highlights the urgent need to integrate underutilized farmer germplasm into structured breeding pipelines through diversity analysis, cluster and principal component studies, to simultaneously improve yield and nutritional quality. Such an approach can generate biofortified, climate-resilient tomato varieties, strengthening dietary diversity and nutritional security for a food-secure Bharat.

Keywords: Farmer varieties; Genetic variability; Heritability; Nutritional security; Quality traits; Tomato.

Effect of Natural Feed Additive on the Performance and Hemato- Biochemical Profile of Broiler Chicken

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ABSTRACT

Hog plum (*Spondias pinnata*) underutilized tropical fruit, rich in ascorbic acid, protein, fiber and bioactive compounds with antioxidant, antibacterial and blood sugar lowering properties. A 42-day feeding trail was conducted to assess the influence of hog plum fruit powder as a natural antibiotic growth promoter replacing in broiler diet. The experimental birds were randomly divided into 5 treatment groups - T_1 (control), T_2, T_3, T_4 and T_5 with five replications per treatment in a Completely Randomized Design. The birds received diets supplemented with hog plum fruit powder containing 0gm, 5gm, 10gm, 15gm and 20gm per kg feed, respectively. Findings revealed that inclusion of Hog plum fruit powder showed significant ($p<0.05$) influence on the growth performance, feed intake, feed conversion efficiency, higher net profit and improved haemato- biochemical profile. Throughout the trail period no mortality was recorded, hence resulting in 100% livability across all groups. Based on the above findings, it can be inferred that supplementation of hog plum fruit powder can serve as a viable alternative growth promoting antibiotic without impairing performance and health. As a low- cost feed additives, Hog plum fruit powder can be used as an effective approach for the antibiotic- free poultry production, strengthening farmer profitability and maintaining nutritional security.

Key words: Broiler; growth performance, feed intake; Hog plum; net profit

Growth and Instability of Rice Production in Tripura: An Analysis of Secondary Data

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ABSTRACT

Rice is the major foodgrain crop of Tripura. In this paper, an attempt has been made to study the performances of rice production in Tripura state of India. This study examined the growth and instability of rice on area, production and productivity in Tripura by using the secondary time-series data of 23 years viz., 2000-01 to 2022-23. The compound growth rate was estimated by fitting a long-linear trend to each series, and instability was measured through the Cuddy-Della Valle Index, which removes the trend component from the coefficient variation. The result revealed that the CAGR of rice on area was seen grew at 0.28 percent, whereas production and productivity increased at 2.00 and 1.71 percent within the aforementioned years, respectively. Production was seen to be significantly increased from 5,13,402 to 8,03,825 MT i.e, +56.6 percent and yield from 2,120 to 3,299 kg/ha i.e., +55.6 percent, indicating that growth was almost entirely productivity based; productivity accounted for roughly 85 percent of the growth in production. Instability remained low once the trend was removed, with CDVI Values of 4.03,2.66 and 3.38 percent for production, productivity and area respectively. The study concludes that further expansion of rice output in Tripura must come from sustained yield grains through improved irrigation, high-yielding varieties and better agronomic practices, since area expansion has reached its limit.

Keywords: Rice: Tripura; Compound growth rate; Cuddy-Della Valle Index; instability

Exploiting Heterosis and Combining Ability in Bottle Gourd for Enhanced Productivity and Nutritional Security

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ABSTRACT

Bottle gourd (*Lagenaria siceraria* (Mol.) Standl.) is an important cucurbitaceous vegetable crop valued for its productivity, nutritional quality and suitability to tropical and subtropical production systems. Genetic improvement of the crop requires the identification of superior parents and promising hybrid combinations with desirable yield and quality attributes. Heterosis breeding, together with combining ability analysis, provides an effective approach for identifying suitable parental lines and superior cross combinations. The present ongoing study is being conducted to estimate heterosis and combining ability for quantitative and qualitative traits in bottle gourd. The experimental material consists of 10 lines and 3 testers, which are being crossed following a Line × Tester mating design to generate 30 F_1 hybrids. A total of 43 genotypes, comprising 30 F_1 hybrids, 10 lines and 3 testers, are being evaluated at the Horticulture Research Farm, Babasaheb Bhimrao Ambedkar University, Lucknow, during 2025–26. The experiment is being conducted in a Randomized Block Design with three replications. Observations are being recorded for earliness, growth, fruit, yield and quality attributes, including days to first staminate and pistillate flower anthesis, days to first and last harvest, number of harvests, vine length, internodal length, number of primary branches, average fruit weight, fruit length, girth, diameter, pedicel length, flesh thickness, number of fruits per plant, yield per plant, fruit yield, seed number and quality parameters such as total soluble solids, crude fibre, sugar and ascorbic acid content. The study will estimate general combining ability (GCA), specific combining ability (SCA), heterosis over the better parent and standard variety, heritability and genetic advance. The investigation is expected to identify superior parental lines and promising hybrid combinations and to elucidate the genetic basis of important yield and quality traits. The generated information may provide useful genetic resources for future bottle gourd breeding programmes aimed at improving productivity and quality, thereby contributing to sustainable vegetable production and nutritional security.

Keywords: Bottle gourd; Combining ability; Heterosis; Hybrid breeding; Nutritional security; Vegetable production

Bio-Repellent Efficacy of Botanical Powders Against *Sitophilus zeamais Motschulsky*: Securing Stored Maize for Food Security

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ABSTARCT

The maize weevil (*Sitophilus zeamais Motschulsky*) is a major post-harvest pest responsible for severe grain loss during storage. While synthetic fumigants and contact insecticides remain widely used, their non-target toxicity, persistence and contribution to resistance necessitate alternative pest control strategies. The present study was conducted in the laboratory of Department of Entomology, College of Agriculture, Central Agricultural University, Imphal to evaluate the repellent efficacy of six plant powders: Neem (*Azadirachta indica*, T_1), Lemongrass (*Cymbopogon citratus*, T_2), Winged Leaf Prickly Ash (*Zanthoxylum armatum*, T_3), Chinese Chaste (*Vitex negundo*, T_4), Sweet Flag (*Acorus calamus*, T_5), and Goat Weed (*Ageratum conyzoides*, T_6) against *S. zeamais* over 1-hour and 24-hour exposure intervals across four replications. At 1 hour, *A. calamus* (T_5) exhibited the highest repellency (62.5%), followed by Chinese chaste (T_4, 52.5%) and winged prickly ash (T_3, 42.5%), while lemongrass (T_2) showed the lowest activity (22.5%). A similar trend persisted at 24 hours, with T_5 again recording the highest repellency (57.5%), followed by T_4 (42.5%) and T_3 (40.0%), whereas T_2 remained least effective (15.0%). Statistical analysis (SEm = 4.68, CD 5% = 13.90 at 1 hr; SEm = 4.60, CD 5% = 13.67 at 24 hr) confirmed significant differences among treatments at both time intervals. These findings indicate that *Acorus calamus* and Chinese chaste possess strong potential as botanical repellents against *S. zeamais* and could serve as sustainable components of integrated stored-grain pest management, reducing reliance on synthetic fumigants.

Keywords: Maize; maize weevil; *Acorus calamus;* plant extract; IPM

Strengthening Nutrition Security through Sustainable Agriculture in Northeast India

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ABSTRACT

The vision of Viksit Bharat 2047, focused on building a prosperous, self-reliant, and inclusive India, requires balanced development across agriculture, nutrition, infrastructure, and social welfare. Northeast India, comprising the seven northeastern states and Sikkim, is strategically and ecologically significant because of its diverse natural resources, cultural heritage, and international borders. However, geographical isolation, limited infrastructure, unemployment, and dependence on vulnerable agricultural systems continue to restrict regional development. Strengthening connectivity, promoting eco-tourism and horticulture, developing renewable energy, and encouraging community-based governance can help the region emerge as an important contributor to the national economy under the Act East Policy. Sustainable agriculture should form a major component of this transformation. Climate-resilient traditional crops, including millets, buckwheat, amaranth, black soybean, horse gram, and ricebean, can improve both farm resilience and household nutrition. These crops generally require fewer resources and provide valuable nutrients such as protein, dietary fibre, iron, calcium, and zinc. Their wider adoption can be supported through improved varieties, biofortification, value addition, better storage, and affordable farm machinery such as seed drills, threshers, and solar dryers. Nutrition security is equally important for developing healthy human capital. Persistent challenges such as childhood stunting and anaemia among women highlight the need for coordinated interventions. Convergence among programmes such as Poshan Abhiyaan, ICDS, and PM POSHAN, together with promotion of locally available nutritious foods, can strengthen dietary diversity and improve health outcomes. Integrating sustainable agriculture, nutrition, technology, infrastructure, and legal entitlements can therefore accelerate inclusive development in Northeast India and contribute substantially to the goal of Viksit Bharat 2047.
Keywords: Biofortification; Nutrition; renewable energy; Sustainable agriculture

NUTRICO: Development of a Millet and Date-Based Instant Health Drink

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ABSTRACT

This study aimed to develop NUTRICO, a do-it-yourself instant health drink formulated from finger millet (ragi), date powder, cardamom, and RO water, targeting protein deficiency and the rising incidence of diabetes and obesity associated with conventional sugar-laden beverages. The process involved two parallel streams: finger millet was soaked overnight, crushed, and extracted to yield millet milk, while dates were de-seeded, sliced, dried, and ground into date powder, with cardamom added to enhance flavour and aid preservation. Proximate analysis of the formulated drink revealed an energy value of 65 kcal, 7-8% protein, 7-9.5% carbohydrates (comprising 1-1.5% dietary fibre, 6.5-8% natural sugar, and 0% added sugar), and 0.24% fat, confirming its low-fat, naturally sweetened, and protein-rich composition. Being free of artificial sugar, preservatives, lactose, and carbonation, the drink is suitable for lactose-intolerant, vegan, diabetic, and obese consumers alike. The results demonstrate the successful development of a nutritionally balanced, health-oriented instant beverage with broad appeal across students, fitness enthusiasts, working professionals, families, and the elderly.

Keywords: Finger millet; Date powder; Instant beverage; Protein-rich drink; Lactose-free; Functional food.

Biofortifying the Nation: Advancing Food and Nutritional Security through Nutrient-Dense Crops

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ABSTRACT

Micronutrient deficiency, also called "hidden hunger" is a major nutritional problem affecting millions of people worldwide, particularly in low- and middle-income countries. Although staple crops provide much of the energy required in daily diets, they often contain inadequate amounts of essential vitamins and minerals. This makes improving the nutritional quality of staple foods an important part of achieving long-term food and nutrition security. Crop biofortification provides a practical and sustainable approach by improving the nutritional value of crops during their production rather than depending only on supplements or food fortification after harvest. Recent progress in biofortification has brought together conventional breeding, agronomic practices and modern biotechnology. Plant breeding and marker-assisted selection have contributed to the development of nutrient-rich varieties of rice, wheat, maize, beans, cassava, sweet potato, etc with higher levels of iron, zinc, provitamin A, protein and other beneficial nutrients. Agronomic practices, such as applying micronutrients through soil and foliar treatments, can further increase nutrient uptake and accumulation in edible parts of crops. The use of beneficial microorganisms and organic amendments can also improve nutrient availability, crop performance, soil health and nutritional quality while reducing dependence on synthetic fertilizers. At the same time, biotechnology has opened new possibilities for improving crop nutrition. Transgenic approaches and CRISPR/Cas9 genome editing allow researchers to target genes involved in nutrient production, transport, storage and bioavailability. These approaches can also help reduce compounds that limit nutrient absorption and improve several nutritional traits at the same time. However, challenges such as environmental variation, limited access to inputs, regulatory concerns, microbial stability and consumer acceptance still need attention. Such an integrated approach can help make every day staple foods more nutritious while supporting sustainable and resilient food systems.

Keywords: Biofortification; micronutrient; malnutrition; food security

Nutrition Security for a Healthy and Developed India

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ABSTRACT

India's journey towards becoming a developed nation depends not only on economic growth but also on the nutritional well-being of its people. Despite significant reductions in poverty, malnutrition continues to manifest through child stunting, wasting, anaemia and micronutrient deficiencies. Addressing these challenges is essential for achieving SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-being). Nutrition security must move beyond calorie availability to ensure access to diverse and nutritious diets, safe drinking water, sanitation, healthcare and appropriate care practices. Maternal health is particularly important, as poor maternal nutrition and inadequate antenatal care increase the risks of low birth weight, child undernutrition and infant mortality. Conversely, early initiation and continued exclusive breastfeeding significantly improve child survival. Maternal education also enhances food choices, hygiene, healthcare utilisation and household food security. A life-cycle approach, with special emphasis on the first 1,000 days and adolescent girls, is crucial to breaking the cycle of intergenerational malnutrition. Policies should promote nutrition-sensitive agriculture and improve access to pulses, millets, eggs, dairy and biofortified foods through programmes such as PDS, ICDS and PM-POSHAN. Vulnerable districts require targeted interventions supported by community participation and stronger local governance. Finally, dedicated financing, outcome-based budgeting, transparent monitoring and cross-sectoral accountability can make nutrition a core pillar of Viksit Bharat. Investing in nutrition today will strengthen India's human capital, productivity and resilience, laying the foundation for sustainable, healthy and inclusive development.

Keywords: Adolescent; Maternal health; Intergenerational; Vulnerable

Scaling Bio-fortified Maize through Advanced Seed Science & Technology: "A Strategic Nutritional Security in Bharat"

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ABSTRACT

Micronutrient deficiencies, often termed "hidden hunger" pose a significant public health challenge in Bharat. Maize serves as a key staple crop across diverse agro-climatic zones, making it an ideal vehicle for bio-fortification initiatives targeting essential vitamins and minerals like iron, zinc, and pro-vitamin A. However, bridging the gap between nutritional development and large-scale agricultural adoption remains a critical challenge. The present review entitled– Scaling bio-fortified maize through advanced Seed science & technology "A strategic nutritional security in Bharat" was under taken to study hidden hunger, driven by micronutrient deficiencies, remains are critical public health challenge across Bharat, disproportionately impacting vulnerable rural communities depended on cereal-based diets. Maize is a vital stable food and multiuse crop, offers the potential for nutritional alleviation through genetic bio-fortification targeting essential micronutrients such as pro-vitamin A carotenoids, lysine, tryptophan, iron & zinc. However, the ultimate success and societal impact of bio-fortified cultivars depend heavily on robust Seed science & Technology frame works to ensure seamless genetic expression, high physiological seed quality, and efficient seed delivery system. This research investigates the integration of advanced seed technology aim to establish or applicable blue point for scaling nutrient dense maize varieties. There by strengthening National food system supporting governmental Nutritional Mission (Poshan Abhiyan) and ensuring sustainable nutritional security for Bharat. Advanced seed technologies ensure that bio-fortified maize seeds maintain superior field performance and high yield potential alongside their enhanced nutritional profiles. This comprehensive approach establishes scalable, sustainable path toward mitigating malnutrition, enhancing rural livelihoods, and fortifying long-term nutritional security throughout Bharat.

Keywords: Bio-fortification; Genetic purity; Maize; Nutritional security; Poshan abhiyan; Seed enhancement.

Nutri Laddoo: A Muesli Based Functional Food to Combat Folate Deficiency in Pregnant Women

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ABSTRACT

Folate deficiency remains a critical public health concern among Indian women, with approximately 41.6% of pregnant women suffering from folic acid deficiency (serum folate <3 ng/mL), as reported by WHO. As per ICMR and WHO recommended dietary allowances, women require 400 micrograms of folic acid daily before conception, 600 micrograms during pregnancy and 500 micrograms during lactation. Inadequate intake is strongly associated with maternal anemia, neural tube defects, low birth weight, preterm delivery and increased maternal mortality risk, while synthetic supplements often face poor compliance due to gastrointestinal discomfort and low palatability. Nutri Laddoo offers a food-based alternative using natural ingredients. Its core is a nutrient-dense muesli of oats, pumpkin seeds, peanuts and dried fruits (black raisins and cranberry), combined with roasted jowar, ragi and corn flakes for crunch and mineral density. It is enriched with a plant-based folic acid extract derived from lemon peel, while dates act as a natural binder, eliminating refined sugar and synthetic additives. A dark chocolate coating improves palatability and shelf stability, encouraging regular consumption among pregnant women who often resist bitter or artificial supplements. By delivering folate through a familiar snack format, Nutri Laddoo addresses the nutritional gap identified by NFHS-5 and ICMR guidelines. Outreach is planned through gynecologists, paediatricians, maternal health NGOs, and schemes such as Anganwadi and POSHAN Abhiyan, reaching women before and during pregnancy and lactation.

Keywords: Folate Deficiency; Functional Food; Maternal Nutrition; Muesli; Nutri Laddoo; Plant-Based Fortification

Speciation and Dynamics of Phosphorus in Some Organically Amended Soils of North Eastern Hill Region of India

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ABSTRACT

Limited information is available on phosphorus management in the acid soils of Meghalaya using locally available organic amendments, particularly regarding their effects on phosphorus fractions, phosphorus mineralization, and release kinetics across the major soil orders. Therefore, the present study was undertaken to evaluate the influence of different organic amendments on phosphorus dynamics in four major soil orders of Meghalaya, namely Inceptisols, Alfisols, Ultisols and Entisols. A field survey was conducted using the Meghalaya soil map (1:250,000 scale; NBSSLUP, 2005) integrated with Google Earth imagery. The soil map was georeferenced and overlaid on the base map of Meghalaya to identify the major soil orders and to generate representative sampling locations. A total of 160 soil samples (0–0.15 m depth) were collected, comprising 40 representative samples from each soil order. The 40 samples collected from each soil order were thoroughly homogenized to prepare a single composite sample representing the respective soil order for subsequent incubation and pot experiment. A 120-day laboratory incubation experiment was conducted at SNRM, CPGS-AS, Umiam, Meghalaya, during April-July 2024. The experiment contains seven treatments: T_1: Control, T_2: Farmyard manure (FYM), T_3: Compost, T_4: Vermicompost, T_5: Neemcake, T_6: Poultry manure, and T_7: Pig manure, applied at a phosphorus-equivalent rate of 40 kg P_2O_5 ha^{-1}, with 3 replications. Soil moisture was maintained at field capacity throughout the incubation period. Phosphorus fractions were evaluated at five incubation intervals (0, 30, 60, 90, and 120 days of incubation). The incubation results were validated through a pot experiment, in which uniform pots (7 kg capacity) were filled with 5 kg of processed soil. The experimental data generated from the incubation & pot study were analysed using repeated measures ANOVA. Result indicated that iron-P (Fe-P) was the dominant fraction in the alfisols (12.6%) and entisols (17.3%) while aluminium-P (Al-P) was dominant fraction in inceptisols (11.3%) and ultisols (11.4) with reductant-P (Red-P) (9.53 - 17.0%) in the all the soil orders. However, organic amendments significantly increased other P fractions such as saloid-P (Sol-P) and calcium-P (Ca-P), available-P (Avi-P) and significantly reduced the proportions of Al-P, Fe-P, Red-P and occluded-P (Occl-P) in all soil order. Among organic treatments, poultry manure (T_6) enhances 104 - 358% Sol-P> 88 - 256% Ca-P> 43 - 120% Avi-P; and reduce 48 - 81% Red-P> 42 - 76% Fe-P> 40 - 62% Al-P>33 - 49 % Occl-P.

Prickly Pear cactus jelly: A Sustainable Pathway for Value Addition

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ABSTRACT

Prickly pear cactus (Opuntia Ficus-indica) is a hardy and underutilized fruit crop with significant potential for food value addition and rural entrepreneurship. The present concept focuses on the development of Prickly Pear Cactus Jelly, transforming an overlooked fruit into an appealing, palatable and marketable food product. The fruit is naturally low in fat and contains dietary fibre, minerals, antioxidants and iron, an essential nutrient involved in haemoglobin formation and normal body functions. However, limited awareness and low consumer familiarity restrict its utilization. Converting the fruit into jelly improves its taste, texture and acceptability, making it easier and more attractive for consumers to include prickly pear in their diet while creating a shelf-stable value-added form of the fruit. The raw material also offers an advantage at the production level: prickly pear can be grown with comparatively low inputs, requires less fertile land and can be utilized on marginal areas. It can additionally be planted along farm boundaries as a live hedge, providing a natural barrier against stray animals. Thus, the development of prickly pear jelly creates a link between underutilized crop utilization, nutritional food production and farmer-oriented value addition. The product has potential for small-scale processing by farmers, rural women and youth, providing an additional source of income and encouraging entrepreneurship at the village level. This innovation demonstrates how a hardy crop with limited conventional utilization can be converted into a desirable food product, adding economic value to the fruit while supporting sustainable agriculture and rural livelihood development.

Keywords: Prickly pear cactus; Opuntia ficus-indica; Cactus jelly; Value addition; Nutritional food; Iron-rich fruit; Marginal land; Live hedge; Rural entrepreneurship.

Beyond Rice and Wheat: Reviving India's Underutilised Foods for Dietary Diversity and Nutritional Security

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ABSTRACT

India has achieved remarkable progress in foodgrain production and food availability; however, ensuring diverse and nutritious diets remains a major challenge. The persistence of malnutrition and micronutrient deficiencies highlights the gap between food security and nutritional security. According to NFHS-5, anaemia affected 57% of women aged 15–49 years in India. At the same time, changing food preferences and dependence on a limited number of staple foods have contributed to the declining consumption of traditional food resources. India possesses rich but underutilised food biodiversity, including kulith, cowpea, amaranth, traditional millets, indigenous leafy vegetables, seasonal fruits and traditional oilseeds, which can provide protein, dietary fibre, minerals, vitamins and bioactive compounds. However, limited awareness, changing perceptions, inadequate processing and storage, weak market linkages and lack of convenient products restrict their wider adoption. Agricultural extension and effective communication can bridge this gap through awareness programmes, method demonstrations, nutrition-sensitive training, women's self-help groups, FPOs, local food fairs and ICT-based communication. Strengthening farmer-consumer linkages can promote behavioural change, market development and greater utilisation of traditional foods. Thus, integrating agriculture, nutrition, communication and livelihoods through participatory extension can support healthier communities, diversified agriculture and resilient food systems, contributing to the vision of Viksit Bharat @2047.

Keywords: Food and nutritional security; Indigenous food resources; Agricultural extension; Viksit Bharat @2047

Nourishing a Nation: Safeguarding Food and Nutritional Security for Bharat

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ABSTRACT

India has achieved cereal based food security through the Green Revolution and National Food Security Act (NFSA) but the nutritional security remains an unresolved issue as manifest in the high burdens of stunting, wasting, anaemia and hidden hunger. Structural factors inhibiting nutritional security include calorie-centric Public Distribution System (PDS) of rice-wheat, poor dietary diversity, fragmentation of programme convergence (ICDS, Poshan Abhiyaan) and climate shocks affecting crop nutrition. Strategic interventions to address hidden hunger include diversification of PDS with pulses and millets, promoting of biofortification and nutrition-linked Minimum Support Price (MSP), strengthening of Health & Wellness Centres as Nutrition Resource Centres and leveraging of Poshan Tracker with women Self Help Groups for community-based delivery. Scaling up of food fortification and blending of nutrition education in agricultural extension and school curriculum, along with improvement in maternal and child care practices are vital adjuncts to the existing programmes. Decentralisation of nutrition actions through Panchayati Raj institutions and building of public-private partnerships will accelerate the pace of convergence for the last-mile delivery of nutrition interventions. In conclusion, this paper argues that the way forward to safeguard Bharat's food and nutritional security lies in transforming from 'feeding' to 'nourishing' through nutrition sensitive agriculture, convergent governance and behavioural change interventions to make every plate nourishing.

Keywords: Food security; Nutritional security; Hidden hunger; PDS; Poshan Abhiyaan; Biofortification; Nutrition-linked MSP; Dietary diversity; Malnutrition; Bharat.

Distribution and stability of aflatoxin M1 during the preparation of Indian dairy products

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ABSTRACT

Aflatoxin M1 (AFM1) in milk is an important food safety concern, particularly in India, where milk undergoes extensive processing into diverse traditional Indian dairy products. This study evaluated the behaviour and distribution of AFM1 (initial concentration: 0.50 µg kg^{-1}) during selected dairy processing operations, including boiling, pasteurization, sterilization, skimming, fermentation to *dahi*, coagulation for *paneer* and *chhana*, and concentration during preparation of *khoa*. AFM1 was determined using a verified HPLC-FLD method exhibiting a limit of detection of 0.0045 µg kg^{-1}, limit of quantification of 0.0135 µg kg^{-1}, and recoveries of 88–101%. The results demonstrated that conventional thermal treatments had no significant effect on AFM1 levels, indicating its considerable stability during heat processing. Milk concentration resulted in a progressive increase in AFM1, reaching approximately 54% at 2.5-fold concentration. Fermentation into *dahi* reduced AFM1 levels by 14%. Skimming resulted in retention of more than 92% of AFM1 in skim milk, demonstrating its limited partitioning into the milk fat fraction. Following coagulation, AFM1 was distributed between curd and whey, with approximately 45–53% retained in the curd and 47–55% transferred to whey. Overall, the findings indicate that conventional dairy processing is insufficient for AFM1 removal and may increase its concentration in products subjected to moisture reduction or protein concentration, particularly *khoa* and *paneer*. The study provides useful processing-based evidence for product-specific AFM1 exposure assessment and may assist regulatory agencies like FSSAI in strengthening regulatory surveillance, setting up maximum residue limits, risk assessment, and consumer protection for traditional dairy products in India.

Keywords: Aflatoxin M1; Distribution; Food Safety; HPLC; Milk; Stability.

Nourishing Bharat: Evaluating the Potential of Natural Farming for Strengthening Food and Nutritional Security

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ABSTRACT

India's food and nutritional security is increasingly challenged by soil degradation, declining agricultural biodiversity, rising input costs, climate variability, and concerns regarding the sustainability of conventional input-intensive farming. In this context, natural farming has emerged as an agroecological approach with potential to improve soil health, reduce dependence on external chemical inputs, enhance farm resilience, and contribute to healthier food systems. The present study aims to assess the potential of natural farming in strengthening food and nutritional security in Bharat, with particular emphasis on agricultural productivity, farm profitability, dietary diversity, environmental sustainability, and resilience to climate-related risks. The study proposes a mixed-method research design combining a systematic review of secondary literature, analysis of relevant government policies and programmes, and primary data collected from selected natural farming practitioners in Uttar Pradesh. A structured interview schedule will be used to collect information on socio-economic characteristics, farming practices, production costs, yields, household food consumption, dietary diversity, and farmers' perceptions. Descriptive statistics, cost-return analysis, comparative assessment, and appropriate inferential techniques will be employed to evaluate outcomes. The study is expected to indicate that natural farming can reduce cultivation costs, improve soil and ecological health, enhance farm resilience, and support food availability and nutritional well-being, although adoption may be constrained by knowledge gaps, transition risks, certification, market access, and institutional support. The findings will provide evidence for strengthening natural farming policies, farmer training, value-chain development, and nutrition-sensitive agricultural strategies to build a sustainable and nutritionally secure Bharat.

Keywords: Natural Farming; Food Security; Nutritional Security; Sustainable Agriculture; Soil Health; Climate Resilience

Plant Health and Nutritional Security in Bharat

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ABSTRACT

Achieving long-term food and nutritional security in India requires a shift from yield-centric agriculture to plant health-driven, nutritionally sensitive production systems. Biotic stresses—caused by fungi, bacteria, viruses, and nematodes—result in 20–40% global yield losses, alongside hidden risks from mycotoxins and nutrient depletion. Shifting climate dynamics further exacerbate these threats by altering pathogen behaviour and increasing epidemic frequency. To build a resilient agro-food system, contemporary plant pathology offers advanced solutions: high-throughput diagnostics (qPCR, LAMP, metagenomics sequencing) for early detection; genomics-assisted breeding (CRISPR/Case, QTL mapping, GWAS, RNAi) for durable resistance; and Integrated Disease Management (IDM) combining biocontrol (*Trichoderma*, *Pseudomonas*), cultural practices, and precision input applications. Furthermore, leveraging soil microbiomes enhances systemic plant resistance and nutrient-use efficiency. Complementing these protection strategies with crop diversification (millets, pulses, horticulture) and bio fortification (iron, zinc, pro vitamin A) directly addresses micronutrient deficiencies. Bridging laboratory breakthroughs and field execution through policy convergence, robust extension networks, and farmer capacity building is essential to secure a resilient, sustainable, and nutrient-dense food supply for the nation.

Keywords: Bio fortification, Biotic Stress; CRISPR/Case; Food and Nutritional Security; Integrated Disease Management; Plant Health.

Nourishing Bharat from the Roots: Endorsing Tribal Horticulture for Sustainable Food and Nutritional Security

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ABSTRACT

Indigenous tribal communities inhabit biodiverse ecosystems rich in traditional agricultural knowledge and underutilized, nutrient-dense native crops. While small-scale horticulture, nursery production, and indigenous food processing are widely practiced among tribal families, these activities often remain at a subsistence level. Aligning tribal farming with national nutritional priorities presents a strategic opportunity to transform tribal belts into sustainable supply hubs for food and nutritional security across Bharat. This study explores the pivotal role of high-value, bio-fortified horticultural crops, agri-processing, and youth-led enterprises in alleviating rural hidden hunger, enhancing dietary diversity, and securing long-term food systems. Through a comprehensive review of recent literature, government policy reports, socio-economic surveys, and field models—including the BAIF Wadi model, Odisha's tribal cashew/millet networks, and micro-farm developments in Southern Rajasthan—this paper evaluates the nutritional and economic impacts of horticultural diversification. Special emphasis is given to technological integration, where AI-driven precision irrigation, climate-resilient farming advisories, digital supply chain tracking, and smart pest detection make horticulture economically viable and appealing to tech-savvy youth. Transitioning tribal horticulture from subsistence to commercial entrepreneurship creates an eco-system where rural youth emerge as central drivers of food distribution and rural wealth generation. By combining indigenous ecological knowledge with AI, protected cultivation, and strategic market linkages, tribal-led horticultural enterprises can strengthen rural supply chains, reduce post-harvest losses, and ensure round-the-year availability of nutrient-rich fruits, vegetables, and medicinal produce for the nation. Horticulture presents a win-win strategy to empower generations of tribal agri-entrepreneurs while simultaneously reinforcing Bharat's long-term food and nutritional security. By fusing indigenous ecological wisdom with modern agricultural innovations and sustainable resource management, tribal communities can transition from subsistence farming to becoming primary suppliers of nutrient-rich produce. Strengthening entrepreneurial skills, digital literacy, rural finance access, and direct market linkages will enable tribal youth to transform into job creators and leaders in the agri-food sector—ensuring inclusive rural development, climate-resilient farming, and a structurally secure food system for the entire nation.

Keywords: Nutritional Security; Bharat; Tribal Horticulture; Youth Agri-Entrepreneurship; Precision Agriculture; Dietary Diversity; Sustainable Food System.

Endorsing Tribal Horticulture for Sustainable Food and Nutritional Security

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ABSTRACT

India is known for its rich agricultural diversity and traditional knowledge systems, particularly among tribal communities that have developed sustainable ways of managing natural resources over generations. Tribal horticulture represents an important yet underutilized resource for strengthening food and nutritional security. Tribal regions possess diverse agro-climatic conditions that support the cultivation of fruits, vegetables, tuber crops, spices, medicinal plants and indigenous underutilized crops. These horticultural resources not only provide food but also contribute to dietary diversity, household income and livelihood security. However, tribal horticultural systems face several challenges, including limited access to quality planting material, irrigation facilities, modern production technologies, post-harvest management, storage, processing and organized markets. Climate variability, changing food habits and the gradual loss of traditional knowledge further increase the vulnerability of these communities. Therefore, strengthening tribal horticulture through a combination of indigenous knowledge and appropriate scientific interventions can play a significant role in achieving sustainable food and nutritional security. The promotion of locally adapted horticultural crops can improve the availability of nutrient rich foods while reducing dependence on external food sources. Kitchen gardens, community-based nurseries, organic and low-input cultivation, rainwater harvesting, value addition and small-scale processing can provide practical solutions for tribal households. Special attention to indigenous fruits, vegetables, tubers and traditional crops can help conserve agrobiodiversity while improving dietary diversity. Farmer Producer Organizations, self-help groups and youth-led agribusiness initiatives can further connect tribal producers with markets and create employment opportunities. Integrating traditional tribal knowledge with modern horticultural technologies, climate resilient practices and digital extension services can make these production systems more productive and sustainable. Capacity building, access to institutional support, improved market linkages and promotion of value-added products are essential for empowering tribal farmers. Thus, endorsing tribal horticulture is not merely an approach to increasing agricultural production; it is a pathway towards nutrition, livelihood security, biodiversity conservation and sustainable rural development. Recognizing and strengthening the horticultural traditions of tribal communities can contribute significantly to the vision of a healthier, self-reliant and nutritionally secure Bharat, while ensuring that development grows from the roots of India's indigenous agricultural heritage.

Keywords: Tribal Horticulture, Food Security, Nutritional Security, Indigenous Knowledge, Agrobiodiversity, Sustainable Agriculture, Value Addition, Tribal Livelihoods.

Development of a Ready-to-Cook *Kikoda* (*Momordica dioica*) Vegetable with Utilization of Tomato ketchup By-Products for Food and Nutritional Security

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ABSTRACT

Ensuring food and nutritional security in Bharat necessitates strategic valorisation of underexploited indigenous crops through technologically advanced and resource-efficient food-processing interventions. *Kikoda (Momordica dioica*), commonly known as spine gourd, is a nutritionally promising yet commercially underutilized vegetable traditionally consumed in rural and tribal food systems. The present investigation aimed to develop and optimize a ready-to-cook *Kikoda*-based product through statistical process optimization while simultaneously valorising tomato-processing residues generated during ketchup manufacture. Tomato processing residue, rich in dietary fibre, lycopene, protein and bioactive constituents, can be valorised as a functional ingredient in Kikodabased foods to promote waste-to-nutrition conversion, dietary diversification and food and nutritional security. Fresh *Kikoda* was sorted, washed and hygienically prepared, followed by convective dehydration at 45°C in a mechanical tray dryer until approximately 7 per cent moisture content was attained. Dehydrated *Kikoda* was subsequently incorporated with standardized quantities of onion, garlic, ginger, green chilli, coriander seeds, cumin, fennel, red chilli, turmeric, salt, amchur, black pepper, asafoetida, *Kasuri methi*, roasted sesame powder and edible oil. Tomato peel–seed residue was incorporated as a value-added by-product of ketchup processing. Optimization was performed using Response Surface Methodology (RSM) employing a Central Composite Design (CCD). Two independent formulation variables were selected: X_1 = dehydrated *Kikoda* and X_2 = tomato peel–seed residue, while all other ingredients were maintained constant. Responses included colour/appearance, flavour, texture, overall acceptability and reconstitution/cooking acceptability. A second-order polynomial model was fitted, with model adequacy assessed through ANOVA, R^2, adjusted R^2, predicted R^2 and lack-of-fit analysis. Numerical optimization using desirability-function methodology identified the optimum formulation. The optimized product demonstrates potential for *Kikoda* utilization, tomato-residue valorisation, agro-processing waste reduction and convenient ready-to-cook food development, supporting sustainable rural processing opportunities, indigenous crop diversification, circular bioeconomy and livelihood-oriented rural food entrepreneurship.

Keywords: By-product utilization; Momordica *dioica*; Rural entrepreneurship; Response optimization; Sensory evaluation; Tomato processing residues

Nourishing a Nation: Safeguarding Food and Nutritional Security for Bharat

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ABSTRACT

Food and nutritional security in Bharat extend beyond adequate food production and includes the availability, accessibility, affordability, safety, quality, and nutritional adequacy of food. Population growth, climate variability, natural resource degradation, changing dietary preferences, and emerging agricultural constraints are increasingly challenging the resilience of food systems. Despite progress in agricultural production, micronutrient deficiencies, malnutrition, post-harvest losses, food-price volatility, and unequal access to nutritious foods remain major concerns. Addressing these challenges requires a shift from a production-centric approach towards an integrated, nutrition-sensitive, climate-resilient, and resource-efficient food system. Agricultural diversification through pulses, millets, oilseeds, fruits, vegetables, indigenous crops, and biofortified varieties can improve dietary diversity, strengthen farm resilience, and enhance farmers' livelihoods. Climate-smart agronomic practices, precision management of water and nutrients, integrated pest management, conservation agriculture, and soil-health management can sustain productivity while conserving natural resources. Biotechnology, artificial intelligence, precision agriculture, digital advisory services, improved storage, processing, and value-chain technologies can further reduce post-harvest losses and improve food quality. Ensuring nutritional security also requires strengthening the entire food supply chain, from production and post-harvest handling to processing, distribution, and consumption. Collaboration among farmers, scientists, policymakers, industries, and consumers, supported by nutrition awareness and enabling policies, is essential for equitable access to diverse and nutritious diets. Thus, safeguarding food and nutritional security in Bharat demands an integrated strategy that harmonizes agricultural productivity, nutritional quality, environmental sustainability, climate resilience, technological innovation, and social equity to build a resilient food system capable of meeting the nutritional needs of a growing population.

Keywords: Food security; nutritional security; climate resilience; sustainable agriculture; biofortification

Insect-Based Bioeconomy: Harnessing Edible Insects for Sustainable Nutrition and Agri-Entrepreneurship in North-East India

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ABASTRACT

The rising global demand for sustainable and nutritionally rich protein sources has intensified interest in alternative food systems. Insect farming, associated with the practice of entomophagy, is increasingly recognized as a sustainable agribusiness opportunity due to its high nutritional value, rapid production cycle, and low environmental impact. According to the Food and Agriculture Organization, edible insects contain 40–70% protein, along with essential amino acids, vitamins, and minerals, making them a highly nutritious alternative to conventional livestock-based protein sources. Compared to traditional livestock production, insect farming requires up to 80% less land, 50% less water, and produces significantly lower greenhouse gas emissions, making it a climate-smart and resource-efficient agricultural practice. Species such as crickets, mealworms, and black soldier flies can reach maturity within 6–8 weeks, enabling multiple production cycles annually and enhancing productivity within limited space. In addition to human consumption, insects can be processed into protein-rich animal feed, while insect waste (frass) serves as an effective organic fertilizer, supporting circular agricultural systems and waste recycling. In the context of North-East India, where biodiversity is abundant and traditional insect consumption already exists, insect farming presents strong entrepreneurial potential. Communities in regions such as Nagaland and Arunachal Pradesh have long practiced insect consumption, indicating cultural acceptance and market feasibility. With support from initiatives like Start-up India, this sector can generate rural employment and promote sustainable food systems while contributing to SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

Assessment of variation in the susceptibility of Fall armyworm *Spodoptera frugiperda* (J.E. Smith) against *Bacillus thuringiensis* (Berliner) toxins

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ABSTRACT

Maize (*Zea mays* L.), a globally important cereal, faces yield losses from biotic and abiotic stresses. The fall armyworm (*Spodoptera frugiperda*) is a destructive invasive pest and chemical control often causes resistance, resurgence and ecological harm. Sustainable alternatives include microbial agents, notably *Bacillus thuringiensis*, a spore-forming bacterium producing Cry and Vip toxins effective against lepidopteran pests. The present study evaluated the efficacy of *Bt* toxins against different developmental stages of *S. frugiperda*. Populations were collected from Meghalaya and maintained under controlled laboratory conditions. *Bt* strain SKM-2 (Accession no. PX281876) and reference strain 4J3 (serovar *aizawai*) expressed multiple lepidopteran-specific *vip3* and *cry* genes, with protein concentrations of 1.653 µg/µl (Vip3Aa), 2.085 µg/µl (Cry9A), and 1.860 µg/µl (reference). Egg hatchability remained unaffected, averaging 53.33 ± 1.15% (Vip3Aa) and 54.33 ± 0.58% (Cry9A), indicating negligible ovicidal activity. Larval bioassays revealed stage-specific susceptibility, with 2nd instars most vulnerable (LC_{50}: 0.315 µg/ml Cry9A; 0.161 µg/ml Vip3Aa), followed by 1st instars, while 3rd instar were least susceptible. Late instars exhibited moulting difficulties and pupal deformities. These findings highlight 2nd instar as the most vulnerable stage for *Bt* toxin application and provide a scientific basis for resistance monitoring, optimization of application timing and the design of location-specific, eco-friendly *Bt*-based pest management strategies to support sustainable maize production.

Keywords: *Bacillus thuringiensis,* susceptibility, neonate, *Spodoptera frugiperd*

Native *Trichoderma* and PGPR for eco-friendly management of Cercospora leaf spot in strawberry (*Fragaria* × *ananassa*) in Meghalaya

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ABASTRACT

Cercospora leaf spot (CLS) is a major foliar disease of strawberry (*Fragaria* × *ananassa* Duch.) in Meghalaya, India which reduced photosynthesis, growth, yield and fruit quality. Indiscriminate fungicide use raises concerns over environmental contamination, soil microbiome disruption and resistance. Furthermore, the pathogen exhibits considerable morphological and physiological variability, while poor sporulation under *in vitro* conditions limits its isolation, characterization and effective management. The present study was undertaken to standardize the isolation and culturing protocol, assess the morpho-physiological variability and evaluate organic management strategies using biocontrol agents (BCAs). *Cercospora* cf. *malloti* was successfully isolated using the single-spore isolation technique after evaluating multiple isolation methods such as hyphal tip and direct conidial transfer from infected leaves. Pathogenicity was confirmed by fulfilling Koch's postulates. Among 15 media, V8 Juice Agar and Malt Extract Agar supported maximal sporulation (12-15 and 10-12 spores/field), whereas Potato Dextrose Agar, Carrot Dextrose Agar and Oat Meal Agar promoted highest mycelial growth (5.45, 5.41 and 5.40 mm/day). The antagonistic potential of native BCAs was evaluated through *in vitro* dual-culture assays using *viz.*, *Trichoderma harzianum* (PX486730), *T. asperelloides* (PP897230), *T. asperellum* (PX760586), *T. hirsutum* (PX486028), *Bacillus subtilis* (PX218702) and *Pseudomonas fluorescens* (PP897642). Among the evaluated BCAs, *B. subtilis* exhibited the highest antagonistic activity against *C. cf. malloti*, recording mycelial growth inhibition up to 74.73%, followed by *T. harzianum* (56.07%) and *T. asperellum* (54.18%). In pot trials, a consortium of *T. harzianum* + *T. asperellum* + *B. subtilis* applied as foliar spray minimized disease severity (11.03%) but the inoculated control showed (54.92%) disease severity. The integrated BCAs approach offers an effective, eco-friendly strategy for organic CLS management in strawberry.

Keywords: biocontrol agents, *Cercospora*, single-spore isolation, *Trichoderma*

Reviving Millets in School Meals and the Public Distribution System: A Pathway to Improved Nutritional Security

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ABSTRACT

Child undernutrition and anaemia remain serious public health concerns in India. The National Family Health Survey (NFHS-5, 2019-21) reported that 67.1% of children aged 6-59 months were anaemic, up from 58.6% in NFHS-4, while 35.5% of children under five were stunted. Meals served under the PM POSHAN (midday meal) scheme and the Public Distribution System (PDS) have centred on rice and wheat, which provide energy but limited dietary diversity. Millets such as ragi, jowar and bajra are climate-resilient grains rich in dietary fibre, minerals and other nutrients. This paper examines the case for mainstreaming millets in midday meals and the PDS as a low-cost strategy to improve the nutritional quality of food reaching schoolchildren and vulnerable households. It reviews policy developments, including the Centre's advisory asking states to introduce millet-based items at least once a week, and state experiences from Odisha, Karnataka and Telangana, whose practices were shared as models with other states. Odisha's Millet Mission, for instance, linked local procurement from farmers with ragi supply through the PDS and ragi laddoos in child nutrition programmes. The paper identifies key constraints, including limited procurement and processing infrastructure, shelf-life, and children's taste acceptance. It proposes a phased model built on locally sourced millets through farmer producer organisations, familiar preparations such as porridge, laddoo and khichdi, and awareness drives in schools and parent meetings. Mainstreaming millets can improve nutrition, support smallholder incomes in rain-fed regions, and restore a traditional grain to the Indian plate.

Keywords: Anaemia, Midday meals, Millets, Nutritional security, PDS, PM POSHAN

Mushroom-Insect Synergy- Establishing Fungal-Entomological Systems for Nutritional Security and Circular Bioeconomy

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ABSTRACT

The proposed system establishes a regenerative circular pathway integrating Oyster Mushrooms (Pleurotus ostreatus) and Black Soldier Fly (*Hermetia illucens*) larvae in which organic residues are converted into edible mushrooms, insect biomass and nutrient-rich frass to minimize waste while recovering nutrients at multiple stages. The primary objective is to increase the protein content of the mushroom. A system of rearing Black Soldier Fly Larvae (BSFL) on Spent Mushroom Substrate (SMS) from oyster mushroom is proposed, wherein the larvae feed on a kitchen waste and SMS mix. The resulting frass is subsequently supplemented with crop residues and selected nutritional and structural amendments to formulate an improved substrate for the oyster mushroom cultivation. Key parameters, including the harvesting time, yield and nutritional composition, particularly protein content, are evaluated. This system is expected to influence the harvesting time, yield and protein content. This integrated system offers a potential approach to addressing the food insecurity, especially hidden hunger, in Bharat, positioning oyster mushrooms as a potential alternative dietary source of protein. The system additionally generates BSF biomass and nutrient-rich frass as potentially useful co-products. The resulting BSF biomass can be explored as a protein-rich feed ingredient for aquaculture and poultry, while frass can serve as a nutrient-rich soil amendment.

Digital Transformation of Food Cold Chains: A Review of Real-Time Monitoring and Predictive Control for Food and Nutritional Security

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ABSTRACT

Efficient cold chain management is essential for preserving the quality, safety, and shelf life of perishable foods. Yet, inconsistent temperatures, inadequate monitoring, and gaps in timely information continue to cause postharvest losses and food waste across supply chains. Advances in digital technology are enabling a shift towards connected cold chain systems that support continuous monitoring and more informed operational decisions. This review examines emerging digital tools for real-time monitoring and predictive control in food cold chains. It covers Internet of Things (IoT)-enabled sensors, wireless sensing networks, cloud platforms, and data analytics used to track temperature and other environmental conditions during storage and transportation. Particular emphasis is placed on artificial intelligence and machine learning for estimating remaining shelf life, identifying temperature abuse at an early stage, and supporting timely corrective action. The role of these technologies in improving traceability, information transparency, and compliance with regulatory requirements is also discussed. Despite their potential, widespread implementation remains constrained by high initial costs, inadequate infrastructure, difficulties in exchanging data between different systems, and adoption barriers, particularly in developing countries. The review concludes by identifying research priorities for affordable, scalable, and sustainable digital cold chains. These include improving predictive capabilities and translating monitoring data into practical decisions that protect food quality, reduce postharvest losses, and strengthen supply chain resilience, thereby supporting food and nutritional security.

Keywords: Artificial intelligence; Cold chain management; Digital technologies; Internet of Things (IoT); Real-time monitoring

Theme 3: "One Table, One Future: Building an Inclusive Agri-Ecosystem for Farmers, Youth and Consumers."

Mapping Value Chains for an Inclusive Agri-Ecosystem in Bihar

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ABSTRACT

Bihar's agricultural economy has undergone substantial diversification, featuring horticulture, livestock, and fisheries sectors that contribute 63 per cent of agricultural output against 56 per cent of the national average. There are still critical issues in the aggregation, post-harvest management, processing, storage, logistics, and market access phases, which often do not translate into a proportionate value for farmers as production levels have been increased. The study aims to identify the key spatial hotspots, key value leakage points, and institutional mechanisms to facilitate wider participation of farmers, youth, and consumers in commodity-specific value chains in Bihar. Secondary information was analysed using a commodity–district hotspot matrix, value-chain node mapping, gap diagnosis, and an inclusion-oriented analytical lens from government sources, published literature, and grey literature. There were eight priority commodities, namely makhana, maize, litchi, dairy, vegetables, sugarcane, honey, and turmeric, for which mapping was done in the majority of the producing districts to identify opportunities, value chain functions, market linkages, youth, and binding constraints. The results suggest that value chain gaps are largely at the post-farm gate level. There are challenges of branding and mechanisation for Makhana, better drying and storage facilities for maize, lack of cold-chain and pulping facilities for litchi, quality testing for dairy, logistical constraints for vegetables, and lack of processing facilities and market integration for sugarcane, honey and turmeric. Farmer realisation is low and farmers receive around 25-31 per cent rupee equivalent for selected high value commodities and there is 21.67 per cent post-harvest losses in bananas and 25-35 per cent in Litchis. Bihar already has enough institutional and physical infrastructure such as over 700 FPOs, around 7,000 PACS/Vyapar Mandal warehouses, 54 agricultural market yards, 20 e-NAM mandis and more than 8,400 food-processing units. However, greater synergies across these assets are needed to enhance value capture. The study suggests a block-based solution for linking PACS and FPOs with digital market intelligence, quality assessment, aggregation, processing, storage, cold-chain, and logistics services, in the form of a "hub-and-spoke" model and architecture. Such an integrated value-chain architecture can help build market connectivity, decrease the post-harvest losses and promote a more balanced value distribution along the chain between farmers, youth and consumers.

Keywords: Agri-Food Systems; Bihar; Market Linkages; Post-Harvest Management; Value Chain Mapping; Value drain.

Empowering Organic Farmers: From a new path to seed to market

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ABSTRACT

Organic farming is gaining importance as a sustainable approach to agriculture that promotes soil health, biodiversity, environmental protection, and safer food production. However, organic farmers often face challenges related to quality seed availability, production practices, certification, input management, value addition, market access, and fair price realization. This abstract explores a farmer-centric pathway that connects the entire organic farming value chain— from quality seed selection to sustainable production and finally to the market. The proposed approach focuses on empowering farmers through access to suitable organic seed and planting material, scientific knowledge, bio-inputs, capacity building, farmer producer organizations, value addition, branding, certification, and direct market linkages. Strengthening farmer–scientist– entrepreneur–consumer connections can reduce dependence on intermediaries and improve the economic returns of organic farming. The "Seed to Market" approach aims to transform organic farming from a production-oriented activity into an integrated and economically viable enterprise. By combining traditional knowledge with modern scientific practices, digital technologies, local resources, and organized marketing systems, farmers can develop resilient and sustainable agricultural models. The initiative ultimately seeks to create a transparent and efficient organic value chain in which farmers are not only producers but also active participants in processing, branding, and marketing.

From Farm to Fork: Reducing Waste, Adding Value & Doubling Income Through Integrated Supply Chain and Food Processing

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ABSTRACT

The present study entitled "From Farm to Fork: Reducing Waste, Adding Value & Doubling Income Through Integrated Supply Chain and Food Processing" was undertaken to analyze the current status of agricultural supply chain in India, to estimate marketing cost, marketing margin, price spread and post-harvest losses in perishable crops and to explore the potential of integrated farm to fork model through FPOs and food processing for doubling farmer's income. The study is based on secondary data collected from Ministry of Food Processing Industries (MoFPI), NITI Aayog, APEDA, India Agri Stat and primary observations from Kaushambi district of Uttar Pradesh. The data pertains to the year 2022-23 to 2024-25. From the investigation, it was found that India is the largest producer of milk and second largest producer of fruits and vegetables in the world, yet only 10 per cent of its agricultural produce is processed as compared to 80 per cent in USA and 83 per cent in Malaysia. About 40 per cent of fruits and vegetables worth Rs. 92,651 crores are wasted annually due to fragmented supply chain, lack of cold storage and absence of processing linkages. The farmer's share in consumer's rupee is only 32 to 42 per cent in traditional channels (Producer-Wholesaler-Retailer-Consumer). Three major interventions were identified under the Farm to Fork approach: (i) Collectivization through Farmer Producer Organizations (FPOs) under 10,000 FPOs schemes, (ii) Decentralized value addition through micro food processing units under PM Formalisation of Micro Food Processing Enterprises (PMFME) scheme and (iii) Digital integration through e-NAM, ONDC and Blockchain based traceability for direct market linkage. The analysis of Sahyadri Farms, Nashik as a successful Farm to Fork model revealed that collective marketing and processing increased farmer's income by 2.8 times and reduced post-harvest losses from 28 per cent to 8 per cent. The study concludes that establishment of Integrated Farm to Fork Clusters at district level comprising FPO, Mini Cold Storage, Grading Unit and Micro Food Park can reduce wastage to below 10 per cent, enhance value addition by 5 times and make India the Food Factory of the World by 2047. Policy suggestions include 35% capital subsidy for village level processing, single window clearance and training of rural youth under Skill India.

Keywords: Cold Storage; Food Processing; FPO; Post-Harvest Loss; Supply Chain; Value Addition

Economics and Value Chain Status of Finger Millet in Ranchi District, Jharkhand

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ABSTRACT

The present study was conducted on economics and value chain status of finger millet in Ranchi district of Jharkhand. The study was conducted pertaining to the agricultural year 2024-2025 with 120 finger millet farmers. The purposively simple stratified random sampling technique was adopted for the selection of total 120 farmers and further divided into three categories viz; marginal (below 1 ha), small (1.01 - 2.00 ha), semi-medium (2.01 - 4.00 ha) based on land size holding. Accordingly maximum number of respondents were in the category of marginal farms (72.50 per cent). Compound growth rate of area, production and productivity of finger millet for last 20 (2001 to 2020) years' time series data of both Jharkhand state as well as Ranchi district were calculated Compound Growth Rate for whole period recorded negative for area, positive for production and productivity in the state but all were non-significant during period-I (2001 to 2011) similarly, productivity of finger millet had shown significant growth period-III (2001 to 2020). The study reveals the total cost of cultivation per ha incurred by marginal farmers recorded lowest of Rs 6234.26/-, followed by small farms and it was highest for semi-medium farms and it comes to B: C ratio recorded highest for semi-medium farms 1.50 followed by marginal farms 1.40 and lowest by small farms 1.40; lack of irrigation facilities was found to the major constraints, followed by high cost of production, incidence of pests and disease, high weed infestation, high labour charge, damaging crop by wild animal non-availability of labour, lack of knowledge, high transportation charges, low market price.

Key words: constraints; economics; Finger millet; trends; value addition

Empowering Organic Farmers: A New Path from Seed to Market

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ABSTRACT

Organic farming in India is gaining importance due to increasing concerns about soil health, chemical input use and the growing demand for safe and sustainable food. However, farmers often face difficulties in accessing certified organic seeds, suitable bio-fertilizers, certification support, reliable markets and better prices for their produce. The article "Empowering Organic Farmers – A New Path from Seed to Market" proposes a vertically integrated model that connects farmers with essential support from seed selection and cultivation to certification, processing and premium markets. The proposed model focuses on certified organic seeds, bio-fertilizers and structured farm support while creating direct market linkages with organic retailers, bulk B2B buyers and export markets. An important feature of the model is the integration of apiculture with farming, which can improve pollination, support biodiversity and provide an additional source of income through honey. The model is supported by multiple revenue streams, including seed partnerships, bio-fertilizer supply, produce sales, honey sales and farm services. Its scaling strategy includes strengthening local farmer networks, developing branded organic products, establishing essential infrastructure and gradually expanding into global markets. Overall, the "Seed to Market" approach aims to improve farmers' income and market access while promoting soil health, biodiversity and sustainable agricultural practices. It highlights that successful organic farming requires not only sustainable production practices but also strong systems and reliable connections throughout the value chain.

Keywords: Organic Farming; Farmer Empowerment; Apiculture; Market Linkages

Livelihood generation among rural youth through PMKVY

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ABSTRACT

The present study entitled **"Livelihood Generation among Rural Youth through PMKVY in Chittorgarh District of Rajasthan"** will be conducted in Chittorgarh district of Southern Rajasthan, selected purposively. The study will assess the role of the Pradhan Mantri Kaushal Vikas Yojana (PMKVY) in generating livelihood opportunities among rural youth through agriculture-related skill development. Three PMKVY training centres, namely Mewar Polytechnic College, PGVS Skill School, Begun and Akola Training Center, will be selected purposively based on the maximum number of trainees enrolled in agriculture-related courses. Mewar Polytechnic College and Akola Training Center provide training under the Organic Growers job role, whereas PGVS Skill School, Begun, provides training under the Dairy Farmer/Entrepreneur job role. A total of 238 trainees, constituting 100 per cent of the enrolled trainee population in the selected centres, will be included in the study. Primary data will be collected through personal interviews using a structured interview schedule, while secondary data will be obtained from the National Skill Development Corporation (NSDC) and other relevant sources. The collected data will be analysed using appropriate statistical tools and techniques in consultation with a statistician. The study is expected to provide empirical insights into the contribution of PMKVY towards skill development, employment opportunities, income generation and improvement in the livelihood status of rural youth, besides identifying constraints and suggesting measures for strengthening skill-based livelihood generation in the region.

Keywords: Dairy Farmer/Entrepreneur; Livelihood generation; Organic Growers; PMKVY; Rural youth; Skill development.

Plasma-Activated Water for Food Safety and Shelf-Life Extension: A Review of Antimicrobial Potential, Sustainability and Industrial Challenges

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ABSTRACT

Plasma-activated water (PAW) is gaining attention as a promising antimicrobial treatment for food preservation because of its effectiveness against microorganisms and its potential environmental benefits. It offers an alternative to conventional disinfection methods, with the possibility of controlling microbial contamination while preserving food quality. Studies have reported its antimicrobial activity across a range of food matrices, although its performance depends on preparation methods and treatment conditions. This review examines recent advances in PAW production, its physicochemical characteristics, and its applications in improving food safety and quality. Particular attention is given to its potential for extending the shelf life of meat, fish, fruits, vegetables, and cereal-based products. Despite encouraging findings, wider adoption is constrained by low production efficiency, difficulties in maintaining antimicrobial activity during storage, and gaps in validation and safety assessment. The review also explores the use of PAW alongside other emerging technologies, considering how combined treatments influence microbial inactivation and food quality. Existing approaches to evaluating PAW safety are discussed, together with the technical challenges and research priorities that must be addressed before industrial implementation. Overall, the review critically evaluates the technological promise, safety considerations, and sustainability of PAW as a food preservation treatment.

Keywords: Plasma-activated water, food applications, antimicrobial efficacy, quality attributes, food quality, and safety

THEME 4: "From Fields to Founders: Catalyzing Agri-innovation and the Start-up Revolution"

Beyond Self-Employment: Measuring the Success, Sustainability and Growth Potential of AC&ABC Agripreneurs

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ABSTRACT

The Agri-Clinics and Agri-Business Centres (AC&ABC) Scheme is an important policy initiative for promoting agripreneurship among agricultural graduates and strengthening the delivery of need-based agricultural extension, advisory and allied services to farming communities. While enterprise establishment and self-employment generation constitute important outcomes of the scheme, the extent to which AC&ABC ventures achieve sustained economic performance, resilience and growth remains relatively less explored. The present study proposes a multidimensional assessment of AC&ABC agripreneurs by moving beyond self-employment as the conventional indicator of entrepreneurial success. Enterprise performance will be assessed across multiple dimensions, including profitability, income enhancement, employment generation, enterprise expansion, diversification, innovation, market linkages and adoption of digital technologies. Sustainability will be examined in terms of financial viability, business continuity, resource-use efficiency, adaptive capacity and resilience to market and production-related uncertainties. The study will further investigate the determinants of enterprise success and growth potential, with emphasis on access to institutional credit, entrepreneurial and technical training, extension support, infrastructure, input and output market linkages, professional networking and convergence with government support programmes. Primary data will be collected from selected AC&ABC agripreneurs using a structured interview schedule, and suitable descriptive, inferential and multivariate statistical techniques will be employed. The study is expected to develop an empirical and composite framework for assessing agripreneurial performance, sustainability and growth potential. The anticipated outcomes may provide evidence-based insights for strengthening post-establishment handholding, institutional convergence and capacity-building mechanisms, thereby supporting the transition of AC&ABC ventures from self-employment-oriented enterprises towards viable, resilient, innovative and scalable agribusiness ventures contributing to rural employment and agricultural development.

Keywords: Agri-Clinics and Agri-Business Centres (AC&ABC); Agripreneurship; Agricultural Graduates; Enterprise Performance; Entrepreneurial Success; Business Sustainability; Growth Potential; Agribusiness; Extension Services; Rural Employment.

Cultivating Innovation: Building the Next Generation of Agri-Entrepreneurs

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ABSTRACT

Agriculture is rapidly evolving through innovation, technology, and entrepreneurship. The theme "Seeds of Innovation: Growing the Next Generation of Agri-Entrepreneurs" focuses on encouraging youth to identify agricultural challenges and transform them into business opportunities. Technologies such as artificial intelligence, drones, Internet of Things (IoT), precision farming, biotechnology, protected cultivation, digital platforms, and food processing are creating opportunities across the agricultural value chain. These innovations can improve productivity, reduce input costs, minimize post-harvest losses, enhance market access, and promote sustainable resource use. Young agricultural graduates and rural youth can contribute by developing affordable, farmer-friendly solutions and innovative enterprises. To succeed, they need technical knowledge, entrepreneurial skills, mentorship, financial support, incubation facilities, and market linkages. Collaboration among farmers, universities, research institutions, industries, and government agencies can strengthen the agri-startup ecosystem. By promoting creativity and entrepreneurship, youth can help make agriculture more profitable, sustainable, and technology-driven while creating employment and supporting rural development.

Keywords: Agri-entrepreneurship, Innovation, Sustainable agriculture, Technology, Yout

From Farm Waste to Farm Income: A Vermicompost Model for Village Women's Groups

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ABSTRACT

Fertilizer prices keep rising while many farm soils are losing organic matter. At the same time, cattle dung and crop residue in villages are often burned, dumped, or left to rot in the open. Women in these households do much of the work of handling this waste, yet few earn anything from it. The article "From Farm Waste to Farm Income" proposes a simple model in which village women's self-help groups run small vermicompost units and sell the compost to nearby farmers. Each unit uses a few shaded beds built near cattle shed. Members bring dung and crop residue from their homes, and earthworms turn it into compost in about two months. The compost goes to local farmers, kitchen gardens, and plant nurseries. Vermiwash collected from the beds can be sold as a liquid spray, and surplus worms can be supplied to new groups as a starter culture. The university and the local Krishi Vigyan Kendra can give training on bed management and quality checks. Early support is needed for shed construction, worm stock, and finding buyers before sales become steady. Payment records are kept by the group so every member sees her share. To grow the model, groups can form clusters, share a common brand and a bagging unit, and supply organic growers who struggle to find good compost. Farmers would spend less on fertilizer and see better soil structure over time, while group members earn a regular income close to home. The approach turns a waste problem into a business that stays in the village.

Keywords: Organic Manure; Self-Help Groups; Soil Health; Vermicompost; Village Income; Women Empowerment.

From Innovation to Impact: Bridging the Gap between Agricultural Research and Market

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ABSTRACT

Agricultural research has generated numerous scientific innovations with the potential to improve productivity, resource-use efficiency, sustainability and farmer livelihoods. However, many promising technologies struggle to move beyond research laboratories and experimental fields into widespread commercial application. The gap between innovation and impact is therefore not merely a technological challenge but also an issue of technology transfer, entrepreneurship, market access, affordability and farmer adoption. Agricultural start-ups can serve as an important bridge between scientific research and market-oriented solutions by converting research outcomes into products and services that respond to real-world agricultural needs. An effective innovation ecosystem requires stronger linkages among agricultural universities, research institutions, farmers, start-ups, industries, incubators, investors and policymakers. Technology validation under diverse field conditions, intellectual property management, product development, regulatory support, business mentoring and access to early-stage finance are important components of this ecosystem. At the same time, innovation should remain farmer-centric, ensuring that new technologies are accessible, affordable and adaptable to the realities of small and marginal farming systems. Strengthening the connection between research and entrepreneurship can create pathways for agricultural technologies to move from proof of concept to practical adoption and commercial scale. Agricultural institutions can contribute not only through knowledge generation but also by fostering incubation, technology licensing, entrepreneurship education and industry partnerships. Start-ups, in turn, can provide the flexibility and market orientation needed to transform scientific discoveries into viable solutions. Bridging the research-to-market gap can consequently generate new enterprises, employment opportunities and scalable solutions while increasing the social and economic impact of agricultural research

Keywords: Agri-innovation; agricultural research; start-ups; technology transfer; commercialization, agripreneurship; innovation ecosystem; farmer-centric innovation; technology adoption; entrepreneurship

Innovation and tradition: A vision for developed Bharat through sustainable agriculture

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ABSTRACT

The future of agriculture in a developed Bharat lies at the intersection of innovation and tradition. A visionary agricultural system requires a harmonious integration of time-tested indigenous practices with modern scientific technologies to build a sustainable, productive, and resilient agricultural ecosystem. Technological advancements such as precision farming, artificial intelligence, biotechnology, remote sensing, digital platforms, and data-driven decision-making can improve crop productivity, input-use efficiency, and farm profitability. At the same time, traditional practices including organic cultivation, indigenous seed conservation, integrated farming, soil management, and water conservation provide valuable ecological knowledge for maintaining biodiversity and long-term resource sustainability. The integration of these approaches can strengthen food and nutritional security while reducing environmental pressures associated with excessive resource use. Farmer-oriented research, digitalization, capacity building, extension services, and access to affordable technologies are essential for translating scientific innovations into practical field-level solutions. Equally important is the recognition and documentation of indigenous knowledge, which can complement modern science and support climate-resilient farming systems. This integrated vision can also create employment opportunities, strengthen agricultural value chains, enhance rural livelihoods, and encourage youth participation in agriculture. Thus, the vision of a developed Bharat in agriculture should not be limited to technological advancement alone; it should focus on inclusive growth, ecological balance, farmer empowerment, and preservation of cultural heritage. By effectively combining innovation with tradition, India can develop a robust, resilient, and inclusive agricultural paradigm and emerge as a global leader in sustainable agriculture.

Keywords: artificial intelligence; indigenous knowledge; organic cultivation; precision farming; sustainability; water conservation

A Comprehensive Study of Women-led Moonj Handicrafts and Market Linkages in Prayagraj District, Uttar Pradesh

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ABSTRACT

Women's involvement in Moonj handicraft production does not necessarily give them control over the business or its earnings. In Prayagraj district, Uttar Pradesh, the relationship between women's production roles, market linkages and enterprise profitability remains insufficiently documented. This proposed study will examine the socio-economic circumstances of women artisans, their role in enterprise management, the channels through which they sell, and the contribution of Moonj income to household livelihoods. It will also identify constraints to market access and enterprise growth. A mixed-method, cross-sectional design will bring together structured surveys, product-cost sheets, sales records, key-informant interviews, focus group discussions and direct observation. Women engaged in production or sales will be selected from verified local records using stratified location selection and random or systematic respondent sampling; sample size will be determined after a pilot survey. Descriptive statistics, product-level cost-and-return analysis, channel comparisons, association tests and regression, where appropriate, will examine how market access and business decision-making relate to price realization, profitability and control over earnings. Costing will value owner and family labour so that cash margins are not mistaken for economic profit. The study will also distinguish actual group services and digital transactions from membership or online presence alone. Findings will be interpreted as associations rather than causal effects. By connecting women's work with the decisions and transactions that shape returns, the study aims to inform practical improvements in procurement, packaging, buyer relationships and payment reliability, supporting viable enterprises and greater control over craft income.

Keywords: Moonj handicrafts; Women-led enterprises; Market linkages; Profitability; Prayagraj

Value Addition in Millets: Development and Evaluation of Millet Based Value Added Products

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ABSTRACT

Millets are Nutri-rich, climate-resilient crops with high dietary fibre, protein, minerals and antioxidants, yet their consumption has declined due to limited processing options and low consumer awareness. Value addition offers a promising pathway to improve their market acceptance, farm income and nutritional security. The present study entitled "Development and evaluation of millet-based value-added products" was undertaken to develop nutritious products from millets, assess their nutritional and sensory quality, and examine consumer acceptability and constraints in their promotion. An experimental research design was adopted. Products such as cookies, ready-to-eat snacks and multigrain flour mixes were formulated using pearl millet, finger millet and sorghum with standard processing techniques. Sensory evaluation was carried out by a semi-trained panel using a nine-point hedonic scale, proximate composition was analysed using standard AOAC methods, and shelf life was assessed during storage. A structured schedule was used to record consumer preferences and constraints. Results revealed that millet-based products were nutritionally superior to conventional cereal based products, with higher fibre, protein and mineral content, and secured good overall acceptability scores. Major constraints identified were lack of awareness, limited processing facilities, short shelf life of millet flour and weak market linkages. The study concludes that millet value addition has considerable potential for enhancing nutritional security and rural livelihoods. Awareness programmes, support for small-scale processing enterprises, improved packaging and stronger market linkages are recommended to promote millet-based products.

Keywords: Consumer preference; Millets; Nutritional quality; Processing; Shelf-life; Value-addition

Development of a Biodegradable Proprietary Plant-Derived Polysaccharide Matrix and Targeted Botanical Bioactive Extract Seed Coating for Enhanced Seed Health and Germination in Soybean

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ABSTRACT

Every year, Farmer lose billions of rupees worth of crop because seed fail to germinate or succumb to fungal attacks in soil. To combat this, industry has traditionally used toxic fungicide coatings - but it results in killing the beneficial micro-organism in the soil. This study explores the dressing a seed in a "green superfood jacket" by biodegradable eco-friendly seed coating formulation combining proprietary plant-derived polysaccharide matrix a natural polysaccharide film - binder and targeted botanical bioactive extract rich in alkaloids, flavonoids, saponins, polyphenols, and tannins, antimicrobial and bioactive compounds to enhance seed health in soybean (Glycine max). The research focused on botanical coating developed using an optimized component proportion and evaluated across three target concentration levels (1%, 2%, 3%) using 3 replications alongside untreated control. Behalf, 2% and 3% concentrates show effective results on soyabean. The key parameters evaluated include germination %, mean germination time, root and shoot length, cost, seedling vigour and fungal infection rates. Among the treatments, the 2% and 3% concentrations demonstrated promising performance in soybean by improving germination and early seedling growth while reducing fungal infection compared with the untreated control. The findings indicate that the bioactive botanical seed coating has potential to enhance seed health and support uniform crop establishment. This study provides valuable insights into developing a cost-effective, scalable, biodegradable, and fully plant-based alternative to synthetic chemical seed treatments, contributing to sustainable crop production and environmentally responsible agriculture.

Keywords: Bioactive; Matrix; Saponins; Scalable

Next-Gen Bio-Fungicides: Smart Chitosan-Alginate Core-Shell Encapsulation of Trichoderma spp. for Controlled Release and Systemic Acquired Resistance

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ABSTRACT

Conventional bio-fungicides face severe operational constraints, including rapid spore mortality, short shelf-life and environmental degradation under field conditions. To address these challenges, this study presents a novel, scalable smart bio-nanotechnology platform: chitosan-coated alginate (CS-ALG) core-shell microcapsules engineered via electrostatic gelation for controlled release of Trichoderma spp. Conidia are encapsulated within a protective sodium alginate hydrogel core and enveloped by a positively charged chitosan-tripolyphosphate cationic shell. The dual-action system delivers controlled spore release along with intrinsic plant immunity priming by triggering systemic acquired resistance (SAR). The CS-ALG encapsulation achieves >92% encapsulation efficiency, maintains 100% spore viability after six months of storage and offers >85% UV protection. In field trials, the formulation demonstrated 88–95% inhibition ratio against major soilborne pathogens (Fusarium spp. and Rhizoctonia spp.), while enabling 40% reduction in application frequency. By mitigating environmental stress and maximizing biological efficacy, this bio-input platform provides a high-impact and eco-friendly for modern sustainable agriculture aligned with national sustainability goals.

Keywords: Chitosan-alginate core-shell; Encapsulation; Electrostatic gelation; *Trichoderma spp*

Invisible Losses, Visible Impact: Tackling Post Harvest Food Losses Through Smart Storage Technologies

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ABSTRACT

Post-harvest food losses represent a major challenge to food security, particularly in developing agricultural systems where inadequate storage, poor handling, temperature fluctuations, pest infestation, and insufficient infrastructure contribute substantially to the deterioration of harvested commodities. These losses reduce the quantity and quality of food available for consumption, diminish farmers' incomes, waste valuable agricultural resources, and increase the environmental footprint of food production. Smart storage technologies offer promising solutions by integrating modern sensing, monitoring, automation, and data-driven management with conventional storage practices. Technologies such as Internet of Things (IoT)-enabled sensors, real-time temperature and humidity monitoring, modified atmosphere storage, controlled atmosphere systems, automated ventilation, solar-powered cold storage, and predictive analytics can help maintain optimal storage conditions and identify potential spoilage at an early stage. Continuous monitoring enables timely intervention and reduces unnecessary exposure of food commodities to adverse conditions. Such systems can improve shelf life, preserve nutritional and market quality, reduce microbial and pest-related deterioration, and minimize quantitative and qualitative losses across the post-harvest supply chain. In addition, affordable decentralized storage solutions can be particularly valuable for small and marginal farmers by reducing dependence on distant storage facilities and enabling better timing of market sales. However, widespread adoption of smart storage technologies is constrained by high initial investment, energy requirements, limited technical skills, inadequate rural infrastructure, and lack of awareness among stakeholders. Therefore, technology adoption should be supported through farmer training, cooperative models, renewable energy integration, financial incentives, and locally appropriate storage solutions. Strengthening smart post-harvest management can bridge the gap between food production and food availability while improving farmer livelihoods and resource-use efficiency. Integrating intelligent storage technologies with sustainable post-harvest practices can thus play a significant role in reducing food losses and building resilient and food-secure agricultural systems.

Keywords: Cold storage; Food security; Internet of Things; Post-harvest losses; Smart storage; Supply chain.

From Fields to Founders: Catalysing Agri-Innovation and the Start-up Revolution

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ABSTRACT

Indian agriculture is undergoing a significant transformation from traditional farm-based production towards a knowledge-driven, technology-enabled and entrepreneurship-oriented ecosystem. The theme "From Fields to Founders: Catalysing Agri-Innovation and the Start-up Revolution" highlights the growing role of innovation, technology and young entrepreneurs in addressing persistent challenges across the agricultural value chain. Agri-startups are emerging as important drivers of change by developing solutions related to precision farming, farm mechanization, climate-smart agriculture, digital advisory services, input delivery, post-harvest management, food processing, supply-chain efficiency, market linkages and traceability. ICAR's technology-transfer and agribusiness incubation initiatives. The programme provides financial and technical assistance, including support at idea/pre-seed and seed stages, while RKVY Agribusiness Incubators facilitate training and incubation. ICAR has also strengthened the innovation ecosystem through Agribusiness Incubators, technology transfer and mentoring. However, sustainable growth of Agri-startups requires stronger farmer–research–industry linkages, accessible finance, incubation facilities, market validation, intellectual-property support, digital infrastructure and effective field-level extension. The future of agricultural entrepreneurship therefore lies not merely in developing new technologies, but in creating farmer-centric, affordable, scalable and environmentally sustainable innovations. By transforming farmers' challenges into entrepreneurial opportunities, India can build a new generation of Agri-founders who contribute to higher farm incomes, employment generation, resilient food systems and inclusive rural development.

Keywords: Agri-innovation, Agri-startups, Entrepreneurship, Agri-tech, Incubation, Digital Agriculture, Farmer-centric Innovation, RKVY, ICAR, Sustainable Agriculture

Evaluating Decentralized Supply Chains and Direct-to-Consumer Models to Enhance Smallholder Farmers' Profitability

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ABSTRACT

The present study entitled "Evaluating Decentralized Supply Chains and Direct-to-Consumer Models to Enhance Smallholder Farmers' Profitability" was undertaken to analyze marketing efficiency, price spread, and gross returns earned by smallholder producers transitioning from traditional supply chains to decentralized direct-to-consumer (D2C) channels. A multi-trial purposive-cum-random sampling technique was applied for the selection of key production clusters, blocks, and farm households. Primary data pertaining to agricultural operations and transactions were collected through structured personal interview schedules. Secondary data were gathered from regional agricultural marketing boards, local mandi administrative records, and trade databases. Findings from the empirical investigation indicate that traditional marketing channels are severely characterized by multi-layered intermediary commissions, high post-harvest handling losses, and persistent price distortion, resulting in reduced farm-gate earnt shares. Conversely, decentralized supply chain interventions—facilitated through farmer-producer organizations (FPOs), digital aggregators, and farm-direct local outlets—significantly diminished transport bottlenecks and eliminated superfluous middleman margins. Major constraints identified in scaling direct-to-consumer frameworks included initial capital constraints, inadequate cold-chain micro-infrastructure, and limited technical familiarity with digital order fulfillment platforms among growers. To overcome these operational bottlenecks, targeted capacity-building workshops on post-harvest grading, subsidized access to decentralized cold storage units, and streamlined micro-financing mechanisms by institutional agencies are strongly recommended. Overall, adopting decentralized direct marketing channels offers a sustainable, highly lucrative model for boosting smallholder income stability and building resilient agri-ecosystems.

Keywords: Direct-to-consumer; Farmer-producer organizations; Marketing efficiency; post-harvest losses; Price spread; Smallholder profitability

Gulkand Craft: A fusion of Tradition, Taste and Wellness

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ABSTRACT

Gulkand chocolate is an innovative food product that combines the traditional Indian ingredient gulkand with the taste and texture of chocolate. Gulkand is a sweet preserve prepared from rose petals and is traditionally valued for its cooling, digestive, and antioxidant properties. Through this project, we explored the idea of converting gulkand into a modern and attractive confectionery product that can provide both taste and traditional value. The product was developed in different varieties, including milk chocolate gulkand, dark chocolate gulkand, dry-fruit chocolate gulkand, and white chocolate gulkand. For preparation, gulkand was mixed with chopped nuts and cardamom to prepare the filling. Melted chocolate was then used to form a shell in the mould, followed by addition of the gulkand filling and sealing with another layer of chocolate. The chocolates were refrigerated until properly set and then removed from the moulds. The project also included a study of the existing market for gulkand chocolates. Existing products mainly focus on presentation, novelty, or specific flavor combinations, which provides an opportunity for a product that maintains a better balance between the natural floral flavor of gulkand and the richness of chocolate. The main target consumers are young urban consumers, gift buyers, wellness-conscious customers, and chocolate lovers. Gulkand chocolates can be marketed through online platforms, social media, retail stores, pop-up stalls, and customized gift packs for festivals, weddings, and corporate occasions. With suitable pricing and attractive packaging, the product has good potential as a small-scale entrepreneurial venture. Overall, this project shows that a traditional ingredient like gulkand can be successfully transformed into a modern gourmet chocolate while preserving its cultural identity and creating a unique and appealing product for consumers with strong market potential.

From farm waste to farm wealth: circular bioeconomy opportunities in Eastern India

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ABSTRACT

Agriculture in Eastern India is predominantly characterized by rice-based production systems, livestock integration and expanding agro-processing activities. These generate substantial quantities of crop residues, animal wastes and agro-industrial by-products. Traditionally treated as waste, they cause nutrient loss, inefficient resource use, open-field burning and environmental concerns. India generates an estimated 511 MT of agricultural residues annually, of which about 145 MT are surplus. In Odisha alone, approximately 4.4 Mha under paddy cultivation produce around 10.3 MT of paddy and an estimated 16 MT of paddy straw each year. Opportunities exist for transforming this biomass through cascading value-addition: in-situ residue incorporation, composting, vermicomposting, biochar production, anaerobic digestion, biogas and Bio-CNG generation, biomass briquetting and palletisation, mushroom cultivation, livestock-feed applications, and production of bio-based materials and chemicals. Agricultural residues can thereby contribute simultaneously to soil fertility, renewable energy, waste reduction and supplementary farm income. Biorefinery-based pathways further enable lignocellulosic biomass to serve as feedstock for biofuels, chemicals and other value-added products, linking agriculture with energy and industrial value Chains. The relevance is clear in Sambalpur, Odisha, where crop residues can be integrated with livestock resources and local agro-processing. A practical village-level circular model follows the pathway: paddy cultivation → collection of surplus straw → decentralized processing into compost/biochar, mushrooms, briquettes or biogas → utilization or sale of products → recycling of nutrients and organic matter back to farms. ICAR work in Odisha demonstrates the use of underused threshed paddy straw for paddy-straw mushroom production, creating additional value and self-employment opportunities. Residue recycling through incorporation, retention and microbial-assisted decomposition also improves soil quality in rice-based systems. At the institutional level, the Ministry of New and Renewable Energy (MNRE) supports energy recovery from agricultural wastes via bio methanation, biogas, Bio-CNG, gasification and other biomass-based technologies. A circular bioeconomy transforms agricultural waste into valuable resources, renewable energy, and income while promoting sustainable agriculture in Eastern India. It shifts agriculture from a linear "produce–use–discard" model towards a circular "produce–recover–convert–reuse–regenerate" framework, strengthening the economic and ecological sustainability of farming communities in the region.

Keywords: Agricultural Residues; Bio-CNG; Bio methanation; MNRE; Nutrient Recycling; Palletisation

Assessing the Role of Agricultural Diversification in Sustainable Income and Employment Generation among Small and Marginal Farmers in Varanasi District, Uttar Pradesh

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ABSTRACT

Small and marginal farmers operate the majority of landholdings in Uttar Pradesh, yet their dependence on traditional cereal based cropping exposes them to income instability, underemployment and climatic and market risks. Diversification towards horticulture, vegetables, livestock, dairy and other allied enterprises is widely advocated to improve rural livelihoods, but its household level contribution in eastern Uttar Pradesh requires empirical assessment. The present study entitled "Assessing the role of agricultural diversification in sustainable income and employment generation among small and marginal farmers in Varanasi district, Uttar Pradesh" was undertaken to examine the extent and pattern of diversification, to compare income and employment of diversified and non-diversified households, and to identify the constraints faced by farmers. A multistage stratified purposive cum random sampling technique was applied for the selection of blocks, villages and respondents. Primary data were collected through a pre-tested interview schedule, and secondary data from district agriculture offices, mandis and published sources. The Simpson Index measured diversification, cost and returns analysis and man-days of employment assessed income and employment, and logit regression identified determinants of adoption. Results revealed that diversified households earned higher net returns and generated more days of employment, particularly for family labour and women, than non-diversified households. Lack of capital, inadequate market access, price fluctuations, limited technical knowledge and poor storage facilities were the major constraints. The study concludes that diversification enhances income stability and rural employment. Strengthening credit access, extension services, market linkages and storage facilities is recommended to promote sustainable diversification.

Keywords: Agricultural diversification, Employment generation, Farm income, Small and marginal farmers, Sustainability, Varanasi

Impact of Farmer Producer Organizations on Farm Income and Market Access: A Study of Selected FPOs in Prayagraj District, Uttar Pradesh

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ABSTRACT

Farmer Producer Organizations (FPOs) offer a way for small and marginal farmers to market produce collectively, but registration and business turnover do not show whether individual farmers' benefit. This proposed study in Prayagraj district, Uttar Pradesh, will examine how actual use of FPO services relates to market access, prices received after marketing costs, and farm income. It will also assess organizational governance and functioning, crop-wise costs and returns, and the constraints faced by farmers and FPO managers. A mixed-method, cross-sectional design will combine farmer surveys with organizational records, key-informant interviews, focus group discussions and field observation. Organizations, villages and respondents will be selected through multistage sampling after verification of the initial FPO records, with sample size determined following a pilot survey. Comparisons will distinguish farmers who sell through FPOs from members who make little or no use of their marketing services and, where feasible, comparable non-members. Descriptive statistics, cost-and-return analysis, net-price calculations and appropriate comparative and association tests will examine differences in buyer access, marketing costs, intermediary dependence and farm returns. Observed relationships will be interpreted as associations, recognising the limits of cross-sectional data and possible selection bias. By linking organizational practices to farmer-level transactions, the study aims to identify where collective marketing delivers value and where service gaps remain. The resulting evidence will inform priorities for working capital, management, payment practices and buyer relationships, with the aim of strengthening farmer benefits and FPO sustainability.

Keywords: Farmer Producer Organizations; Farm income; Market access; Price realization; Prayagraj

Ultrasound-Assisted Enzymatic Extraction (UAEE): An Emerging Green Technology for Sustainable Recovery of Bioactive Compounds from Food Processing By-products

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ABSTRACT

The food processing industry generates large quantities of agro-industrial by-products, including fruit and vegetable peels, pomace, seeds, cereal brans and oilseed cakes, which are rich sources of polyphenols, flavonoids, carotenoids, dietary fibre, pectin, proteins and other bioactive compounds. However, conventional extraction methods are often limited by high solvent consumption, prolonged processing time, elevated energy demand and degradation of thermolabile constituents, reducing both process efficiency and sustainability. Ultrasound-assisted enzymatic extraction (UAEE) has emerged as a promising hybrid green technology that combines the physical effects of acoustic cavitation with the specificity of enzymatic hydrolysis to enhance the recovery of intracellular bioactive compounds under mild processing conditions. Ultrasound-induced cavitation disrupts plant cell structures, improves solvent penetration and accelerates mass transfer, while hydrolytic enzymes such as cellulase, pectinase and hemicellulase selectively degrade structural polysaccharides, facilitating the release of target compounds. Their synergistic action significantly improves extraction yield, extraction kinetics and preservation of heat-sensitive compounds while reducing solvent usage, processing time and energy consumption compared with conventional or single-mode extraction techniques. In comparison with conventional extraction techniques, UAEE reduces processing time, solvent consumption and energy demand while improving extract quality and supporting circular bioeconomy principles. This review critically discusses the principles, mechanisms and key process variables governing UAEE, together with its applications in recovering high-value biomolecules from diverse food processing by-products. Recent advances in process optimization, green solvents, hybrid extraction technologies, artificial intelligence-assisted optimization, industrial scale-up and sustainability within the circular bioeconomy are also highlighted. Furthermore, current challenges, research gaps and future prospects are discussed to support the development of efficient, scalable and environmentally sustainable extraction systems for next-generation food processing.

Keywords: Ultrasound-assisted enzymatic extraction; Acoustic cavitation; Enzymatic hydrolysis; Green extraction; Bioactive compounds; Food processing by-products.

From Farm Problems to Business Opportunities: The Role of Agri-Innovation and Start-ups in Transforming Indian Agriculture

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ABSTRACT

Agriculture is undergoing a significant transformation driven by technological advancement, entrepreneurship, and the growing need for sustainable and profitable farming systems. The transition from field to founders represents a new approach in which challenges faced by farmers are converted into innovative business opportunities through agri-start-ups. In India, issues such as low farm profitability, climate variability, post-harvest losses, inefficient input use, fragmented markets, and limited access to modern technologies create substantial opportunities for agricultural innovation. Agri-start-ups are emerging as important catalysts by developing solutions in precision agriculture, artificial intelligence, drones, farm mechanization, digital advisory services, biotechnology, bio-inputs, waste-to-wealth technologies, supply-chain management, food processing, and direct farmer-to-consumer marketing. The integration of traditional agricultural knowledge with modern scientific technologies can further improve the relevance and adoption of these innovations at the grassroots level. Start-ups can also create new employment opportunities for rural youth while strengthening farmers' access to markets, finance, information, and value-added technologies. However, successful scaling requires supportive policies, incubation facilities, research–industry collaboration, access to finance, skilled human resources, and stronger linkages between farmers, universities, investors, and entrepreneurs. This paper highlights the potential of agri-innovation and start-ups to transform agriculture from a production-oriented sector into a knowledge-, technology-, and entrepreneurship-driven ecosystem. Strengthening the connection between farmers, innovators, institutions, and markets can accelerate sustainable agricultural development, enhance farmers' income, generate rural employment, and contribute to a resilient and competitive agricultural economy.

Keywords: Agri-innovation, Agri-start-ups, Agricultural entrepreneurship, Precision agriculture, Digital agriculture, Rural youth, Farmer income, Sustainable agriculture, Value addition, Technology adoption

From Fields to Founders: Unlocking Agripreneurship Potential in Indian Horticulture

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ABSTRACT

India's horticulture sector has a role in the country's farming economy. It gives people and farmers in certain areas hope for starting their own businesses. This paper looks at how horticulture-based start-ups can help traditional farmers become agripreneurship. This shift can create jobs in villages. Develop agriculture from the ground up. Many types of business models have been studied. These include growing nursery plants, operating polyhouses or shade-net farms processing fruits and vegetables after harvest, adding value to produce, running flower farms and low-cost options like mushroom farming. Each of these offers a way in depending on how much money someone has, how much land they own and what skills they already have. The paper highlights that combining knowledge with modern tools makes a big difference. Digital marketing helps farmers reach customers. Cold storage helps keep produce. I think Government start-up support programmes help first-time entrepreneurs begin their journey There are challenges too. Many people struggle to get loans from banks. They find it hard to connect with buyers or markets. There is not training in new techniques. Many don't know about the policies or schemes that could help them. To solve this, the paper suggests a framework that brings together skill-building, mentorship and financial help. This can guide students and farmers from working the land to owning their enterprises. Horticulture start-ups are shown to be risky, easy to scale and adaptable across different regions—whether hot, cold, dry or wet. That makes them a strong choice for youth-led development in India. In the end the paper says that better connections between universities, incubation centres and financial institutions are key. When these groups work together, it speeds up the journey from farmer to founder. The goal is to create a farming system that can take care of itself and come up with ways to do things. Is full of fresh thinking

Keywords: Agripreneurship, horticulture start-ups, entrepreneurship, value addition, protected cultivation

Traditech to Smartscape: Technology-Driven Floriculture and Landscaping for Youth Entrepreneurship and Sustainable Growth

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ABSTRACT

Floriculture and landscape horticulture offer income diversification, employment, urban greening and entrepreneurship in Indian agriculture. However, the sector faces challenges related to fragmented production, quality planting material, post-harvest losses, market linkages, skilled manpower and technology adoption. Integrating traditional horticultural knowledge with digital technologies can create a resilient, market-oriented ecosystem. Protected cultivation, precision irrigation, sensor-based monitoring, climate-smart production, nursery automation and digital decision-support tools can improve productivity and quality while reducing water, fertilizer and labour use. Artificial intelligence, remote sensing, Internet of Things (IoT) devices and digital marketplaces can support crop scheduling, pest surveillance, demand forecasting, traceability and direct market access. In landscaping, digital design, smart irrigation, native and climate-resilient plants, vertical gardens and green infrastructure can promote sustainable urban development. Technology-enabled value chains can create opportunities for youth, women and small entrepreneurs in nurseries, flower production, value-added products, landscape services, floral design, event decoration, garden maintenance and digital marketing. Farmer Producer Organisations, start-ups, cooperatives and public-private partnerships can improve aggregation, processing and market access. Skill-oriented education and practical training are essential to prepare a workforce for emerging technologies. The proposed "farm-to-market-to-landscape" ecosystem combines scientific knowledge, traditional practices, entrepreneurship and digital tools to improve profitability, resource efficiency and climate resilience while generating employment. Incubation, technology transfer, extension services, quality standards and accessible digital platforms can accelerate adoption, particularly among small and marginal growers. Floriculture and landscaping should be recognised not merely as ornamental activities, but as technology-driven, knowledge-intensive enterprises. Collaboration among researchers, educators, farmers, entrepreneurs, policymakers and consumers, with finance, infrastructure, market intelligence and mentoring, can reduce entry barriers. This strategy can strengthen value chains, meet changing consumer preferences, support farmer prosperity and scontribute to greener cities and a self-reliant, developed India.

Keywords: floriculture; landscaping; digital technologies; precision horticulture; protected cultivation; entrepreneurship; start-ups; sustainable urban greening; youth employment.

Agricultural Waste to Wealth: Opportunities for Sustainable Agribusiness

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ABSTRACT

India generates several hundred million tonnes of agricultural residues every year, a large share of which is burnt or left to decompose in fields, causing air pollution, greenhouse gas emissions and loss of valuable biomass. Converting this waste into marketable products offers an opportunity to combine environmental protection with enterprise development. The present study entitled "Agricultural waste to wealth: opportunities for sustainable agribusiness" was undertaken to examine the types and availability of agricultural waste, to identify value addition pathways, and to assess the economic potential and constraints of waste-based agribusiness enterprises. A descriptive and analytical approach was followed, based on secondary data collected from government reports, research publications, agricultural statistics and documented case studies of waste utilisation enterprises. Technologies such as composting, vermicomposting, biogas and bioenergy production, briquette and biochar making, mushroom cultivation, animal feed formulation and extraction of bio-based materials were reviewed, and their economic viability was assessed through cost and returns analysis. The findings indicate that agricultural waste can generate additional farm income, create rural employment and reduce dependence on chemical inputs and fossil fuels. Major constraints identified were poor collection and logistics, lack of technical knowledge, limited access to finance, inadequate processing infrastructure and weak market linkages. The study concludes that waste valorisation is a promising pathway towards a circular bioeconomy. Policy support, farmer training, financial assistance and the promotion of farmer producer organisations and start-ups are recommended to strengthen sustainable agribusiness.

Keywords: Agribusiness; Agricultural waste; Circular economy; Sustainability; Value addition; Waste valorisation.

From Fields to Founders: Catalysing Agri-Innovation and the Start-Up Revolution

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ABSTRACT

For a long time, agriculture and entrepreneurship were viewed as two separate worlds—one associated with farming and production, and the other with business, technology, and investment. This distinction is gradually changing. Across India, a new generation of agri-startups is emerging at the intersection of agriculture, technology, and enterprise. These ventures are not only introducing digital tools and modern business models into farming but are also creating opportunities for farmers, rural youth, researchers, and entrepreneurs to participate in the agricultural innovation process. The present paper explores this transition from "fields to founders" and examines how agri-innovation is contributing to the growth of India's start-up ecosystem. It discusses the emergence of farmer-led, technology-led, and rural enterprise-led ventures working in areas such as precision agriculture, farm advisory services, digital marketplaces, supply-chain management, agricultural finance, drones, artificial intelligence, farm infrastructure, and value addition. The paper also considers the role of government initiatives such as Startup India, RKVY-RAFTAAR, AgriSURE, the Agriculture Infrastructure Fund, and the Digital Agriculture Mission in creating an enabling environment for agricultural entrepreneurship. At the same time, the growth of agritech should not be viewed only through the number of start-ups or the amount of investment received. Small and fragmented landholdings, limited digital access, seasonal income patterns, farmer trust, high customer-acquisition costs, regulatory uncertainties, and difficulties in accessing patient capital continue to influence the sustainability of agri-enterprises. The paper therefore emphasizes a farmer-centred approach in which technology is developed around real field-level needs rather than introduced as an end in itself. Stronger connections among farmers, researchers, start-ups, incubators, financial institutions, and government agencies can help convert local agricultural problems into viable and scalable enterprises. The paper concludes that India's next phase of agricultural transformation will depend not only on adopting technology but also on enabling rural communities to become creators, owners, and entrepreneurs within the innovation ecosystem.

Keywords: Agritech; Agri-innovation; Start-ups; Agricultural Entrepreneurship; Digital Agriculture; Rural Entrepreneurship; Farmer-led Innovation; India.

A Study on Value Addition and Processing Opportunity of Radish

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ABSTRACT

Radish (Raphanus sativus L.) is a fast-growing, cool-season root vegetable of the Brassicaceae family, widely cultivated across Asia, Europe, and North America. It is valued for its nutritional profile, offering vitamin C, dietary fibre, potassium, folate, and bioactive compounds such as glucosinolates, isothiocyanates, anthocyanins, and phenolics, which have antioxidant, anti-inflammatory, and digestive health benefits. Despite its high production, radish is largely sold fresh, and its high moisture content (about 90–95%) makes it highly perishable. This leads to substantial post-harvest losses, price fluctuations, and low returns to farmers. This study explores value addition and processing opportunities for radish to reduce losses, extend shelf life, and improve farm income. Processing options examined include drying and dehydration (chips, powder, flakes), pickling and fermentation (kimchi, brined and sauerkraut-style products), preserves and candies, juices and extracts, and ready-to-cook or minimally processed products. Radish leaves, often discarded, can also be used in powders, soups, and animal feed, supporting a zero-waste approach. Radish seeds and sprouts offer further scope for oil extraction and nutraceutical applications. The study also considers key factors affecting processing viability, including raw material quality, pungency management, nutrient retention, packaging, storage, and economic feasibility. Findings indicate that value-added radish products can improve shelf life, create new market channels, generate rural employment, and encourage agro-based entrepreneurship. Promoting small-scale processing units, farmer producer groups, and supportive policies, along with consumer awareness, can strengthen the radish value chain and contribute to food security and sustainable agricultural development.

Keywords: Radish; Raphanus sativus; value addition; processing; post-harvest losses; dehydration; pickling; nutraceuticals.

How to become agriprenuar in india

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ABSTRACT

Agriculture remains a major contributor to India's economy and rural employment; however, farmers and rural youth continue to face challenges such as low farm profitability, limited market access, unemployment, inadequate value addition, and dependence on traditional production systems. Agripreneurship offers an important pathway to address these challenges by integrating agricultural knowledge with entrepreneurship, innovation, technology, and market-oriented business practices. This study aims to examine the opportunities, requirements, challenges, and practical pathways for becoming a successful agripreneur in India, with particular emphasis on youth and agriculture graduates. A descriptive and exploratory research approach is proposed, using secondary information from government reports, agricultural institutions, entrepreneurship development programmes, research publications, and relevant policy documents. The study will analyse major agribusiness opportunities including input supply, food processing, organic farming, protected cultivation, mushroom cultivation, dairy, fisheries, agri-tourism, digital agriculture, farm machinery services, and agricultural marketing. The findings indicate that access to finance, technical knowledge, incubation support, digital technologies, market linkages, skill development, and government schemes are critical determinants of successful agripreneurship. The study further highlights the need for systematic training, mentoring, business planning, and institutional support for aspiring agripreneurs. It concludes that promoting agripreneurship can enhance farm incomes, generate rural employment, encourage value addition, and strengthen India's agricultural economy. Strengthening entrepreneurship education and improving access to credit, technology, and markets can therefore play a significant role in developing a sustainable agripreneurial ecosystem in India.

Keywords: Agripreneurship; Agricultural Entrepreneurship; Agribusiness; Rural Youth; Innovation; India.

Seed Potato Production Systems in India: Conventional and Advanced Approaches

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ABSTRACT

Potato is one of the major food and vegetable crops in India, with an annual production of around **60 million tonnes from approximately 2.33 million hectares**, making India the world's second-largest potato producer. The availability of healthy, genetically pure and quality seed potato is fundamental to sustaining productivity and profitability. India has developed a well-established seed potato production system, particularly in the north-western plains and hilly regions, based largely on conventional field multiplication of breeder, foundation and certified seed. However, the conventional system is associated with progressive accumulation of viruses and other seed-borne pathogens, high multiplication costs, degeneration of seed quality and substantial seasonal dependence on favourable agro-climatic conditions. To address these constraints, advanced seed production technologies have gained increasing importance. Tissue culture-based production of disease-free plantlets, aeroponic and hydroponic systems for rapid mini-tuber multiplication, protected cultivation, pathogen indexing, precision irrigation and fertigation are being increasingly integrated into quality seed production programmes. True Potato Seed (TPS), particularly hybrid TPS, also offers opportunities for rapid multiplication, reduced seed-borne disease transmission and easier transportation and storage. These technologies have the potential to substantially increase the multiplication rate and shorten the time required for production of quality planting material. The present review provides an overview of the **current status of seed potato production in India**, including conventional seed multiplication systems, major seed-producing regions, quality seed requirements and emerging production technologies. It further discusses the advantages, limitations, infrastructure requirements and prospects of advanced approaches. An integrated seed production strategy combining conventional field multiplication with modern technologies, supported by effective seed certification, disease diagnostics, quality assurance and traceability, is essential for meeting the growing demand for quality seed potato. Such an integrated approach can contribute to improved seed health, higher productivity, resource-use efficiency and sustainable development of the Indian potato sector.

Keywords: Breeder seed production; conventional; hi-tec seed production

From Genetic Gains to Farmers' Gains: Bridging Crop Improvement, Productivity and Farm Profitability in India

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ABSTRACT

Crop improvement has contributed substantially to agricultural productivity, yet higher yields do not necessarily translate into higher or more stable farm incomes. Evidence from India demonstrates that improved varieties can enhance productivity and economic returns, but the benefits depend on crop management, adoption conditions and farmers' access to complementary resources (Roy et al., 2021; Sharma et al., 2015). Rising cultivation costs, climate-related risks, market-price fluctuations and institutional constraints further influence farm profitability. This review examines how genetic gains and agricultural innovations can be translated into improved net returns and sustainable rural livelihoods. A structured integrative literature review will synthesise peer-reviewed studies and authoritative institutional publications identified through academic databases and relevant agricultural research repositories. The review will examine evidence on improved crop varieties, stress tolerance, resource-use efficiency and technology adoption, alongside cultivation costs, crop diversification, post-harvest management, market access and farmer-producer organisations. Particular attention will be given to the factors influencing the conversion of productivity gains into farm-level economic benefits, especially for small and marginal farmers. Indian evidence indicates that crop diversification can improve farm income under favourable conditions, while the performance of producer organisations depends on their capacity to strengthen market access, services and farmers' bargaining power (Basantaray et al., 2024; Cherukuri & Reddy, 2014). The review will critically assess interactions among crop genetics, production costs, risk management, market institutions and technology adoption. It will identify evidence gaps and develop a farmer-centric conceptual framework linking crop improvement with cost-effective production, economic risk reduction and value-chain development. By integrating perspectives from crop science and agricultural economics, the review aims to advance a broader assessment of agricultural progress in which genetic gains are evaluated not only through yield improvement but also through their contribution to farm profitability, income stability and sustainable livelihoods.

Keywords: Agricultural innovation; Crop improvement; Farm income; Farm profitability; Genetic gains; Value chains

The Orange Revolution: Giving Carrot Waste a Second Life

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ABSTRACT

Food waste has become a major global issue, with about one-third of the food produced for human consumption being lost or wasted every year. In garden crops, carrots (Daucus carota L.) contribute significantly to post-harvest losses due to market quality standards, processing residues, and contamination during storage and transportation. Even then, carrot waste is a rich source of valuable nutrients and bioactive compounds, including beta-carotene, dietary fiber, polyphenols, vitamins, minerals, and natural antioxidants. These components have the potential to create value-added products that not only enhance environmental sustainability but can also improve people's health. The idea of the 'Orange Revolution,' combined with new technology and a circular economic system, shows that carrot waste need not contribute to environmental burden but can be turned into a valuable bio-resource. This review discusses the production of carrot by-products, their nutritional properties, emerging value addition strategies, industrial use, environmental and economic benefits, current challenges, and future opportunities for sustainable use.

Keywords: Carrot waste, β-carotene, Food waste valorization, Circular economy, Functional foods, Bioeconomy, Sustainability

Theme 05- Roots to Routers Reviving Traditional Wisdom through Digital and Emerging Technologies

GIS-driven digital agricultural monitoring through Kharif crop acreage assessment in Sirsa, Haryana

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ABSTRACT

Accurate and timely crop acreage estimation is central to evidence-based agricultural planning, especially in states like Haryana where cropping patterns directly influence farmer income, water resource allocation, and food security policy. This study presents a Sentinel-2 imagery-based unsupervised classification approach to estimate Kharif crop acreage across the Sirsa district, demonstrating how open-access satellite data and GIS techniques can support traditional field surveys. Paddy constituted the largest proportion of the mapped area (41.42%), followed by cotton (20.64%). Non-agricultural land and fallow land accounted for 14.24% and 11.82%, respectively. Guar occupied 7.59% of the total area, whereas other crops, bajra, and moong accounted for 1.68%, 1.63%, and 1.00%, respectively. The classification accuracy was assessed using ground-truth data, yielding an overall accuracy of 82.9%. Paddy exhibited the highest classification reliability, with a user's accuracy of 90.8% and a producer's accuracy of 94.1%. In contrast, relatively lower classification accuracies were observed for bajra and guar, which may be attributed to their similar spectral characteristics and spectral mixing with other crops during the Kharif season. The study demonstrates the potential of a cost-effective and reproducible geospatial framework for district-level crop-area estimation, strengthening data-driven agricultural monitoring, resource planning, and digital decision-making in India.

Keywords: Accuracy; Crop acreage; Precision agriculture; Remote sensing; Sentinel-2; Unsupervised classification

Permanent water-permeable mulching cloth for sustainable agriculture

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ABSTRACT

Conventional plastic mulch is widely used in agriculture for moisture conservation and weed management, but its limited reusability and potential contribution to plastic and microplastic pollution create environmental concerns. The present project aims to develop a durable, water-permeable mulching cloth as a long-term alternative to conventional plastic mulch. The proposed material is designed to allow rainwater and irrigation water to infiltrate into the soil while reducing moisture loss from the soil surface. Under the proposed tested conditions, the system targets more than 90% water retention. The mulching cloth also functions as a physical barrier against weed emergence, with the potential to reduce repeated weeding operations and associated labour requirements. By maintaining a more favourable soil-moisture environment, the cloth may support better crop establishment and reduce the frequency of irrigation interventions. Unlike conventional plastic mulch, the proposed cloth is intended for long-term use and reuse, thereby reducing dependence on single-use plastic materials and helping to minimize microplastic pollution. Its water-permeable structure is expected to improve the balance between water infiltration, evaporation control, and soil surface protection. The project integrates water conservation, weed management, durability, and sustainable material utilization into a single agricultural mulching system. Overall, permanent water-permeable mulching cloth represents a promising approach for improving soil-water management, reducing labour requirements, and lowering the environmental impact of plastic-based mulching practices in sustainable agriculture.

Keywords: Microplastic reduction; Soil moisture; Sustainable agriculture; Water conservation; Water-permeable mulch; Weed management

AI-driven smart orchards: transforming fruit crop management

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ABSTRACT

The rapid convergence of artificial intelligence, edge computing, computer vision and Internet of Things (IoT) technologies is profoundly transforming contemporary pomology through the realization of AI-driven smart orchards. Conventional fruit crop management has traditionally relied upon labour-intensive manual orchard scouting, empirical human intuition and uniform broadcast chemical applications, which routinely cause sub-optimal yields, high input wastage, delayed pathogen responses and substantial post-harvest losses. This study presents a comprehensive, integrated framework for intelligent fruit crop management designed to optimize tree architecture, resource allocation and harvest logistics. Multi-modal sensor networks combined with autonomous unmanned aerial vehicles (UAVs) equipped with multispectral and LiDAR sensors were deployed to acquire continuous canopy-level and tree-specific geospatial data. Deep convolutional neural networks and vision transformers were implemented for real-time phenotyping, automated blossom counting, early foliar disease detection and high-accuracy fruit load quantification. In addition, an array of in-situ microclimate and soil moisture sensors operating via LoRaWAN telemetry fed dynamic machine learning algorithms to automate precision drip irrigation and variable-rate fertigation schedules, achieving a 29.4% reduction in irrigation volume and a 23.8% decrease in synthetic agrochemical use without compromising fruit quality. Predictive machine learning models demonstrated an operational accuracy exceeding 94.6% in pre-harvest yield forecasting and maturity grading, directly facilitating the deployment of autonomous harvesting mechanisms and streamlined post-harvest supply chains. By replacing subjective manual assessments with high-resolution, data-driven actionable intelligence, smart orchards mitigate labor shortages, augment resource-use efficiency, and elevate net economic returns for fruit growers. The findings confirm that the adoption of artificial intelligence and robotic automation represents an indispensable technological paradigm for achieving sustainable, high-density and climate-resilient commercial fruit production systems.

Keywords: Computer vision; Deep learning; Fruit crop management; Precision horticulture; Smart orchards; Yield forecasting

From the farmer's eye to edge intelligence: digital extension of traditional crop-care wisdom in strawberry

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ABSTRACT

Traditional strawberry management rests on the grower's trained eye and accumulated experience: scouting leaves for disease, judging when plants need water and reading weather stress before it becomes damage. This knowledge is valuable but difficult to scale, varies between individuals and is increasingly strained by labor shortages and by the heavy agrochemical use that late diagnosis invites. Peer-reviewed evidence on strawberry (Fragaria × ananassa Duch.) to show how emerging digital technologies can encode and extend this experiential wisdom rather than replace it. Three strands were examined. First, a low-cost edge-computing and IoT platform, combining LoRa sensor nodes with a Raspberry Pi running YOLOv5s, detected seven common strawberry diseases in the field without internet connectivity (mAP@0.5 of 78.7% on the test set) at a hardware cost of about US$241, while an Isolation Forest model screened out faulty sensor readings. Second, drainage-rate-controlled irrigation in hydroponic strawberry gave marketable yield (342 g per plant at 20% drainage) equivalent to six-times-daily timer irrigation (341 g) with about 27% less nutrient solution, although yield differences were not statistically significant. Third, deep learning studies on disease, ripeness, quality grading, leaf wetness and yield estimation report high accuracies, yet small datasets, occlusion, variable lighting and weak recognition of some diseases such as angular leaf spot limit field reliability. On this basis, a farmer-in-the-loop framework is proposed that maps traditional practices (scouting, irrigation timing and ripeness judgement) to affordable, offline-capable digital counterparts, with the grower retaining final decision-making. Local validation, affordability and farmer trust emerge as the key conditions for adoption by smallholders.

Keywords: Deep learning; Disease detection; Edge computing; Internet of Things; Strawberry; Traditional knowledge

Role of artificial intelligence in transforming modern agriculture

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ABSTRACT

The present study entitled "Role of Artificial Intelligence in Transforming Modern Agriculture" was undertaken to examine the potential of Artificial Intelligence (AI) in transforming agricultural practices, improving resource-use efficiency and enhancing farm productivity and sustainability. The study aims to analyse the major applications of AI in crop production, crop health monitoring, precision irrigation, pest and disease detection, yield prediction, weather forecasting and agricultural decision-making. A descriptive and analytical research approach was adopted based on secondary information collected from research articles, government reports, agricultural databases, institutional publications and relevant scientific literature. The findings indicate that AI-enabled technologies, including machine learning, computer vision, remote sensing, drones and smart sensors, can facilitate timely and data-driven decisions at different stages of crop production. AI-based systems have considerable potential to identify crop diseases at an early stage, optimise the application of water and fertilizers, forecast crop yields and reduce production risks associated with climatic variability. However, the adoption of AI in agriculture is constrained by high initial investment, limited digital literacy, inadequate rural connectivity, fragmented farm holdings and concerns regarding data accessibility and affordability. The study suggests strengthening digital infrastructure, farmer training, extension services and institutional support to promote inclusive adoption of AI technologies. Integrating AI with traditional agricultural knowledge can contribute significantly to productive, resource-efficient, climate-resilient and sustainable agriculture.

Keywords: Artificial intelligence; Digital agriculture; Precision agriculture; Smart farming; Sustainable agriculture; Yield prediction

Integrating artificial intelligence with participatory rural appraisal (AI-PRA) for precision problem diagnosis and targeted technology transfer in veterinary extension

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ABSTRACT

Participatory Rural Appraisal (PRA) remains the primary bottom-up framework for livestock problem diagnosis, needs assessment, and community technology dissemination in veterinary extension. However, traditional methodologies—relying on manual sketch maps, seasonal calendars, and matrix scoring—are constrained by qualitative subjectivity, documentation decay, and an inability to perform predictive forecasting across wider agro-climatic zones. The convergence of grassroots participatory techniques with Artificial Intelligence (AI), specifically Machine Learning (ML), Natural Language Processing (NLP), and Geographic Information Systems (GIS), presents a transformative paradigm termed AI-PRA to convert indigenous community wisdom into data-driven, precision veterinary interventions. The operational methodology of AI-PRA integrates a three-stage computational synthesis: participatory data digitization, analytical layering, and targeted technology transfer. Field-level participatory focus group discussions and vernacular spoken queries are transcribed and analyzed via dialect-trained speech-to-text and NLP pipelines to detect early syndromic flags, unusual disease incidence, and vaccine hesitancy trends. Concurrently, community-drawn participatory resource maps are digitized and layered over satellite remote sensing (NDVI) and GIS spatial data to forecast seasonal biomass deficits, water contamination, and vector-breeding hotspots weeks prior to conventional recognition. Supervised machine learning algorithms and multicriteria decision matrices subsequently convert aggregated community problem rankings into micro-targeted advisory packages, delivering tailored feeding, breeding, and disease prophylaxis schedules according to herd scale and resource vulnerability. While technical challenges related to rural digital connectivity, dataset representation of indigenous tropical livestock breeds, and the need for human-in-the-loop veterinary validation persist, AI-PRA effectively bridges the persistent lab-to-land adoption gap. Combining grassroots community participation with predictive artificial intelligence establishes a scalable, responsive, and precision-driven foundation for sustainable livestock health management.

Keywords: AI-PRA; Machine learning; Natural language processing; Precision extension; Technology transfer; Veterinary extension

Not disruption, but devotion: how technology can deepen, not dilute, natural farming

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ABSTRACT

Agricultural technology is often developed with the aim of increasing productivity, controlling farm processes, and reducing the uncertainty associated with natural systems. However, this approach does not always fit well with the philosophy of natural farming, which is based on observing ecological processes, maintaining soil health, and working with nature rather than trying to control it. An alternative way of thinking about agricultural technology, in which technology supports the farmer's understanding of the ecosystem instead of replacing natural processes or increasing external intervention. Technology works best as a tool for observation and ecological learning. Technologies such as soil bio-acoustic sensors, computer vision, and geospatial tools like Geographic Information Systems (GIS) and remote sensing can help farmers understand spatial distributions and build resilience against climate change by noticing shifts that may otherwise be difficult to detect. These technologies do not need to be used to automatically control the farm or trigger chemical-based interventions. Instead, they can provide useful information about soil organisms, plant succession, and other ecological changes. For instance, carefully applied technologies like rain pipe irrigation can be utilized to gently maintain Whapasa—the critical balance of soil moisture and aeration—thereby preventing waterlogging and fostering an ideal habitat for beneficial soil microbes. Furthermore, this observational approach can validate and support Indigenous Technical Knowledge (ITK). Modern monitoring tools can be used to observe the positive impacts of traditional, traditional wisdom-based formulations like Jeevamrut and Beejamrut, helping to enhance soil health and crop growth while systematically reducing reliance on high-cost external inputs. In this approach, technology is not viewed as a means of controlling nature but as an extension of the farmer's ability to observe and understand it. The paper argues that when technological development is guided by ecological values and careful observation, modern tools can complement natural farming rather than undermine it. Such an approach may contribute to more resilient and sustainable farming systems while preserving the central principle of natural farming: working with the intelligence of the ecosystem rather than against it.

Keywords: Agricultural technology; Climate resilience; Ecological monitoring; Indigenous technical knowledge; Natural farming; Soil health

AI-driven precision poultry farming and AI-based early disease detection: transforming productivity, sustainability and farmer income in India

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ABSTRACT

India's poultry sector is expanding rapidly and has become an important contributor to food and nutritional security, employment and rural livelihoods. India produced an estimated 149.11 billion eggs in 2024–25, a 4.44% increase over the previous year, with commercial poultry contributing 84.49% of national egg production. Such a large and increasingly commercialized production system requires a transition from observation-based management towards predictive, preventive and precision poultry farming. Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), computer vision and multimodal sensing can provide this transition by integrating bird behaviour, images, vocalisation, body weight, feed and water intake, mortality patterns and microclimatic variables into real-time decision-support systems. A machine-learning approach detected experimentally Newcastle disease virus-infected chickens as early as 36 hours post-infection, achieving 82.39% test accuracy after feature optimization. Similarly, a two-stage deep-learning framework for avian pox achieved 92.71% overall accuracy, 97.67% anomaly precision and 97.92% specificity, while YOLOv8n achieved 99.8% mAP@50 for chicken-head localization. These findings indicate that subtle visual and behavioural changes can be converted into actionable early-warning signals before disease becomes clinically obvious. Beyond diagnosis, AI-IoT systems can continuously optimize temperature, humidity and ventilation. A recent review reported thermal stability of approximately ±0.5°C, feed conversion ratios of 1.42–1.50 and daily weight gain of 64–68 g/day across reported smart-farming applications, although high initial costs, sensor ageing and rural connectivity remain important barriers. The proposed framework therefore conceptualizes the **AI-enabled Digital Poultry Farm**, integrating health, behaviour, environment and production data into a single predictive platform. AI can support early disease alerts, precision environmental control, feed-efficiency monitoring, mortality-risk prediction, biosecurity surveillance and farm-level decision making. For small and medium farmers, affordable edge-AI devices, regional datasets, vernacular mobile applications, veterinary integration and digital extension services will be essential for scalable adoption. The convergence of AI and veterinary health management can shift poultry production from reactive treatment to predictive and preventive management, with potential to reduce avoidable losses, improve resource-use efficiency, strengthen animal welfare and enhance farmer profitability. Thus, responsible adoption of AI can become a key technological pathway for a sustainable, resilient and self-reliant Indian poultry sector.

Keywords: Artificial intelligence; Computer vision; Early disease detection; IoT; Machine learning; Precision poultry farming

Technological validation of ancient agroecology

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ABSTRACT

Traditional agroecological systems rely on centuries of localized observation, yet their integration into modern sustainability efforts often lacks empirical validation. This review explores how contemporary scientific technologies can be leveraged to rigorously test and quantify the agronomic and ecological functions of ancient farming practices. Rather than accepting historical methods on anecdotal merit, we propose a comprehensive validation framework that treats traditional ecological knowledge as testable hypotheses. We synthesize recent applications of advanced diagnostics—including soil metagenomics for microbial diversity, IoT sensor networks for microclimate and moisture tracking, drone-based remote sensing for yield mapping, and spatial modelling for water harvesting. By mapping these modern tools to specific traditional practices like intercropping, agroforestry, and organic amendments, the review demonstrates how complex parameters such as carbon sequestration, water-use efficiency, and climate resilience can be objectively measured. Ultimately, we argue that combining historical agricultural frameworks with modern empirical diagnostics provides a concrete pathway for designing highly productive, resilient agricultural systems that are both scientifically sound and ecologically grounded.

Keywords: Agroecology; Climate resilience; Remote sensing; Soil metagenomics; Technological validation; Traditional ecological knowledge

Ancient seeds, adaptive futures: epigenetic stress memory for resilient Indian agriculture

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ABSTRACT

Indian agriculture faces mounting challenges from drought, salinity, heat waves and pathogen outbreaks, all intensified by climate change and threatening yield stability. Plants, however, possess an extraordinary adaptive mechanism known as epigenetic stress memory, where prior stress exposure leaves molecular imprints through DNA methylation, histone modifications, small RNAs and chromatin remodeling. These changes fine-tune gene expression without altering DNA sequence, enabling plants to mount faster and stronger defenses when re-exposed to similar conditions. Traditional practices of seed selection from stress-surviving plants unknowingly preserved such resilience traits and modern epigenomics now validates this wisdom by showing that stress memory can persist across generations. The epigenetic toolkit provides a framework for understanding how plants stabilize stress responses, regulate chromatin accessibility and direct gene activation or silencing. Future research must identify stable epigenetic markers, determine the persistence of stress memory and integrate these insights into breeding programs to develop climate-resilient crops without compromising yield. By bridging ancient seed wisdom with cutting-edge molecular tools, epigenetic stress memory offers a transformative pathway to secure sustainable agriculture in India's diverse agro-climatic zones. This approach aligns with the theme "Roots to Routers," where traditional knowledge converges with digital and emerging technologies, ensuring robust, farmer-friendly solutions for food security in the face of global climate challenges.

Keywords: Climate adaptation; DNA methylation; Epigenetic memory; Indian agriculture; Seed selection; Stress resilience

Youth-led digital transformation in agriculture

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ABSTRACT

This study examined youth engagement with digital agriculture through primary data collected using a structured online survey. The objective was to understand how young individuals utilize digital technologies in agriculture and the broader agrifood system. The survey was targeted at researchers, students, and young professionals and generated 65 valid responses, collected exclusively for research purposes. The socio-demographic profile indicated that nearly 60% of the respondents belonged to the 20–25 years age group, while females constituted 56.9% of the sample. Students represented the largest group (80%), followed by researchers (16.9%). Among the various digital technologies, mobile applications were the most widely used tools for agrifood-related activities, particularly for accessing weather and climate information and facilitating communication and networking. Poor internet connectivity was identified as the major challenge, reported by 43.1% of respondents. The most prominent benefit of using digital technologies was improved decision-making (63.1%), followed by enhanced access to knowledge and time savings. Regarding future improvements, 60% of respondents emphasized the need for affordable digital tools, while 49.2% highlighted the importance of government support and appropriate policy interventions. Lack of funding was identified as the leading constraint to technology development by nearly half of the respondents. Personal experience was reported as the primary source of inspiration for developing future agricultural technologies. Mentorship emerged as the most important resource required by young innovators, followed by access to technology. Approximately 40% of respondents agreed that digital technologies promote youth engagement in the agrifood system, with artificial intelligence (AI) tools (29.2%) and social media (23.1%) identified as the most influential technologies. Furthermore, 53.8% of respondents reported using digital tools for decision-making, while 33% considered knowledge sharing to be the major benefit of involving youth through digital technologies. Lack of interest was identified as the leading challenge to youth participation in decision-making, accounting for 40% of responses.

Keywords: Agrifood system; Artificial intelligence; Digital agriculture; Digital technologies; Sustained innovation; Youth engagement

Phytoremediation of sodic soils integrated with IoT technology

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ABSTRACT

The present study entitled "Phytoremediation of sodic soils integrated with IoT technology" poses a severe threat to agricultural productivity and environmental sustainability, particularly in rural farming regions. Sodic soils are characterized by high exchangeable sodium percentages, which damage soil structure, restrict water infiltration, and inhibit plant growth. Traditional chemical reclamation methods are often expensive and ecologically disruptive. To address this challenge, this study proposes an eco-friendly and economically viable approach by combining biological phytoremediation with modern Internet of Things (IoT) technology for smart soil health management. The system utilizes specific salt-tolerant halophytic plants to naturally extract, accumulate, and remove excess sodium ions from the degraded soil matrix. Concurrently, an advanced IoT-based sensory framework is deployed in the field to monitor the dynamic process of soil reclamation in real time. Low-cost sensors continuously measure critical soil parameters, including electrical conductivity (EC), pH levels, moisture content, and ambient temperature. This environmental data is transmitted wirelessly to a cloud-based dashboard, enabling automated data logging and precise mapping of soil recovery trends without the need for frequent, destructive manual soil sampling. Experimental evaluations indicated that integrating IoT monitoring with phytoremediation significantly enhances the management efficiency of soil reclamation. The continuous stream of real-time data allowed for optimized irrigation scheduling, which accelerated the leaching of displaced sodium ions and reduced the overall remediation timeline by 25%. Furthermore, the system successfully restored soil structure and improved organic matter content, gradually returning the land to an arable state suitable for standard crop cultivation. In conclusion, this integrated framework offers a scalable, sustainable, and high-tech solution for restoring degraded lands. By merging environmental biotechnology with smart agriculture, this model provides rural farming communities with a practical, cost-effective tool to reclaim sodic soils, thereby ensuring long-term food security and sustainable land management.

Keywords: Environmental biotechnology; Internet of Things; Phytoremediation; Smart agriculture; Sodic soils; Soil health management

Harnessing green nanotechnology for water chestnut production and enhanced crop performance

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ABSTRACT

Water chestnut serves as an essential aquatic vegetable which produces edible fruits that provide nutritional benefits to people who follow its traditional agricultural practices. Modern agriculture needs sustainable methods which boost crop yield and crop quality because farmers face changing environmental conditions in their farming operations. Nanotechnology through green nanoparticle synthesis presents an innovative method which scientists use to develop sustainable agricultural solutions for crop cultivation. The current research investigates the environmentally friendly production of nanoparticles. The produced nanoparticles through a plant-based biological method which functions as an alternative to traditional chemical manufacturing processes. The research will measure essential development metrics together with plant functions and production values to evaluate how water chestnut plants respond to nanoparticle treatment. The research will reveal how green nanotechnology methods affect crop yield while teaching farmers better sustainable farming practices. The research findings will support nanotechnology development for aquatic vegetable farming because they demonstrate how modern technology systems collaborate with established agricultural practices which include water chestnut cultivation.s

Keywords: Crop yield; Emerging technologies; Green nanotechnology; Nanoparticles; Sustainable agriculture; Water chestnut

Digital roots, intelligent shoots: machine learning for predictive optimization of plant tissue culture

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ABSTRACT

Plant tissue culture rests on a large body of practical knowledge built up over decades of laboratory work. Much of this knowledge is empirical: protocols are refined through repeated trials, and the experience that guides choices of explant, basal medium, plant growth regulator combinations and incubation conditions is often held by individual practitioners rather than captured in a form that can be systematically reused. Because culture responses arise from nonlinear interactions among these factors, conventional trial-and-error or one-factor-at-a-time optimization is slow, consumes reagents and plant material, and leaves much of the factor space unexplored. This study proposes a machine learning framework that turns accumulated culture records into a predictive tool for protocol optimization. The work aims to (i) compile experimental data into a structured dataset linking culture conditions to measurable responses such as shoot induction, shoot multiplication and rooting; (ii) develop and compare machine learning models able to capture nonlinear relationships among these variables; and (iii) use the trained models to identify culture conditions predicted to give favorable responses, for subsequent experimental verification. Model performance will be evaluated on data withheld from training, and the contribution of individual culture factors will be examined so that predictions remain interpretable and consistent with established tissue culture understanding. The framework is expected to reduce the number of treatments requiring bench screening, shorten protocol development, and make practitioners' empirical knowledge explicit, testable and transferable. In this way, the study connects a long-standing experimental tradition with digital tools, preserving the value of existing practice while making it more systematic. The approach may be especially useful for medicinal, economically important and conservation-priority species that are difficult to propagate.

Keywords: Digital agriculture; In vitro regeneration; Machine learning; Micropropagation; Plant tissue culture; Predictive modelling

Roots to Routers: reviving traditional agricultural wisdom through digital and emerging technologies

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ABSTRACT

India has a rich tradition of agricultural knowledge developed by farmers through generations of experience, observation, and the use of locally available resources. Traditional practices related to soil management, seed selection, crop protection, water conservation, and natural farming have contributed to sustainable agricultural production. However, rapid changes in farming systems, climate conditions, and lifestyles are creating a need to preserve this valuable knowledge and make it useful for future generations. Digital and emerging technologies can provide an effective bridge between traditional wisdom and modern agriculture. This paper explores an integrated approach for documenting, preserving, sharing, and improving traditional agricultural knowledge through technologies such as Artificial Intelligence (AI), Internet of Things (IoT), sensors, mobile applications, digital databases, remote sensing, and smart farming systems. Digital platforms can help record farmers' experiences and local practices in an organized form, while AI and data-driven tools can support the analysis and application of this knowledge in changing agricultural conditions. IoT-based sensors can provide real-time information about soil moisture, temperature, humidity, and crop conditions, supporting more precise and efficient farm management. Biotechnology can further contribute by scientifically studying traditional bio-inputs, beneficial microorganisms, plant-based preparations, and other sustainable agricultural practices. The integration of traditional knowledge with emerging technologies can also create opportunities for youth participation, digital learning, innovation, and rural entrepreneurship. Rather than replacing traditional wisdom, technology can help preserve it, improve its accessibility, and connect it with scientific knowledge. The proposed approach, therefore, aims to develop a stronger relationship between farmers' traditional experience, biotechnology, and digital innovation. Such a TradiTech-based agricultural system can support sustainable resource use, climate resilience, knowledge preservation, and the development of a more innovative and self-reliant Indian agricultural sector.

Keywords: Artificial intelligence; Biotechnology; Digital agriculture; Internet of Things; TradiTech; Traditional agricultural knowledge

From indigenous practice to Traditech: a preliminary investigation of household litchi storage without added chemical preservatives

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ABSTRACT

Litchi (Litchi chinensis) is a highly perishable fruit with a short post-harvest life, creating challenges for household-level storage and small-scale producers. Traditional post-harvest practices may provide locally adapted approaches for extending the storage period of perishable fruits; however, many such practices remain insufficiently documented and scientifically evaluated. The present study documents and preliminarily examines a traditional household storage practice for litchi in the absence of added chemical preservatives. Freshly harvested litchi fruits were tied or bundled and suspended from bamboo supports in a naturally ventilated household kitchen, particularly in the vicinity of a chimney. The fruits were stored using this practice from the last week of May 2026 until approximately July 2026. During storage, observable changes in peel colour, texture, moisture status and flavour were noted. Following removal from the chimney-associated storage environment and subsequent storage under ordinary household conditions, visible fungal growth was observed within approximately two weeks. The observation represents a preliminary, first-year household study rather than a controlled preservation experiment. No replicated treatments, laboratory-based microbial identification, physicochemical analysis or nutritional assessment were conducted during the study period. Therefore, the observations do not establish the efficacy or mechanism of the practice but provide a basis for further scientific investigation. The study highlights the research value of documenting indigenous post-harvest practices and provides a basis for future controlled experiments to evaluate storage conditions, physicochemical changes, microbial dynamics, quality retention and the possible applicability of the practice as a low-cost household storage approach.

Keywords: Fungal deterioration; Household storage; Indigenous knowledge; Litchi chinensis; post-harvest storage; Traditional preservation

Optimizing system productivity, profitability and soil health of rice-based system through integrated nutrient management under conservation agriculture

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ABSTRACT

Conservation agriculture (CA) offers an important pathway to enhance resource-use efficiency, soil health, productivity, and profitability in intensive cropping systems through reduced soil disturbance, residue retention, and integrated nutrient management. A field experiment was conducted during the Kharif, Rabi and Summer seasons of 2024–25 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The study aimed to evaluate the performance of diversified cropping systems and integrated nutrient management (INM) practices under conservation agriculture, with particular emphasis on crop productivity, soil health and economic sustainability. The experiment was laid out in a split-plot design comprising two cropping systems, viz. rice–wheat–greengram (CS1) and rice–mustard–greengram (CS2), and six INM treatments involving different combinations of 50 or 75% of the recommended dose of nutrients (RDN), crop residue retention and 0–2 applications of Kunapajala under zero-tillage conditions. Results showed that the rice–wheat–greengram system generally produced higher system productivity, rice equivalent yield (REY), and economic returns than the rice–mustard–greengram system. CS1 recorded the highest system REY (10,761.66 kg ha^{-1}), compared with 9,809.70 kg ha^{-1} under CS2. Among nutrient management treatments, NM6 (75% RDN + two applications of Kunapajala + residue retention) consistently enhanced crop growth, yield attributes, and productivity of rice, wheat, and greengram. NM6 recorded the highest system REY of 11,421.12 kg ha^{-1}, system productivity of 35.96 kg ha^{-1} day^{-1} and system profitability of ₹425.55 ha^{-1} day^{-1}. The combined treatment CS1NM6 recorded the highest gross return (₹2,73,130.4 ha^{-1}), net return (₹1,46,379.8 ha^{-1}) and B:C ratio (1.15). Soil fertility indicators also responded positively to integrated nutrient management, with NM6 maintaining comparatively higher available nitrogen and phosphorus and improving soil organic carbon, whereas the rice–mustard–greengram system showed relatively greater conservation of available N, P and K. Overall, the findings demonstrate that integrating partial substitution of inorganic fertilizers with Kunapajala and crop residue retention under zero-tillage can improve crop productivity, soil fertility and economic returns. The rice–wheat–greengram cropping system combined with 75% RDN, two applications of Kunapajala and residue retention emerged as a promising management strategy for enhancing the productivity, profitability and sustainability of diversified cropping systems under conservation agriculture.

Keywords: Conservation agriculture; Cropping system; Integrated nutrient management; Kunapajala; Soil health; System productivity

From Roots to Routers: integrating traditional forestry knowledge with digital technologies for sustainable forest management in India

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ABSTRACT

Forests are vital components of India's ecological and socio-economic systems, supporting biodiversity, climate regulation, soil and water conservation, forest-based resources and the livelihoods of millions of people. However, increasing pressure on forest resources, climate variability, land-use changes and the growing demand for sustainable resource management highlight the need for innovative approaches that connect traditional ecological knowledge with emerging technologies. In this context, integrating traditional forestry wisdom with digital technologies can provide an inclusive and efficient pathway towards sustainable forest management. Traditional communities possess valuable knowledge related to indigenous tree species, natural regeneration, seed collection, agroforestry, soil and water conservation, sustainable harvesting of non-timber forest products and seasonal resource management. Much of this knowledge is preserved through intergenerational transmission and remains insufficiently documented in systematic and accessible formats. Digital technologies offer opportunities to document, spatially map, preserve and disseminate such knowledge while retaining community participation and local relevance. Technologies including Geographic Information Systems (GIS), remote sensing, GPS-based field mapping, mobile applications, drones, digital databases and artificial intelligence can strengthen forest resource assessment, monitoring and decision-making. These tools can support forest-cover assessment, plantation planning, identification of degraded areas, vegetation monitoring and documentation of community-based forestry practices. Digital knowledge repositories can further connect traditional practices with students, researchers, forest managers and local communities. The integration of traditional knowledge and technology can also contribute to agroforestry, farm forestry, urban forestry, degraded-land restoration and sustainable utilization of forest resources. Importantly, technology should complement rather than replace traditional knowledge, with participatory approaches ensuring that communities remain active contributors to planning, monitoring and decision-making. This paper proposes a "Roots to Routers" framework for connecting traditional forestry wisdom with digital innovation to strengthen sustainable forest management, support climate-resilient landscapes, enhance community participation and create opportunities for India's youth in the forestry sector.

Keywords: Agroforestry; Artificial intelligence; Digital forestry; Geographic information systems; Remote sensing; Traditional knowledge

Synchronizing heritage and harvest: transforming traditional ecological knowledge through SMS and app platforms

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ABSTRACT

For centuries, indigenous agricultural communities have synchronized their planting, harvesting, and pest management with lunar cycles, localized weather lore, and astrological almanacs. This deeply rooted traditional ecological knowledge is increasingly vulnerable to both generational attrition and the unpredictable seasonal shifts driven by climate change. This paper outlines a digital framework to bridge ancestral agronomy and modern technology by transforming indigenous crop calendars into accessible mobile applications and low-bandwidth SMS services. The core of this initiative involves translating qualitative, observation-based farming traditions into quantitative, real-time agricultural advisories. By cross-referencing traditional lunar and astrological timelines with modern, localized meteorological data, the proposed digital platforms generate actionable daily and weekly schedules tailored to specific micro-climates and native crop varieties. This dual-knowledge approach serves a vital twofold purpose. First, it actively archives fading cultural heritage in a functional, living format rather than a static museum context, making the wisdom accessible and engaging for younger generations. Second, it provides smallholder farmers with adaptive, culturally resonant tools to improve crop resilience, optimize resource use, and secure better yields. Ultimately, this integration demonstrates that traditional agricultural wisdom and emerging digital innovations are not mutually exclusive, but complementary forces capable of driving sustainable, community-led farming in the 21st century.

Keywords: Climate-resilient farming; Digital agriculture; Indigenous crop calendars; Lunar almanacs; Mobile extension services; Traditional ecological knowledge

Eco Krishi: accessible mobile platform for natural farming

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ABSTRACT

The transition from chemical-intensive practices to sustainable, natural farming is critical for environmental preservation and public health. However, smallholder farmers and beginners frequently face barriers such as low digital literacy, complex user authentication, language obstacles, and fragmented market linkages. This paper presents the design and implementation of an integrated, multilingual mobile application tailored to simplify natural farming education. To enhance accessibility for rural growers, the application replaces conventional password-based credentials with a secure, lightweight facial recognition login system. The platform bridges educational gaps by offering structured, beginner-oriented digital tips and tricks which are used directly by experienced farmers, seasonal agronomic tips, and bio-input preparation guides. It features a built-in multilingual interface supporting Gujarati, Hindi, and English, ensuring users can interact with instructional content in their regional vernacular. Furthermore, the application incorporates a dedicated e-commerce marketplace that serves a dual purpose: enabling farmers to procure authentic, chemical-free inputs—such as indigenous non-hybrid seeds, bio-fertilizers, and organic pest repellents—while allowing them to sell naturally harvested vegetables directly to consumers without intermediary exploitation. By combining biometric security, regional linguistic localization, practical learning, and direct market access into a unified mobile environment, this project demonstrates a feasible socio-technical solution. It empowers rural agrarian communities, fosters sustainable farming practices, and facilitates transparent farm-to-fork supply chains.

Keywords: E-commerce marketplace; Facial recognition authentication; Farmer education; Mobile application; Multilingual interface; Natural farming

Role of artificial intelligence in modern agriculture

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ABSTRACT

Artificial Intelligence (AI) is emerging as an important technology for transforming modern agriculture towards higher productivity, resource-use efficiency and sustainability. AI-based tools can support farmers in crop monitoring, disease and pest detection, yield prediction, precision irrigation, weather-based decision making and efficient use of agricultural inputs. Integration of AI with remote sensing, drones, sensors, Internet of Things (IoT) and machine learning can provide timely and location-specific information for better farm management. These technologies have the potential to reduce input losses, improve crop health monitoring, enhance decision-making and increase the efficiency of agricultural operations. However, challenges such as limited digital literacy, high initial cost, inadequate rural connectivity, data availability and the need for location-specific solutions may restrict their adoption, particularly among small and marginal farmers. Capacity building, affordable digital services, reliable rural infrastructure and farmer-oriented extension support are therefore essential for effective adoption of AI in agriculture. The present abstract highlights the role and potential applications of Artificial Intelligence in modern agriculture with emphasis on smart and sustainable agricultural development.

Keywords: Artificial intelligence; Crop monitoring; Machine learning; Precision agriculture; Smart agriculture; Sustainability

Soil to smartphone: digital traceability in natural farming

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ABSTRACT

Natural farming is becoming very important approach because it focusses on the soil health, food security and ecological balance. it focusses on reducing external inputs and maintain soil health. However, one major challenge in promoting natural farming is how crop is produced. Consumer often do not have enough information about the farm practices followed in farm to produce product before it reaches to the market. Digital traceability helps to solve this problem by creating connection between farm and consumer. Digital traceability includes farm location, crop grown, sawing date, harvesting date, natural farming practices followed in farm, farm inputs, and other post-harvest handling details. This information can be recorded using mobile applications or digital farmer databases. Technologies such as GPS, QR codes and blockchain can also be used to store and share this information. For example, a QR code on the product can be scanned using a smartphone, allowing consumers to see information about where and how the crop was produced. Such a system can make the natural farming supply chain more transparent and can help to build up consumer confidence. It can also help farmers and various organization keep proper records of farming practices and give better recognition to naturally produced products in the market. In the future, digital traceability can help convert farming practices at the field level into simple and accessible information for consumers. Therefore, combining digital technology with natural farming can create a clear link from soil to smartphone, it connecting the farmer, the product and the consumer.

Keywords: Blockchain; Consumer trust; Digital traceability; Farm-to-market; Natural farming; QR code

The economics of preservation: integrating traditional seed stewardship with modern digital commerce

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ABSTRACT

E-Commerce for Heritage Seeds: Building accessible online digital seed banks that connect rural farmers to global buyers, helping preserve and monetize native, drought-resistant seed varieties. The rapid homogenization of global agriculture threatens the survival of indigenous, climate-resilient crop varieties. Rural farmers, the traditional custodians of these heritage seeds, often lack the market access and financial incentives necessary to sustain their cultivation. This paper explores the development of specialized e-commerce platforms that function as digital seed banks, creating a direct conduit between rural agricultural communities and a global network of conservationists, researchers, and sustainable cultivators. By leveraging digital supply chain logistics and secure online marketplaces, these platforms enable the monetization of native, drought-resistant seed varieties. This technological intervention transforms ecological preservation into a viable, community-driven economic model, actively incentivizing farmers to maintain ancestral biodiversity rather than shifting entirely to commercial hybrids. Ultimately, integrating traditional seed stewardship with modern digital commerce not only safeguards vital agricultural genetics but also empowers smallholder farmers and strengthens global food system resilience against climate change.

Keywords: Agricultural e-commerce; Agrobiodiversity; Climate-resilient agriculture; Digital seed banks; Digital supply chains; Heritage seeds

Roots to Routers: reviving traditional wisdom through digital and emerging technologies for sustainable agricultural extension

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ABSTRACT

Agriculture in India is deeply rooted in traditional knowledge, indigenous practices and locally evolved wisdom developed through generations of farmers. Such knowledge encompasses crop management, soil and water conservation, seed preservation, livestock care, biodiversity management and climate adaptation. However, rapid technological transformation, changing climatic conditions and socio-economic transitions are creating a need to systematically document, validate and integrate traditional wisdom with modern digital and emerging technologies. The present paper explores the potential of combining indigenous agricultural knowledge with digital tools to create a more inclusive, farmer-centric and sustainable agricultural extension system. Technologies such as artificial intelligence, mobile applications, GIS, remote sensing, Internet of Things (IoT), drones, digital knowledge repositories, community radio and multilingual advisory platforms can facilitate the documentation, validation, dissemination and wider adoption of locally relevant agricultural practices. Digital platforms can also connect farmers with agricultural experts, researchers, extension personnel and fellow farmers, thereby strengthening horizontal as well as vertical knowledge exchange. Particular emphasis is placed on participatory approaches in which farmers are recognized as knowledge holders and co-creators rather than merely recipients of technology. Integrating traditional knowledge with scientific validation can enhance climate resilience, resource-use efficiency, biodiversity conservation and sustainability of farming systems. At the same time, issues related to the digital divide, data privacy, intellectual property rights, accessibility and reliability of digitally transmitted indigenous knowledge require careful consideration. The paper proposes a "Roots-to-Routers" extension framework, linking indigenous knowledge, scientific validation, digital documentation and technology-enabled advisory services. Such integration can contribute to a resilient, inclusive and knowledge-driven agricultural ecosystem while preserving India's rich agricultural heritage for future generations.

Keywords: Agricultural extension; Artificial intelligence; Climate resilience; Digital agriculture; Sustainable agriculture; Traditional knowledge

Awareness and utilization of mobile-based advisory services among farmers in Kushinagar district of Uttar Pradesh

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ABSTRACT

Information and communication technologies (ICTs) are emerging as an important tool for the transmit or receive information electronically mobile-based advisory services into vital tools for bridging knowledge gaps among smallholder farmers. However, the operational effectiveness of these digital channels heavily depends on local adoption dynamics and ground-level awareness. The study was conducted in Kushinagar district of Uttar Pradesh, a sample size of 140 farmers was randomly selected from the four blocks to study of Awareness and Utilization of Mobile-Based Advisory Services. The data were collected through personal interview. The responses were measured on a five-point continuum scale ranging from strongly agree to strongly disagree, with scores of 5, 4, 3, 2, and 1, respectively. The collected data were systematically tabulated and analyzed using descriptive statistics statistical tool. The findings revealed that farmers generally showed a high level of awareness (81.56%) of mobile based advisory services, however, actual utilization for crucial decision-making remained moderate (54.41%), mainly on weather updates, market prices and pest or disease management. Information can be easily transferable and is context independent, while knowledge is a process of contextualizing information through awareness so that it becomes situation specific. Bridging this bridge requires extension agencies and ICT providers to deliver localized, crop-specific advisory content alongside digital literacy workshops, ensuring sustainable technology adoption and improved farm livelihoods.

Keywords: Agricultural extension; Digital literacy; Farmer awareness; ICT; Mobile-based advisory; Utilization

Application of hyperspectral imaging technologies coupled with machine learning and deep learning techniques for quality evaluation of fruits and vegetables: a review

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ABSTRACT

Fruits and vegetables are highly perishable commodities whose quality attributes such as freshness, presence of surface or internal defects, and ripeness stage directly influence consumer acceptance, marketability, and post-harvest losses. Conventional quality assessment methods remain largely destructive, labour-intensive, and subjective, driving growing interest in rapid, non-destructive, and objective evaluation tools. Hyperspectral imaging (HSI), which integrates spectroscopy and imaging to capture both spectral and spatial information, has emerged as one of the most promising techniques for non-destructive food quality analysis. This review synthesizes recent research employing HSI systems operating in the visible and near-infrared (VIS-NIR, 400–1000 nm) range for evaluating freshness, defects, and ripeness in fruits and vegetables. Reported workflows typically involve hypercube acquisition, pre-processing, and region-of-interest and feature extraction, followed by predictive modelling. Studies applying conventional machine learning algorithms i.e. Partial Least Squares Discriminant Analysis, Support Vector Machine, Random Forest, and k-Nearest Neighbours on selected wavelengths are reviewed alongside more recent work adopting deep learning architectures such as Convolutional Neural Networks and hybrid spectral-spatial CNN models, which exploit joint spectral-spatial information with reduced manual feature engineering. Across the literature reviewed, deep learning approaches are consistently reported to outperform conventional machine learning methods in classification and prediction accuracy for freshness discrimination, defect detection, and ripeness estimation. This review highlights key trends, methodological challenges, and existing research gaps, and underscores the potential of VIS-NIR hyperspectral imaging combined with deep learning as a robust framework for real-time, in-line quality evaluation of fruits and vegetables in food processing and post-harvest management.

Keywords: Deep learning; Fruits and vegetables; Hyperspectral imaging; Machine learning; non-destructive quality evaluation; VIS-NIR spectroscopy

AI/ML-based pest and disease detection using image processing: a TradiTech approach to precision plant protection

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ABSTRACT

Detecting crop pests and diseases on time is a major challenge in Indian farming. Checking fields by hand is slow and depends on having a trained expert nearby, which is often not possible. Because of this delay, farmers can lose 10–30% of their crop every year, hitting small farmers the hardest. This study builds a simple AI-based tool that uses photos of leaves to spot diseases and pests early. The goal is not to replace what farmers already know, but to support it with easy-to-use technology — matching the "TradiTech" idea of combining old farming wisdom with new tools. The tool works in simple steps: a photo of the leaf is taken on a phone or camera, the image is cleaned up (resized and made clearer), a computer model (CNN) looks for patterns in the image, and then it tells whether the leaf is healthy or has a disease, along with how serious it is. To build and test this model, we use the PlantVillage image collection along with photos taken directly from fields, so it works well in real conditions too. Early results show the model can correctly identify diseases about 91–96% of the time, depending on which version of the model is used. It is also built to run on ordinary smartphones, even without internet access, so it can be used easily by farmers with limited resources. Later, this can be connected with local agriculture support workers to give even faster help to farmers. Overall, this shows that a simple photo-based AI tool can help farmers catch plant problems early, at low cost. In the future, this can be improved further with a real-time phone app, drone cameras for scanning whole fields, and support for multiple languages and voice commands, so more farmers across India can use it easily.

Keywords: Deep learning; Image processing; Plant disease detection; Precision agriculture; Smart farming; TradiTech

Application of UAV-based multispectral remote sensing for early stress detection and crop performance assessment

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ABSTRACT

The present research had the objective to assess the capability of UAV-based multispectral remote sensing for monitoring crop phenology and detecting field-level stress in wheat under various nutrient management conditions. Multispectral imagery was collected at various agricultural growth stages using a MicaSense RedEdge-MX sensor and NDVI, GNDVI and NDRE were derived from the acquired imagery. The vegetation indices were evaluated in relation to ground-truth parameters representing crop water status, physiological condition, chlorophyll status and grain productivity. Temporal variations showed an increase in vegetation indices values from early vegetative growth to flowering and early grain filling stage followed by a declined towards physiological maturity. The vegetation indices effectively differentiated crop responses across nutrient management regimes, reflecting variations in crop vigour and physiological condition. Correlation analysis demonstrated strong relationships between vegetation indices with ground observations where NDVI closely related to soil water content and chlorophyll status, NDRE to relative leaf water content and GNDVI to grain yield. Regression analysis revealed that early-vegetative stage NDVI showed the strongest relationship with final-grain yield indicating its potential for early stress detection and yield prediction. Furthermore, KNN-based classification differentiated the field into distinct crop performance zones with significant differences in yield among the identified classes demonstrating its capability for spatial characterization of crop variability. Overall, UAV-based multispectral remote sensing demonstrated its potential for non-destructive monitoring of wheat phenology, early stress detection, field variability assessment and grain productivity estimation.

Keywords: Early stress detection; Multispectral remote sensing; NDVI; UAV; Wheat; Yield prediction

Agricultural drone technology in India

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ABSTRACT

Agricultural drone technology is revolutionizing modern farming in India by offering smart, efficient, and sustainable alternatives to traditional practices. Drones enable real-time crop health monitoring, precision spraying of pesticides and fertilizers, and yield assessment, significantly reducing input costs while improving operational safety and efficiency. However, regional variations in cropping patterns such as cereal dominance in the Northern Plains, intensive horticulture in the Southern States, and specialized terrain farming in the Hilly & Eastern Regions—require localized adoption strategies. To accelerate deployment, the Government of India provides substantial central financial assistance through dedicated funding schemes. Financial subsidies range from 40% for individual general category farmers up to 100% for ICAR, KVKs, and agricultural universities, alongside targeted support for Women Self Help Groups (Namo Drone Didi), FPOs, and Agri-Graduates. These initiatives are integrated with broader national frameworks including the Sub-Mission on Agricultural Mechanization (SMAM), Drone Shakti Scheme, PM-KISAN, and Startup India. Commercial deployment is supported through scalable business models such as Custom Hiring Centres (CHCs) offering Drone-as-a-Service (DaaS) and B2B partnerships. Adherence to regulatory guidelines set by the Director General of Civil Aviation (DGCA) including mandatory Remote Pilot Certificates, Type-Certified drones, Unique Identification Numbers (UIN), and airspace permits remain critical for lawful operations. Despite substantial benefits, broad adoption faces challenges such as high initial costs, limited battery life, weather dependencies, privacy concerns, and the need for skilled operators. Strategic policies, coupled with robust infrastructure and capacity building, are essential to overcoming these barriers and establishing sustainable, tech-driven agriculture across India.

Keywords: Agricultural drones; Central subsidies; DGCA compliance; Precision farming; Regional applications; Sustainable agriculture

Digital agriculture for climate-resilient carbon farming: enabling technologies, verification frameworks, and the human capital imperative for agricultural education

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ABSTRACT

Agriculture is both a significant source of greenhouse gas emissions and a major opportunity for climate mitigation through soil carbon sequestration: global agrifood systems emitted 16.5 Gt CO_2-eq in 2023, roughly 32% of total anthropogenic emissions. Carbon farming practices such as conservation tillage, cover cropping, agroforestry, diversified cropping systems, and improved nutrient and water management can enhance soil organic carbon while strengthening resilience to climate variability. However, large-scale adoption remains constrained by the cost, uncertainty, and limited credibility of measuring, reporting, and verifying (MRV) carbon outcomes. This paper examines how digital agriculture can address these constraints. Enabling technologies, including satellite remote sensing, Internet of Things (IoT) sensor networks, unmanned aerial vehicles, proximal soil spectroscopy, machine learning, and process-based crop and soil simulation models, are reviewed for their role in quantifying soil carbon, monitoring management practices, and generating site-specific advisories. Verification frameworks are then discussed, including hybrid measurement-and-modelling approaches, digital MRV platforms, and blockchain-enabled traceability, along with the issues of additionality, permanence, leakage, and data transparency that determine the integrity of carbon credits. The environmental footprint of digital infrastructure itself is also considered: the International Energy Agency projects global data-centre electricity consumption to rise from 415 TWh in 2024 to 945 TWh by 2030, which underlines the need for right-sized, low-power solutions and net-benefit assessment. In India, a framework for a voluntary agricultural carbon market was introduced in January 2024, and the Digital Agriculture Mission (₹2,817 crore) targets digital identities for 11 crore farmers by 2026–27; yet 86.1% of farmers are small and marginal so inclusion depends on capacity as much as on infrastructure. A central argument is that technology alone cannot deliver credible carbon farming; the binding constraint is human capital. Extension professionals, students, and farmers require competencies in data literacy, geospatial tools, carbon accounting, and digital ethics. The paper proposes integrating digital agriculture and carbon-farming modules into agricultural curricula, strengthening experiential and farmer-participatory learning, and building institutional partnerships for continuous skill development. Aligning technology, verification, and education can make carbon farming scalable, inclusive, and climate-resilient, particularly for smallholder systems in developing regions.

Keywords: Agricultural education; Carbon farming; Digital agriculture; Digital MRV; Remote sensing; Soil organic carbon

Aloe vera–pahadi haldi coating as a Tradi-Tech post-harvest solution for extending shelf life of hill-grown apples (Gala and Red Delicious)

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ABSTRACT

Post-harvest losses remain a persistent challenge for apple growers in the hill regions of Uttarakhand, reducing farmer income and market value. Framed under the theme of Tradi-Tech Led Transformation, this study investigates a low-cost, indigenous-knowledge-based coating solution — a blend of aloe vera gel and organic pahadi haldi (turmeric) powder — as a natural post-harvest treatment for two commercially important apple varieties, Gala and Red Delicious. Fruits were treated with the aloe vera–haldi solution at three concentrations, 5% (T1), 2.5% (T2), and 100% (T3), and compared against an untreated control (T4), using a completely randomized design with four replications, followed by cold storage at –23°C. Key physico-chemical parameters evaluated across successive storage readings included fruit weight, length, diameter, volume, firmness, shape index, seed number, physiological loss in weight (PLW%), fruit circumference, specific gravity, total soluble solids (TSS), moisture content, and colour. Preliminary observations indicate that treated fruits exhibited markedly lower physiological loss in weight compared to the untreated control by the final storage reading, with the 5% concentration (T1) showing the least weight loss (0.11%) against 1.58% in the control, suggesting improved moisture retention. Firmness and TSS values remained broadly comparable across treatments, indicating that the coating's primary benefit lies in reducing weight loss rather than delaying ripening. These findings suggest that the aloe vera–pahadi haldi coating, rooted in traditional hill farming practice, can serve as an accessible, chemical-free alternative for improving apple shelf life, offering a practical way to align indigenous knowledge with modern post-harvest technology for the benefit of small and marginal hill farmers.

Keywords: Aloe vera; Apple; Pahadi haldi; Post-harvest; Shelf life; Tradi-Tech

Bridging Roots and Routers: reviving indigenous agricultural wisdom through digital and emerging technologies for a resilient Bharat

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ABSTRACT

India has a long history of traditional agriculture knowledge, such as traditional seed conservation, intercropping and mixed cropping, organic nutrient management, water harvesting, and botanical pest management and climate-friendly farming practices. But, with the fast pace of technology change and evolving agricultural hopes, there is a widening split between what has been learned and traditional agriculture systems. In this paper, the journey of how digital and emerging technologies can help address this gap is documented, validated, preserved and disseminated, so as to create a resilient Bharat using indigenous agriculture. The study is conducted using secondary data analysis and conceptual analysis with data sources from published reports, agricultural statistics, indigenous practices and literary works regarding digital agriculture. There is a total of more than 140 million operational holdings in India; the small and marginal farmers represent about 86% of the operational holdings, which makes locally adapted, low cost and knowledge intensive technologies critical. Indigenous practices can be scientifically validated and disseminated at the local level using digital platforms, mobile applications, artificial intelligence, remote sensing, Internet of Things (IoT), drones and geospatial technologies. AI tools like advisory systems can combine farmer experience, like soil, weather, pest, and crop observations, with scientific data to provide farmer-specific advice. Digital documentation is also a way of retaining lost knowledge and sharing knowledge amongst farmers, researchers, and extension agencies. The paper suggests a Roots–Digital–Resilience framework, wherein indigenous knowledge serves as the roots, the digital technologies are the links, and the outcomes are climate resilience, resource-use efficiency and sustainable livelihoods. Therefore, blending traditional knowledge with the new technologies can help to make indigenous knowledge a digitized, and scientifically robust, source for sustainable agricultural development and Viksit Bharat at 2047.

Keywords: Artificial intelligence; Climate resilience; Digital agriculture; Indigenous knowledge; Sustainable agriculture; Viksit Bharat@2047

Sensor-driven precision agriculture: optimizing crop management, soil health and resource efficiency

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ABSTRACT

Global agriculture must substantially increase productivity to meet the food demand of a growing population while improving resource-use efficiency and maintaining soil health. Precision agriculture provides a data-driven alternative to conventional uniform field management through a "Sense–Analyze–Act" framework, enabling site-specific and timely crop and nutrient management. The present study, undertaken as part of an ISRO-NRSC collaborative project, evaluated an integrated sensor-based approach for differentiating organic and conventional crop production systems and assessing their effects on crop growth and soil nutrient dynamics. A field experiment was conducted with maize (Zea mays L.), variety LQMH-1, using 18 grid-based monitoring points. The organic treatment received farmyard manure, vermicompost, and poultry manure, whereas the conventional treatment received recommended NPK fertilizers. Direct soil sensors, crop-canopy reflectance measurements, and wireless sensor networks were integrated to monitor plant height, leaf area index (LAI), chlorophyll status, and available soil N, P, and K at critical growth stages, including tasseling, silking, milking, and harvest. The results indicated that conventional management produced relatively higher plant height and LAI during the early growth stages, whereas the organic system showed better maintenance and retention of available soil nutrients throughout the crop season. Continuous monitoring revealed that available N, P, and K in organic plots generally increased or remained relatively stable up to harvest, while conventional plots exhibited a marked decline in nutrient availability after silking. These observations highlight the advantage of continuous sensor-assisted monitoring for understanding temporal nutrient dynamics and improving input management. Integration of multi-sensor observations with Variable Rate Technology (VRT) offers a pathway for converting real-time field information into site-specific management decisions and incorporating harvest information into subsequent crop planning. The study demonstrates the potential of sensor-driven precision agriculture to operationalize the 5R principles—right source, right rate, right time, right place, and right manner—for improving resource-use efficiency, sustaining soil health, and promoting climate-resilient and sustainable agricultural production.

Keywords: 5R principles; Maize; Precision agriculture; Sensor-based monitoring; Soil nutrient dynamics; Variable rate technology

Harnessing indirect plant defence: HIPV-mediated tritrophic interactions for sustainable pest management

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ABSTRACT

Plants possess sophisticated defence systems that integrate molecular perception, chemical signalling and ecological interactions to withstand herbivore attack. Indirect plant defence represents a crucial component of this system, whereby herbivore-induced plant volatiles (HIPVs) mediate chemically driven interactions between plants and the natural enemies of herbivores, particularly predators and parasitoids. This chemically mediated communication forms an important basis of tritrophic interactions, linking plants, herbivores and natural enemies and enabling plants to indirectly influence herbivore pressure. Herbivore-associated signals and tissue damage activate interconnected defence signalling pathways involving jasmonic acid (JA), salicylic acid (SA) and ethylene, whose crosstalk regulates the biosynthesis and emission of volatile compounds. These include green leaf volatiles, terpenoids, (E)-β-caryophyllene, DMNT, methyl salicylate and TMTT, which can provide olfactory cues to natural enemies and influence their searching behaviour. Through this chemically mediated communication, plants can recruit predators and parasitoids, strengthening naturally occurring tritrophic interactions. The effectiveness of this defence, however, depends on ecological context and the ability of natural enemies to perceive and respond to plant-derived signals. Harnessing HIPV-mediated signalling therefore offers a promising new dimension of sustainable pest management, where plant defence and biological control can be integrated to enhance natural-enemy activity and suppress herbivores with reduced dependence on conventional insecticides. Thus, understanding plant–herbivore–natural enemy communication can help transform naturally occurring ecological interactions into innovative and environmentally compatible pest-management strategies.

Keywords: Biological control; HIPVs; Indirect plant defence; Natural enemies; Sustainable pest management; Tritrophic interactions

Effect of sewage sludge application on growth, yield, nutrients and toxic metals uptake by mustard [Brassica juncea (L.) Czern. & Cosson]

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ABSTRACT

Recycling sewage sludge on farmland provides a practical outlet for a fast-accumulating urban waste while returning organic matter and plant nutrients to the soil, but the toxic metals it carries make the choice of application rate critical. A pot experiment was carried out in a net house during the rabi season of 2021–2022 on a red soil (Alfisol) to trace how mustard [Brassica juncea (L.) Czern & Cosson] responds to rising sludge doses in terms of growth, yield, seed quality, nutrient acquisition and heavy-metal accumulation, and to gauge the effect on post-harvest soil fertility. Sludge was incorporated at eight rates from 5 to 40 t ha^{-1} on top of the recommended fertilizer dose (120:40:40 kg N: P_2O_5: K_2O ha^{-1}), with a fertilizer-only treatment as control, laid out in a completely randomized design replicated thrice. Growth and yield responded strongly to sludge: seed yield climbed from 7.31 g pot^{-1} under fertilizer alone to 26.86 g pot^{-1} at 25 t ha^{-1}, after which further additions up to 40 t ha^{-1} produced no statistically meaningful gain. Seed oil (peaking near 42%), protein (close to 17%) and the uptake of N, P, K, S, boron and micronutrients all strengthened as the dose increased. The treated soil left after harvest was richer in available nutrients, with organic carbon more than doubling from 0.28 to 0.68%, though its pH eased downward. Working against these benefits, the seed, stover and soil burdens of cadmium, chromium, nickel and lead mounted steadily with every increment of sludge and were heaviest at 40 t ha^{-1}. Because grain yield levelled off from 25 t ha^{-1} onward while metal loading kept climbing, sludge at 25 t ha^{-1} with the recommended fertilizer dose gave the best compromise full attainable yield at the lowest metal cost and is proposed as the optimum rate for mustard, subject to routine monitoring of metal build-up under repeated use.

Keywords: Brassica juncea; Heavy metals; Nutrient content; Seed yield; Sewage sludge; Soil fertility

From Traditional Wisdom to Smart Farming: Integrating Indigenous Agricultural Knowledge with AI, IoT and Remote Sensing

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ABSTRACT

Agriculture is not merely about food, it's a relationship between people, nature and a generation of accumulated knowledge. From centuries farmers continuous efforts have developed the practices by observing the soil, crop, nature climate and ecosystem. But as this knowledge risks being lost with changing agricultural systems, a new question emerges: Can the wisdom of our ancestors become the intelligence of the farms of tomorrow? Integrating indigenous agricultural knowledge with Artificial Intelligence, IoT, GIS and remote sensing offers a pathway to preserve traditional wisdom while making it relevant to modern, sustainable and climate-resilient agriculture. At the same time, digital technologies like Artificial Intelligence (AI), the Internet of Things (IoT) and remote sensing are changing how farms are monitored and managed, though their advices often ignore local conditions and farmers' own experience. This paper is a review of existing literature, government reports and documented farmer practices. It explores how traditional wisdom and modern technologies can work together rather than compete. It discusses how farmer knowledge can be recorded and organised in digital databases, how AI models can be trained on both scientific and local knowledge, how IoT sensors can verify the logic behind traditional practices such as soil moisture management and sowing time, and how satellite imagery can support crop monitoring and early warning at the village level. The paper also looks at the main barriers, including low digital literacy, poor internet connectivity, high costs for small and marginal farmers, language barriers and the lack of protection for community knowledge. It suggests that farmer-friendly mobile apps in local languages, community knowledge repositories, training programmes through Krishi Vigyan Kendras and farmer producer organisations, and policy support for knowledge protection can help bridge this gap. The study concludes that combining roots with routers can make farming more resilient, sustainable and profitable while keeping the farmer's own wisdom at the centre.

Keywords: Artificial intelligence, Indigenous knowledge, Internet of Things, Remote sensing, Smart farming, Sustainable agriculture

Managed Pollination and Beekeeping: Two Ways to Increase Crop Yield and Farm Income in the North Eastern Hill Region of India

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ABSTRACT

Many crops in the North Eastern Hill (NEH) region depend on insects, especially bees, for good fruit and seed production. However, pollination is rarely planned as part of farming. Crops such as kiwi, mandarin, orange, passion fruit, litchi, large cardamom, rapeseed-mustard and cucurbits give better yields when bees visit their flowers. The region's native bees, *Apis cerana* and stingless bees, are well suited to hill conditions. Combining beekeeping with crop production through managed pollination focuses on (i) keeping the right number and type of bee colonies for each crop's flowering time, (ii) moving colonies from place to place to follow the flowering seasons, (iii) protecting bees by spraying pesticides at safe times and using eco-friendly management practices, (iv) growing more bee-friendly plants on field borders and in agroforestry, and (v) renting bee colonies to farmers for pollination, with farmer producer organisations (FPOs) linking beekeepers and growers. This approach can improve fruit set, fruit quality and seed yield. It also gives beekeepers extra income apart from honey, wax and propolis. Managed pollination is therefore a low-cost and eco-friendly way to improve hill agriculture and strengthen rural livelihoods in the NEH region.

Keywords: Managed pollination, beekeeping, *Apis cerana*, stingless bees, NEH region

Smart Irrigation, Smart Harvest: Iot Based Water Management for Sustainable Crop Production

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ABSTRACT

Water scarcity, irregular rainfall and inefficient irrigation practices are emerging as major constraints to sustainable agricultural production. Conventional irrigation methods often rely on fixed schedules or farmers' visual assessment of crop water requirements, which can result in over-irrigation, under-irrigation, nutrient leaching and unnecessary energy consumption. Internet of Things (IoT)-based irrigation systems offer an opportunity to address these challenges through real-time monitoring and automated water management. The present study focuses on the application of IoT technology for improving irrigation efficiency and promoting sustainable crop production. The proposed system integrates soil moisture sensors, temperature and relative humidity sensors, a microcontroller, wireless communication and an automated irrigation mechanism to monitor field conditions continuously. Soil moisture data can be transmitted to a cloud-based platform, where predefined moisture thresholds are used to determine irrigation requirements. When soil moisture falls below the optimum level, the system can automatically activate irrigation, while irrigation is stopped when adequate moisture is restored. Such real-time decision-making can minimize unnecessary water application and maintain a favourable soil moisture regime for crop growth. Integration of weather information and crop-specific water requirements can further improve irrigation scheduling and enhance water-use efficiency. The approach also enables farmers to remotely monitor field conditions through mobile or web-based interfaces, reducing labour requirements and improving timely decision-making. IoT-enabled irrigation has considerable potential to conserve water, reduce energy use, improve crop productivity and support climate-resilient agriculture. However, challenges including initial installation costs, sensor calibration, connectivity, technical knowledge and system maintenance need to be addressed for large-scale adoption, particularly among small and marginal farmers. Overall, smart irrigation represents a promising pathway towards precision water management by transforming irrigation from a conventional schedule-based practice into a data-driven, responsive and resource-efficient system.

Keywords: Automated irrigation; Internet of Things; Precision agriculture; Sustainable agriculture; Water management; Water-use efficiency

Rooted in the Field, Reaching for Scale: India's Agritech Revolution

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ABSTRACT

Indian agriculture stands at an inflection point where traditional farming wisdom is converging with entrepreneurial ambition to redefine the sector's future. The emergence of agri-startups spanning precision farming, farm-to-fork supply chains, agri-fintech, biotechnology, and rural service platforms signals a paradigm shift from agriculture as subsistence livelihood to agriculture as a viable, scalable enterprise. This transformation is critical for a nation where over half the workforce depends on farming, yet contributes a disproportionately smaller share to GDP, reflecting deep inefficiencies ripe for innovation-led disruption. This work explores how policy ecosystems such as RKVY-RAFTAAR, the Agriculture Infrastructure Fund, and incubation support from agricultural universities and ICAR institutes are nurturing first-generation agripreneurs from rural and semi-urban backgrounds. It examines key innovation domains IoT-based farm monitoring, drone technology for input application, AI-driven pest and yield prediction, blockchain-enabled traceability, and direct market-linkage platforms — that are dismantling long-standing barriers of information asymmetry, post-harvest losses, and exploitative middlemen networks. Particular attention is given to the role of Farmer Producer Organizations (FPOs) as launchpads for collective entrepreneurship, and to venture capital's growing interest in agritech as a high-impact investment frontier. The narrative also addresses persistent challenges limited rural digital infrastructure, capital access for first-time founders, and the need for stronger industry-academia linkages that must be resolved to sustain this momentum. It concludes that the future of Indian agriculture lies not merely in producing more, but in building resilient, technology-driven enterprises rooted in the field itself where the farmer of today becomes the founder of tomorrow, transforming agriculture into a magnet for innovation, investment, and youth participation.

Transcriptomic Profiling of Wheat Under Phosphorus Deficiency Using RNA-Seq and Computational Genomics

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ABSTRACT

Phosphorus (P) is essential for plant growth, but in many soils very little of phosphorus is available to crops. As a result, yields suffer and farmers lean heavily on chemical fertilizers. To breed wheat (Triticum aestivum) that uses nutrients more efficiently, as a result the plant itself copes when phosphorus runs short. We studied this by comparing the root transcriptomes of hexaploid wheat grown under control and low-phosphorus conditions. The analysis was done as a full RNA-seq pipeline on a High-Performance Computing (HPC) cluster. Paired-end reads were quality-checked and trimmed with Trimmomatic, aligned to the International Wheat Genome Sequencing Consortium (IWGSC) reference genome with STAR and counted per gene with featureCounts. We then tested for differential expression in DESeq2, using cutoffs of $|\log_2 \text{fold change}| \geq 1$ and an adjusted p-value < 0.05. Low phosphorus changed the expression of 314 genes: 218 were upregulated and 96 were downregulated. Gene Ontology (GO) and Kyoto Encyclopedia of Genes and Genomes (KEGG) enrichment showed that how the roots had undergone broad transcriptional reprogramming mainly in genes tied to phosphate transport, phosphorus mobilization and membrane lipid remodeling. PHT1-family phosphate transporters, acid phosphatases and lipidrelated enzymes stood out among them. altogether, these changes suggest that roots step up phosphate uptake and recycling while keeping their cells stable under nutrient limitation.

Keywords: Agricultural biotechnology, Bioinformatics, DESeq2, Low-phosphorus stress, RNA-seq, Transcriptomics, Triticum aestivum

Roots to Routers Reviving Traditional Wisdom through Digital and Emerging Technologies

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ABSTRACT

India has a rich tradition of agricultural knowledge developed through generations of farmers' experience and close interaction with local ecosystems. Traditional practices related to seed selection, soil management, natural inputs, pest management, water conservation, and crop cultivation represent valuable knowledge for sustainable agriculture. However, rapid technological, environmental, and social changes may lead to the loss of this knowledge if it is not properly documented, preserved, and shared. Digital and emerging technologies can provide an effective connection between traditional agricultural wisdom and modern scientific approaches. Technologies such as Artificial Intelligence (AI), Internet of Things (IoT), digital databases, mobile applications, sensors, remote sensing, and smart farming systems can help document traditional practices and make this knowledge accessible to farmers, students, researchers, and younger generations. IoT-based sensors can support the monitoring of soil and crop conditions, while AI and data-driven tools can help interpret agricultural information and support better decision-making. Biotechnology can further contribute by scientifically evaluating traditional bio-inputs, plant-based preparations, and beneficial microorganisms associated with sustainable farming practices. The integration of traditional knowledge with emerging technologies should focus on supporting and strengthening farmers' knowledge rather than replacing it. Such a TradiTech approach can encourage youth participation, digital learning, innovation, and rural entrepreneurship while promoting sustainable resource use and climate-resilient agriculture. Preserving traditional wisdom through digital platforms can also create a bridge between generations and ensure that valuable agricultural knowledge remains useful for future farming systems. Therefore, combining India's traditional agricultural heritage with modern digital and emerging technologies can contribute to a more sustainable, innovative, inclusive, and resilient agricultural future.

Keywords: Traditional Agricultural Knowledge, Digital Agriculture, TradiTech, Natural Farming, Artificial Intelligence, IoT, Smart Farming, Sustainable Agriculture.

Effect of Soybean Digital Farmer Field School on Knowledge Levels of Respondents in Maharashtra

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ABSTRACT

The study was conducted in 2023-2024 to assess the knowledge level of participant and non-participant farmers regarding Standard Operating Procedures (SOPs) for soybean cultivation in Ahilyanagar district, Maharashtra. An ex-post-facto research design was used, covering 150 soybean growers (75 participants and 75 non-participants) selected from fifteen villages across three talukas through multistage sampling and were assessed on their knowledge level of Standard Operating Procedures (SOPs)for soybean cultivation. Results showed that 76% of participants had high knowledge versus 6.67% of non-participants. Significant differences across nine key soybean cultivation aspects were confirmed by Z-tests. Higher knowledge among participants may be attributed to live expert-led sessions and collaborative group learning, fostering practical skills and experience sharing. Regression analysis identified education, scientific orientation, and techno-savviness as key predictors, while traditional socio-economic factors were less influential in participants' knowledge score on SOPs for soybean cultivation. The study highlights DFFS's potential to overcome traditional barriers, empowering farmers through enhancement in their knowledge about SOPs for soybean cultivation, ultimately promoting sustainable soybean cultivation and improved productivity.

AI-Powered Optimisation of Millet-Enriched Bakery Products: Balancing Quality, Nutrition, and Consumer Acceptability

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ABSTRACT

Millets are nutrient-dense, climate-resilient cereals with considerable potential for the development of healthier, functional, and sustainable bakery products. Their incorporation into bakery formulations can improve nutritional quality by enhancing dietary fibre, minerals, bioactive compounds, and other health-promoting components; however, high levels of millet incorporation may adversely affect dough rheology, volume, texture, colour, flavour, and consumer acceptability. This review critically examines the current knowledge on the utilization of different millets in bakery products, with particular emphasis on the relationship between millet incorporation levels, nutritional enhancement, technological performance, sensory quality, and consumer acceptance. The review further explores the emerging application of Artificial Intelligence (AI), machine learning, predictive modelling, and data-driven optimization approaches in food formulation and bakery product development. AI-based approaches offer opportunities to integrate complex datasets involving formulation variables, nutrient profiles, physical and textural properties, sensory attributes, and consumer responses to predict product quality and identify optimum formulation conditions. Compared with conventional trial-and-error approaches, these tools can facilitate faster and more efficient product optimization while reducing experimental resources and development time. The review also highlights challenges associated with millet-based bakery products, including gluten dilution, impaired structural development, undesirable textural changes, flavour limitations, and variability among millet varieties and processing conditions. Particular attention is given to the potential of combining AI-assisted formulation with nutritional and sensory optimization to develop millet-enriched bakery products that achieve an appropriate balance between health benefits, technological functionality, and consumer appeal. Finally, existing research gaps and future directions for AI-enabled, sustainable, and consumer-oriented millet bakery product development are discussed. The integration of food science with AI-driven predictive tools represents a promising pathway for accelerating the wider utilization of millets in nutritious, functional, and value-added bakery foods.

Keywords: Artificial Intelligence; Machine Learning; Nutritional Quality; Predictive Modelling; Product Optimization; Sensory Evaluation

Exploration, Documentation, Mapping, and Conservation of Indigenous Crop Diversity in Madhya Pradesh: A Farmer-Participatory Approach

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ABSTRACT

Indigenous landraces are a vital part of India's agricultural heritage, embodying generations of farmer knowledge in selecting and maintaining crop varieties suited to local soil, climate, and needs. As uniform, high-yielding cultivars have spread, many traditional varieties have declined, putting both genetic diversity and this knowledge at risk. This study set out to explore, document, and begin conserving indigenous crop genetic resources maintained by farming communities across Madhya Pradesh, India. Using a participatory approach, traditional seed resources were identified and collected through direct engagement with farmers at village Choupals, Kisan Sangoshthis, and farmer meetings. The resulting database now includes 232 indigenous seed collection records from 13 districts, covering cereals, millets, pulses, oilseeds, vegetables, and other crops. Little millet, rice, kodo millet, Indian mustard, maize, field pea, chickpea, and lentil were among the most widely represented, with Mandla, Anuppur, Narsinghpur, Raisen, Dindori, and Ratlam districts contributing the largest share. Farmer-given local names, such as Dhanpuri Kodo, Trichhula Rice, and Shuklu Chand Kutki, were carefully recorded, preserving traditional knowledge alongside the seed material itself. Each accession was documented with photographs and GPS coordinates for traceable passport data, and preliminary germination tests assessed seed viability ahead of further conservation work. Together, these efforts provide a geographically grounded baseline of farmer-maintained crop diversity in Madhya Pradesh, and a foundation for future morphological and molecular characterization, including traits such as drought tolerance, nutritional quality, and resilience to climatic stress. Continued exploration, documentation, characterization, and conservation of these landraces will be essential for safeguarding agricultural biodiversity, preserving indigenous farmer knowledge, and supporting more sustainable, climate-resilient agricultural systems.

Keywords: Indigenous landraces, Genetic diversity, Participatory conservation, Farmer knowledge, Germplasm characterization, Climate resilience

Application of Artificial Intelligence on Vegetable Production

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ABSTARCT

Artificial Intelligence (AI) transforms vegetable production through precision monitoring, automated labor, and real-time data analysis that boost crop yields while reducing water and chemical use. AI is being used in the vegetable production sector for disease and pest detection, precision irrigation and soil management, automated harvesting and handling and of harvested produce, targeted weeding and spraying of chemicals, controlled environment and hydroponics and post-harvest quality grading. Predictive analytics powered by AI can predict plant health, growth patterns, and yield predictions, allowing farmers to make data-driven decisions and minimize waste. By integrating AI and robotics, it is possible to automate tasks such as nutrient delivery, planting, and harvesting, thereby reducing operational costs and enhancing labor efficiency. AI also enables the farmer with the ability to monitor and manage of farms remotely through AI driven applications giving them greater control and decision-making capabilities. Modern vegetable production is becoming more efficient, sustainable, and responsive to real-world challenges by integrating technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Machine Learning (ML). These tools assist farmers in making more informed decisions, such as adjusting irrigation based on real-time data or utilizing drones to monitor crop health. The implementation of AI in vegetable production is not without its obstacles, despite its benefits. The need for technical expertise, limited access to AI technology for small-scale producers, and high initial costs present substantial obstacles.

Keywords: Artificial Intelligence, Machine Learning, Robotics, Predictive Analyse

Theme 06- White and Blue Revolutions 2.0 Transforming Livestock, Dairy and Allied Enterprises

Aqua-Waste to Eco-Products: Sustainable Dhoop and Cleansing Agent

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ABSTRACT

The rapid proliferation of *Eichhornia crassipes* (Water Hyacinth) has emerged as a serious ecological challenge, particularly in freshwater ecosystems, where its dense growth can obstruct waterways, reduce light penetration, deplete dissolved oxygen, and adversely affect aquatic biodiversity. This study proposes a circular bioeconomy model that converts this invasive aquatic weed into two functional and value-added products: natural dhoop (incense) and antibacterial herbal hand wash. The approach aims to transform an environmental liability into useful, eco-friendly consumer products while supporting sustainable resource utilization. The high cellulose and lignocellulosic fiber content of Water Hyacinth provides a suitable organic structural material and slow-burning base for dhoop production. After harvesting, the biomass can be properly washed, dried, and finely ground before being processed into incense products. In parallel, bioactive compounds can be obtained through controlled extraction of the plant material. Phytochemicals such as flavonoids, tannins, phenolic compounds, and other naturally occurring constituents may contribute antimicrobial and antioxidant properties, making the extract potentially useful in the formulation of herbal hand wash. The proposed production workflow involves biomass harvesting, controlled drying, size reduction, extraction, formulation, and quality evaluation. This scalable and locally feasible technology promotes the utilization of invasive biomass while reducing its accumulation in water bodies. The production of natural dhoop and herbal hand wash can also reduce dependence on selected synthetic ingredients and encourage the development of environmentally responsible alternatives. Furthermore, the model has potential to generate livelihood opportunities through community-based harvesting, processing, and product development. Thus, valorization of Water Hyacinth can simultaneously support freshwater ecosystem management, waste-to-value conversion, sustainable entrepreneurship, and the development of a practical circular bioeconomy.

Keywords*:* Aquatic Waste Management; Bioactive Extractions; Circular Bioeconomy; Eco-Friendly Consumer Goods; Eichhornia crassipes

Manual Extraction of a Large Cystolith in a Mare: A Case Report

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ABSTRACT

Urolithiasis is an important cause of lower urinary tract signs in horses and may manifest as dysuria, stranguria and difficulty in urination. The present case describes the successful manual extraction of a large urinary bladder calculus in a mare presented to the Veterinary Clinical Complex, LUVAS, Hisar. A 7-year-old mare was presented with a history of colic signs, severe straining during urination and dysuria. Based on the clinical history and examination, urinary bladder urolithiasis was suspected. Following appropriate clinical evaluation and stabilization, manual extraction of the calculus was undertaken. A single large urinary bladder calculus, weighing approximately 250 g and lodged at the bladder neck, was manually extracted. During extraction, the calculus fragmented into multiple pieces which were collected and weighed. The recovered fragments exhibited a hard consistency, irregular morphology and brownish to greenish-brown coloration with prominent mineral deposition. Following removal of the calculus, supportive postoperative treatment was instituted, and improvement in urination was observed. The case highlights the occurrence of large urinary bladder calculi in mares and demonstrates that manual extraction can be an effective approach for removal of sizeable cystoliths when appropriately indicated. Early recognition of characteristic clinical signs, particularly persistent straining during urination, is important for timely diagnosis and management of equine urolithiasis.

Keywords: Cystolith; Mare; Equine urolithiasis; Manual extraction; Stranguria; Urinary bladder calculus; Urolithiasis

Ecological Impacts of Trawling and Tuna Longlining on Indian Ocean Biodiversity and Management Pathways for Sustainable Marine Resources

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ABSTRACT

Trawling and pelagic tuna longlining are the principal industrial fishing methods affecting the biodiversity of the Indian Ocean, yet their ecological footprint remains poorly quantified. This study synthesises published data from the Indian Ocean Tuna Commission (IOTC), ICAR-Central Marine Fisheries Research Institute, the Fishery Survey of India and peer-reviewed journals to assess the impacts of both gears and to identify management options. The 2025 IOTC assessment classified bigeye tuna as overfished (54% probability) but not subject to overfishing, with spawning biomass at 98% of the level supporting maximum sustainable yield, whereas yellowfin tuna has moved to a not-overfished status following catch reductions. Longline bycatch is substantial: sharks contributed 20.83% of the catch by number and 23.36% by weight in Indian longline surveys, including 18 species, while turtle and seabird interactions, though numerically small, involve threatened taxa, and the IOTC reports considerable seabird risk where mitigation is not applied. Trawling exerts greater pressure on coastal biodiversity. Off Karnataka, low value bycatch formed 20.4% of multiday trawler landings, nearly 47.5% of it juveniles of commercially important species, an estimated loss of 14,044 t, while midwater trawls off north-west India recorded 53% bycatch comprising 123 species. Low value bycatch landings by Indian trawlers rose from 14% to 25% between 2008 and 2011, masking discards while depleting recruitment. Sustainable management requires 35 mm square-mesh codends, juvenile fish excluder devices and spatial and seasonal effort reduction in trawling, together with circle hooks, night setting, bird-scaring lines, hook shielding and observer coverage in longlining. Stronger stock assessment, compliance with IOTC resolutions and ecosystem-based management are essential to conserve biodiversity and secure long-term fishery resources.

Keywords: Bycatch; Indian Ocean; Longline; Sustainable management; Trawling; Tuna

Duckweed (*Wolffia Globosa*) as a Potential Source for Replacing Conventional Aqua Feed Ingredients

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ABSTRACT

The rising costs and limited supply of fishmeal and soybean meal threaten the sustainability of aquaculture. This review aims to evaluate duckweed *Wolffia globosa*, the smallest flowering plant, as a partial or complete replacement for conventional aqua feed ingredients. The methodology involved a systematic synthesis of published research on its proximate composition, amino acid and fatty acid profiles, anti-nutritional factors, biomass productivity and cultivation in nutrient-rich wastewater, together with feeding trials in carps, tilapia and catfish assessing growth, feed conversion, digestibility, immunity and flesh quality. The effects of processing methods such as drying, fermentation and enzymatic treatment were also compared. *Wolffia globosa* shows high crude protein (20–45% on dry matter basis), a balanced essential amino acid profile and valuable pigments, vitamins and minerals, with biomass doubling within one to three days at low cost. Moderate dietary inclusion is expected to improve growth, feed utilisation and health, while higher levels may reduce performance because of fibre, oxalate and phytate, which processing can mitigate. The future potential is considerable, as integrating cultivation with aquaculture wastewater can create circular, low-cost feed systems, reduce dependence on fishmeal, lower environmental impact and support smallholder farmers. Standardised cultivation, processing protocols, species-specific inclusion levels and large-scale commercial trials are needed to realise this potential.

Keywords: Alternative protein; Aquaculture; Duckweed; Fishmeal replacement; Sustainable feed; Wolffia globosa

Digital Reproductive Records for Indian Dairy Farms: Transforming Fertility Data into Actionable Herd Management

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ABSTRACT

Reproductive information is generated continuously on dairy farms through calving, estrus observation, artificial insemination, pregnancy diagnosis and treatment of reproductive disorders. When these events are recorded inconsistently, valuable information is lost and herd-level reproductive problems may be recognized only after productivity has declined. Digital reproductive records can convert routine observations into a practical management resource. A farm-level digital reproductive system should begin with simple and clinically relevant data. Calving date, parity, estrus observation, insemination date, semen details, pregnancy diagnosis, postpartum disease and treatment history can form the basic record. Additional information such as body condition and milk production may improve interpretation of reproductive performance. The major value of digital recording is the ability to identify patterns rather than isolated events. The system can calculate indicators such as conception rate, services per conception, days open, calving interval and repeat-breeder frequency. Automated reminders can support pregnancy diagnosis, postpartum examination and follow-up of animals that remain open beyond the expected period. For small and medium dairy farms, digitalization should be affordable and simple enough for routine use. A mobile-based platform with local-language support and veterinary access may be more useful than complex infrastructure that requires specialized personnel. Data should also be structured so veterinarians can use it during farm visits for rapid decision-making. Digital reproductive records can create a bridge between farm observations and veterinary expertise. Instead of merely storing information, the system can identify animals requiring attention and generate herd-level indicators for preventive management. This transformation from records to actionable information can improve reproductive efficiency, reduce avoidable delays and strengthen farmer participation in herd health programmes. It represents a practical example of technology supporting the modernization of Indian dairy enterprises.

Keywords: Dairy farms; Digital agriculture; Decision support; herd fertility; reproductive records

Heat Stress and Reproductive Failure in Dairy Animals: From Climate Risk to Technology-Driven Adaptation Strategies

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ABSTRACT

Heat stress is an important challenge for dairy production in warm regions because elevated environmental temperature can disrupt feed intake, endocrine function, ovarian activity and embryonic survival. Reproductive consequences may include weak or missed estrus, altered follicular dynamics, reduced conception and increased pregnancy loss. These effects can reduce herd productivity and increase the economic burden of prolonged calving intervals. Effective adaptation requires reproductive management to be integrated with environmental monitoring. Temperature-humidity information can be combined with animal-level observations such as body condition, milk yield, activity and reproductive history. Heat-stress alerts could help farmers identify periods of increased reproductive risk and modify breeding decisions accordingly. Technological tools can support this approach through automated activity monitoring, digital reproductive records, remote temperature assessment and timely veterinary examination. Ultrasonography can provide objective information on ovarian structures and pregnancy status when reproductive performance is compromised. Such information can help distinguish delayed ovarian activity from other causes of poor fertility. Management interventions should remain practical for Indian dairy farms. Adequate water availability, shade, ventilation, feeding management and appropriate breeding schedules remain fundamental. Technology should complement rather than replace these basic measures. A digital decision-support system could combine environmental risk with reproductive records and generate farm-level recommendations for closer monitoring of vulnerable animals. Climate-resilient reproductive management requires a shift from treating reproductive failure after it occurs to anticipating periods of elevated risk. Linking conventional husbandry with digital monitoring and veterinary reproductive assessment can improve the timing of interventions. This integrated approach supports sustainable dairy production and aligns with the conference focus on climate adaptation, resource efficiency and technology-led transformation of livestock systems.

Keywords: Climate adaptation; Dairy cattle; Heat stress; Precision livestock farming; Reproductive failure

Fisheries and Aquaculture Development in India

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ABSTRACT

Fisheries and aquaculture in India have evolved from traditional livelihood activities into an increasingly commercial and technology-oriented sector. They contribute significantly to food and nutritional security, employment, rural development and export earnings. India is the second-largest fish-producing country globally, contributing around 8% of world fish production. The development of India's livestock and fisheries sectors has been closely associated with major production revolutions. The White Revolution, led by Operation Flood, transformed India into the world's leading milk producer through dairy cooperatives, improved breeding, veterinary services and organised marketing. Similarly, the Blue Revolution promoted the expansion of fisheries and aquaculture through improved production technologies, infrastructure, seed and feed availability, and market development. India's total fish production reached about 197.75 lakh tonnes in 2024–25 (provisional), including 151.60 lakh tonnes from inland fisheries and aquaculture and about 46.15 lakh tonnes from marine fisheries. Freshwater aquaculture is dominated by Catla, Rohu and Mrigal, while farming of tilapia and Pangasianodon hypophthalmus is expanding. Brackish water aquaculture is dominated by white-leg shrimp (*Penaeus vannamei*), with shrimp production reaching about 11.84 lakh tonnes in 2023–24. The sector faces challenges such as disease, climate variability, declining coastal resources, poor-quality seed and feed, post-harvest losses and inadequate cold-chain infrastructure. Government initiatives such as PMMSY, FIDF and PM-MKSSY aim to address these constraints. Future development depends on sustainable deep-sea fishing, mariculture, open-sea cages, RAS, IMTA, seaweed farming, digital technologies, improved cold chains and stronger Fish Farmer Producer Organisations. These measures can help make India's fisheries sector more productive, sustainable and inclusive.

Keywords: Aquaculture, Infrastructure, Operation, Variability

Modernizing Allied Agricultural Enterprises: A Synergistic Approach through White and Blue Revolutions 2.0

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ABSTRACT

The transformation of India's allied agricultural sectors—specifically livestock, dairy, and fisheries—is crucial for ensuring national food security, empowering rural economies, and positioning India as a global export leader. This study provides a comprehensive analysis of the ongoing White Revolution 2.0 and Blue Revolution 2.0, two interconnected paradigms designed to shift traditional practices toward technology-driven, formalized cooperative ecosystems. White Revolution 2.0 builds upon the historic Operation Flood by targeting a 50% increase in cooperative milk procurement (reaching 100 million kg daily by 2028-29). It emphasizes the empowerment of women farmers, the expansion of Multipurpose Dairy Cooperative Societies (MDCS), and the integration of cutting-edge reproductive technologies such as sex-sorted semen and In Vitro Fertilization (IVF) to enhance per-animal productivity. Concurrently, Blue Revolution 2.0, anchored by the Pradhan Mantri Matsya Sampada Yojana (PMMSY) and the Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana (PM-MKSSY) scheme, aims to scale total fish production to 22 million metric tonnes while reducing post-harvest losses to 10%. It transitions the sector from extensive capture fishing to intensive aquaculture utilizing Recirculating Aquaculture Systems (RAS) and Biofloc technology. Both revolutions are unified by their heavy reliance on digital formalization—utilizing Data Processor Milk Collection Units (DPMCUs) in dairy and the National Fisheries Digital Platform (NFDP) for seafood traceability. By decentralizing infrastructure through Primary Agricultural Credit Societies (PACS) and promoting sustainable circular economies like biogas production and seaweed cultivation, these parallel revolutions foster robust micro-entrepreneurship. The strategic synergy between the White and Blue Revolutions 2.0 not only addresses climate change vulnerabilities and regional developmental disparities but also plays a vital role in doubling farmers' incomes, generating widespread employment, and laying a resilient foundation for a self-reliant India (Viksit Bharat).

Keywords: Aquaculture; Blue Revolution 2.0; Dairy Cooperatives; PMMSY; Viksit Bharat; White Revolution 2.0

Optimize the salinity level of Inland Saline Water for Culture of *Heteropneustes fossilis*

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ABSTRACT

The present study focuses on the optimization of salinity levels for the culture of *Heteropneustes fossilis* (Singhi) in inland saline water conditions. With the increasing salinization of freshwater resources in many inland regions, exploring the potential of freshwater fish species for saline aquaculture has become crucial for sustainable fish production. *H. fossilis*, a hardy, air-breathing catfish with high market demand, exhibits tolerance to a wide range of environmental conditions, making it a promising candidate for culture in low to moderate saline waters. The experiment was conducted to evaluate the effects of different salinity levels (0,1, 2, 4, and 8 ppt) on growth performance, feed utilization, and survival of *H. fossilis* juveniles reared under controlled indoor conditions. Water quality parameters were regularly monitored to ensure stable environmental conditions. Growth parameters such as weight gain, specific growth rate (SGR), feed conversion ratio (FCR), and survival rate were analyzed to determine the optimum salinity range for maximum performance. The study aims to identify the optimum salinity level that supports better growth and survival of *H. fossilis* in inland saline waters, thereby expanding the scope of brackish and saline aquaculture in inland regions. The findings are expected to contribute to the sustainable utilization of saline-affected lands for fish culture and enhance livelihood opportunities for inland fish farmers.

Keywords: Growth performance; Heteropneustes fossilis; Inland saline water; Salinity optimization, Singhi; Sustainable aquaculture

ARIMA Modelling and Forecasting of Milk Production in Madhya Pradesh and India

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ABSTRACT

This study analyzed long-term trends and forecasts of milk production in Madhya Pradesh and India from 1990 to 2024. We collected secondary data on cow, buffalo, and total milk production from official sources. We then used descriptive statistics, trend analysis, and time series modeling to examine growth patterns and predict future production. Various trend models were fitted to assess changes in milk production, and the Box–Jenkins ARIMA approach was used for model selection, validation, and forecasting up to 2030.Results showed a continuous increase in cow, buffalo, and total milk production in both Madhya Pradesh and India. Instability in milk production decreased in later periods, indicating greater consistency over time. For cow milk production, ARIMA (1,1,2) was the most suitable model for both Madhya Pradesh and India. For buffalo milk, ARIMA (1,1,5) was selected for Madhya Pradesh, while ARIMA (0,1,5) was suitable for India. For total milk production, ARIMA (1,1,2) provided the best fit for both regions. Forecasts indicate continued growth in milk production until 2030, with total milk production projected to reach approximately 30,031.5 thousand tonnes in Madhya Pradesh and 298,724 thousand tonnes in India. The study concludes that milk production exhibits a positive growth pattern, and ARIMA models offer valuable estimates for future production planning. These findings underscore the importance of ongoing improvements in animal breeding, feed and fodder availability, veterinary services, dairy infrastructure, and effective management practices to sustain the dairy sector's growth.

Keywords: ARIMA modelling; Forecasting; India; Milk production; Madhya Pradesh; Trend analysis

Transforming Indian Agriculture through Sustainable, Technology-Driven and Income-Centric Farming

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ABSTRACT

Since independence, Indian agriculture has transformed from a food-deficit sector into a major global agricultural producer. This achievement has been supported by progressive agricultural policies, public research institutions such as the Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs), and major production initiatives, including the Green, White, Yellow, Blue, and Golden Revolutions. These developments have improved food security, diversified production, and supported rural livelihoods. However, Indian agriculture continues to face challenges such as soil degradation, water scarcity, climate change, technological constraints, market instability, and slow growth in farmers' incomes. These concerns highlight the need to move beyond a production-oriented approach toward an income-driven, sustainable, and resource-efficient agricultural system. Public-Private Partnerships (PPPs) can strengthen the connection between agricultural research and field-level adoption. Collaboration in areas such as improved seeds, biotechnology, biopesticides, livestock health, food processing, and marketing can accelerate innovation and improve agricultural value chains. The dairy and fisheries sectors are also undergoing significant modernisation. White Revolution 2.0 can use technologies such as artificial intelligence, the Internet of Things, blockchain, and big-data analytics to improve dairy quality, traceability, supply-chain efficiency, and consumer safety. Similarly, a sustainable Blue Revolution can promote responsible fisheries and aquaculture through improved hatcheries, certified inputs, digital traceability, and environmentally friendly practices. Digital agriculture is further enhancing precision farming through artificial intelligence, remote sensing, spatial technologies, and data-based advisory services. Future agricultural development in India therefore requires increased investment in research and development, post-harvest management, value addition, secondary agriculture, market linkages, and digital technologies. Such an integrated approach can raise farm incomes while ensuring long-term food, nutritional, and environmental security.

Keywords: Bipesticides; biotechnology; blockchain; modernisation

Cage Aquaculture Innovations: A Journey from Traditional Methods to Modern Technology for Food and Nutritional Security

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ABSTRACT

Cage aquaculture has emerged as one of the most productive and rapidly growing methods of fish farming that can help address the food and nutritional security needs of the present and future generations. This method refers to the enclosure of fish within simple structures made of wood, bamboo, or nets as the traditional and informal approach using local skills and knowledge. These cages can be placed in different water bodies such as rivers, lakes, reservoirs, and coastal areas. Although cage culture seems appropriate for the aquaculture industry as it is cheap to set up and easy to manage, it had several shortcomings that hindered its large-scale propagation. Modern cage aquaculture has witnessed the application of advanced equipment and technologies that have helped in the control of diseases, improvement of water quality, increased stock production and enhanced performance of the caged fish. For example, the use of High-Density Polyethylene material has improved the production process and ensured quality results while maintaining the ecology of the water bodies. Similarly, the use of floating, submerged, and offshore cages, demand-responsive feeding technologies, and remote sensing instruments have augmented cage aquaculture production. Besides the adoption of such technologies as mentioned above, the introduction of biotechnology, vaccines, breeding programs, genetic improvement strategies, and precision fish farming approaches have improved breeding stock, feeds and feeding strategies, and disease control in aquaculture. This paper highlights the historical development and current trends of cage aquaculture technology and their implications on food security. The paper explores the potential of modern cage aquaculture in promoting nutrition and food security while considering the different types of farms and their implications on the socio-economic status of local coastal fishing communities and marginalized groups. The paper also emphasizes the future prospects and challenges of cage aquaculture and how this new technology can enhance nutritional security and improve the livelihoods of the locals in the current and future scenarios.

Keywords: Cage aquaculture; nutritional security; smart aquaculture technology; sustainable farming; traditional farming

Renewable Natural Gas from Dairy Manure: Climate Benefits, Methane Leakage, Economics and Sustainability Trade-Offs

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ABSTRACT

India's expanding dairy sector generates substantial quantities of cattle manure, creating both an environmental challenge and an opportunity for renewable energy production. Conversion of dairy manure into biogas and its subsequent upgrading to Renewable Natural Gas (RNG) or Bio-CNG offers a promising pathway for reducing methane emissions, managing organic waste and producing a low-carbon alternative to conventional fossil fuels. This study examines the climate benefits, methane leakage risks, economic feasibility and sustainability trade-offs associated with manure-based RNG production. Methane capture through anaerobic digestion can prevent uncontrolled emissions from manure management while producing a useful renewable energy resource. However, methane losses during manure collection, anaerobic digestion, gas upgrading, compression, storage and transportation can significantly influence the overall greenhouse-gas mitigation potential. Economic performance depends on manure availability, collection and transportation systems, plant scale, biogas yield, upgrading efficiency, capital investment and the utilization of digestate as an organic fertilizer. Sustainability considerations include water and energy requirements, nutrient management, infrastructure needs and long-term feedstock availability. Dairy-based Bio-CNG projects can establish a circular economy by converting livestock waste into clean energy and nutrient-rich digestate while supporting rural livelihoods and energy security. Effective methane-leak monitoring, efficient plant operation and integrated manure and digestate management are essential to maximize environmental and economic benefits. Such integrated dairy-waste-to-energy systems can contribute to sustainable dairy development, climate-resilient agriculture and India's transition towards a low-carbon and resource-efficient economy.

Keywords: Bio-CNG; Climate mitigation; Circular economy; Dairy manure; Methane leakage; Renewable Natural Gas; Sustainable dairy development

From Lab to Field: Scaling Reproductive Technologies (Sexed Semen & IVF) through Cooperative Models and Start-ups while Optimizing Field-Level Bovine Fertility for Reduced Inter-Calving Period and Inclusive Farmer Prosperity – with Special Reference to Rajasthan

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ABSTRACT

Sex-sorted semen and in-vitro fertilization (IVF) are pivotal technologies under the Rashtriya Gokul Mission and White Revolution 2.0 for accelerating genetic improvement and dairy productivity in India. Field studies across India report conception rates of 39–55% with sex-sorted semen and female calf ratios of 90–93%. However, laboratory success is limited by field-level fertility constraints, particularly subclinical endometritis (SCE), thermal stress, and low sperm concentration per dose (~2.1×10^6), which significantly prolongs inter-calving periods and reduces conception rates of advanced reproductive technologies. This paper presents an integrated lab-to-field framework combining the scaling of sex-sorted semen and IVF through dairy cooperatives and agri-start-ups with practical fertility optimization. Nationally, over 1.28 crore sex-sorted semen doses have been produced, with indigenous technology reducing cost to ₹250 per dose. In Rajasthan, the Animal Husbandry Department has launched a sex-sorted semen scheme with a work order for one lakh doses and an MoU with NDDB for in-state production (starting at Bassi laboratory), aiming to benefit ten lakh farmers with up to 90% female calves while conserving indigenous breeds and reducing stray bulls, offering a replicable template for other states. Field success is enhanced by cow-side diagnostics (Metricheck and endometrial cytology), non-antibiotic and ethno-veterinary intrauterine therapies, fixed-time AI protocols, cold-chain integrity, and deep cornual deposition. These interventions can reduce open days by 45–60 days per animal, generating a net economic saving of ₹8,000–₹12,000 per lactation via saved maintenance feed and recovered peak milk production. Embedding these technologies within cooperative networks (like RCDF/NDDB) and start-up-driven delivery systems offers a scalable, commercially viable pathway for higher productivity and sustainable income growth for smallholder dairy farmers of Rajasthan and India.

Keywords*:* Sex-sorted semen; Subclinical endometritis; Inter-calving period; Deep cornual AI; Dairy cooperatives; White Revolution 2.0; Rashtriya Gokul Mission

Real-Time Health Monitoring and Wearable Devices for Cattle and Automated Water Quality Management System in Fish Farming

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ABSTRACT

The integration of health-monitoring wearable devices introduces a paradigm shift in cattle management by establishing continuous surveillance systems. These advanced devices simultaneously track critical physiological parameters—including body temperature, heart rate, muscle activity, and blood pressure—alongside real-time location tracking. Equipped with automated immediate communication frameworks, any detected problem or defect instantly alerts the farmer. Leveraging this continuous monitoring technology drastically reduces livestock mortality rate. An Automatic Water Quality Management System in fish farming is a smart technology used to continuously monitor and maintain the quality of water in fish ponds or tanks. It uses sensors to measure important parameters such as temperature, pH, dissolved oxygen, turbidity, ammonia, and water level. The collected data is processed by a controller, which automatically activates equipment such as aerators, water pumps, filters, heaters, or dosing systems whenever a parameter goes beyond its safe range. This system reduces the need for constant manual monitoring, maintains a healthy aquatic environment, improves fish growth and survival, and helps prevent disease and sudden fish mortality. It also saves time, labour, and water and supports efficient and sustainable fish farming.

Key words: Aquatic environment; automatic water quality management system; monitoring technology; paradigm; surveillance

Advancing Integrated Farming for Rural Resilience

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ABSTRACT

India's cattle, dairy and fishing industries are vital cornerstones of rural livelihoods, food security, nutrition and employment. The first White Revolution transformed India from a milk-deficient nation to one of the leading milk producers in the world, and the Blue Revolution enhanced the significance of fisheries and aquaculture as sources of food, revenue and rural employment. The current aim of the White and Blue Revolutions 2.0 is to shift from production growth to inclusive, sustainable, and technologically advanced development. The key objectives of White Revolution 2.0 are empowering dairy cooperatives, increasing milk procurement, improving milk quality, empowering women, promoting value addition, and adopting digital and climate-smart technology. Blue Revolution 2.0 (Neel Kranti Mission) aims to achieve economic prosperity of fishers through technology development and management. Integrated farming systems offer an important approach to achieve these targets through integration of crops with dairy, livestock, poultry, fisheries, beekeeping, horticulture and other allied activities. Such diversification improves the use of land, water, labour and farm residues while increasing farm income, employment and resilience to climatic risks. Crop residues can be used as feed for livestock, and animal waste can be recycled as manure or used for biogas production, which promotes a circular and resource-efficient farming system. Precision livestock farming, digital monitoring, and sustainable aquaculture are key focuses for future agricultural revolutions, prioritizing improved animal health and effective value chains. These approaches aim to reduce resource waste, lower environmental impacts, and create opportunities for rural communities. Ultimately, White and Blue Revolutions 2.0 represent a shift from traditional farming to integrated, innovative, and climate-resilient practices that promote food security and sustainable rural development.

Keywords: Aquaculture; Dairy farming; Fisheries; Integrated farming systems; Livestock; Sustainable agriculture

MAAS-POSHAN: A fish-based solution to all of your Animal's Nutritional Requirements

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ABSTRACT

Ensuring adequate nutrition for livestock and aquaculture species is essential for sustainable animal production and long-term food security. Feed quality plays an important role in determining animal growth, productivity, immunity and overall health. Fish waste products i.e heads, bones, viscera, skin and fins are highly nutritious and are mostly thrown off as waste. These nutritious waste products are considered into constituting MAAS-POSHAN, an innovative, fish based nutritional solution designed to address the dietary requirements of a wide range of animals including poultry, livestock and cultured fish. MAAS-POSHAN focuses on the production of high-quality fish meal derived from fish processing by-products and low value fish species. Through proper processing techniques such as drying, grinding and nutrient stabilization, these raw materials are converted into a protein-rich feed ingredient containing essential amino acids, fatty acids, minerals and vitamins. In addition to its nutritional benefits, MAAS-POSHAN promotes sustainable resource utilization and environmental management. The initiative emphasizes the conversion of fish waste into valuable feed products, reducing environmental pollution. This approach not only minimizes wastage but also creates additional income opportunities within fisheries and agricultural sectors. The concept of MAAS-POSHAN also aims to support small scale farmers and rural entrepreneurs by providing an affordable and locally producible feed alternative. This initiative not only enhances farm productivity but also reduces dependency on expensive commercial feeds.

Keywords: feed alternative; fish based; MAAS-POSHAN; rural entrepreneurs

Can Targeted Enhancement of Mammary Blood Flow Improve Milk Production in Dairy Cattle? A Novel Approach to Precision Dairy Production

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ABSTRACT

Milk production is a highly energy-intensive physiological process requiring continuous delivery of oxygen, nutrients, hormones and metabolic substrates to the mammary gland. Mammary blood flow is closely associated with the supply of precursors required for the synthesis of lactose, milk protein and milk fat. However, whether targeted enhancement of mammary perfusion can directly improve milk production remains insufficiently explored. Understanding this relationship could provide a novel approach to improving dairy productivity while maintaining animal health. The present study proposes to investigate whether safe, targeted enhancement of mammary blood flow can improve milk yield and milk composition in lactating dairy cattle. Healthy lactating dairy cattle would be randomly allocated into control and intervention groups and maintained under standardized nutritional and management conditions. Mammary blood flow would be evaluated using colour Doppler ultrasonography at predetermined intervals. The intervention group would receive a scientifically selected, non-invasive approach designed to enhance mammary perfusion, while the control group would receive routine management. Daily milk yield, milk fat, protein and lactose percentages, feed intake, body condition score and physiological parameters would be recorded. Infrared thermography may additionally be used to monitor changes in udder surface temperature. The relationship between changes in mammary blood flow and milk production would subsequently be analysed. It is hypothesized that targeted enhancement of mammary perfusion, when combined with adequate nutritional support, may increase the availability of oxygen and milk-synthesis precursors to mammary tissue, potentially resulting in improved milk yield and favourable changes in milk composition. The study may also help determine whether a measurable relationship exists between mammary blood flow and productive performance. Targeting mammary blood flow represents a potentially novel avenue for precision dairy production. Rather than relying solely on nutritional or hormonal manipulation, understanding and optimizing mammary perfusion could provide an additional physiological tool for improving milk production. Further controlled studies are required to identify safe and effective methods of enhancing mammary blood flow and to establish their economic and practical feasibility under field conditions.

Keywords: Dairy cattle; Doppler ultrasonography; mammary blood flow; mammary perfusion, milk production; precision dairy farming

Early Disease Detection in Poultry Flocks Using Ai-Driven Image and Sound Analytics: A Step Toward Sustainable Poultry Health

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ABSTRACT

Poultry diseases are significant challenges that impact flock health, productivity, animal welfare, and the economic viability of commercial poultry farming. Quick recognition of diseases is crucial for prompt veterinary care and minimizing mortality, production losses, and unnecessary therapeutic interventions. Traditional methods of disease surveillance primarily rely on manual observations, visible symptoms, and laboratory tests, which can be labor-intensive and may overlook subtle signs during the initial phases of illness. Recent developments in Artificial Intelligence (AI), computer vision, machine learning, and acoustic analysis offer innovative avenues for the continuous and non-invasive monitoring of poultry populations. This review examines the possibilities of utilizing AI-based image and sound analytics for the early identification of diseases and health monitoring in poultry. Image-based artificial intelligence systems can evaluate variations in posture, movement, gait, feeding habits, body condition, activity levels, and flock distribution, which can act as early signs of health issues. Likewise, sound-based technologies are able to assess vocalization patterns, respiratory noises, coughing, sneezing, and distress calls to detect potential respiratory illnesses, stress, and irregular behavior in flocks. The combination of cameras, microphones, environmental sensors, and Internet of Things (IoT) devices with AI-driven analytical models can enable real-time surveillance and automated notifications. Deep learning techniques such as convolutional neural networks (CNN), object detection frameworks, and recurrent neural networks (RNN) have demonstrated significant promise for analyzing image, video, and audio data. However, challenges related to the quality of datasets, environmental variations, accuracy of models, computational demands, costs, data standardization, and validation in commercial farming environments persist. Future advancements should concentrate on creating affordable, transparent, and resilient multimodal AI systems that are integrated with veterinary decision support. These technologies have the potential to enhance precision poultry farming, advance disease monitoring, promote better animal welfare, and support sustainable poultry health management.

Keywords: Acoustic Analysis, Artificial Intelligence, Computer Vision, Deep Learning, Disease Detection, Poultry Health

Impact of Microclimatic Modifications in Loose Housing System on Stress-Related Hormones of Lactating Murrah Buffaloes

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ABSTRACT

Heat stress adversely affects the physiological mechanisms governing thermal regulation and maintenance energy. The present study was conducted to evaluate the effect of microclimatic modifications on stress-related hormonal responses in lactating Murrah buffaloes during summer conditions. Eighteen lactating Murrah buffaloes were distributed into three treatment groups (n=6) under a loose housing system: T_1, concrete flooring with corrugated asbestos roofing (control); T_2, concrete flooring with 50 mm glass wool insulation on the false ceiling and white-painted upper roof; and T_3, concrete flooring with 70 mm expanded polyethylene (EPE) sheet on the ceiling and white-painted upper roof. Blood samples were collected at fortnightly intervals to estimate cortisol, thyroxine (T4), and triiodothyronine (T3) concentrations. The overall mean Cortisol Levels (ng/ml) were 1.44, 1.41 and 1.43 ng/ml in T_1, T_2, and T_3, respectively, with no significant difference among treatments. However, cortisol concentrations were significantly lower ($P<0.05$) in T_2 than T_1 and T_3 during the IV and V fortnights, indicating a transient reduction in physiological stress under the glass wool-based modification. The overall mean Thyroxine (ng/ml) concentration remained similar among T_1, T_2 and T_3, although significant treatment differences were observed during the II and IV fortnights. Similarly, there was a non-significant difference ($P>0.05$) in the overall mean triiodothyronine (T3) concentrations among the treatment groups. Overall, improved thermal conditions through roof insulation appeared to support better endocrine homeostasis in lactating Murrah buffaloes exposed to heat stress.

Keywords: Heat stress; buffaloes; microclimatic modifications; insulation; stress hormones

Mapping Dairy Value Chains 2.0 in India: An Inclusive Pathway

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ABSTRACT

India's dairy sector has entered a new phase in which growth must be matched by stronger, more inclusive and resilient value chains. Milk production reached 247.87 million tonnes in 2024-25, up from 17 million tonnes in 1951, while per-capita availability increased to 485 grams per day, reaffirming India's position as the world's largest milk producer. Against this background, the paper conceptualizes "Dairy Value Chains 2.0" as an inclusive pathway under White Revolution 2.0, linking productivity enhancement with efficient aggregation, quality assurance, processing, value addition and market access. The framework integrates improved breeding and animal-health services, balanced nutrition, climate-smart feed and fodder systems, digital advisory and payment platforms, village-level testing and chilling, renewable energy, manure management and traceable marketing. It places small and marginal farmers, women, youth, cooperatives and Farmer Producer Organisations at the centre of dairy enterprise development. This direction is consistent with the White Revolution 2.0 agenda to form 75,000 new Dairy Cooperative Societies, strengthen 46,422 existing societies and raise cooperative milk procurement to about 1007 lakh kg per day by 2028-29. FAO evidence further shows that organised smallholder dairy systems can improve productivity and market access, while generating employment across collection, processing and marketing activities. However, fragmented marketing channels, weak access to services, uneven cold-chain infrastructure and limited institutional finance continue to constrain many producers. The paper therefore argues that India's next dairy transformation should move beyond volume expansion toward connected, quality-assured, low-carbon and farmer-centred value chains. Such a transition can enhance farm incomes, women's economic participation, rural entrepreneurship, food safety and long-term sustainability while ensuring that a larger share of value remains with primary producers.

Keywords: Climate-smart livestock; dairy Value Chains 2.0; dairy cooperatives; smallholders; White Revolution 2.0; women's empowerment

Development of pH-Responsive Ethno-Veterinary 'Smart Patches' for Sustainable Wound Management

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ABSTRACT

This study introduces biodegradable, pH-responsive "Smart Patches" designed for accessible, sustainable livestock wound management by integrating North East India's ethno-veterinary heritage with modern biomaterials science. The patches incorporate bio-active extracts from invasive indigenous flora *Mikania micrantha* (Japani Lota) and *Chromolaena odorata* (Germany Bon) selected for their proven anti-inflammatory, antimicrobial, hemostatic, and antioxidant properties. To enable non-invasive diagnostics, anthocyanin pigments extracted from *Clitoria ternatea* (Aparajita) petals serve as natural pH-sensitive indicators. These smart dressings exhibit a visible color shift triggered by the microenvironmental alkaline shift characteristic of bacterial proliferation and exudate accumulation. By delivering real-time, equipment-free visual diagnostics at the point of care, the system allows farmers and veterinarians to detect early-stage infections rapidly, facilitating timely antibiotic intervention and mitigating livestock health risks. By valorizing abundant botanical resources, this technology bypasses traditional diagnostic laboratory constraints in rural regions. Ultimately, this eco-friendly innovation provides an affordable healthcare solution while creating viable opportunities for regional agri-entrepreneurship and standardized commercial ethno-veterinary medicine.

Keywords: Ethno-veterinary medicine, Smart dressings, pH-responsive indicators, Wound management, Sustainable livestock healthcare, Agri-entrepreneurship

Livestock and Dairy Sector Development in Rajasthan and India

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ABSTRACT

The study entitled "Livestock and Dairy Sector Development in Rajasthan and India" was compiled using secondary data drawn from the Basic Animal Husbandry Statistics (BAHS 2025), the 20th Livestock Census and reports of the Rajasthan Cooperative Dairy Federation (RCDF) to examine production patterns, dairy performance and policy support across the two decades ending 2024-25. Nationally the livestock sector recorded a Compound Annual Growth Rate of 12.77 per cent between 2014-15 and 2023-24, currently contributing over 31 per cent of agricultural Gross Value Added and 5.5 per cent of national GVA. India retained its position as the world's largest milk producer with output reaching 247.87 million tonnes and per capita availability of 485 grams per day in 2024-25 supported by an animal population of 535 million livestock units and 851 million poultry birds. The sector sustains over 70 per cent of the rural population and remains a principal source of daily cash income for landless and marginal farmers, besides supplying manure, draught power and nutrition-rich animal-source foods. Rajasthan emerged as the 2nd largest milk-producing state, contributing 14.82 per cent of national output, while ranking first in goat, camel and sheep populations and supplying nearly 40-48 per cent of the country's wool. Milk production in the state nearly doubled over eight years, supported by the Saras cooperative network and central schemes including Operation Flood, Rashtriya Gokul Mission, National Livestock Mission and National Dairy Plan, which together strengthened veterinary healthcare, breed improvement and procurement infrastructure. Despite this progress constraints such as low animal productivity, fodder shortages, disease burden, climate stress and weak cold-chain infrastructure continue to limit sectoral efficiency. The study recommends strengthening veterinary and breeding services, expanding cold-chain and market infrastructure, and scaling up scientific dairy practices to sustain inclusive, resilient growth of the livestock economy.

Keywords: cooperative, dairy, GVA, livestock, Rajasthan, trends

Blue Revolution 2.0: Integrating sustainable aquaculture with livestock and dairy enterprises for resilient farm livelihoods in India

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ABSTRACT

India, the world's second-largest fish producer, contributes nearly 8% of global production, with annual output exceeding 17 million tonnes. Building on the White and Blue Revolutions, this paper examines how a second phase of transformation can be achieved by integrating sustainable aquaculture with livestock, dairy and other allied enterprises. The study synthesizes secondary information from policy documents, including the Pradhan Mantri Matsya Sampada Yojana, national statistical reports and peer-reviewed literature on production systems, value chains and resource-use efficiency. Emphasis is placed on technology-led intensification through recirculating aquaculture systems, biofloc technology, cage culture in open waters and genetically improved seed, alongside integrated farming models such as fish–duck, fish–poultry, fish–dairy and fish–pig systems that recycle livestock waste as pond inputs, reduce feed and fertilizer costs and enhance farm income. Cooperative-based milk marketing, as demonstrated by the White Revolution, is discussed as a replicable institutional model for aggregating small-scale fish farmers, improving cold-chain access, price realization and traceability. The major constraints identified are inadequate availability of quality seed and feed, disease outbreaks and antimicrobial residue concerns, limited credit and insurance coverage, post-harvest losses, fragmented markets and climate variability. Integrated systems show strong potential to diversify income, generate year-round employment, particularly for women and youth, and improve nutritional security through affordable animal protein. The paper concludes that Revolution 2.0 requires convergence of technology, digital advisory services, farmer producer organizations and supportive policy, with priority given to biosecurity, circular resource use and climate-resilient practices. Strengthening extension services, institutional credit and market linkages will be central to ensuring that productivity gains translate into equitable rural prosperity and the sustainable growth of the allied sector.

Keywords: Aquaculture; Blue Revolution; Dairy cooperatives; Integrated farming; Livestock; Value chain

AquaLog: A Low-Cost Real-Time Water Quality Monitoring System for ClimateResilient Aquaculture

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ABSTRACT

Aquaculture is increasingly vulnerable to climate-driven fluctuations in water temperature, dissolved oxygen, pH, and nitrogenous waste, which can compromise fish health, growth, and production efficiency. Conventional waterquality monitoring systems are often expensive, laboratory-dependent, or require frequent manual measurements, limiting their accessibility for small and medium-scale aquaculture farmers. To address this challenge, the present study proposes **AquaLog**, a low-cost, real-time water-quality monitoring and early-warning system designed specifically for aquaculture environments. AquaLog is based on an **ESP32 microcontroller** and integrates sensors for continuous monitoring of key water-quality parameters, including **temperature, pH, total dissolved solids (TDS), and dissolved oxygen (DO)**. The system incorporates local data storage through an SD card, enabling time-stamped recording and offline monitoring even in locations with limited internet connectivity. Bluetoothbased communication enables interaction with a farmer's smartphone for convenient access to monitoring information. In addition, the proposed system incorporates a low-cost colorimetric approach for **nitrite/nitrate detection**, providing a pathway toward monitoring nitrogen-cycle disturbances that are commonly associated with intensive aquaculture systems. The compact and modular design of AquaLog is intended to reduce the cost and technical complexity associated with conventional multi-parameter monitoring equipment. By enabling continuous observation rather than intermittent manual measurements, the system can facilitate early detection of deteriorating water-quality conditions and support timely management interventions such as aeration and water exchange. AquaLog therefore represents a **technology-oriented approach to precision and climate-resilient aquaculture**, with potential applications in fish hatcheries, grow-out ponds, recirculating aquaculture systems, biofloc systems, and small-scale aquaculture farms. Further sensor calibration, laboratory validation, and field testing will be undertaken to establish the accuracy, reliability, and practical performance of the system under diverse aquaculture conditions.

Keywords: AquaLog; climate-resilient aquaculture; IoT; precision aquaculture; ESP32; water-quality monitoring

Beyond Antibiotics in Modern Aquaculture: Mechanistic Frontiers in Nanovaccine Delivery, Phage Therapy, and Virulence Attenuation

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ABSTRACT

Aquaculture supplied about 103 million tonnes of aquatic animals in 2024, roughly 53% of all aquatic animal production, and much of that growth still leans on antimicrobials to manage bacterial disease. Modelled global antimicrobial consumption in aquaculture was about 10,000 tonnes in 2017 and was projected to rise by about one third by 2030, a trajectory that sustains selection for resistance across aquatic, animal and human compartments. As routine prophylactic use is progressively restricted, producers need interventions that protect fish and shrimp without adding to that selection pressure. This review examines three mechanistically distinct strategies that have advanced quickly since 2023. Mucosal nanovaccines use engineered carriers to protect antigens from gastric and aquatic degradation and to reach gut-, gill- and skin-associated lymphoid tissue, and the best current formulations report 73% to 86% protection in challenge trials. Lytic bacteriophages and phage-derived endolysins provide precise, self-amplifying (phage) or rapid enzymatic (endolysin) control of opportunistic pathogens such as Aeromonas hydrophila and Vibrio spp., with survival reaching 93% to 100% in some Aeromonas trials. Quorum sensing inhibition and quorum quenching blunt virulence and biofilm formation without killing the target, although in vivo evidence remains thin. For each strategy we set out the mechanism, weigh the recent primary evidence, and state what still separates laboratory success from farm use: delivery stability, antigen and host-range coverage, phage resistance, outermembrane barriers to lysins, extract standardization, nanomaterial safety, regulation and cost. We close with a layered, One Health-aligned framework that combines vaccination, phagebased biocontrol and virulence attenuation with surveillance and biosecurity, and we list priority research questions.

Keywords: Antimicrobial resistance; Nanovaccine; Mucosal immunity; Endolysin; Quorum sensing inhibition; Aeromonas hydrophila; vibrio

Next-Gen Tides and Pastures: Catalyzing White and Blue Revolutions 2.0 for Resilient Allied Enterprises

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ABSTRACT

The urgent imperative to secure holistic nutrition and build climate-resilient agrifood systems has necessitated a paradigm shift from traditional production models toward the White and Blue Revolutions 2.0. As rising global demands for high-quality animal protein and micronutrient-dense foods escalate, the livestock, dairy, and fisheries sectors face unprecedented constraints, including resource depletion, climatic volatility, and genetic stagnation. This comprehensive review explores the transformative frameworks underpinning these secondary revolutions, emphasizing the integration of advanced molecular breeding, precision livestock management, and regenerative agricultural practices. By leveraging modern animal biotechnology—such as genomic selection, targeted gene editing, and optimized milk and meat processing technologies governed by rigorous sanitation standards—the White Revolution 2.0 aims to exponentially enhance per-capita dairy productivity while minimizing ecological footprints. Concurrently, the Blue Revolution 2.0 envisions a modernized aquaculture ecosystem driven by integrated farming systems, disease-resistant aquatic breeds, and sustainable feed biofortification. Our synthesis highlights the synergistic potential of these parallel movements in creating a robust circular bioeconomy that recycles organic outputs effectively. Furthermore, we underscore the critical role of institutional policy support, comprehensive biological databases, and frontline extension systems in disseminating these technological innovations from specialized research laboratories directly to grassroots farming communities, ensuring equitable access to advanced tools. The transition from volume-centric yields to value-driven, nutritionally optimized production not only secures domestic food sovereignty but also positions allied agricultural enterprises as formidable engines for the socioeconomic upliftment of marginalized farmers and rural youth. Ultimately, the strategic confluence of the White and Blue Revolutions 2.0 represents a comprehensive blueprint for securing long-term human nutritional security, mitigating climate change vulnerabilities, and sustainably transforming the competitive landscape of Indian and global livestock, dairy, and aquatic enterprises.

Keywords: Animal Biotechnology, Regenerative Agriculture, Holistic Nutrition, Circular Bioeconomy, Biofortification, Precision Livestock Management

Theme 07- Cultivating Minds, Empowering Futures Reimagining Agricultural Education and Human Capital

From Farmers to Agripreneurs: Agricultural Education, Skill Development and Human Capital Transformation in India

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ABSTRACT

Indian agriculture is increasingly evolving from a production-centred activity toward a more diversified and market-oriented agribusiness system which involves processing, value addition, marketing, digital platforms and rural enterprises. This transition requires farmers and rural youth to develop capabilities that extend beyond conventional production knowledge. Existing research on agricultural education, farmer skills, human capital and agripreneurship in India is spread across several strands of literature, including agricultural extension, entrepreneurship and agribusiness. To bring these strands together, this review examines studies published in Scopus-indexed sources between 2015 and 2025 using the PRISMA 2020 framework. The findings are interpreted through a literature-derived human capital perspective that links agricultural education and practical learning with capability development, entrepreneurial application and, ultimately, value creation in agriculture. The review also considers the role of institutional support and the wider context in shaping this process. The synthesis indicates four major findings. First, agricultural capability requirements are expanding from technical and production skills toward entrepreneurial, managerial, digital and market-oriented competencies. Second, practical learning, extension interaction, peer learning, networks and incubation support are repeatedly associated with the application of knowledge in enterprise-oriented activities. Third, agripreneurial development is constrained when education, extension, training and enterprise-support institutions operate in isolation. Fourth, the evidence remains fragmented in terms of capability measurement, geographical coverage and longitudinal assessment, limiting understanding of how skills accumulate into sustained entrepreneurial outcomes. The findings point to a need for closer coordination between skill development and the changing requirements of agriculture. Training programmes may need to give greater attention to digital use, market understanding, enterprise management and practical decision-making alongside technical farming skills. The review also shows that more evidence is needed on how these capabilities develop and how they influence farmers' movement into agribusiness activities. Future studies could therefore examine skill development over longer periods and pay greater attention to the links between agricultural universities, extension agencies, incubators, markets and rural enterprises. The study contributes an integrated pathway for understanding how agricultural learning and capability development can support the transition from farmers to agripreneurs in India.

Keywords: Human Capital; Skills; Agricultural Education; Agripreneurship; Digitalisation

Economic Effect of Late Blight on Potato

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ABSTRACT

Potato late blight, caused by *Phytophthora infestans*, is one of the most destructive diseases of potato that can cause large yield losses and incur high production costs. Management of the disease is thus critical, especially during severe epidemics. The current study aimed to assess the economic importance of managing potato late blight using fungicides in terms of control of the disease and the cost of its applications. Field trials were conducted using late blight susceptible potato variety Kufri Sindhuri, and the results showed that fungicide application significantly reduced disease development and increased tuber yield as compared to the untreated plots. Among the various treatments tested, Dithane M-45 (mancozeb 75%) at 0.3% was found to be the best treatment for disease suppression, giving the lowest disease severity (2.4) with three sprays, and the highest tuber yield (6.08 kg per 4.5 m 2 plot) with four sprays. However, economic analysis revealed that two sprays of Dithane M-45 at 10-day intervals gave the highest benefit-cost ratio (1.54) and thus, further repeated spray was not justifiable on an economic front. The economic importance of managing late blight was further illustrated by the situation in the Columbia Basin where a severe epidemic led to significant increases in the use of fungicides and the associated costs of disease management. The study therefore emphasizes the need to have appropriate and economical fungicide spray schedules to ensure adequate suppression of the disease and reduction of yield losses without incurring huge control costs.

Keywords: Potato late blight; *Phytophthora infestans;* Economic effects; Benefit-Cost ratio; Yield loss; Fungicide management

Reimagining agricultural education and extension: building human capital for resilient agriculture

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ABSTRACT

Agriculture is moving away from resource-intensive production and toward sustainable systems that depend on knowledge. Agricultural education and extension have to change with it, so that rural people can cope with climate variability, market integration and technological disruption. This argues that agricultural education should be rethought around building human capital. Instead of the usual top-down transfer of technology, it proposes capacity building based on learning by doing, digital literacy and entrepreneurial skills. If university curricula and field-level extension methods took in climate-smart practices, value-chain dynamics and inclusive teaching, farming could become a more realistic and appealing option for rural youth. The role of the extension professional changes too. Rather than passing scientific information down to farmers, the extension worker facilitates community-led innovation, encourages critical thinking and helps peer learning networks form. Capacity has to be built at every level, in university classrooms and village meetings alike, because that is how research done in institutions reaches farmers who might adopt it. Judging whether these approaches work calls for reliable measurement scales and well-targeted survey instruments that pick-up changes in the knowledge, attitudes and skills of farming communities. Such instruments also give extension agencies evidence they can act on, and let them compare programmes across villages and over time. The approach is presented as a conceptual framework rather than a finished model, and it is meant to be tested and adjusted in different agro-ecological and institutional settings. Investing in the minds of farmers, agricultural graduates and extension agents is the most lasting investment the sector can make, and it supports an agriculture that holds up under pressure, with better food security and fairer rural incomes.

Keywords: Capacity building; Climate-smart agriculture; Digital literacy; Extension education; Human capital; Rural youth

Climate-Resilient Carbon Farming in South Asia: Soil Carbon Losses, Practice-Specific Sequestration Potential, Measurement Constraints, and the Human-Capital Agenda for Scaling

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ABSTRACT

Agrifood systems emit roughly 30% of anthropogenic greenhouse gases, and agricultural land use has depleted soil carbon stocks by an estimated 133 Pg C in the top 2 m. Carbon farming, the management of agricultural land to increase carbon removal and reduce emissions, is promoted as a way to recover part of this debt while building climate resilience. This review quantifies the problem and the opportunity. We summarise estimates of soil carbon loss, which depend strongly on method and boundary: historical reconstructions indicate losses above 0.3 Pg C yr^{-1} during the nineteenth century and about 0.13 Pg C yr^{-1} over the last century , whereas top-down regional estimates report net losses of up to about 0.5 Pg C yr^{-1} in the dry tropics. We then compile practice-specific sequestration rates, which are typically 0.2–0.6 t C ha^{-1} yr^{-1} for improved cropland management over two decades, equivalent to about 0.7–2.2 t CO_2-eq ha^{-1} yr^{-1}, with higher but less certain values for agroforestry. IPCC AR6 places the global potential of soil carbon sequestration in croplands and grasslands at 0.4–8.6 Gt CO_2-eq yr^{-1}, and an older assessment for India estimates a total potential of 39–49 Tg C yr^{-1}, of which about half (22–26 Tg C yr^{-1}) is secondary carbonate formation and only 6–7 Tg C yr^{-1} comes from improved management of agricultural soils. Three constraints qualify headline figures: shallow, fixed-depth sampling; the finite and dynamic stabilisation of mineral-associated carbon; and nitrous oxide feedbacks. We then examine measurement, reporting and verification (MRV), India's emerging carbon-market architecture, and evidence on knowledge gaps that limit adoption. We argue that human capital is the binding constraint on scaling, and propose a competency framework linking agricultural education, extension and MRV. Research priorities include long-term, deep-profile trials in the eastern Indo-Gangetic Plains (IGP).

Keywords: agricultural education; carbon farming; climate-smart agriculture; human capital; Indo-Gangetic Plains; MRV; soil carbon debt; soil organic carbon

Cultivating One Health: Reimagining Soil Health and Agricultural Education

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ABSTRACT

For over six decades, global agriculture has prioritized yield maximization through heavy reliance on synthetic NPK fertilizers and broad-spectrum agrochemicals. While this approach resolved mid-20th-century caloric deficits, it has triggered severe unintended consequences like soil biological degradation, crop nutrient dilution, groundwater contamination and escalating health issues including rising rates of cancer, infertility and metabolic disorders in both livestock and humans. Aligned with the World Health Organization's (WHO) One Health concept-an integrated, unifying framework that recognizes the health of humans, animals, plants and ecosystems as inextricably linked. This paper positions living soil as humanity's most vital non-renewable biological asset: the "next gold." It advocates for a shift from downstream disease management to upstream agricultural stewardship, mapping the unbroken continuum from soil microbiome vitality and plant nutritional synthesis to livestock health and human metabolic well-being. Modern biomedical evidence underscores that the functional health of the human gut microbiome directly mirrors the biological complexity of the rhizosphere. To operationalize WHO's One Health approach, agricultural education must undergo comprehensive reform. Reimagining human capital requires replacing input-centric training with interdisciplinary curricula that integrate advanced soil microbiology, regenerative agronomy, human nutrition and systems ecology. Elevating agricultural professionals from crop producers to key stewards of global public health provides a sustainable foundation to restore soil vitality, ensure nutritional security and cultivate a resilient future.

Keywords: Agriculture Education; Human Capital; Nutrient Density; One Health (WHO); Public Health Soil; Biological Health

Reimagining Indian Agriculture: TradiTech-led Transformation

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ABSTRACT

Seed selection in Himachal Pradesh's hill villages has traditionally run through informal, community-level channels, farmers holding back a portion of each harvest, trading varieties with neighbours, and passing judgement on what grows well where, based on years of direct observation rather than written records. Much of this knowledge lives in a shrinking number of older farmers, and as younger generations move toward wage labour or migrate out of hill districts, that transmission chain is thinning. At the same time, the advisory support available to smallholders on the ground, covering sowing dates, pest outbreaks, and irrigation timing, tends to arrive late or not at all, particularly on smaller and more remote terrace holdings. This paper asks whether formalising community seed banks and linking them to an AI-based advisory tool addresses both problems at once, rather than treating seed conservation and digital advisory as separate efforts. Under the model discussed, local seed varieties are documented and stored through community seed banks, with basic records kept on yield history, disease tolerance, and suitability to specific terrace conditions. Farmers accessing these seed banks are then connected to an advisory platform that uses this documentation, together with weather and soil data, to generate recommendations tailored to individual plots rather than generic regional advice. Cases from other Himalayan states where similar advisory tools have been piloted alongside seed-conservation efforts are used to weigh what has worked and where such pairings have struggled to scale. The paper argues that anchoring digital advisory in locally documented seed knowledge, instead of importing advisory systems built around commercial seed varieties elsewhere, gives farmers guidance that is more likely to match what they are actually growing, while also creating a practical reason for seed banks to stay active and maintained rather than falling into disuse.

Keywords: AI crop advisory; community seed banks; farmer knowledge documentation; Himachal Pradesh; hill agriculture; TradiTech

Cultivation of Human Capital for Sustainable Agricultural Transformation: A Review of Emerging Approaches

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ABSTRACT

Human capital plays a crucial role in enabling sustainable agricultural transformation by equipping farmers and agricultural stakeholders with entrepreneurial skills and knowledge to face emerging challenges. This review synthesizes literature across agricultural education, extension, and innovation systems to examine how strategic human capital investments drive productivity, climate resilience, and resource management. While capacity building consistently enhances technology adoption and farm outcomes, evidence reveals that expanding agricultural graduate numbers alone fails to translate into productivity gains without a strong pathway of knowledge to practice. The BRECR approach, which emphasizes brain re-engineering and reimagination has also been highlighted to alter perceptions of agriculture and to encourage new ideas. Overall, sustainable agricultural transformation requires not only technological solutions but also adaptable people who can effectively implement them; which is possible only after strengthening human capital through continuous learning, experiential training, digital tools, effective extension, and stronger links among educational institutions, research organizations, and farming communities.

Keywords: Agricultural education and extension, Entrepreneurial skills, Human capital investments, Technology adoption, The BRECR approach, Sustainable agriculture

Reimagining Agricultural Education and Extension: Competency-Based Human Capital Development for Sustainable Agricultural Transformation

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ABSTRACT

Sustainable agricultural development rests on the quality of human capital in farming systems, and building it demands a shift from technology transfer to competency development. Agricultural education, delivered through formal, non-formal, and informal channels, generates knowledge and skills that mature into technical, managerial, digital, entrepreneurial, and socio-emotional competencies. These consolidate as human capital, which raises extension effectiveness and translates into farmer and rural outcomes such as technology adoption, productivity, income diversification, market linkage, nutritional security, empowerment, and climate resilience. Realising this pathway calls for competency-gap and training needs assessment, outcome-based curriculum reform, experiential and problem-based learning, and continuous professional development of extension personnel in facilitation, digital advisory, and climate-smart practices. Participatory approaches such as farmer field schools, farmer-to-farmer extension, demonstration plots, and community-based learning strengthen local knowledge exchange, while ICT-enabled and blended models, including mobile advisories, social media, and AI-supported decision tools, widen reach and personalise learning. Gender-responsive and youth-inclusive design, agripreneurship and start-up incubation, and the role of farmer producer organisations and self-help groups extend the benefits to women, youth, and smallholders. Convergence among research, education, extension, the private sector, and policy institutions, in line with the agricultural knowledge and innovation systems (AKIS) perspective, further supports coordinated action across value chains, natural resource management, and rural livelihoods. Monitoring, evaluation, and learning built on competency-based and impact-oriented indicators complete the feedback loop. Reimagining agricultural education in this way positions extension as a driver of human capital formation, empowering farming communities and securing sustainable agricultural futures.

Keywords: Agricultural education, Digital agriculture, Extension effectiveness, Human capital, Participatory extension, Sustainable agricultural development

Reimagining Agricultural Education in India: A Competency-Based Framework for Innovation, Entrepreneurship, and a Future-Ready Agricultural Workforce

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ABSTRACT

Agriculture remains central to India's economic and social development, employing 46.1% of the country's workforce while contributing nearly one-fifth of national income at current prices. This employment–productivity relationship highlights the critical need for a highly skilled, innovative, and future-ready agricultural workforce. The transformation of agriculture through climate change, artificial intelligence, precision agriculture, biotechnology, digital technologies, automation, changing food systems, and emerging agribusiness models demands a corresponding transformation in agricultural education. The Indian Council of Agricultural Research (ICAR) has identified strengthening the quality, relevance, and human-resource capacity of agricultural higher education as a key priority, with emphasis on innovative teaching, research, and outreach. However, the challenge is not merely to produce more graduates, but to develop competent problem-solvers, entrepreneurs, researchers, innovators, and change-makers capable of translating scientific knowledge into field-level solutions. Initiatives such as the National Agricultural Higher Education Project have emphasized practical education, modernized infrastructure, industry–academia linkages, skill development, entrepreneurship, incubation, and exposure to emerging areas of agriculture. The future agricultural education system therefore needs to shift from a predominantly degree-oriented approach towards competency-, innovation-, and impact-oriented learning. Experiential learning, farmer-centric research, multidisciplinary curricula, internships, start-up incubation, digital literacy, data analytics, artificial intelligence, entrepreneurship, and stronger university–industry–farmer partnerships should become integral components of agricultural education. This approach is also aligned with the direction of NEP 2020, which emphasizes multidisciplinary education, skill development, innovation, and the integration of knowledge with emerging technologies. Globally, FAO emphasizes that investment in agricultural human capital is fundamental to building resilient, sustainable, and climate-smart agrifood systems. Education, technology, science, and supportive policies can further strengthen youth participation and innovation across agrifood systems. This paper therefore proposes a future-oriented framework for reimagining agricultural education based on five interconnected pillars: (i) competency-based and experiential learning, (ii) digital and emerging technologies, (iii) entrepreneurship and innovation, (iv) industry–academia–farmer partnerships, and (v) inclusive human-capital development. Such an approach can transform agricultural students from job seekers into knowledge creators, entrepreneurs, innovators, and solution providers, ultimately contributing to a more productive, sustainable, and resilient agricultural sector.

Indian Agriculture in Transition: Challenges, Opportunities and Future Prospects

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ABSTRACT

Indian agriculture is experiencing significant transformation due to globalisation, technological advancement, climate change, evolving consumer preferences, and the growing integration of domestic and international markets. Traditionally, agricultural policies in India have focused on food security, price support, subsidies, rural employment, and protection of farmers' livelihoods. Although these measures have contributed to agricultural development, the sector continues to face challenges such as fragmented landholdings, market instability, inadequate infrastructure, limited access to institutional finance, post-harvest losses, and climate-related risks. These challenges require a transition from conventional support-based policies toward a more market-oriented, innovative, and sustainable agricultural framework. Government initiatives have improved access to credit, technology, infrastructure, and markets, but small and marginal farmers often remain excluded from profitable value chains. Agricultural development has also tended to emphasise physical assets and financial assistance while giving comparatively less attention to entrepreneurship, managerial skills, digital literacy, market intelligence, and human capital development. Strengthening these capabilities is essential for creating sustainable and competitive farming enterprises. A more effective approach requires greater collaboration among government, private enterprises, cooperatives, Farmer Producer Organisations (FPOs), and farming communities. The state should act as a developmental facilitator by correcting market failures, improving infrastructure, promoting investment, and strengthening agricultural risk-management systems. Farmers can be supported through market linkages, affordable finance, crop insurance, technical training, digital advisory services, and mentorship. Furthermore, Indian agribusinesses and FPOs must adopt professional management, technology, value addition, food processing, and export-oriented strategies. Re-imagining Indian agriculture therefore requires integrating public policy, market opportunities, entrepreneurship, innovation, and human capital development to improve farmers' incomes, strengthen food security, promote rural prosperity, and achieve sustainable agricultural growth.

Keywords: Inadequate, Strengthening, Agribusinesses, Capabilities

Reimagining Indian Agriculture: TradiTech-led Transformation

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ABSTRACT

The hill agriculture systems of Himachal Pradesh, shaped over centuries around terrace farming, traditional seed conservation, and agroforestry, are increasingly threatened by soil erosion, erratic rainfall, and declining farm productivity linked to climate change. This study examines "TradiTech" the deliberate integration of indigenous hill-farming knowledge with modern agricultural technology as a targeted solution to these challenges, using the terraced and mid-hill farming belts of Himachal Pradesh as the primary reference context. The core problem addressed is twofold: first, the gradual erosion of traditional practices such as community seed banks, terrace bunding, and mixed cropping, which historically conserved soil and water in fragile hill terrain; and second, the slow uptake of modern precision tools among smallholder hill farmers owing to cost, terrain constraints, and limited digital literacy. This study proposes a specific TradiTech pairing as its central model: traditional community seed banks combined with AI-based crop advisory systems. In this model, indigenous seed varieties preserved through generations-old community seed-saving practices are catalogued and matched with AI-driven advisory platforms that provide localized recommendations on sowing windows, pest alerts, and micro-climate-based irrigation for terrace fields, thereby retaining genetic diversity and climate resilience while improving decision-making precision for farmers. Complementary interventions are also discussed, including low-cost IoT soil-moisture sensors suited to terrace plots and drone-based mapping for erosion-prone slopes, both designed to work alongside, rather than replace, existing traditional land-management practices. The paper draws on documented experiences from hill-farming communities and government-backed horticulture and watershed programmes in the region to assess feasibility. The study concludes that a seed bank-AI advisory TradiTech model offers a scalable, low-cost, and culturally grounded pathway to reversing soil degradation and yield instability in the hill agriculture of Himachal Pradesh, while preserving indigenous crop diversity. This region-specific approach demonstrates how TradiTech can move beyond broad conceptual application toward a replicable model for climate-resilient hill farming across the wider Himalayan belt.

Keywords: AI crop advisory, climate resilience, community seed banks, hill agriculture, Himachal Pradesh, TradiTech

TradiTech: Integrating Traditional Agricultural Wisdom with Modern Technologies for Sustainable and Climate-Resilient Indian Agriculture

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ABSTRACT

Indian agriculture has always been the backbone of our economy, but today it stands at a turning point. On one hand, we have generations of traditional farming wisdom passed down through families. On the other, we have new technologies that promise higher yields, better efficiency, and smarter decision-making. This paper looks at how combining the two, referred to here as TradiTech, can help address many of the problems faced by Indian farmers today. For centuries, Indian farmers have used practices like crop rotation, mixed cropping, natural composting, and traditional water-harvesting methods such as johads and zabo farming. These methods work in harmony with nature and have kept the soil healthy for generations. However, with a growing population, unpredictable weather, and shrinking farmland, traditional methods alone are no longer sufficient to meet current demands. At the same time, purely technology-driven farming often overlooks local knowledge and can be costly or difficult for small farmers to access. This paper argues that instead of replacing tradition with technology, the two should be blended together. Simple tools such as soil sensors, weather-based mobile alerts, AI-based crop advisory systems, and apps connecting farmers directly to buyers can be layered onto traditional practices rather than replacing them. Drawing on examples from states such as Punjab, Karnataka, and Odisha, this study shows how small and marginal farmers using native seeds alongside drip irrigation and mobile market linkages achieved better yields, lower input costs, and higher income, while also preserving local biodiversity. The paper further discusses measures needed to scale this approach, including digital literacy programs for farmers, improved rural internet connectivity, and government schemes supporting hybrid farming models. In conclusion, the future of Indian agriculture does not lie in choosing between old and new methods, but in thoughtfully combining both, ensuring food security for the country while protecting its environment and cultural roots.

Keywords: agri-tech; digital farming; precision farming; rural development; sustainable agriculture; traditional knowledge

Tradition Meets Technology: A TradiTech Approach to Sustainable and Climate-Resilient Agriculture in India

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ABSTRACT

Across Himachal Pradesh's hill and dryland tracts, farmers have long timed sowing, irrigation, and pest management using cues drawn from close observation rather than instruments: the flowering of particular shrubs signalling the onset of pest activity, the behaviour of local birds and insects hinting at rainfall, and generation-old sowing calendars adjusted to a specific slope, aspect, and soil type. This body of agro-ecological knowledge is rarely written down, and as older cultivators age out of active farming and fewer younger family members remain on the land, much of it is at risk of being lost before it is ever recorded. In parallel, AI and machine-learning advisory tools reaching Indian farmers are increasingly built on satellite, weather-station, and generic agronomic datasets that are rarely calibrated to the microclimates of terraced or rain-fed hill plots, leaving their recommendations poorly matched to what farmers actually observe on the ground. This paper examines whether systematically documenting indigenous agro-meteorological and pest-management indicators, and using them as structured inputs alongside sensor and satellite data, can make AI/ML-based advisory both more locally accurate and more trusted by the farmers it is meant to serve. Under the model proposed, participatory documentation exercises are used to record local indicators village by village, which are then encoded as features that inform or adjust machine-learning advisory outputs for sowing dates, irrigation scheduling, and pest alerts on a plot-by-plot basis. Early pilots of similarly hybridised advisory tools in other Himalayan states are reviewed to identify where such integration has improved farmer uptake and where purely data-driven tools have struggled to gain trust. The paper argues that treating indigenous knowledge as a live input to AI advisory, rather than as heritage to be archived separately, produces recommendations farmers are more willing to act on, while also giving communities a continuing incentive to document and pass on practices that would otherwise fade from use.

Keywords: AI/ML crop advisory; farmer knowledge documentation; hill agriculture; Himachal Pradesh; indigenous agro-meteorological knowledge; TradiTech

Reimagining Agricultural Education in India: Building Human Capital through Skill Development, Innovation, and Inclusive Learning for Sustainable Agricultural Development

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ABASTRACT

Agricultural education plays a pivotal role in shaping human capital, a key determinant of agricultural productivity, rural livelihoods and sustainable development. Despite India's dependence on agriculture for employment, the sector faces low productivity, skill gaps, limited technology adoption and youth disengagement from farming. This paper examines the role of agricultural education in building human capital and explores ways of reimagining it to meet emerging challenges. The study draws on secondary sources, including government reports, policy documents and published research, within the framework of human capital theory. A descriptive and analytical approach is used to synthesise evidence on education, skills, technology adoption and rural livelihoods. The analysis shows that conventional agricultural education remains largely theory-oriented, with weak linkages among classrooms, research institutions, farmers and markets. Women, small and marginal farmers and rural youth remain underserved by existing training and extension systems. Investment in quality education, vocational training, extension services and digital learning, including mobile advisory services and farmer field schools that extend learning to remote areas, improves farmers' decision-making, adoption of innovations, income and resilience to climate and market risks. The paper emphasises curricula integrating experiential learning, entrepreneurship, agribusiness management, climate-smart practices and information and communication technologies. Strengthening public–private partnerships, institution–industry collaboration and inclusive access for women, small farmers and rural youth are identified as essential strategies. The study concludes that reimagining agricultural education as a dynamic, skill-based and innovation-driven system can make agriculture an attractive and profitable career, enhance rural employment and contribute to food security and inclusive growth. Policy implications include aligning education with the National Education Policy 2020, expanding practical training facilities in regional institutions and developing continuous capacity-building programmes for farmers, with regular monitoring and evaluation to ensure the quality and relevance of programmes. Such an approach will cultivate not only crops but also minds, empowering future generations and ensuring a resilient, knowledge-based agricultural economy.

Keywords: Agricultural education; Food security; Human capital; Rural development; Skill development; Sustainable agriculture

Reimagining Agricultural Extension as A Lifelong Learning System: Farmer Field Schools, Peer Learning and Fpo-Based Training in India

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ABASTRACT

Agricultural extension in India has long functioned as a one-way transfer of technology from research institutions to farmers, an approach ill-suited to climate variability, volatile markets and fast-changing digital knowledge. This paper reviews published secondary evidence, drawing on peer-reviewed studies, impact evaluations and policy reports, to examine how extension can be reimagined as a lifelong learning system in which farmers are continuous learners rather than periodic recipients of advice. Focusing on Indian and comparable South Asian contexts, the review analyses three complementary models: farmer field schools (FFS), peer and video-mediated learning, and farmer producer organisation (FPO) based training. It applies adult learning theory and the "best-fit" framework for pluralistic advisory services. The evidence suggests that FFS build knowledge and experiential learning effectively but are resource-intensive and show uneven benefits across gender and wealth groups. Peer and video-based models extend reach and trust at low cost: Digital Green's trials reported markedly higher adoption than conventional extension and favourable cost-effectiveness, while Uttar Pradesh's Million Farmers School shows that structured mass training can improve farmer knowledge. FPOs offer a durable institutional base linking learning to inputs, credit and markets, yet their extension capacity remains uneven and evidence on their training outcomes is largely descriptive. Evidence on long-term behavioural change and gender equity remains thin. We argue these models work best when integrated: FFS for deep learning, peer networks for diffusion, and FPOs for continuity and economic relevance. The paper proposes a framework for a lifelong learning extension system built on learning pathways, skill certification, blended physical-digital delivery, and convergence with agricultural universities, Krishi Vigyan Kendras and ATMA. Implications include investing in facilitator capacity, inclusive and youth-friendly formats, and monitoring learning outcomes rather than training numbers. Reframing extension as a continuous, community-anchored learning ecosystem is essential to build the human capital needed for resilient, profitable and sustainable Indian agriculture.

Keywords: agricultural extension, lifelong learning, farmer field schools, peer learning, farmer producer organisations, human capitals

Bridging the Farm-to-Plate Gap: Towards an Equitable and Resilient Food System

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ABSTRACT

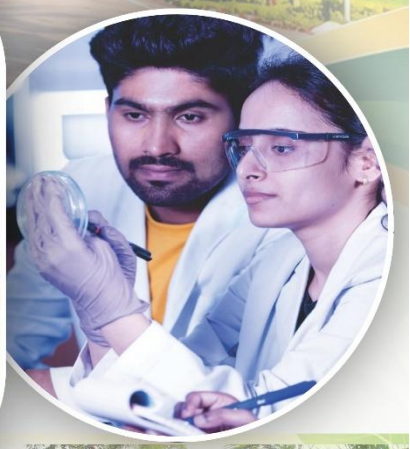
Today, our food systems stand at a critical crossroads. Despite producing enough to feed the world, we face deep-rooted challenges aging farming communities, economic instability for smallholders, disconnected consumers, and limited career pathways for the next generation. "One Table, One Future" envisions a transformed agri ecosystem where everyone from the soil to the plate shares a connected, equitable, and sustainable journey. This model bridges the generational and supply-chain gaps by bringing farmers, tech savvy youth, and conscious consumers together around a single table of shared value. For farmers, it offers digital market access, fair pricing, and regenerative training to boost resilience. For youth, it unlocks exciting opportunities in agritech, sustainable supply chains, and green entrepreneurship, reframing farming as a modern, high-impact career. For consumers, it fosters deep transparency, reconnecting them with the origin of their food and empowering them to make health- and planet-conscious choices. By merging traditional farming wisdom with modern innovation, this inclusive ecosystem drives circular local economies, cuts food waste, and secures a thriving food future for all. Ultimately, it proves that when we share the table, we share the responsibility and the rewards of feeding our world right.

Key Words: Agri Ecosystem, Sustainable Agriculture, Youth in Agriculture, Farm to Table, Food Transparency, Agricultural Innovation.









SHUATS

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UGC UNDER SECTION 2(f)
Recognized under Section 2(f) of the UGC Act, 1956

23 CROP VARIETIES DEVELOPED
High yielding, climate resilient, disease resistant varieties of wheat, rice, maize, linseed, moong and chickpea

16 VARIETIES NOTIFIED
by Ministry of Agriculture and Farmers Welfare, Government of India for seed production and general cultivation

1,050+ RESEARCH PUBLICATIONS (2023–24)
Indexed in Scopus, Web of Science, Google Scholar, SCI, ICI, CiteSeer and other peer-reviewed journals

45 EXTERNALLY FUNDED RESEARCH PROJECTS
ICAR / DBT / DST / UP-CST / Ministry of Agri. / Novod Board / UPCAR etc.

56 MoU's (NATIONAL)
with reputed institutions, universities and research organizations

35 MoU's (INTERNATIONAL)
with international universities and research organizations

130 Ph.D. DEGREES AWARDED (2023–24)
in Agriculture, Agricultural Engineering, Home Science, Forestry, Food & Dairy Technology, Animal Husbandry and Biotechnology

291 PG & Ph.D. SCHOLARS ON NATIONAL FELLOWSHIPS
ICAR, UGC, DST, Rajiv Gandhi, Maulana Azad, INSPIRE and other fellowships

12 PATENTS
15 Crop Variety Registrations

SPECIALIZED LABORATORIES
Seed Testing, National Referral, Food Processing, Tissue Culture, Nano-Technology, Remote Sensing & GIS and more

FARM MECHANIZATION
Development & popularization of farm implements for small and marginal farmers

INNOVATIONS & TECHNOLOGIES
Solar E-Rickshaw, Portable Solar Generator, Air Quality Monitoring System, 3-D Printer, Electricity from Farm Waste, Bamboo Flute Technology and more

SEED PRODUCTION
5000 q Wheat, 4000 q Paddy, 200 q Pulses & Oilseeds
Produced through farmers' participation and supplied to Govt. of U.P.

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By State Government, ICAR, UPCAR and National-International Societies and Professional Bodies

GOSPEL AND PLOUGH
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Banda University of Agriculture and Technology, Banda 210001, UP, India



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ICAR NAAC IIRF

UNIVERSITY AT A GLANCE

Total Area: 948 Acres

UG Programmes: 07 | PG Programmes: 16

Ph.D. Programmes: 14 | Students: 1634

Faculty Members: 138+ | Residential Campus: 100%

CONSTITUENT COLLEGES

1. College of Agriculture
2. College of Horticulture
3. College of Forestry
4. College of Community
5. College of Food Technology
6. College of Agricultural Engineering & Technology
7. College of Veterinary & Animal Sciences

SPORTS FACILITIES

Stadium | Gymnasium

Running Track | Sports Ground

RESEARCH & INNOVATION

05 Research Stations | 07 KVKs

05 Centres of Excellence

Central Lab Facility & Library

04 Genetic Stocks | IPR: 07

BUAT Til-1

BUAT Alsi-3

BUAT Alsi-4

BUAT Alsi-5

Banda Alsi-1

Ken Swadisth (Spong gourd)





Varieties Released

AARAMMBH

AGRI-BUSINESS INNOVATION AND INCUBATION CENTRE

Agriculture and Allied Sector, Rural Area Based Micro and Medium Businesses Hub

What AARAMMBH offers?

- Pre-incubation and incubation support
- Mentoring and handholding for agri-startups
- Networking with industry and academia
- Co-working space for incubatees
- Access to laboratories and technical facilities
- Funding and grants opportunity
- Idea generation to market launch, pitching and venture connect
- Capacity building and technological support

FOCUS AREAS

Incubation Facility



Chaudhary Charan Singh Haryana Agricultural University

Hisar–125 004, Haryana, INDIA

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Inspiring Agripreneurs



Prof. B.R. Kamboj
Vice-Chancellor
CCSHAU, Hisar

A Premier Institution for

Carrier Opportunities in

AGRICULTURE and ALLIED SECTORS

The University offers (Degree Programmes)

9 Under Graduate

47 Masters

42 Ph.D.

Prestigious Academic Establishment of High Repute

- Full Fledged University Since 1970
- Quality Research, Teaching and Extension
- State of the Art Infrastructure
- High-tech laboratories
- World Class Sports Facilities
- Wi-Fi connected campus
- One of the most beautiful campuses in India with a lot of biodiversity both in terms of flora and fauna.
- Research on Natural farming
- All the hostels have solar water system
- 7 Community Radio Stations in various districts

- Twice Recipient of ICAR Best Institution Award
- First Stop for International Students
- First Recipient of Haryana Kisan Ratna Award
- Among the Top Ranked Agricultural Universities of the Country
- Best ABIC of the country Award 2021
- All India Champion of Agriculture Sports Meet 2017 and 2023

Constituent Colleges

- ✓ College of Agriculture, Hisar
- ✓ College of Agriculture, Bawal
- ✓ College of Agriculture, Kaul
- ✓ College of Basic Sciences and Humanities
- ✓ College of Biotechnology
- ✓ Indira Chakravorty College of Community Sciences
- ✓ College of Agricultural Engineering &Technology
- ✓ College of Fisheries Science
- ✓ Institute of Business Management and Agripreneurship, Gurugram

The faculty of this university have served on various coveted positions such as Director General (ICAR), Chairman (ASRB), Advisor (Planning Commission), Vice-Chancellors, Deputy Director General (ICRISAT), Deputy Director Generals (ICAR), Directors of National Institutes etc. Alumni of this university are working all over the world and are holding important positions in administration of various sectors.

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Facebook link:- https://www.facebook.com/Chaudhary-Charan-Singh-Haryana-Agricultural-University-Hisar-1073782446062928/
YouTube link:- https://www.youtube.com/channel/UCoHPHYtc3-9AC20oOMaBQzw?view_as=subscriber



FSII is an association of research based plant science industry committed to deliver quality seeds for farmers.

Alliance for Agri Innovation, a special interest group of FSII, promotes technology innovations in agriculture.

FSII India
india.fsii
www.fsii.in

AllianceAgri
Agrinnovation.india
www.agrinnovation.in

GBPUAT, PANTNAGAR

Knowledge | Innovation | Sustainable Agriculture

Growing for a Greener Tomorrow

Salient initiatives/achievements of
RISING PANTNAGAR

1 BRAIN 3.0 Vision – AI-Enabled University

Vice-Chancellor Dr. S.K. Kashyap launched BRAIN 3.0 (Boosting Research, Academics, Innovation and Networking). Attended by illustrious alumni of the university from all colleges. Early outcome - series of 5-day Faculty Development program "AI for Educators: Basics to Practice" led by FDC mentored by alumnus Vaibhav Dobriyal, LUMIQ. Aim to make Pantnagar India's first AI-ready agri university.

2 9 New Climate-Smart Varieties Released

3 varieties one each of wheat, Barley and Field pea cleared by CVRC- Pant Gehun 3145 (Biofortified-protein 12.6%, Fe content 43.85ppm, Zn 36.0ppm, Glu-1 score 10), Pant Jau 1121 (a hulless variety with low glycemic index -suitable for diabetic patients), Pant Pea 574 (resistance to powdery mildew & rust); 6 varieties cleared by State Seed Sub-Committee - Pant Dhan 29 (115 days, 50 q/ha), Pant Jau 1091 (21% higher yield, rust resistant), Pant Hybrid Maize 9, PRB 2015-2 Mustard, Pant Chari 16 and Pant Oat-5 - for food and fodder security. VC termed it major step to raise farmer income.

3 Bharat Ratna Sri Nanaji Deshmukh Abandoned Cattle Conservation and Research Project -65 Acres

Flagship initiative announced by the Vice-Chancellor-developing cattle-based self-employment model. Research on cow dung for organic fertilizer, biogas, vermicompost, natural paint, incense, handicrafts to solve stray cattle crisis and create rural economy.

4 Rs. 28 Crore Campus & Village Road Overhaul

The Vice-Chancellor announced reconstruction of ~30 km roads with Chief Minister Shri Pushkar Singh Dhami approval, including concrete roads in Nagla, Beni, Pattharchatta, Matkota and 2-meter interlocking footpaths on College Road/Hostel Road. Work tendered.

5 Industry-Academia MoUs for Smart Farming

Three major MoUs signed in the presence of the VC in Sept 2026:

a) TERI, New Delhi - mountain agriculture, climate-resilient farming, startup promotion
b) Roshni Agri Information Pvt Ltd, Mohali - AI, Satellite Technology & Precision Agriculture
c) MoU for traditional knowledge & food systems. VC stated *"linking research with needs of society"*.

6 Uttarakhand Agri-Roadmap Formation

The University has been given the responsibility of formation of Uttarakhand Agri-Roadmap-2047under the chairmanship of the Vice-Chancellor in which University and the Government officials are working together.

7 Harit Yagya

Green Campus Mission: Resolved to celebrate Uttarakhand's Harela Festival as "Green Yajna / Harit Yagya" from 16-31 July 2026. Plantation along university farms, thousands of plants sown across the campus and out-campus.

8 Historic Kisan Mela as Economic Platform

Reoriented Kisan Mela from only seed distribution to economic opportunity - VC reported turnover of Rs. 2 Cr by University seeds/planting material and Rs. 12-15 Cr by private agri-businesses, with farmers from UP, Rajsthan, Panjab, Haryana, Bihar and other states and Nepal. Focus on market linkage.

ASSAM AGRICULTURAL UNIVERSITY

(The Glorious University)

Since 1969



FACULTIES & COLLEGES



AAU currently has

1. Two Faculties
2. Six Constituent Colleges
3. Six Zonal Research Stations
4. Three Commodity Research Stations
4. 23 KVKs
6. 20,000+ Allumni Strength

EDUCATION & STUDENT DEVELOPMENT

Programme	Enrolled (2025–26)	Passed out (2025–26)
Bachelor's Degree	475	371
Master's Degree	209	193
Ph.D. Degree	55	64
Total	739	628

68 skill courses are running in the University.

Open Distance Learning (ODL)
1800 learners completed 37 different Short & Certificate Courses

Atal Incubation Centre
Incubated 250 ventures accross eight Northeast States

RESEARCH, INNOVATION & COMMERCIALIZATION

- Total AICRPs/AINPs: 43
- Total ad-hoc projects: 90
- Patents obtained by AAU: 5
- Technologies commercialized in the last 5 years: 10

AMIU
Established 2021 for product processing and marketing of AAU Select brand product

Technologies for commercialization

- Xaaj Pani
- Purple Rice – Labanya
- Beverage Powder of Elephant Apple Juice
- EPF bioformulations of BP organic and IP organic
- *Isaria javanica* microbial biopesticides
- *Trichoderma harzianum*
- Additive Free Fresh Assam Lemon Juice









EXTENSION & FARMER OUTREACH

Extension is led through **23 KVKs** and *1 Agricultural Technology Information Centre* (ATIC).

Farmers and rural youth reached in the last 10 years:

87,29,269







RESEARCH NETWORK & COLLABORATIONS

Research Network

Director of Research (Agriculture) coordinates research in Agriculture and Community Science.

GI Tag received

1. Joha rice	2017
2. Assam lemon	2019
3. Chakua rice	2020
4. Judima	2021
5. Gamocha	2022

Funding Collaborations

International: NIBIO, GIZ, UN-WEP, CABI, IRRI.

National: ICSSR, DBT, DST, NABARD, NIF, ISRO, ASTEC, BRNS, CITH, NEIAFMR, SERB, NMPB, NCIPM, DSIR, NBB, ASBB, IISR, etc.

Govt. of Assam projects: RKVY, Natural Farming, SITA, Char Area Development

TECHNOLOGIES COMMERCIALIZED IN LAST 5 YEARS

Name of the firm	Technology Transferred	Date
Shri Deepjyoti Dowari, Sivasagar	Xaaj Pani	05.03.2021
One Horn Brewery Pvt. Ltd., Chirang	Xaaj Pani	20.09.2022
Nilachal Agriscience LLP	Purple Rice-Labanya	19.10.2022
Bhargav Jyoti Roy, Barpeta	Xaaj Pani	07.11.2023
Phukan Heritage Breweries	Xaaj Pani	10.05.2024
R2W Bio-Solutions & Engineering Pvt. Ltd.	Beverage Powder of Elephant Apple Juice	06.06.2024
Green Harvest (India) Bio-Tech Pvt. Ltd., Guwahati	EPF bioformulations of BP organic and IP organic	18.03.2025
Greengen Agri Biotech Pvt. Ltd., Dibrugarh	Isaria javanica (IP organic) microbial biopesticides	13.08.2025
Prantika CLF Primary Cooperative Society Ltd.,TSK	Trichoderma harzianum	13.08.2025
Trinity Fructa Pvt. Ltd., Mangaldoi	Additive Free Fresh Assam Lemon Juice	05.12.2025

AWARDS & RECOGNITION



- ★ Sardar Patel Outstanding Institution Award
- ★ Agriculture Leadership Award
- ★ Best Zonal KVK Award
- ★ Fakhruddin Ali Ahmed Award
- ★ Awards for Best AICRP/AINP Centres
- ★ Best Farmer Award & Others

PRIORITY THRUST AREAS

- Organic & natural farming
- Smart irrigation with renewable energy integration
- AI & sensor-based technology research
- Climate-smart agriculture and efficient nutrient delivery
- Agripreneurship and startup promotion
- Microbial bioformulations and tissue culture planting materials



HyFarm

The Agribusiness Unit of HyFun Foods

Transforming Agriculture Empowering Farmers



HyFarm, The Agribusiness Unit of HyFun Foods, strengthens farmer partnerships through advanced Seed to Shelf model. Integrating **IoT-driven precision farming and AI-powered Real-time Quality Assessment** to reduce costs and increase productivity. These initiatives optimise irrigation, fertigation, efficient pest & disease management, reinforcing our focus on regenerative agricultural practices.

With a mission to collaborate with **20,000 farmers** to produce **One Million Metric Tonnes of Potatoes** by 2028, HyFarm is driving sustainability and technology-led growth in Indian agriculture.



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राजमाता विजयाराजे सिंधिया कृषि विश्वविद्यालय ग्वालियर (म.प्र.)

जैव प्रौद्योगिकी केन्द्र

ऐरोपोनिक्स (मृदा रहित खेती)

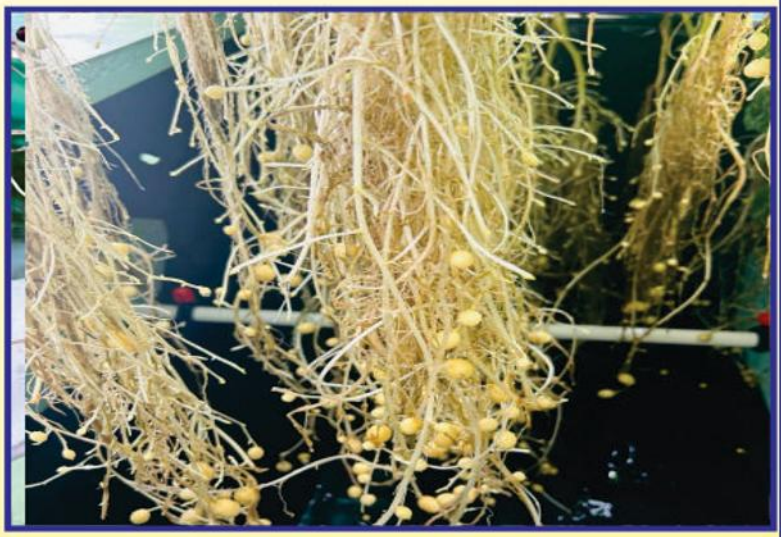
ऐरोपोनिक्स तकनीक के माध्यम से टिश्यू कल्चर द्वारा रोग मुक्त आलू के बीजों/कंदो का उत्पादन

- ऐरोपोनिक तकनीक पौधों की जड़ों को बिना मिट्टी के हवा में लटकाकर पोषक तत्वों का वाष्प के रूप में छिड़काव किया जाता है।
- ऐरोपोनिक प्रणाली में पौधों की जड़ो को हवा मे पोषक तत्वों के घोल का छिड़काव किया जाता है।
- पारंपरिक खेती की तुलना में ऐरोपोनिक पद्धति में 90% तक कम पानी की आवश्यकता होती है
- आलू के बीज से रोग मुक्त पौधे एवं 10 प्रतिशत अधिक उत्पादन
- इस विधि से बीजोत्पादन उन क्षेत्रों में भी किया जा सकता है जहाँ पर जुताई योग्य मिट्टी उपलब्ध नहीं है ।









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Central Agricultural University, Imphal - 795004, Manipur, India

- Year of establishment : 1993
- 13 constituent colleges with 6 KVKs and 6 MTTCs & VTCs spread across 7 North Eastern States of India
- 10 UG, 51 PG, and 37 Ph.D programs in Agriculture and Allied sciences
- Designated as Center of Excellence in Natural Farming under NMNF by MoA&FW, GoI
- Launched B.Sc. (Hons) Natural Farming in 2023
- 3,093 students with a 1:1.39 male-to-female ratio from all 28 states with successful graduation 8226 students along with 16 foreign students from 8 countries.
- 128 alumni working as ARS scientists.
- Skill mapping under NEP-2020 with publication of Compendium of Skill Sets manual & 10 nos of Policy documents
- Exploring new dimensions in agricultural innovation—from drones and bio-resources to traditional knowledge and food technologies by collaborations with Regional, National & International Institutions
- Released 8 region-specific rice varieties, 1 groundnut, 1 soybean & 1 cassava variety
- Secured 66 patents, developed 38 prototypes, 7 copyrights and 06 technologies were licensed and commercialized.
- Established a BSL-II Laboratory for transboundary animal diseases, 5G Lab and 3D Printing Laboratory,4 Centre of Excellences on Honey bee, Millets, Fisheries and Aquaculture, and Oil Palm & a state-of-art Pesticide Residues Analysis Laboratory.
- Implemented 60 FPO's & Nurtured 115 startups across the NEH region via RKVY-RAFTAR.
- Mobile-based Agro Advisory System connecting over 44,259 farmers across 53 districts and 2,000+ villages in the region with 1.48 lakh advisories issued so far
- 19 nos. of Satellite Villages/ Chemical Free Villages.
- Implemented "ADITYA PRABHA Gram" project sanctioned by NEC (M-DoNER) GOI, for sustainable agricultural development, livelihood enhancement, and rural prosperity across selected border districts of Arunachal Pradesh and Sikkim.















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Rani Lakshmi Bai Central Agricultural University

Jhansi – 284 003, Uttar Pradesh, INDIA

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5 Constituent Colleges	**6** Under Graduate	**36** Masters Programmes	**28** Ph.D. Programmes	**1,351** Students on Roll

A Young University of National Importance with World-class Facilities

- ☐ **Mandate:** Teaching, Research, Extension & Training for Bundelkhand (14 districts of U.P. & M.P.)
- ☐ **850-acre multi-campus** presence at Jhansi, Datia, Morena & Niwari
- ☐ **22 state-of-the-art central laboratories** & Central Instrumentation Facility
- ☐ **Speed Breeding Facility** and Plant Genetic Resources Centre with >16,000 germplasm accessions
- ☐ **Centres of Excellence** – Nutri-cereals (Millets), Natural & Organic Farming, Mushroom, Honey Processing; Incubation Centre for agri-startups; Centre of Geospatial Science & Technology
- ☐ RFID-enabled Central Library, e-library, smart classrooms, 24×7 Wi-Fi campus
- ☐ NEP-2020 aligned, inter-institutional & inter-disciplinary programmes; MoUs with >50 institutions

- ● **Krishi Vigyan Mandapam** – 700-seat auditorium; **77,500 sq ft Veterinary Clinical Complex** at Datia
- ● Modern Boys' & Girls' Hostels (expanding to 3,000 students), Sports Complex, Swimming Pool, Guest House & Farmers' Hostel
- ● **Green, net-zero campus** – 50% solar energy, >5,000 trees, arboretum & Biodiversity Park; recognised Agri-Tourism site by U.P. Tourism
- ● Students from **28 States/UTs** – a "Mini India"; strong placement, NSS & student READY programmes
- ● Kabuli chickpea varieties **RLBGK 1 & 2** and machine-harvestable **RLBMH 4**; 200+ NAAS-rated research papers
- ● Linkages with ICRISAT, ICARDA, CIMMYT, IRRI & ICAR institutes; 47 FPOs; Mobile Plant Health Clinic, Radio Pathshala & Bundeli Vipdan app; 25,000+ farmers at Kisan Melas

Constituent Colleges & Programmes

- ✓ **College of Agriculture, Jhansi** – B.Sc. (Hons.) Agriculture; M.Sc. in 11 disciplines; Ph.D.
- ✓ **College of Horticulture & Forestry, Jhansi** – B.Sc. (Hons.) Horticulture & Forestry; M.Sc.; Ph.D.
- ✓ **College of Horticulture, Morena** (M.P.)
- ✓ **College of Veterinary & Animal Sciences, Datia** – B.V.Sc. & A.H. (5½ yrs, 80 seats)
- ✓ **College of Fisheries, Datia** – B.F.Sc. Fisheries Science


Krishi Vigyan Mandapam (700 seats)


Veterinary Clinical Complex, Datia


State-of-the-art Central Laboratories


Convocation of the University

Inspiring an academic community for innovation & invention – developing emerging technologies, employability and enterprise for the farmers and youth of Bundelkhand and the nation.

DR. RAJENDRA PRASAD CENTRAL AGRICULTURAL UNIVERSITY

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14th
NIRF 2025
Agriculture & Allied Sectors

8th
IIRF 2026
Agriculture & Horticulture

100%
MBA Agribusiness & Rural Management Placement

100%
Natural Farming Programme First-batch Placement

AIR 1
ICAR PG JRF 2026
Food Technology

AIR 1
GATE 2023
Agricultural Engineering

RESEARCH, INNOVATION & INTELLECTUAL PROPERTY

- 10 Centres of Excellence and advanced research centers in Makhana, Millets, water management, climate change, mushrooms, food processing, millets and indigenous livestock.
- 34 improved crop varieties and 29 farmer-oriented technologies developed.
- Advanced Makhana Research & Development Centre established in 2025 with a budget provision of ₹209 lakh.
- 256 research projects implemented: 33 ICAR-AICRP, 44 externally funded and 179 university-funded projects.
- More than 2,100 research papers, review articles and book chapters published.
- 15 patents and 1 GI tag for the celebrated Marcha rice; 8 copyrights.





STUDENT ACHIEVEMENTS & CAREER OUTCOMES

- 100% placement in MBA (Agribusiness & Rural Management).
- ICAR PG JRF 2026: All India Rank 1 in Food Technology.
- GATE 2023: All India Rank 1 in Agricultural Engineering.
- New academic programme in Natural Farming; the first graduating batch of B.Sc. Agriculture (Hons.) in Natural Farming achieved 100% placement.
- 77 academic programmes: 10 UG, 32 PG, 22 Ph.D., 3 PG Diploma and 10 Certificate programmes; student strength exceeds 2100.
- Deeksharambh orientation strengthen experiential and multidisciplinary learning - 5th Batch (One of first in pioneering Deeksharambh).





DIGITAL & CLIMATE-SMART AGRICULTURE

- Selected under the national Top 100 5G Labs Initiative; AR/VR laboratories.
- DGCA-approved drone pilot training centre: over 430 certified drone pilots and 24 drone trainers trained.
- AI-enabled agriculture research collaboration with IIT Ropar; initiative with NIT Patna for B.Tech. in Digital Agriculture.
- Eddy Covariance Tower established with SAC–ISRO in January 2026 for research on carbon fluxes in the paddy–wheat system.




FARMER OUTREACH & ENTREPRENEURSHIP

- 16 Krishi Vigyan Kendras have trained more than 5 lakh farmers and rural youth.
- Extension outreach includes 17,361 frontline demonstrations and 183 large farmer fairs.
- 36 start-ups associated with the Agri-Innovation and Incubation Centre, with mentoring and technical support.
- Radio Pusa 89.6 FM, Pusa Show, Krishi Connection and the University Media Centre deliver farm advisories and agricultural knowledge.






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