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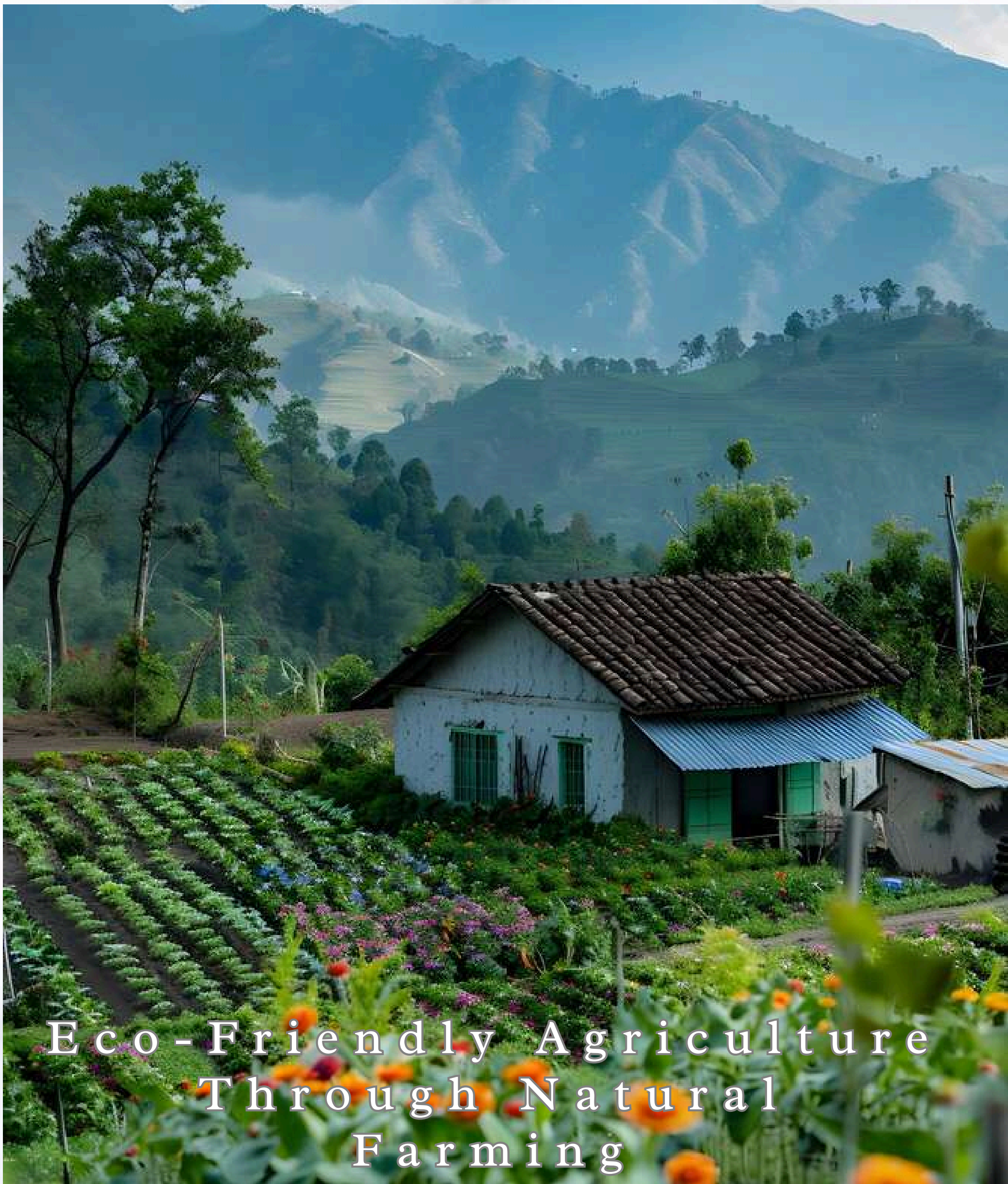
A STEP TOWARDS AGRICULTURE

Agri Roots
e-Magazine



"Lets the Earth heal as it feeds us"

DECEMBER 2025
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"ECO-FRIENDLY AGRICULTURE BEGINS WHERE NATURAL FARMING LETS THE EARTH HEAL AS IT FEEDS US."

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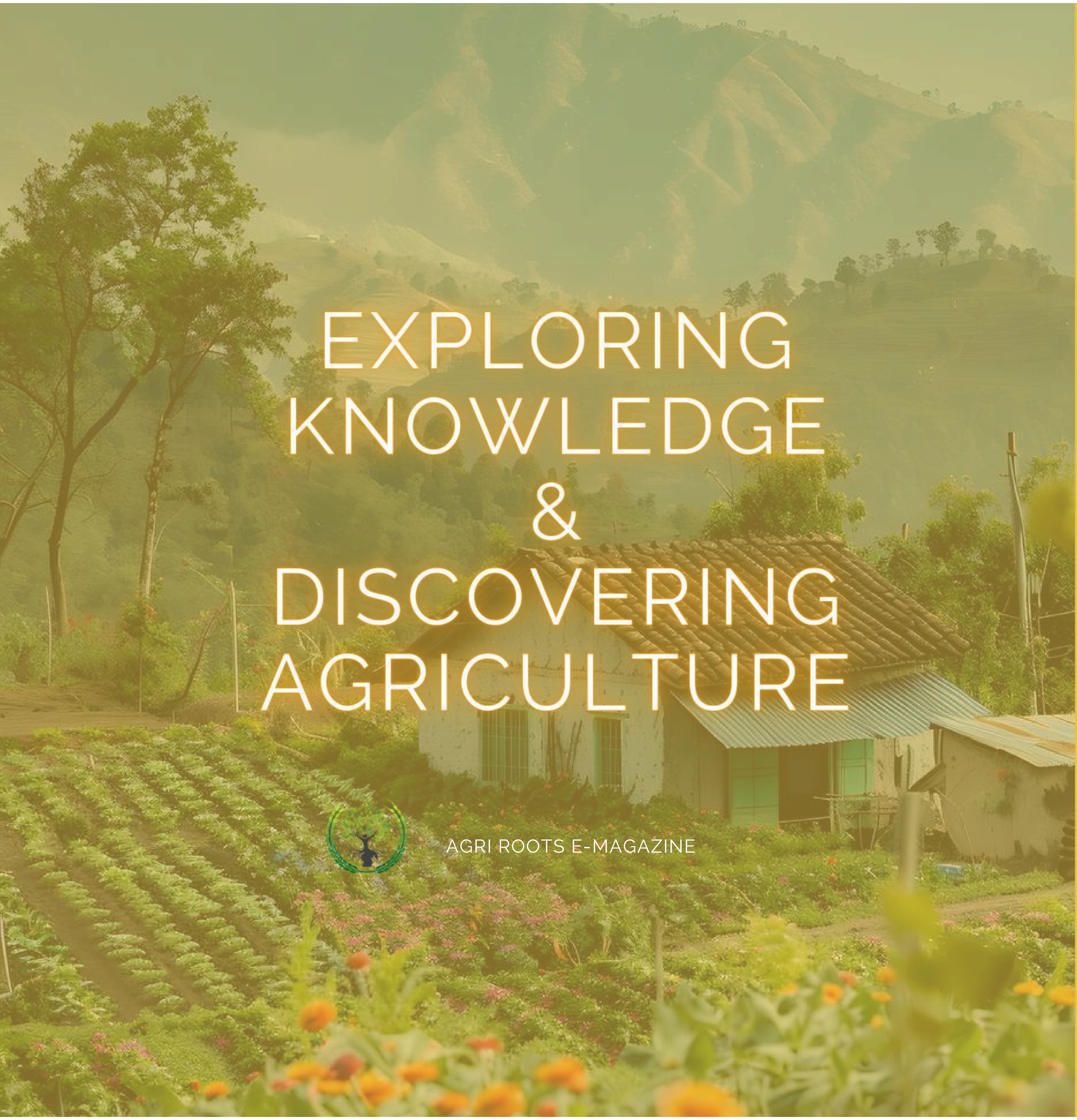
Eco-friendly agriculture stands at the forefront of today's global movement toward sustainable food production, and natural farming emerges as one of the most promising pathways to achieve this vision. As environmental concerns intensify—ranging from soil degradation and biodiversity loss to rising input costs and climate instability—farmers, researchers, and policymakers are increasingly recognizing the need for agricultural systems that work with nature rather than against it.

Natural farming embodies this philosophy by eliminating synthetic fertilizers, pesticides, and intensive tillage, instead relying on on-farm resources, biological processes, and ecological balance. This approach not only reduces the environmental footprint of farming but also enhances soil life, improves crop resilience, and promotes long-term sustainability. By nurturing beneficial microorganisms, protecting soil structure, optimizing natural nutrient cycles, and encouraging biodiversity, natural farming creates a regenerative model that enriches the land season after season.

This issue highlights the principles, practices, and benefits of natural farming while showcasing how farmers across regions are adopting innovative eco-friendly approaches. From utilizing indigenous microbial formulations like Jeevamrit and Beejamrit to integrating crop residues, mulching, mixed cropping, and natural pest management, the articles herein emphasize practical, low-cost, and highly effective strategies that empower farmers to reduce dependence on chemical inputs.

Moreover, natural farming plays a crucial role in climate-smart agriculture by enhancing carbon sequestration, increasing water retention, and building resilient agroecosystems that can better withstand droughts, floods, and pest outbreaks. As global discussions around food security intensify, natural farming offers a pathway toward producing healthier food while safeguarding the environment and supporting the livelihoods of farming communities.

Dr. Deepak Kumar
FOUNDER & EDITOR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Eco-Friendly Agriculture Through Natural Farming: Opportunities for Arunachal Pradesh

ARTICLE ID: 0298

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Agriculture forms the backbone of the Indian economy, particularly in Arunachal Pradesh, where more than half of the population depends directly or indirectly on farming (Sharma et al., 2023). Unlike many other parts of India where chemical-based farming dominates due to high population pressure, Arunachal Pradesh has maintained relatively low chemical input usage, increasing marginally from 0.54 to 0.82 thousand tons between 2007 and 2010 (Ministry of Agriculture and Farmers Welfare, 2010).

The Green Revolution of the mid-1960s transformed Indian agriculture but also introduced a range of environmental and health concerns due to excessive chemical use, leading to severe degradation of soil biological health. This highlighted the need for sustainable farming systems that enhance income while reducing dependency on external inputs.

Natural farming has emerged as a promising alternative. Based on the principles of Masanobu Fukuoka and later popularized in India by Subhash Palekar through Zero Budget Natural Farming (ZBNF), the system aims to reduce cultivation costs while increasing farm profitability (Mandla & Sharma, 2022). ZBNF is now being recognized as a holistic, ecologically sound, and farmer-friendly approach.

Salient Features of Zero Budget Natural Farming (ZBNF)

1. Farmers do not need to invest in seeds, fertilizers, or plant protection chemicals from the market.

2. Seeds can be locally produced or exchanged among farmers, with no reliance on external chemical inputs.
3. Minimal dependence on hired labour, as ZBNF discourages frequent intercultural operations.
4. The philosophy promotes farmer self-reliance and reduces vulnerability to debt and market-driven input costs.

The Four Pillars of ZBNF

(Naik & Ashokkumar, 2021)

1. Jeevamrita/Jivamrutha

A fermented microbial culture that enhances soil microbial activity and earthworm populations. Made using cow dung, cow urine, pulse flour, jaggery, water, and healthy topsoil, it enriches the soil and supports plant health.

2. Beejamrita/Beejamrutha

A microbial seed treatment mixture used to protect seeds and seedlings from soil- and seed-borne diseases. It enhances early-stage plant vigour.

3. Acchadana (Mulching)

Mulching helps conserve soil moisture, suppress weeds, and improve soil aeration. Types include:

- **Soil Mulch:** Protects topsoil and promotes reduced or zero tillage.
- **Straw Mulch:** Uses dried biomass to retain moisture and suppress weeds.
- **Live Mulch:** Uses intercrops that enhance biodiversity and nutrient cycling.

4. Whapsa (Moisture Condition)

Emphasizes maintaining a soil condition where both air and water coexist, reducing the need for excessive irrigation. Palekar recommends irrigation only at noon and in alternate furrows.

Preparation of Jeevamrit

Sl. No.	Methods	Preparation Details	Benefits
1	**Jeevamrita/Jivamrutha**	Prepared using indigenous cow dung (50 kg), urine (50 L), jaggery (10 kg), dicot flour (10 kg), topsoil (10 kg), and water (1000 L). The mixture is fermented for 7–10 days. Apply 500 L/ha once or twice a month through irrigation. Foliar spray: 5% during early crop growth (up to 25 DAS), then 10% every 20–25 days. Fruit trees: 2–5 L per tree per month.	Supplies nutrients, enhances soil microbial activity, boosts earthworms, and reduces fungal and bacterial diseases. Jeevamrit is essential for the first 3 years; after that, the system becomes self-sustaining (Kumari et al., 2022).
2	**Beejamrita/Beejamrutha**	Made with water (20 L), cow dung (5 kg), urine (5 L), lime (50 g), and a handful of	Protects seeds and seedlings from fungal, soil-borne, and

		soil. Seeds are coated and dried before sowing. Seedlings may be dipped.	seed-borne diseases (Kumari et al., 2022).
3	**Acchadana/Mulching**	Soil, straw, or live mulch.	Conserves soil moisture and reduces evaporation (Kumari et al., 2022).
4	**Whapsa/Moisture**	Reduced irrigation; water only at noon in alternate furrows.	Ensures ideal soil moisture condition where both air and water molecules coexist, improving root health (Kumari et al., 2022).

Jeevamrit Preparation and Packaging at ICAR RC NEH, Arunachal Pradesh

The Mission Organic programme launched in Arunachal Pradesh in 2017 guided ICAR Basar in promoting natural and organic farming practices. This resulted in the development of Jeevamrit**,** a versatile, zero-budget input functioning as a fertilizer, pesticide, and fungicide.

Prepared using locally available resources—including dung and urine from the region's indigenous Balang (Bos indicus) cattle strain—the product was officially showcased on Independence Day (15 August 2023). The technology demonstrated a favourable Benefit–Cost ratio (B:C ratio) of 3.29**,** indicating strong economic viability.

Purpose of Ingredients in Jeevamrit

Sl. No.	Ingredient	Purpose
1	Cow dung	Provides nitrogen and nutrients; supplies beneficial microbes.
2	Cow urine	Supplies nitrogen and micronutrients; enhances microbial activity.
3	Jaggery	Energy source for microbial proliferation.
4	Besan (pulse flour)	Nitrogen source for microbial growth.
5	Water	Ensures proper dilution and fermentation.
6	Fertile topsoil	Introduces native microbial populations.

Conclusion

Sustainable agriculture requires a holistic focus on nutrition, productivity, and farmer resilience. Zero Budget Natural Farming offers a pathway to debt-free farming while regenerating soil health. Its success depends on supportive government policies, institutional involvement, and farmer participation.

The integration of livestock, eco-friendly inputs, and traditional wisdom—combined with scientific validation—can transform agriculture in Arunachal

Pradesh. Initiatives such as Mission Organic and innovations like Jeevamrit highlight the capacity of natural farming to promote environmentally sound and economically viable agricultural systems.

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Pre-Breeding: A Strategic Tool For Advanced Crop Improvement

ARTICLE ID: 0299

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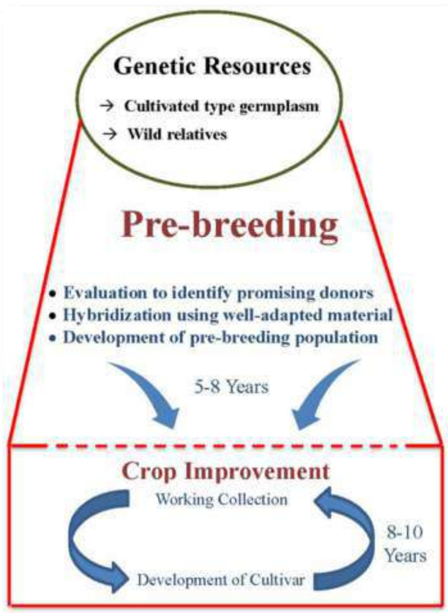
In the face of climate change, population growth, and increasing resource limitations, the demand for resilient and productive crops has become a global priority. Pre-breeding serves as a critical bridge between the vast genetic diversity preserved in crop wild relatives (CWRs), landraces, and genebanks, and the elite cultivars used in modern agriculture. By systematically transferring valuable traits from non-adapted genetic sources into breeding-ready materials, pre-breeding lays the foundation for developing climate-resilient, high-yielding, and nutritionally enhanced crop varieties.



Modern agriculture has gradually narrowed its genetic base due to intensive selection for yield and uniformity. This genetic erosion has resulted in increased vulnerability to emerging biotic and abiotic stresses. Pre-breeding addresses this challenge by reintroducing adaptive traits from diverse germplasm sources into elite breeding lines. It is a critical step for expanding genetic variability and enhancing the long-term sustainability of crop improvement programs.

Understanding Pre-Breeding

Pre-breeding refers to the process of identifying, evaluating, and introgressing beneficial genes or quantitative trait loci (QTLs) from wild relatives, landraces, or unadapted germplasm into cultivated varieties to create intermediate breeding materials. These pre-bred lines serve as bridge materials for developing improved cultivars.

Unlike conventional breeding, which operates within a narrow genetic base, pre-breeding widens the breeding pool and reduces the risks associated with uniformity. The outputs—commonly known as *pre-bred lines* or *bridge materials*—help eliminate reproductive barriers, minimize linkage drag, and provide genetically stable materials for downstream breeding.

Role of Pre-Breeding in Modern Agriculture

Agricultural intensification has significantly reduced crop genetic diversity, with estimates suggesting that nearly 70% of genetic variation in major crops has been lost during domestication and modern breeding. This decline has increased susceptibility to pests, diseases, and climatic stresses.

Pre-breeding plays a crucial role by:

- Reintroducing adaptive traits such as drought tolerance, salinity tolerance, pest and disease resistance, and improved nutrient use efficiency.
- Enhancing breeding efficiency by providing characterized, accessible genetic materials.
- Reducing the time and cost required in breeding programs.
- Integrating genomic tools and genebank data to ensure precise donor selection and trait tracking.

Pre-Breeding Process

Pre-breeding typically follows a structured, multi-step workflow:

1. Germplasm Evaluation

Screening of CWRs and landraces using high-throughput phenotyping and genomic tools to identify donors of target traits.

2. Controlled Crossing

Hybridization between wild or unadapted donors and elite cultivars, often requiring techniques like embryo rescue to overcome incompatibility.

3. Backcrossing and Selection

Repeated backcrossing to recover desirable agronomic traits while retaining target genes. Marker-assisted selection (MAS) helps reduce linkage drag.

4. Validation and Stabilization

Multi-location field trials and genomic selection to confirm trait stability and yield performance.

Advanced tools such as MAS, genomic selection (GS), and speed breeding have significantly increased the precision and efficiency of pre-breeding efforts.

Success Stories in Pre-Breeding

Wheat

Synthetic hexaploids derived from crosses between durum wheat and *Aegilops tauschii* have introduced novel rust resistance genes (e.g., Sr59**,** Lr67). These have contributed to the development of disease-resistant and stress-tolerant wheat lines.

Rice

The SUB1 gene for submergence tolerance was introgressed from the landrace FR13A into high-yielding varieties like Swarna through marker-assisted backcrossing. These varieties can survive up to two weeks of flooding.

Alfalfa

Pre-breeding programs integrating genomic data from *Medicago truncatula* have enhanced forage quality and salinity tolerance, achieving up to an 18% improvement in nitrogen-use efficiency.

Maize

Pan-genomic analyses of teosinte and landraces have revealed drought-adaptive alleles, which are introgressed into elite inbreds using genomic selection to improve water-use efficiency and drought tolerance.

Potato and Tomato

Wild *Solanum* species have contributed late blight resistance genes (e.g., RB**,** Rpi-blb2**),** resulting in durable, stacked resistance in commercial varieties.

Challenges in Pre-Breeding

Despite its advantages, pre-breeding faces several limitations:

- **Linkage Drag:** Undesirable traits co-inherited with target genes.
- **Reproductive Barriers:** Hybrid sterility or embryo inviability in distant crosses.
- **High Resource Requirement:** Time-consuming and expensive processes.
- **Data Gaps:** Incomplete phenotypic and genomic profiles of germplasm accessions.

Emerging Technologies and Opportunities

Several modern technologies are helping overcome these challenges:

- CRISPR-Cas gene editing allows precise gene transfer without linkage drag.
- High-throughput sequencing accelerates trait discovery.
- AI-driven predictive models enhance donor selection and breeding design.
- Global initiatives**,** such as the Crop Wild Relatives Project, have pre-bred over 1,500 lines across 19 crops, demonstrating the scalability of pre-breeding efforts.

Conclusion

Pre-breeding is a foundational pillar of sustainable crop improvement. By unlocking the genetic potential of wild and underutilized germplasm and integrating it into modern breeding pipelines, it enables the development of resilient, productive, and nutrient-rich crops capable of meeting future global food security challenges.

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An Insight – Making of Floral Arrangements

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Floral arrangement is an artistic expression that blends creativity, scientific understanding, and aesthetic sense to present flowers in an appealing and meaningful manner. We, the IV Year B.Sc. (Hons.) Horticulture students (11 in number) from the College of Horticulture, Anantharajupeta, Dr. YSR Horticultural University, are currently undergoing our Rural Horticultural Work Experience Programme (RHWEP) at Bhimavaram village of Chandragiri mandal under the supervision of the Regional Horticultural Research Station, Tirupati.

As part of the RHWEP, we interact with farmers, learn various farm practices, conduct method demonstrations, and participate in vocational training programmes. One such important activity was learning and practicing floral arrangement techniques using various flowers and foliage.

Importance of Floral Arrangements

A significant component of our training emphasized floral arrangements as a valuable value addition activity. Floral design not only enhances the natural beauty of flowers but also increases their market appeal by transforming simple blooms into artistic creations.

We learned that floral arrangements play an important role across diverse settings, such as:

- Events and celebrations
- Hospitality and décor
- Religious and cultural functions
- Festivals and ceremonies

Through demonstrations, we understood how creativity, proportion, balance, and colour harmony blend seamlessly to form a perfect arrangement. The hands-on sessions were invaluable, helping us grasp concepts more effectively than theory alone.

Foliage and Flowers Used

- *Asparagus densiflorus* var. myers
- *Asparagus densiflorus* var. sprengeri
- *Gomphrena globosa*
- *Tradescantia spathacea*
- *Pandanus baptistii* (Golden Pandanus)
- *Sansevieria trifasciata* (Snake Plant)

- *Acalypha* spp. (Variegated)
- Chrysanthemum (White, Yellow, Purple, Orange)
- Roses (White, Yellow, Pink, Red)

Materials Used: Baskets (Wooden, Silver-coated Plastic), Floral Brick (Oasis)

Hands-on Experience: Creating Floral Designs

As part of our vocational training, we actively created different floral designs and centrepieces. Each student participated in:

- Preparing floral brick of appropriate size
- Proper soaking of floral brick
- Selecting suitable flowers and foliage
- Trimming and conditioning plant material
- Arranging flowers with symmetry and balance
- Completing unique designs based on imagination and creativity

These sessions enhanced our precision, patience, teamwork, and appreciation for the art and science of floriculture.

Types of Floral Arrangements Made

We attempted multiple styles, including Western and mixed forms. Three major arrangements we created included:

1. Round Compact Arrangement

Using multi-coloured roses and chrysanthemums, *Gomphrena globosa*, foliage of golden pandanus, and *Tradescantia* leaves.

2. Tall Fan-shaped / Vertical Arrangement

Made with roses of various colours, golden pandanus foliage as the background, and filler materials such as *Asparagus* (myers and sprengeri).

3. Semi-circular Horizontal Arrangement

Designed using white, yellow, and orange chrysanthemums, along with *Asparagus* foliage as filler material.

Conclusion

Overall, this hands-on experience strengthened our technical skills and inspired us to explore floriculture as a potential entrepreneurial venture. The training enhanced our confidence in creating artistic floral products and highlighted the scope for value addition in flower crops. This exposure has been truly insightful and has enriched our learning journey in horticulture.

We express our sincere thanks to the RHWEP incharges Dr. K.C. Bhanu Murthy, Dr. L. Ranjith Kumar, Dr. Ch. Ruth (ADR, Rayalaseema Zone, RHRS Tirupati), Dr. Sreelatha (RHWEP Coordinator), Dr. P.T. Srinivas (AD, COH Anantharajupeta) and Dr. YSRHU for providing us with this valuable learning opportunity under the RHWEP programme

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National Farmers Day: A Day of Nation's Pride

ARTICLE ID: 0301

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Thanking Those Who Work on Acres, Not in Hours

Let us salute our farmers on this great day—National Farmers' Day.

A farmer is not just a farmer; he is a magician who produces wealth from the soil. Working through winter's chill and summer's heat, he ensures that the world has food on its plate. Farmers are the founders of human civilization. They deserve our gratitude every day of the year, for we are fed three times a day only because of their relentless efforts.

Farmers form the backbone of India's economy and significantly contribute to rural prosperity. To honour and appreciate their vital role in the nation's development, National Farmers' Day is celebrated every year on **23 December**.

This day is dedicated to acknowledging the hard work, commitment, and sacrifice of the Indian farming community. Across the country, 23 December is observed as National Farmers' Day or Kisan Diwas, highlighting the contributions of farmers to the nation's progress.

About National Farmers' Day

National Farmers' Day is celebrated annually to commemorate the birth anniversary of Chaudhary Charan Singh, India's fifth Prime Minister and a revered leader of farmers. He was a strong advocate for farmers' rights and welfare.

The day is marked by various activities such as seminars, speeches, agricultural exhibitions, awareness campaigns, and community gatherings. These events highlight both the challenges and achievements of the farming community, providing an opportunity to express gratitude for their contributions.

India has always been an agriculture-based nation, with the primary sector forming a major part of the economy. Farmers are the strength and building blocks of rural India. Kisan Diwas is widely celebrated across agriculturally rich states like Uttar Pradesh, Haryana, Punjab, and Madhya Pradesh.

National Farmers' Day is also observed globally:

- **Ghana** – First Friday of December
- **USA** – 12 October
- **Zambia** – First Monday of August
- **Pakistan** – 18 December (since 2019)

History of National Farmers' Day

Kisan Diwas was first celebrated in **2001**, when the Government of India decided to honour the legacy of Chaudhary Charan Singh by observing his birth anniversary as National Farmers' Day.

India, often described as a land of villages and agricultural abundance, depends heavily on farming for livelihoods—nearly half of the population is engaged in agriculture. Recognizing Chaudhary Charan Singh's significant contributions to agricultural reforms, rural development, and farmers' welfare, his birth anniversary was designated as Kisan Diwas.

Since then, the day has been marked by awareness campaigns and events across the country to emphasize the role of farmers and their indispensable contribution to the Indian economy.

Chaudhary Charan Singh: The Champion of Farmers

Chaudhary Charan Singh (1902–1987) was a prominent leader known for his unwavering commitment to farmers' rights. Born into a middle-class peasant family in Noorpur, Meerut district, he pursued higher education in science and law from Agra University. A strong proponent of rural development, he worked throughout his political career to advance the interests of farmers.

Early Life & Education

- Graduated in Science (1923)
- Post-graduation (1925), Agra University
- Trained as a lawyer; practiced in Ghaziabad and later Meerut

Political Career

- First elected to the U.P. Legislative Assembly in 1937 (Chhaprauli constituency)
- Served multiple terms (1946, 1952, 1962, 1967)
- Parliamentary Secretary under Pt. Govind Ballabh Pant
- Held ministerial portfolios including Revenue, Agriculture, Home, and Transport
- As Chief Minister, introduced the Land Holding Act, 1960
- Served as the 5th Prime Minister of India (28 July 1979 – 14 January 1980)

Major Contributions

- Led the formulation of the Debt Redemption Bill, 1939, offering relief from rural indebtedness
- Chief architect of land reforms in Uttar Pradesh
- Led efforts to abolish the Zamindari system (1952)
- Founded the Kisan Trust (1978), dedicated to educating rural communities
- Authored several influential works: *Co-operative Farming X-rayed*, *India's Poverty and Its Solution*, *Abolition of Zamindari*
- Known for simple living, integrity, discipline, and strong administrative values

Legacy

Chaudhary Charan Singh is remembered as a visionary leader dedicated to farmers' welfare. His birth anniversary is celebrated as Kisan Diwas to honour his monumental role in strengthening Indian agriculture and rural society.

Kisan Diwas Celebrations

On National Farmers' Day, numerous events are organized across the country, including:

- **Seminars & Workshops:** Discussions on innovations, challenges, and policies related to agriculture
- **Awards & Recognition:** Honouring outstanding farmers for their achievements
- **Awareness Campaigns:** Promoting modern farming techniques, government schemes, and sustainable practices
- **Tributes:** Cultural programs and speeches to honour Chaudhary Charan Singh

Significance of National Farmers' Day

Kisan Diwas highlights the immense value of farmers in nation-building. The day emphasizes:

- Recognition of farmers' dedication, sacrifice, and contribution
- Awareness of their social and economic well-being
- Importance of agriculture in India's GDP and employment base
- Need for policies supporting sustainable farming
- Challenges such as climate change, financial limitations, and technology adoption

Conclusion

National Farmers' Day is a momentous occasion that honours the tireless efforts of farmers who feed the nation and sustain the economy. Observed on 23 December, this day commemorates the legacy of Chaudhary Charan Singh and reminds us of the critical challenges farmers continue to face.

Kisan Diwas provides a platform for farmers to voice their concerns and encourages society to appreciate their hard work. Modern agricultural advancements offer new opportunities for sustainable and climate-resilient farming, ensuring a better future for rural communities.

As we celebrate National Farmers' Day 2024, it is essential to continue supporting farmers through better policies, technology, and awareness. Farmers are the backbone of the nation, and honouring their labour is our collective responsibility.

Happy National Farmers' Day to all the farmers who nurture the land and feed the world!

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Multi-Omics Integration to Accelerate Crop Trait Improvement: From Genomics to Metabolomics

ARTICLE ID: 0302

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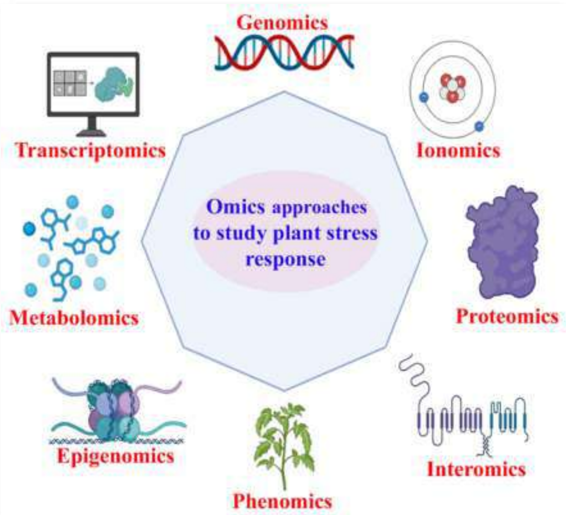
The rapid advancement of multi-omics technologies has transformed the exploration of complex biological systems, offering in-depth understanding of the molecular mechanisms that govern key traits across diverse organisms. Progress in next-generation sequencing, biomolecular detection methods, and bioinformatics has driven remarkable developments in genomics, resequencing, functional genomics, epigenomics, transcriptomics, proteomics, metabolomics, ionomics, and microbiomics—collectively reshaping modern strategies for crop improvement. These integrated omics approaches now play a pivotal role in plant science, facilitating more precise and practical identification of genetic determinants and their functional impact on trait expression and development. The integration of multi-omics methodologies has significantly enhanced every stage of the crop breeding pipeline—from the identification of novel genetic variations to more detailed phenotypic characterization and the elucidation of key biological components such as genes, transcription factors, and regulatory proteins involved in growth, disease resistance, stress tolerance, and metabolic regulation. Comprehensive multi-omics investigations have yielded valuable insights into complex phenotypes and their adaptive mechanisms across diverse environmental conditions. Such understanding is fundamental for developing improved crop varieties with enhanced resilience and adaptive traits. Moreover, recent reductions in the cost of generating multi-omics data have facilitated the creation of large, interconnected datasets that offer a systems-level perspective of crop biology. These datasets encompass the interactions and functional impacts of genes,



proteins, metabolites, and other biomolecules, derived from numerous replicated samples across varying experimental scenarios. Developing crop varieties with traits such as drought and salinity tolerance, early maturation, and resistance to diseases and pests remains a critical goal in modern agriculture. Traditional approaches, including mutagenesis and cross-breeding, have contributed to genetic improvement but often result in random and non-specific genetic alterations. Encouraged by the successes of genetic manipulation, researchers have increasingly sought more precise and controllable strategies for transferring desirable traits among plants. In response, precision genetic modification technologies have emerged, aiming to reduce unintended mutations while enabling targeted and predictable genetic enhancements. Omics technologies hold immense promise for agricultural research, encompassing fields such as food security, human and plant health, bioenergy, industrial bioproducts, and environmental sustainability. With the continuous advancement of high-throughput platforms and computational tools, the integration of omics approaches into crop science has become increasingly feasible. Moreover, open-access datasets combined with powerful computational resources have enabled *in silico* functional prediction of previously uncharacterized genes, proteins, and metabolites. Looking ahead, omics-driven innovations are anticipated to play a transformative role in plant breeding and crop improvement over the coming decades.

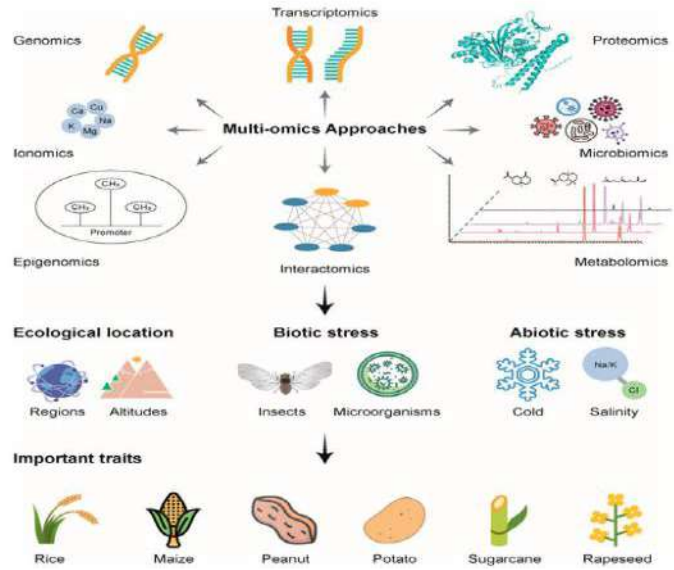


Figure 1. Schematic diagram of the integrative analysis of important traits using multi-omics methodologies.

The Omics Revolution in Plant Biochemistry

The "omics" era represents a transformative phase in plant biochemistry, characterized by large-scale molecular profiling across multiple biological layers—genomics, transcriptomics, proteomics, metabolomics, and epigenomics. These disciplines capture comprehensive molecular data that enable systems-level understanding of plant function .

Role of Systems Biology in Understanding Plant Traits

Systems biology integrates data from multiple omics layers to reveal regulatory and metabolic networks underlying complex plant traits such as stress tolerance, yield, and development. By modelling gene–protein–metabolite interactions, systems biology enables the prediction of phenotypic outcomes from molecular changes.

- **Integration of Multi-Omics Data for Holistic Insights**

Integrative multi-omics approaches link information from genomics, transcriptomics, proteomics, and metabolomics to construct a complete view of plant physiology. Such integration has been pivotal in identifying biosynthetic pathways and key metabolic regulators.

Genomics: Foundation of Crop Improvement

High-throughput sequencing technologies such as Illumina, PacBio, and Oxford Nanopore have enabled chromosome-level genome assemblies in many crops, providing foundational data for genetic improvement. QTL mapping and genome-wide association studies (GWAS) identify genomic regions associated with desirable traits, facilitating marker-assisted breeding. CRISPR/Cas genome editing enables functional validation of genes identified through omics studies and targeted improvement of crop traits. Genomic data have been instrumental in enhancing yield potential, disease resistance, and abiotic stress tolerance through targeted breeding and gene editing.

Transcriptomics: Decoding Gene Expression Dynamics

RNA sequencing (RNA-Seq) allows quantification of gene expression and alternative splicing, revealing condition-specific transcriptional responses. Transcriptomics provides insights into gene regulatory networks that mediate plant stress responses and developmental processes. Co-expression network analysis and pathway enrichment studies help identify candidate genes and modules associated with agronomic traits.

Proteomics: Understanding the Functional Players

Advances in mass spectrometry-based proteomics enable large-scale identification and quantification of plant proteins. Proteomic studies reveal post-translational modifications such as phosphorylation and glycosylation that regulate protein function and signalling.Mapping protein–protein interactions supports the functional annotation of novel proteins and pathway elucidation.

Metabolomics: Chemical Phenotyping for Trait Discover

Metabolomics uses GC-MS, LC-MS, and NMR to profile small molecules that reflect the biochemical phenotype of a plant. Metabolomic analyses have revealed pathways responsible for osmolyte accumulation, antioxidant metabolism, and secondary metabolite synthesis during stress responses. Integration of metabolomic data with genomics and transcriptomics provides metabolite QTLs (mQTLs) that link metabolic traits to genetic loci.

Integrative Multi-Omics Approaches

Computational frameworks for integrating multi-omics data, such as correlation networks and AI-based models, facilitate holistic crop analysis. Network biology enables the construction of gene, protein, and metabolite networks that explain trait regulation. Integrative omics studies in rice and maize have identified molecular mechanisms of salt and drought tolerance. Challenges include heterogeneity of data, computational demands, and translation of omics findings into field applications.

Applications in Crop Breeding and Biotechnology

Omics-derived markers are used for genomic selection to accelerate breeding cycles and improve trait prediction accuracy. Multi-omics insights guide metabolic engineering and synthetic biology for improved crop metabolites and stress resilience. Integration of omics data with field-level sensors and phenomics supports precision agriculture practices.

Future Perspectives

AI and ML approaches are increasingly applied for omics data integration, trait prediction, and pathway discovery. Coupling multi-omics with phenomics and environmental data is crucial for predictive breeding under real-world conditions. Future applications of omics in agriculture must consider ethical use, equitable access, and sustainability implications.

Conclusion

The advancement and integration of multi-omics technologies, including genomics, transcriptomics, proteomics, and metabolomics, have profoundly transformed modern crop improvement by enabling a systems-level, comprehensive understanding of the molecular mechanisms underlying complex traits like stress tolerance and yield. This technological shift, driven by high-throughput sequencing and advanced bioinformatics, provides unprecedented precision in identifying genetic determinants, key regulatory networks, and biosynthetic pathways, which is crucial for moving beyond the limitations of traditional, non-specific breeding methods. By generating and analyzing large, interconnected datasets, multi-omics supports the development of precision genetic modification strategies, accelerates breeding cycles through genomic selection markers, and guides metabolic engineering efforts, ultimately ensuring the creation of more resilient, high-yield crop varieties necessary for global food security and sustainable agriculture.

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Crisis Management And Extension Education

ARTICLE ID: 0303

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Crisis management is the systematic process of identifying, preparing for, responding to, and recovering from situations that pose significant threats to an organization, community, or individual. It involves the coordination of resources, communication strategies, and strategic planning to minimize negative impacts and facilitate timely recovery. The primary aim of crisis management is to protect people, assets, and reputation while ensuring continuity of operations.

Need for Effective Crisis Management

Effective crisis management is crucial for navigating unexpected and challenging situations. Key reasons include:

- Risk Mitigation
- Reputation Protection
- Resource Optimization
- Financial Impact Reduction
- Community Impact Management
- Strategic Decision-Making
- Continuous Improvement
- Public Health Protection

Role of Extension and Education in Crisis Management

Extension and education play multifaceted roles in effectively responding to and mitigating crisis impacts.

A. Risk Communication and Disaster Management

Extension services actively support communities in disaster preparedness, risk communication, and promoting collective action.

B. Capacity Building and Preparedness

Strengthening the risk management capacity of extension personnel is essential. For example, the Extension Disaster Education Network (EDEN) in the USA enhances community preparedness.

C. Information Dissemination and Community Support

Extension systems provide reliable information, stress management support, and crisis-related guidance to affected populations.

D. Training and Development

Training equips extension personnel with the knowledge and skills needed to lead crisis response efforts effectively.

E. Integration and Collaboration

Extension workers collaborate with institutions, farmer collectives, and media to ensure coordinated crisis management.

F. Community Development and Support

Extension services support agriculture, youth development, and home economics—critical components of community recovery.

G. Crisis Management Activities

Extension staff participate in crisis audits, risk analysis, emergency operations, incident documentation, and recovery planning.

Extension Services in Crisis Management

1. Role of Extension Workers

- **Providing Information and Guidance**

Extension agents offer timely and reliable information during crises. For example, during the 1980s farm crisis, they conducted stress management workshops, financial planning sessions, and communication seminars.

- **Community Engagement**

They work closely with local institutions, farmer groups, and media to reduce vulnerability and ensure coordinated responses.

- **Information Dissemination**

During droughts and floods, extension services provide critical updates, including 24-hour stress hotlines and advisories.

2. Utilizing Technology in Extension Services

- **ICT Tools:** Blogs, social media, and digital platforms help disseminate information quickly.
- **Mobile Applications:** Provide farm management tools, record-keeping support, and on-the-go advisory services.
- **Radio and Television:** Traditional media remain valuable for reaching remote communities during crises.

Education Continuity in Crisis

1. Integrating Crisis Management into Formal Education

- **Curriculum Development:** DRR (Disaster Risk Reduction) should be incorporated into school and college curricula.
- **Training Educators:** Teachers must be equipped to manage crises and provide psychosocial support.

2. Informal Education Approaches

A. Community Workshops

- Conduct accessible workshops on preparedness and response.
- Ensure cultural relevance and involve local leaders.

B. Digital Learning Platforms

- Develop online modules and conduct interactive webinars.

C. Public Awareness Campaigns

- Media partnerships for PSAs
- Printed materials like posters and pamphlets
- Community fairs and exhibitions on crisis preparedness

Case Study 1: Locust Attack in Gujarat (2020)

The 2020 locust attack posed severe threats to crops such as cumin, rapeseed, and mustard. Agricultural universities, KVKs, and extension workers played vital roles.

Key Contributions

- **Information Dissemination:** Provided guidance on crop rehabilitation and soil management (Biswas, 2021).
- **Technology Transfer:** Shared best practices to improve resilience.
- **Coordination:** Worked with government agencies to control the infestation.

Impact

Timely interventions helped farmers take proactive measures, reducing crop losses and protecting livelihoods.

Case Study 2: Cyclone Feni in Odisha

Cyclone Feni caused widespread agricultural damage. Extension workers, scientists, and KVKs assisted farmers in recovery.

Key Contributions

- **Information Dissemination:** Early warnings and advisories (Davis, 2021).
- **On-field Support:** Damage assessment and restoration guidance.
- **Technology and Practice Transfer:** Introduction of resilient crop varieties (Singh et al., 2020).
- **Government Coordination:** Ensured the timely availability of resources.

Impact

Their efforts significantly reduced the long-term agricultural impact of the cyclone.

Challenges and Solutions

1. Challenges

A. Resource Constraints

- Limited funding
- Insufficient human resources
- Limited IoT/ICT infrastructure
- Reduced field mobility

B. Communication Barriers

- Language and cultural differences
- Disrupted communication networks
- Information overload during crises

2. Proposed Solutions

A. Collaborative Efforts

- Partnerships with government, NGOs, and community groups
- Cross-sector collaboration

B. Innovation in Extension and Education

- Technology integration (mobile apps, digital tools)
- Culturally adaptive educational content
- Community-based approaches
- Capacity-building initiatives

Conclusion

Crisis management is essential in today's dynamic world. Integrating crisis management into school curricula and extension education programs is necessary to build a resilient society. Educators and extension personnel must be trained in crisis response, while modern technologies should be adopted to enhance preparedness, response, and recovery. Strengthening partnerships among institutions, extension systems, and government agencies will ensure more effective crisis management and community resilience.

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Cultural Practices of Pest Management

ARTICLE ID: 0304

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Cultural practices in pest management form the foundation of sustainable agriculture. These methods involve manipulating the farming environment and crop production practices to naturally reduce pest populations. Unlike chemical control, cultural methods are environmentally safe, economically viable, and help conserve beneficial organisms.

Pest management is a critical component of modern crop production. With increasing concerns over pesticide residues, environmental degradation, and the development of pest resistance, cultural pest management has become an essential element of Integrated Pest Management (IPM). Cultural methods aim to modify the crop ecosystem to make it unfavorable for pest survival, reproduction, and spread.

Main Cultural Practices of Pest Management

1. Crop Rotation

Growing different crops in a planned sequence helps break the life cycle of pests specific to a particular crop. For example, rotating rice with pulses reduces populations of rice stem borer and gall midge.

2. Field Sanitation

Removing weeds, crop residues, and volunteer plants eliminates breeding and hiding sites for pests. Clean cultivation reduces pest carry-over to the next season.

3. Timely Sowing and Harvesting

Adjusting sowing and harvesting times allows crops to escape peak periods of pest attack. For instance, early sowing of wheat helps avoid wheat stem fly infestation.

4. Use of Resistant Varieties

Choosing pest-resistant varieties is an effective and economical approach. Resistant varieties also reduce dependence on chemical pesticides.

5. Proper Spacing and Plant Density

Maintaining appropriate plant spacing reduces humidity and improves air circulation, making the crop environment less conducive for pest development, especially for fungal pathogens and insect pests.

6. Water and Nutrient Management

Balanced fertilization and proper irrigation prevent excessive vegetative growth, which often attracts pests such as aphids and whiteflies.

7. Trap Cropping

Trap crops divert pests away from the main crop. For example, mustard is used as a trap crop in cotton fields to attract aphids.

8. Intercropping and Mixed Cropping

Growing multiple crops together disrupts pest movement and reduces the chances of large-scale infestation.

9. Tillage Practices

Deep ploughing exposes pest larvae and pupae to sunlight and predators, reducing their survival.

10. Use of Clean Seeds and Planting Material

Using certified pest-free seeds and planting material prevents the introduction of pests into the field.

Advantages of Cultural Practices

- Environmentally friendly and non-toxic
- Promote long-term pest suppression
- Enhance soil health and biodiversity
- Reduce dependency on chemical pesticides and associated costs

Conclusion

Cultural pest management plays a vital role in sustainable agriculture. When integrated with other IPM techniques, these practices effectively control pest populations, maintain ecological balance, and reduce environmental pollution. Farmers should be encouraged to adopt such eco-friendly strategies for a more resilient and sustainable farming system.

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Identification and Management of Cabbage Pests

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Cabbage (*Brassica oleracea* var. *capitata*) is an important vegetable crop rich in essential nutrients but highly susceptible to insect pests. These pests cause significant losses in yield and quality if not properly managed. The major pests include the diamondback moth, aphids, cabbage butterfly, leaf webber, and cutworms. This article focuses on the identification, damage symptoms, and management strategies of major cabbage pests, emphasizing integrated pest management (IPM) techniques.

Cabbage is a vital vegetable crop grown globally for its edible leaves. However, pest infestations pose a major challenge to achieving optimum yield and market quality. Early identification of pests and the adoption of eco-friendly management practices are essential for sustainable production. Integrated Pest Management (IPM) provides a holistic approach to managing pests while minimizing environmental impact.

Major Pests of Cabbage

1. Diamondback Moth (*Plutella xylostella*)

- Adult moths are small and greyish-brown with a distinctive diamond-shaped pattern on folded wings.
- Larvae feed on the underside of leaves, creating small holes.
- Severe infestations result in skeletonized leaves and reduced head formation.

2. Cabbage Aphid (***Brevicoryne brassicae***)

- Soft-bodied, grey-green aphids that form dense clusters on young leaves and shoots.
- They suck plant sap, causing yellowing, curling, and stunted growth.
- Honeydew secretion favors the development of sooty mold.

3. Cabbage Butterfly (***Pieris brassicae***)

- White butterfly with characteristic black spots on the wings.

- Larvae are greenish with black hairs and feed on leaf margins.
- Heavy feeding leads to irregular holes and defoliation.

4. Cabbage Head Borer (*Hellula undalis*)

- Larvae bore into cabbage heads, damaging internal tissues.
- Infestation leads to rotting, contamination, and unmarketable produce.

5. Leaf Webber (*Crocidolomia binotalis*)

- Green caterpillars web leaves together and feed from within.
- Affects leaf expansion and head formation, especially in young plants.

6. Cutworm (*Agrotis ipsilon*)

- Dark brown larvae that remain in the soil and cut seedlings at the base during nighttime.
- Causes plant wilting and death, particularly in nursery and early field stages.

Integrated Pest Management (IPM) Strategies

1. Cultural Practices

- Rotate cabbage with non-cruciferous crops.
- Remove plant residues and deep plough fields before sowing to expose and kill pupae.
- Maintain overall field sanitation to reduce pest carryover.

2. Mechanical and Physical Control

- Handpick larger larvae when feasible.
- Install light traps and sticky traps to monitor and reduce adult moth populations.
- Use protective nets in nurseries and around young plants.

3. Biological Control

- Release *Trichogramma chilonis* to parasitize eggs of major pests.
- Apply *Bacillus thuringiensis* (Bt) formulations for effective caterpillar control.
- Conserve natural predators such as ladybird beetles, lacewings, and spiders.

4. Botanical Control

- Apply Neem Seed Kernel Extract (NSKE) 5%.
- Use Azadirachtin (1500 ppm) for aphid and caterpillar suppression.

5. Chemical Control *(Use only as a last resort)*

- Spinosad 45 SC @ 0.3 ml/L or Emamectin benzoate 5 SG @ 0.4 g/L for caterpillars.
- Imidacloprid 17.8 SL @ 0.3 ml/L for aphids.
- Follow proper waiting periods and avoid excessive chemical use.

Conclusion

Cabbage is highly vulnerable to a wide range of insect pests that cause heavy economic losses. Accurate pest identification and timely adoption of IPM strategies ensure increased yield and better crop quality. Combining cultural, mechanical, biological, and botanical methods reduces the reliance on chemical pesticides and promotes sustainable cabbage cultivation.

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Smart Biodegradable Packaging for Extending Shelf Life of Produce

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In recent years, the horticulture and fresh-produce sector has faced two interlinked challenges: the rapid perishability of fruits and vegetables post-harvest, and the environmental burden of conventional plastic packaging. To address both issues, research is increasingly focusing on smart biodegradable packaging—materials and systems that not only degrade more sustainably than petroleum-based plastics but also actively monitor or regulate the storage environment. These may include antimicrobial additives, freshness indicators, sensors, or improved gas-barrier properties.

Fresh produce typically exhibits high respiration and water-loss rates, making it vulnerable to microbial contamination, ethylene-induced ripening, and mechanical injury. Traditional packaging (e.g., single-use plastics, polystyrene trays) provides physical protection and some barrier functions but generally lacks active or intelligent features. Moreover, conventional plastics contribute significantly to landfill accumulation and environmental pollution.

Biodegradable packaging, derived from biopolymers such as PLA (polylactic acid), chitosan, alginate, starch, proteins (e.g., zein) and agricultural waste fibres, offers a sustainable alternative. When combined with "smart" functionalities—such as antimicrobial release, freshness indicators, oxygen scavengers, and embedded sensors—such packaging systems show strong potential to enhance both sustainability and the shelf-life of produce.

For example, biodegradable films made from zein–starch infused with natural antimicrobials (thyme oil and citric acid) have been reported to extend the shelf life of strawberries from 4 days (in conventional plastic boxes) to 7 days. Similarly, composite materials such as chitosan/titanium dioxide nanocomposites have shown promise in delaying ripening and microbial spoilage in fruits and vegetables.

A summary of key aspects of smart biodegradable packaging used for horticultural produce is provided below.

Key Aspects of Smart Biodegradable Packaging

Aspect	Description / Functionality	Examples and Evidence	Key Benefits
Base Biodegradable Materials	Biopolymers derived from renewable sources (PLA, starch, chitosan, alginate, proteins, agricultural residues)	PLA-based films with antimicrobials; films from alfalfa, soy hulls, and corncob residues extended strawberry and raspberry shelf life by 2–6 days	Reduced plastic pollution; compostability; alignment with circular-economy goals
Smart/Intelligent Features	Embedded sensors, freshness indicators, gas sensors, QR/RFID traceability	Packaging with oxygen/pH-sensitive pigments (e.g., anthocyanins); gas/temperature sensors enabling real-time monitoring	Quality tracking; improved supply-chain management; reduced waste
Produce-Specific Applications	Tailored for fruits and vegetables with high respiration/transpiration rates	Biodegradable films on cherry tomatoes, kiwi, grapes reduced respiration/transpiration and delayed browning	Extended freshness; reduced post-harvest losses
Environmental & Sustainability Impact	Lower landfill waste, reduced CO_2 emissions, compostability	Smart Bioplastic project: replacement of plastics reduces tonnes of plastic waste and CO_2 emissions	Dual benefit: shelf-life extension + environmental sustainability
Challenges & Barriers	Need for adequate mechanical, barrier, and thermal properties; cost; scalability; regulatory safety	Many lab-developed materials do not yet meet industrial requirements	Further development required for commercial adoption
Future Directions	IoT-enabled packaging, AI-integrated systems,	Recent reviews highlight advanced preparation methods and sustainability trends	Cost-effective, efficient, and

	nanocomposites, waste-derived biopolymers		traceable packaging systems

Key Considerations for Horticultural Crop Packaging

Fresh fruits and vegetables require packaging that addresses several technical challenges:

1. Respiration and Gas Exchange

Produce continues to respire after harvest, releasing CO_2 and consuming O_2. Packaging must regulate the internal atmosphere using modified atmosphere packaging (MAP). Smart biodegradable films with tailored gas permeability can slow respiration without inducing anaerobic conditions.

2. Moisture Control

Both dehydration and excess moisture lead to quality loss. Active films incorporating moisture absorbers or enhanced water-vapour regulation help maintain optimal humidity.

3. Microbial Spoilage

Surface microorganisms are a major cause of spoilage. Antimicrobial packaging (using essential oils, nanoparticles, organic acids) can significantly delay microbial growth.

4. Ethylene and Ripening

Ethylene accelerates ripening in climacteric fruits. Smart packaging can include ethylene scavengers or sensors to regulate ripening.

Benefits and Impact

Smart biodegradable packaging offers multiple advantages:

- **Extended Shelf Life:** Even a few extra days significantly reduce food waste and improve market availability.
- **Improved Quality Retention:** Better colour, texture, flavour, and nutrient retention increase consumer acceptance.
- **Reduced Losses and Higher Profitability:** Less spoilage benefits farmers, retailers, and supply chains.
- **Sustainability Gains:** Reduced fossil-carbon use, lower landfill waste, and support for circular-economy initiatives.

Challenges and Implementation Issues

Despite its promise, several challenges limit large-scale adoption:

- High cost of biopolymers and smart components.
- Performance limitations (mechanical and barrier properties often inferior to plastics).
- Scalability issues, as many films succeed at lab scale but not at industrial production levels.
- Regulatory concerns, especially regarding migration of active agents or nanoparticles into food.

Emerging Trends and Future Outlook

Key future directions include:

- **Nanocomposites & Multifunctional Films:** Incorporation of TiO_2, ZnO nanoparticles, essential oils, and natural extracts to improve antimicrobial and barrier properties.

- **Iot-Enabled Sensor Packaging:** Gas, temperature, and humidity sensors for real-time monitoring and dynamic release of active compounds.
- **Waste-Derived Biopolymers:** Use of agricultural residues (soy hulls, alfalfa, citrus peel) to reduce production costs.
- **Lifecycle Assessment (LCA):** Ensuring that new materials offer real net environmental benefits.

Conclusion

Smart biodegradable packaging presents a powerful combination of post-harvest quality enhancement and environmental sustainability**,** particularly for perishable horticultural produce. Integrating active functionalities (antimicrobials, ethylene/moisture control) and intelligent features (sensors, indicators) helps extend shelf life, reduce losses, and strengthen supply-chain efficiency.

To move from laboratory innovation to commercial reality, further progress is needed in material performance**,** cost reduction**,** regulatory clearance**,** and waste-management infrastructure**.** For countries like India—where post-harvest losses in fruits and vegetables are high—investment in smart biodegradable packaging offers significant economic, environmental, and food-security benefits**.**

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Lotus Stem: A Biofunctional Aquatic Vegetable with Multifaceted Benefits

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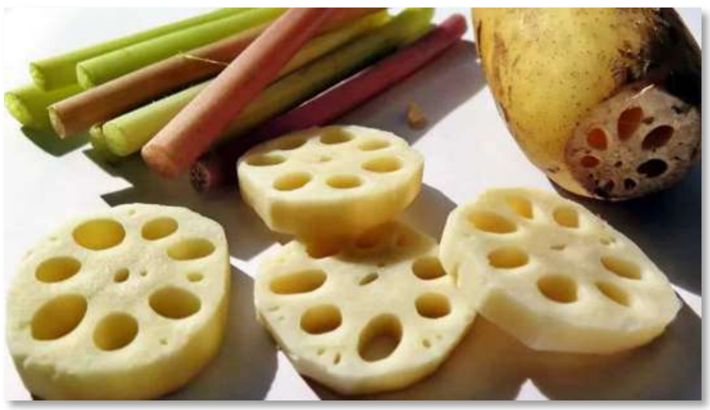
Lotus (*Nelumbo nucifera*), commonly known as the holy lotus or Asian lotus, belongs to the family Nelumbonaceae and is native to Asia. It is a perennial aquatic flowering plant whose various parts are widely used for medicinal, nutritional, and cultural purposes. The plant arises from creeping rhizomes bearing nodes, each producing a single leaf (Matthews & Seymour, 2006). Lotus flowers possess thermogenic properties that help regulate floral temperature and attract pollinators.



The plant bears aerial and floating orbicular leaves with self-cleaning abilities due to their hydrophobic surface. Lotus leaves are traditionally used in herbal medicines for treating hyperlipidemia and regulating blood lipids, whereas its seeds maintain viability for several decades or even centuries. Gas exchange occurs through the leaves: oxygen-rich air is transported to the rhizomes, and excess air escapes through the same pathway.

Different plant parts—buds, flowers, leaves, stems, and roots—contain valuable metabolites such as alkaloids, flavonoids, polyphenols, and steroids. Lotus also influences cuticular wax formation in plants like *Arabidopsis* by producing extra-long-chain fatty acids. Lotus roots (rhizomes) efficiently absorb water pollutants, including heavy metals, helping to mitigate eutrophication and maintain aquatic ecosystem balance. Additionally, lotus biomass can be converted into biochar with a porous structure suitable for soil amendments and carbon sequestration.

The lotus stem (kamal kakdi) is widely consumed as a vegetable due to its delicate flavor and sweet taste. It is a modified subterranean, elongated rhizome that enlarges during autumn. Typically brown to yellowish-green externally with white flesh and characteristic air cavities, it withstands submergence and low-oxygen conditions owing to its extensive aerenchyma tissue (Lin et al., 2019). Lotus stem is consumed fresh, dried, fried, roasted, or pickled across India, China, Southeast Asia, and Japan. Lotus stem starch serves as a thickener and stabilizer in food industries.

After the harvesting of flowers and seeds, leftover lotus biomass provides a sustainable resource for producing electrochemical carbon materials, attributed to its high cellulose content and naturally porous anatomy. Various forms of lotus stem are also used in metal fabrication industries for developing energy-efficient, eco-friendly carbon materials.

Nutritional Importance

- High vitamin C content strengthens immunity, prevents oxidative stress, and helps combat viral diseases.
- Considered part of healthy diets due to high dietary fiber and low fat levels.
- Rich in fiber, supporting improved digestion and gut health.
- Contains proteins, carbohydrates, vitamins (Vitamin B6 and C), and essential minerals such as calcium (6 mg/100 g), iron (2.4 mg/100 g), and zinc (0.2 mg/100 g), along with trace elements like copper, magnesium, manganese, and potassium, contributing to its nutritional and therapeutic value (Ogle et al., 2001).
- Dried lotus stem serves as an excellent source of iron, important for healthy blood metabolism.

Fig. *Overview of lotus plant in its natural aquatic habitat with submerged stems.*

Benefits and Uses

- Phytochemicals in lotus stem aid in preventing cancer, asthma, ulcerative colitis, and cardiovascular disorders.
- Used in traditional medicine to treat diarrhea, dyspepsia, and piles.
- Exhibits antifungal, antibacterial, antiviral, and anti-obesity properties.
- Contains a high amount of starch, useful in textile, food processing, and pharmaceutical industries; also a natural source of cellulose.
- Employed in Ayurveda for treating leprosy, skin allergies, emotional exhaustion, and diuretic problems (Sridhar & Bhat, 2007).
- Aids in red blood cell formation, regulates blood pressure, and enhances blood circulation due to vasodilatory properties (Zaidi et al., 2021).
- Enhances antioxidant activity through amino acids like tryptophan.
- Used in the development of high-performance sodium-ion batteries due to its natural porous structure (Zhang et al., 2018).
- Supports production of porous activated carbon with strong CO_2 adsorption capacity.

- Used to create nitrogen-doped porous carbon with efficient oxygen reduction reaction (ORR) activity and high stability, suitable for electrochemical applications (Weththasinha et al., 2017).
- Lotus stem fibers are used in producing eco-friendly, biodegradable polymer composites.
- Lotus stem flour, after drying, is used as a functional ingredient in health-oriented value-added food products.
- Demonstrates antibacterial activity against *Bacillus subtilis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli*.

Conclusion

Lotus stem is an underutilized yet highly valuable part of the lotus plant, offering nutritional, medicinal, industrial, and environmental benefits. Its structural adaptations allow it to thrive under submergence while providing diverse applications ranging from functional foods to advanced industrial materials. The presence of polysaccharides, fiber, essential minerals, vitamins, and bioactive compounds enhances its significance in health, nutrition, pharmaceuticals, and emerging technologies. With increasing interest in natural and sustainable resources, lotus stem holds promising potential in modern healthcare and industrial innovation.

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Environmental Significance of Neem (*Azadirachta indica*) in Sustainable Pest Management

ARTICLE ID: 0308

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Agriculture is a vital sector providing food, fiber, biofuels, and other essential resources for human survival. However, rapid urbanization and global population growth have significantly reduced the land available for agriculture. To maintain productivity, farmers increasingly rely on chemical fertilizers and pesticides, which contribute to soil degradation, loss of fertility, and harmful impacts on human health and the environment.

This situation highlights the urgent need to shift from synthetic inputs to eco-friendly alternatives such as biofertilizers and biopesticides. These biological agents enhance ecological sustainability, improve nutrient availability, support soil regeneration, and reduce pollution.

Neem (*Azadirachta indica*), popularly known as the "Village Pharmacy" (Figure 1), is native to the Indian subcontinent and belongs to the family Meliaceae. It is a hardy, evergreen tree capable of thriving in nutrient-poor and dry conditions. Neem has gained global attention due to its potent insecticidal, fungicidal, and nematicidal properties, attributed to its bitter leaves and fruits (Table 1). Neem-based bio-products play a significant role in sustainable agriculture, offering solutions to environmental issues such as climate change, soil pollution, and biodiversity loss.

***Figure 1.** Neem: (a) Leaves (b) Fruit (c) Flower (d) Stem.*

Phytochemistry

Neem contains a wide variety of bioactive phytochemicals responsible for its medicinal and pesticidal attributes. These secondary metabolites are distributed across the leaves, bark, roots, flowers, seeds, and fruits. Major compounds include limonoids, flavonoids, alkaloids, tannins, glycosides, sterols, and saponins. These constituents contribute to neem's antibacterial, antifungal, antifeedant, and insecticidal activities.

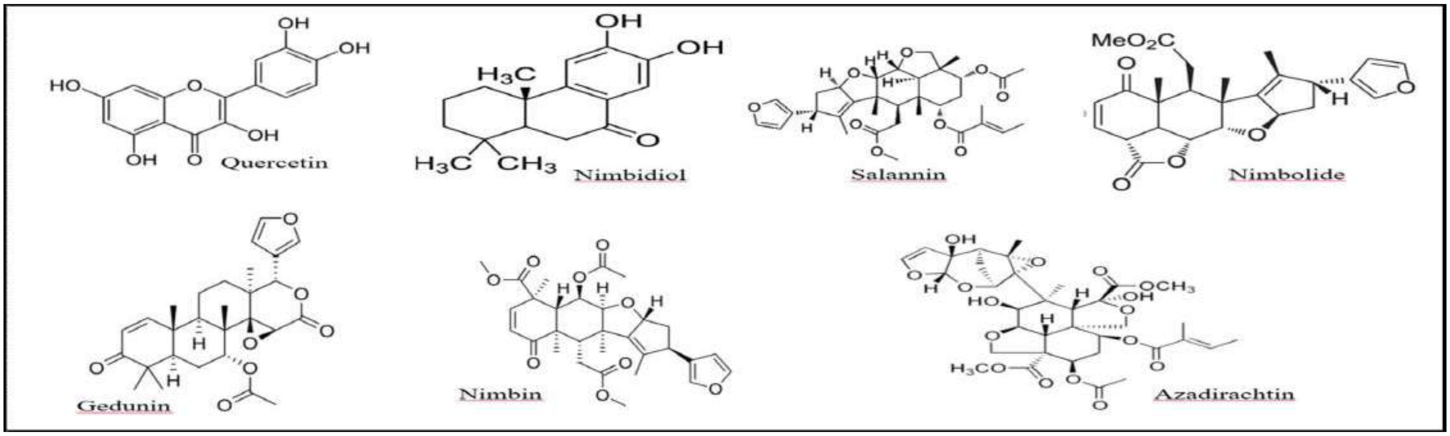

Figure 2. *Important bioactive compounds of Neem.*

Table 1. Phytochemicals present in Neem and their pharmacological potential

Compound	Bioactivity
Azadirachtin	Anti-hormonal, Antifeedant, Repellent
Nimbidol	Antipyretic, Anti-protozoan, Anti-tubercular
Gedunin	Anti-malarial, Antifungal, Vasodilator
Quercetin	Antibacterial, Antioxidant, Anti-protozoal, Anti-inflammatory
Sodium nimbinate	Anti-arthritic, Diuretic, Spermicidal
Nimbin	Antihistamine, Antipyretic, Antifungal, Anti-inflammatory
Salannin	Repellent
Nimbidin	Antibacterial, Analgesic, Anti-ulcer, Anti-arrhythmic, Antifungal

Biopesticidal Activities of Neem for Sustainable Farming

1. Insecticidal Activity

Neem produces defensive compounds that act as repellents, feeding deterrents, oviposition inhibitors, growth regulators, and toxicants to harmful insects. Among these, azadirachtin (Figure 2) is the most important insecticidal compound and a key ingredient in commercial neem-based formulations.

Although azadirachtin is effective, its instability (requiring storage at −40°C) limits direct usage. According to Isman et al. (1990), commercial formulations of azadirachtin perform better than the pure compound. Neem extracts have successfully managed several resistant insect populations. Mazid et al. (2011) reported that neem-based products significantly impact the eggs of *Bactrocera zonata* while remaining harmless to pollinators and other beneficial organisms.

2. Antifungal Activity

Neem constituents such as azadirachtin, nimbin, and nimbidin exhibit strong antifungal effects. Commercial neem products (Achuk, Trilogy, Neemark) are effective against *Alternaria solani*, *Podosphaera xanthii*, and *Fusarium oxysporum*. Azadirachtin has demonstrated greater inhibitory effects on pathogenic fungi than synthetic fungicides like mancozeb.

Neem oil suppresses fungal spore germination and is effective against diseases such as collar canker in tea caused by *Glomerella cingulata*. It also protects tomato crops against pathogens including *Pyricularia oryzae*.

3. Ovipositional Deterrent

Neem acts as a potent oviposition deterrent, reducing egg-laying in insect pests such as *Bactrocera carambolae*, *Mamestra brassicae* (cabbage moth), *Bactrocera zonata*, and *Phthorimaea operculella* (potato tuber moth). Neem leaves contain nonacosane, a saturated fatty acid that adversely affects the fecundity of pests like *Stephanitis pyrioides* (Wang et al., 1999).

4. Antifeedant Properties

Neem exhibits strong antifeedant activity, discouraging insects from consuming plant tissues. Compounds such as azadirachtin, salannin, and melandriol cause digestive disturbances in insects, leading to starvation and reduced pest damage (Vijayalakshmi et al., 1985).

5. Nematicidal Activity

Neem seed extracts have shown significant nematicidal effects against root-knot nematodes. In vitro studies revealed 100% mortality of nematode juveniles within 24 hours using an aqueous extract of *A. indica* (300 mg/ml). Methanolic extracts demonstrated similar results within 8 hours. Alkaloids, polysaccharides, and saponins present in neem contribute to its effective nematicidal action.

Challenges and Limitations

Despite their potential, biopesticides including neem-based products face several challenges:

- Limited shelf life and stability
- Sensitivity to environmental conditions
- Slower action compared to synthetic pesticides
- Need for broad-spectrum activity
- Long and costly registration processes
- Use of single microbial strains in many formulations, reducing efficacy

Enhancing biopesticide formulations with multiple strains or stabilizing agents can improve their effectiveness and commercial viability.

Conclusion

Neem-based pesticides, especially azadirachtin formulations, offer environmentally safe and effective alternatives to chemical pesticides. They provide insecticidal, antifungal, antifeedant, and nematicidal actions while remaining biodegradable and non-toxic to beneficial organisms. These features make neem highly suitable for Integrated Pest Management (IPM), promoting sustainable agriculture. Awareness and adoption of neem-based technologies can significantly enhance crop productivity while ensuring ecological balance.

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Pros and Cons of Natural Farming in India

ARTICLE ID: 0309

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Agriculture has been the backbone of India's economy for centuries, supporting nearly half of its population and contributing significantly to the national GDP. With industrialization and modernization, chemical-based farming practices were introduced to increase food production. However, these intensive practices have resulted in soil degradation, water contamination, biodiversity loss, and health concerns. In response, natural farming has emerged as a sustainable, eco-friendly alternative that operates in harmony with nature rather than attempting to dominate it.

Natural farming—popularly known in India as Zero Budget Natural Farming (ZBNF)—avoids synthetic fertilizers, pesticides, and genetically modified organisms (GMOs). It relies on natural inputs such as cow dung, cow urine, compost, green manure, crop rotation, and intercropping to maintain soil fertility and manage pests. Promoted by agricultural reformers like Subhash Palekar, natural farming aims to restore soil health, reduce production costs, and enhance farmers' livelihoods.

While natural farming offers several ecological and social benefits, it also faces constraints related to productivity, implementation, and large-scale adoption. This article discusses in detail the pros and cons of natural farming in India, examining its implications for farmers, consumers, and the agricultural sector.

Concept and Principles of Natural Farming

Natural farming is based on the philosophy that agricultural systems should mimic natural ecosystems where soil, water, microorganisms, flora, and fauna operate in balance. The approach relies on four core principles:

1. **No Chemical Fertilizers or Pesticides:** Only natural inputs are used for soil nourishment and pest control.
2. **No Tillage:** Soil is left undisturbed to protect its structure and microbial life.

3. **No Chemical Weed Control:** Weeds are managed naturally or integrated into the ecosystem.
4. **No Dependency on External Inputs:** Farmers use locally available resources such as cow dung, cow urine, jaggery, and pulse flour.

This approach promotes low-cost, self-sustaining farming that uplifts farmers by reducing dependence on industrial inputs.

Pros of Natural Farming in India

1. Environmental Sustainability

Natural farming has several environmental benefits:

- **Improved Soil Health:** Organic matter, compost, and beneficial microbes enhance soil fertility and structure.
- **Reduced Pollution:** Eliminating synthetic agrochemicals minimizes water and air pollution.
- **Carbon Sequestration:** Organic practices help capture atmospheric carbon, mitigating climate change.
- **Biodiversity Conservation:** Diverse cropping systems support pollinators, insects, earthworms, and beneficial fauna.

Overall, natural farming contributes to a resilient, sustainable agricultural ecosystem.

2. Cost-Effectiveness for Farmers

A major advantage of natural farming is the reduced cost of cultivation.

- **Use of Local Inputs:** Bio-formulations like *Jeevamrutha* can be prepared from farm materials.
- **Lower Credit Dependency:** Reduced input costs help farmers avoid debt traps.
- **Higher Profit Margins:** Savings on fertilizers and pesticides often compensate for slightly lower yields.

This is especially important for small and marginal farmers who form more than 85% of India's farming community.

3. Health Benefits

Natural farming produces safer, more nutritious food.

- **Chemical-Free Produce:** Free from pesticide residues and synthetic fertilizers.
- **Reduced Health Risks:** Minimizes exposure to harmful agrochemicals linked to cancer, endocrine disorders, and respiratory problems.
- **Nutritional Richness:** Naturally grown crops often have higher levels of vitamins, minerals, and antioxidants.

Growing consumer awareness has increased demand for naturally farmed produce.

4. Soil and Water Conservation

Natural farming enhances soil and water resource management.

- **Mulching and Organic Matter:** Reduce erosion, enrich soil, and maintain moisture.
- **Water-Use Efficiency:** Enhanced water retention reduces irrigation needs.
- **Groundwater Protection:** Absence of chemical runoff improves groundwater quality.

This makes natural farming effective in drought-prone regions.

5. Employment Generation and Rural Empowerment

Natural farming strengthens rural livelihoods.

- **Use of Traditional Knowledge:** Encourages farmer-led innovation and indigenous techniques.
- **Labor Opportunities:** Composting, mulching, and manual weeding increase rural employment.
- **Women Empowerment:** Women frequently take active roles in preparing inputs and managing bio-farming tasks.

These benefits contribute to inclusive and sustainable rural development.

6. Long-Term Sustainability and Resilience

- **Climate Resilience:** Naturally managed soils withstand droughts, floods, and pests better.
- **Sustainable Yields:** Soil fertility improves over time, stabilizing production.
- **Reduced Market Dependency:** Farmers avoid volatile chemical input markets, improving economic security.

Cons of Natural Farming in India

Despite its many strengths, natural farming has certain limitations.

1. Lower Initial Yields

- **Transition Phase Decline:** Yields typically drop during the shift from chemical to natural methods.
- **Food Security Concern:** Lower productivity may challenge India's food supply demands.

This discourages farmers from adopting natural farming without assured support.

2. Labor-Intensive

- **Manual Weeding:** Required due to the absence of herbicides.
- **Bio-Input Preparation:** Formulations like *Beejamrutha* and *Jeevamrutha* require time and effort.
- **Higher Workload:** Additional labor may be difficult for farmers with limited support.

3. Knowledge and Skill Gaps

- **Lack of Awareness:** Many farmers remain unfamiliar with natural farming practices.
- **Training Requirements:** Effective implementation requires knowledge of soil biology, composting, and pest control.
- **Insufficient Extension Support:** Limited government outreach affects adoption.

4. Market Challenges

- **Absence of Certification:** Natural produce often lacks standardized certification.
- **Restricted Market Access:** Difficulty in reaching consumers willing to pay premium prices.
- **Price Instability:** Lack of assured markets affects income stability.

5. Pest and Disease Management Issues

- **Limited Control Options:** Severe pest outbreaks are harder to manage without chemicals.
- **Varied Effectiveness:** Natural pest management depends on local biodiversity.
- **Risk of Crop Loss:** Especially during initial years of transition.

6. Policy and Institutional Barriers

- **Uneven Support:** Some states actively promote natural farming, others prioritize conventional or organic practices.
- **Subsidy Imbalance:** Chemical inputs receive higher subsidies than natural alternatives.
- **Infrastructure Gaps:** Lack of training centers, compost units, and seed banks.

Government Initiatives and Success Stories

India has initiated several efforts to promote natural farming, such as:

- **Bhartiya Prakritik Krishi Paddhati (BPKP):** Implemented under PKVY to support natural farming.
- **Andhra Pradesh Community-Managed Natural Farming (APCNF):** One of the world's largest natural farming programs; shows improved soil health and reduced costs.
- **Sikkim:** India's first fully organic state, setting a benchmark for chemical-free agriculture.
- **Himachal Pradesh:** Successfully implementing the Prakritik Kheti Khushhal Kisan Yojana.

These examples demonstrate the potential of natural farming with proper training, policy support, and community involvement.

Future Prospects of Natural Farming in India

Natural farming shows strong potential for shaping India's sustainable agricultural future. To expand its adoption:

- Governments should provide financial and technical support during the transition period.
- Research institutions must develop innovative methods to improve yields and pest management.
- Certification and market linkages must be strengthened.
- Large-scale training and awareness programs are needed through universities, KVKs, and NGOs.

Effective implementation can enhance sustainability, climate resilience, and farmer prosperity.

Conclusion

Natural farming represents a return to ecological balance and traditional wisdom, promoting the health of soil, environment, and people. Its benefits—reduced costs, environmental protection, enhanced soil fertility, and healthier food—make it a promising alternative to chemical-intensive agriculture. However, challenges such as lower initial yields, labor requirements, limited markets, and inadequate policy support hinder widespread adoption.

A balanced approach—combining natural farming principles with scientific advancements—can help India achieve sustainable, resource-efficient agriculture. With strong policy interventions, farmer training, and consumer awareness, natural farming can emerge as a cornerstone of India's agricultural transformation.

Ultimately, natural farming is not just a cultivation method; it is a philosophy of harmonious coexistence with nature, essential for ecological sustainability and long-term food security.

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Heat-Resilient Crops: How Plants Survive Extreme Temperatures

ARTICLE ID: 0310

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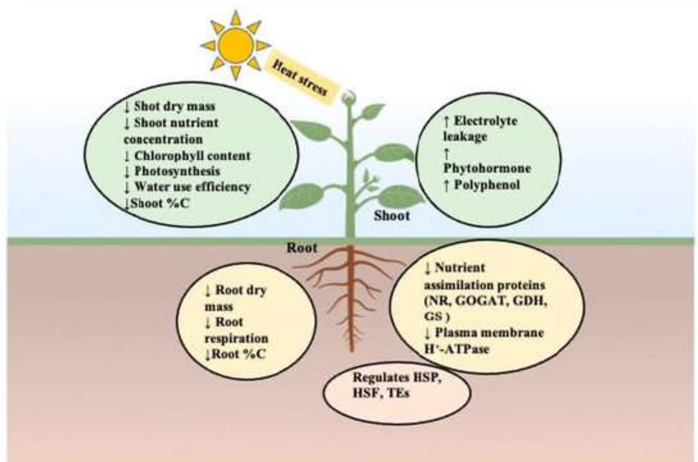
In recent years, farmers across India have observed a worrying trend—summers are becoming hotter, longer, and more difficult to manage. Heatwaves now arrive earlier, persist longer, and strike with greater intensity. In states such as Telangana, Andhra Pradesh, Maharashtra, and Rajasthan, daytime temperatures frequently cross 40–45°C, pushing crops far beyond their comfort limits. Even a slight rise in temperature can disturb a plant's internal processes, and prolonged heat spells can destroy pollen, reduce flowering, damage leaves, and cut yields by 20–60%.



Yet, amid this harsh environment, some crops stand firm. Their leaves stay greener, their flowers last longer, and grain formation continues even when surrounding fields struggle. These crops are heat-resilient, equipped with extraordinary internal mechanisms that allow them not just to survive but to perform under extreme temperatures. Their story is one of science, evolution, and adaptation—knowledge every farmer and agriculture student should understand.

Heat Stress: A Silent Threat to Indian Agriculture

Heat stress often operates silently. Unlike pests or diseases, heat does not leave visible symptoms immediately, yet the internal damage begins quickly. High temperatures accelerate water loss, interrupt nutrient flow, destabilize cell membranes, and hinder photosynthesis—the plant's most vital food-producing process.

Heat stress is especially dangerous when it strikes at sensitive stages like flowering. Crops such as rice, wheat, maize, red gram, and groundnut suffer irreversible yield losses when exposed to high temperatures during reproductive phases. Pollination fails, grains remain empty, and leaves lose vigour.

Another rising concern is night-time warming**.** Warm nights prevent plants from resting or recovering. Increased respiration results in higher carbohydrate loss and reduced energy reserves. All of this leads to significant drops in productivity—even if daytime temperatures are manageable.

This highlights why understanding and developing heat-resilient crops is essential for India's climate-smart agriculture.

How Heat-Resilient Crops Keep Their Cool

Plants may appear still and silent, but internally they are constantly adjusting, repairing, and adapting. Heat-resilient crops depend on a range of finely tuned survival mechanisms, some inherited from ancestors and others shaped through natural selection. Key mechanisms include:

1. Cooling Through Evaporative Loss — Transpiration

Plants cool themselves primarily through transpiration**,** the evaporation of water from leaf surfaces. When temperatures rise, this evaporation carries heat away.

Heat-resilient plants excel in precise stomatal control**,** enabling them to:

- Open stomata just enough to stay cool
- Minimize excessive moisture loss
- Coordinate stomatal activity with sunlight intensity

This fine balance often keeps their leaf temperatures several degrees lower than the surrounding air.

2. Deep and Efficient Root Systems

Heat and drought often occur together. While surface soil dries quickly, deeper layers retain moisture. Heat-tolerant crops use this advantage by developing:

- Deep taproots
- More lateral roots
- Thicker root tissues
- Greater root length density

These root traits help crops like millets, sorghum, pigeon pea, and cotton access deeper water reserves and essential nutrients, ensuring continued growth during heatwaves.

3. Heat-Shock Proteins (HSPs)

Heat-shock proteins act as the plant's emergency repair system**.** High temperatures can cause essential proteins to lose their shape, leading to failure of critical processes. HSPs stabilize, refold, and protect these proteins, allowing plants to maintain photosynthesis, respiration, and growth under stress.

4. Antioxidants: Internal Firefighters

Heat stress increases the production of Reactive Oxygen Species (ROS)—harmful molecules that damage cells. Heat-resilient crops produce antioxidants to neutralize ROS, including:

- Ascorbic acid (Vitamin C)
- Glutathione
- Carotenoids
- Enzymatic antioxidants such as catalase and peroxidase

These molecules prevent internal tissue damage and delay aging.

5. Thicker, Waxy Leaves

Some crops develop structural adaptations like:

- Thicker leaves for water storage
- Waxy leaf coatings that reduce water loss
- Reflective surfaces that reduce heat absorption

Crops such as sorghum, pearl millet, and sesame use leaf wax as a protective "natural sunscreen."

6. Stable Cell Membranes

At high temperatures, cell membranes become leaky, causing ions and nutrients to escape. Heat-resilient varieties have membranes rich in stable lipids that maintain flexibility under stress, helping to:

- Prevent ion leakage
- Maintain nutrient transport
- Preserve metabolic functions

This invisible adaptation often determines survival during heatwaves.

Naturally Heat-Tolerant Crops

Some crops evolved in dry, harsh environments and naturally possess strong heat-resilience traits:

- **Sorghum** — strong roots and waxy leaves
- **Pearl millet** — thrives even at 45–48°C
- **Foxtail & Barnyard Millets** — rapid recovery after stress
- **Pigeon Pea** — deep roots and strong antioxidant systems
- **Black Gram & Cowpea** — withstand extreme summer heat
- **Cotton** — heat-friendly canopy and physiology

Such crops are gaining renewed interest as climate stress intensifies.

Can Sensitive Crops Be Made Heat-Resilient?

Yes. Plant breeders are identifying heat-tolerance genes from hardy crops and transferring them into rice, wheat, maize, and pulses. Important physiological markers used in selecting heat-tolerant varieties include:

- Cooler canopy temperatures
- High membrane stability
- Greater pollen viability
- Strong antioxidant activity
- Robust root traits

Modern tools like genomic selection, marker-assisted breeding, and CRISPR gene editing are accelerating the development of heat-resilient varieties.

Alongside improved genetics, farming practices such as mulching, micro-irrigation, crop diversification, and adjusting sowing windows also boost heat tolerance.

Looking Ahead: The Future Belongs to Heat-Resilient Crops

By 2050, India will require far more food to support its growing population. Yet rising temperatures threaten to reduce yields of major crops. Heat-resilient crops offer a powerful solution. They form the backbone of climate-smart agriculture, ensuring food security even under unpredictable weather.

These crops are not merely survivors—they are the future drivers of global agriculture, capable of feeding millions in a warming world. Understanding their physiology is essential for building a resilient and sustainable farming system capable of meeting future challenges.

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Sustainable and Plant-Based Eating: A Pathway to a Healthier Planet and People

ARTICLE ID: 0311

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Sustainable and plant-based eating has become a global priority due to the growing challenges of climate change, resource depletion, and diet-related health disorders. This article examines how plant-based diets can simultaneously improve human health and safeguard the environment. Sustainable eating emphasizes the ethical production and consumption of food to maintain ecological balance, social justice, and economic viability for present and future generations. Plant-based diets—centered on fruits, vegetables, grains, legumes, nuts, and seeds—offer several benefits, such as reducing greenhouse gas emissions, conserving biodiversity, and minimizing water and land use. They also promote longevity, weight management, and improved cardiovascular health.

The article explores cultural and economic aspects of dietary transitions, barriers to adopting sustainable diets, and the educational and policy measures needed to overcome them. Real-world examples such as traditional Indian food systems, urban gardening, and global initiatives like the Planetary Health Diet demonstrate the practicality and urgency of this shift. Overall, sustainable and plant-based eating represents an integrated approach to achieving nutritional security, ecological resilience, and holistic well-being for people and the planet.

The global food system is at a crucial turning point in the twenty-first century. As the world's population continues to rise, the Earth's natural resources—soil, water, and biodiversity—are being depleted at alarming rates. Environmental degradation, diet-related health issues, and climate change have become major concerns. Consequently, sustainable and plant-based eating has emerged as a powerful and practical approach to achieving both improved human health and environmental stability.

Sustainable eating refers to choosing foods that are produced and consumed in ways that protect the environment, support local communities, and promote animal welfare while ensuring adequate nutrition for present and future generations. Plant-based eating emphasizes foods derived primarily from plants, such as fruits, vegetables, grains, legumes, nuts, and seeds, with limited or no consumption of animal products.

Plant-based diets are gaining global attention not as a trend, but as a scientific response to health and ecological challenges. By adopting sustainability-oriented dietary patterns, we can reduce greenhouse gas emissions, preserve biodiversity, and promote equitable food systems. According to the Food and Agriculture Organization (FAO), sustainable diets are those that have "low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations."

Sustainability in food systems encompasses:

- **Environmental Responsibility:** reducing carbon emissions, minimizing pollution, and protecting soil and water resources.
- **Social Equity:** ensuring fair labor standards and equal access to nutritious food.
- **Economic Viability:** supporting local businesses and farmers to guarantee stable livelihoods.

A shift toward plant-based foods is central to transforming food production, processing, distribution, and consumption systems.

Understanding Plant-Based Eating

Plant-based eating does not necessarily require strict vegan or vegetarian adherence. Rather, it prioritizes plants as the central component of meals while reducing dependence on meat, dairy, and animal-derived foods.

Types of Plant-Based Diets

- **Vegan Diet:** excludes all animal products.
- **Vegetarian Diet:** includes dairy and eggs but excludes meat and fish.
- **Flexitarian Diet:** primarily plant-based with occasional consumption of meat or fish.
- **Whole-Food, Plant-Based Diet:** emphasizes minimally processed plant foods and restricts refined sugars and oils.

Plant-based foods are rich in fiber, vitamins, minerals, and phytochemicals, while being low in saturated fats and cholesterol.

Environmental Benefits of Plant-Based Eating

One of the strongest motivations for adopting plant-based diets is their potential to reduce environmental damage caused by industrial food production.

1. **Reduced Greenhouse Gas Emissions:** Livestock production contributes nearly 14.5% of global greenhouse gas emissions. Plant-based diets drastically reduce these emissions due to lower resource requirements.
2. **Lower Land and Water Use:** Animal agriculture demands vast land for grazing and feed. Producing plant-based foods requires significantly less land and water.
3. **Biodiversity Conservation:** Livestock expansion leads to deforestation and habitat loss. Plant-based

diets indirectly help preserve ecosystems and wildlife.

4. **Waste and Pollution Reduction:** Plant-based systems usually generate less waste and enable composting, improving soil health.

Health Benefits of Plant-Based Diets

Scientific research consistently links plant-based diets to improved health outcomes.

1. **Cardiovascular Health:** Rich in fiber and antioxidants, plant-based foods reduce risk factors such as high blood pressure, cholesterol, and inflammation.
2. **Weight Management and Diabetes Prevention:** The high fiber content supports weight control and enhances insulin sensitivity.
3. **Cancer Prevention:** Plant foods contain phytochemicals and antioxidants that protect against colon, breast, and prostate cancers.
4. **Improved Digestive Health:** Increased fiber promotes a healthy gut microbiome and strengthens immunity.
5. **Longevity and Quality of Life:** Populations consuming predominantly plant-based diets often exhibit higher life expectancy and lower rates of chronic diseases.

Economic and Social Dimensions

Shifting toward sustainable, plant-based eating also influences economic and social systems.

- **Supports Local Farmers:** Encourages consumption of local, seasonal produce.
- **Affordable Nutrition:** Grains, pulses, and vegetables are cost-effective.
- **Food Security:** Plant-based diets can feed more people with fewer resources.
- **Cultural Relevance:** Many traditional diets, especially in India, are naturally plant-rich.

Barriers to Adoption

Despite obvious benefits, several challenges limit widespread adoption:

1. Cultural norms and preferences
2. Lack of awareness regarding environmental impacts
3. Limited access to diverse plant foods in some regions
4. Economic dominance of the meat and dairy industries
5. Nutritional misconceptions about plant-based diets

Strategies for Promoting Sustainable Eating

A comprehensive, multi-level approach is needed to promote plant-based and sustainable diets:

1. Nutrition Education across schools and communities
2. Policy Support through subsidies for plant-based foods
3. Food Industry Innovation to improve plant-based alternatives
4. Public Awareness Campaigns promoting benefits
5. Research and Development in sustainable agriculture
6. Institutional Integration in schools, hospitals, and workplaces

Examples of Sustainable Plant-Based Practices

1. Urban Gardening and Rooftop Farming
2. Farm-to-Table Initiatives
3. Traditional Indian Diets

4. Plant-Based Food Innovations like plant-based meats and dairy substitutes

Global and National Initiatives

Organizations like FAO, WHO, UNEP, and the EAT-Lancet Commission advocate for sustainable food systems. The Planetary Health Diet, proposed in 2019, is a globally adaptable model emphasizing sustainable, plant-rich eating.

In India, initiatives such as the International Year of Millets (2023) and the promotion of organic farming align strongly with sustainability goals.

Conclusion

Sustainable and plant-based eating is not merely a dietary preference—it is a commitment to planetary health and future generations. As climate change and health crises intensify, responsible food choices become increasingly critical. Transitioning toward plant-based diets can reduce environmental impact, enhance public health, and strengthen global food security.

Achieving this transformation requires collaboration among individuals, communities, policymakers, and industries. Each meal has the power to impact the planet—either contributing to its degradation or its restoration. Choosing sustainable and plant-based foods is a meaningful act of care for ourselves, society, and the Earth.

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Triple Super Phosphate (TSP): A High-Efficiency Phosphatic Fertilizer for Sustainable Agriculture

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Triple Super Phosphate (TSP) is a highly concentrated phosphatic fertilizer widely used in modern agriculture to enhance crop productivity and soil fertility. It provides a readily available source of phosphorus (P), a critical nutrient responsible for energy transfer, root development, flowering, and crop maturation. TSP is the preferred choice in systems requiring high phosphorus supply without additional nitrogen.

Chemical Composition and Key Nutrients

TSP is produced by reacting finely ground phosphate rock with phosphoric acid, followed by curing and granulation. Its typical composition includes:

- **Phosphorus (P):** 46–48% as P_2O_5 (≈20% elemental P)
- **Calcium (Ca):** 13–15%
- **Sulphur (S):** Trace amounts (≈1%)

This high nutrient concentration allows efficient transportation, handling, and targeted nutrient application.

Solubility and Nutrient Availability

TSP is known for its excellent solubility:

- **Water Solubility:** More than 89%
- **Citric Solubility:** Over 95%
- **Slow-Release Fraction:** 4–5% of P_2O_5

The high water solubility ensures that phosphorus becomes available to plant roots immediately after application. TSP does not contain nitrogen, making it ideal for crops requiring phosphorus without additional N input.

Behavior of TSP in Soil

Upon application, TSP granules dissolve quickly in moist soil, producing a localized acidic zone around each granule. This temporary acidity:

- Enhances phosphorus solubility

- Improves nutrient accessibility
- Supports early-stage root proliferation

As phosphorus diffuses from the granule, it gradually reacts with soil minerals, creating moderately insoluble compounds that contribute to the fertilizer's residual effect. The calcium content also supports soil structure improvement in acidic soils, though its liming effect is limited.

Improving Nutrient Use Efficiency (NUE)

Interaction of TSP with Urea

When used with urea, TSP:

- Slows the rate of urea hydrolysis
- Lowers pH at the application site
- Reduces ammonia volatilization
- Enhances nitrogen retention

Studies show that this combination delays peak ammonia release and improves both nitrogen use efficiency (NUE) and phosphorus use efficiency (PUE).

Global Relevance

Ammonium phosphate fertilizers like DAP and MAP contribute nearly 8% of nitrogen applied to fields worldwide, yet their nitrogen content is often overlooked. Proper integration of TSP and urea helps reduce nitrogen mismanagement, greenhouse gas emissions, and nutrient runoff.

Methods of Application

TSP may be applied through:

- **Basal application:**

1. Broadcasting and incorporating
2. Band placement (3–5 cm from seed) for higher efficiency

- **Blending:** Compatible with most granular fertilizers except strongly alkaline materials
- **Horticulture:** Applied in planting pits, drip lines, or localized zones

Band placement is generally preferred to reduce phosphorus fixation and enhance early root growth.

Agronomic Benefits of TSP

- Promotes strong early root development
- Enhances tillering, branching, flowering, and fruiting
- Supports energy transfer and metabolic activity
- Improves grain quality and crop yield
- Requires lower application rates due to high concentration
- Helps rebuild soil phosphorus in depleted soils

Suitable Crops and Soil Types

Crops

TSP is suitable for:

- **Cereals:** Wheat, rice, maize
- **Oilseeds:** Mustard, groundnut
- **Legumes:** Chickpea, lentil, pea, soybean
- Vegetables, fruits, flowers, sugar crops, and forage grasses

It is especially beneficial for legumes, which need phosphorus for nodule formation and biological nitrogen fixation.

Soil Conditions

Optimal performance is observed in:

- Slightly acidic to neutral soils
- Moderately alkaline soils

In very acidic or calcareous soils, phosphorus fixation increases, making proper placement essential.

Advantages Over Other Phosphate Fertilizers

Compared with SSP

- TSP contains over double the P_2O_5 (46% vs. 16–20% in SSP)
- Lower application volume and cost per unit of phosphorus
- However, SSP contains more sulfur; additional S sources may be needed when using TSP

Compared with DAP/MAP

- TSP is nitrogen-free → useful when nitrogen levels must be controlled
- Lower salinity risk relative to DAP/MAP
- Suitable for sensitive horticultural and high-value crops

Salinity Considerations

TSP has the weakest salinizing effect among major phosphate fertilizers, making it suitable for arid and semi-arid soils prone to salinity.

Environmental and Management Considerations

Efficient TSP use should align with soil testing and crop nutrient requirements. Key management practices include:

- Incorporation to prevent P runoff
- Strategic banding and split applications
- Integration with organic manures to improve P availability
- Avoiding surface application on sloping land

Use of low-impurity TSP helps minimize heavy metal accumulation.

Environmental and Safety Aspects

Phosphorus loss from TSP occurs primarily through:

- Runoff
- Soil erosion

This may contribute to eutrophication in water bodies.

Therefore, the 4R nutrient stewardship approach is recommended:

- Right source
- Right rate
- Right time
- Right place

Modern TSP standards limit heavy metals such as cadmium, lead, arsenic, and chromium, making it safe for long-term use.

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Utilization of Crop Residues in Vegetable Farming

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Crop residues are the plant parts left in the field after the harvesting of crops. In recent years, crop residue burning has become a common practice among farmers in North India. Most farmers burn leftover plant materials from rice and wheat crops to clear their fields ahead of the next planting season. Although this practice is quick and convenient, it has serious consequences. The smoke from residue burning contributes significantly to air pollution, which leads to respiratory and other health problems for nearby populations. In addition, the heat generated from burning damages soil structure, ultimately reducing its fertility over time.

Fortunately, there are more sustainable and environmentally friendly alternatives. Instead of burning residues, farmers can convert them into compost or mulch, which enhances soil health, conserves moisture, and reduces the dependency on chemical inputs. Residues can also be used for cultivating vegetables or mushrooms, thereby providing farmers with additional income opportunities.

Crop residue–based vegetable production is a resource-conserving method in which materials such as straw, stalks, husks, and leaves are retained as mulch or organic matter to protect and enrich the soil. This method conserves moisture, suppresses weeds, enhances soil fertility, and reduces erosion.

Agricultural sustainability has become a global concern. Farmers are increasingly seeking alternatives to improve productivity without degrading soil. Utilizing crop residues in vegetable farming offers an eco-friendly approach to improve soil fertility, retain moisture, and suppress weeds, while paving the way for sustainable agricultural systems.

Understanding Crop Residue Vegetable Production

Crop residues include plant materials remaining after crop harvest, such as maize stalks, wheat straw, rice straw (parali), and legume haulms. Instead of burning or discarding them, farmers can incorporate these materials into the soil or use them on the surface to improve sustainability and soil health.

Advantages of Utilizing Crop Residues in Vegetable Growing

1. Soil Fertility Improvement

Crop residues decompose gradually, releasing essential nutrients such as nitrogen, phosphorus, potassium, and micronutrients. This natural fertilization reduces the need for synthetic fertilizers and promotes a balanced soil ecosystem.

2. Water Conservation

Residues reduce evaporation and help retain soil moisture—particularly useful in arid and semi-arid regions. This ensures consistent hydration for vegetables even under dry conditions.

3. Weed Suppression

Mulching with residues creates a protective layer that suppresses weed growth by blocking sunlight. This reduces nutrient competition and lowers herbicide requirements, making farming more economical and environmentally safe.

4. Erosion Control

Residues act as a natural barrier against wind and water erosion, protecting soil structure—especially important in sloping fields where erosion risks are high.

5. Reduction of Greenhouse Gas Emissions

Avoiding residue burning helps reduce emissions of harmful gases such as CO_2, SO_2, and NO_2. Using residues productively lowers the carbon footprint of farming systems.

Methods of Incorporating Crop Residues in Vegetable Farming

1. Mulching

Mulching is an essential practice in modern horticulture. Applying crop residues—such as maize stalks, rice straw, or wheat husks—over the soil surface helps conserve moisture, regulate temperature, and suppress weeds.

2. Composting

Crop residues can be composted into nutrient-rich organic manure. Compost improves soil structure, fertility, and microbial activity.

3. Green Manuring

Residues, especially those from leguminous crops, can be incorporated into the soil to improve nitrogen content and enhance soil organic matter.

4. No-Tillage or Conservation Agriculture

This method involves leaving residues intact on the soil surface and planting vegetables directly into the soil. It reduces soil disturbance, maintains moisture, and encourages beneficial microbial life.

5. Biochar Production

Crop residues can be converted to biochar—a carbon-rich product that enhances soil fertility, improves water retention, and supports long-term soil health.

Best Vegetables for Crop Residue-Based Farming

Many vegetables perform well under residue-based systems, including:

- **Leafy Greens:** Lettuce, spinach, kale
- **Root Vegetables:** Carrots, radishes, beets
- **Fruiting Vegetables:** Tomatoes, peppers, cucumbers
- **Legumes:** Beans, peas

Challenges and Considerations

- **Residue Management:** Residues may harbor pests or diseases and require proper handling.
- **Nutrient Imbalance:** Slow-decomposing materials may temporarily immobilize nutrients, requiring planned fertilization.
- **Labor Requirements:** Collecting, spreading, and managing residues can be labor-intensive, especially for smallholder farmers.

Conclusion

Burning crop residues poses serious threats to air quality, soil health, and the environment by releasing toxic gases and particulate matter. Sustainable residue management is thus essential. Utilizing crop residues in vegetable production allows farmers to improve soil fertility, conserve water, and reduce dependence on chemical inputs. As agriculture transitions towards sustainability, integrating crop residues into vegetable farming will play a key role in enhancing long-term productivity, climate resilience, and food security.

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Major Pests of Okra and Their Life Cycle

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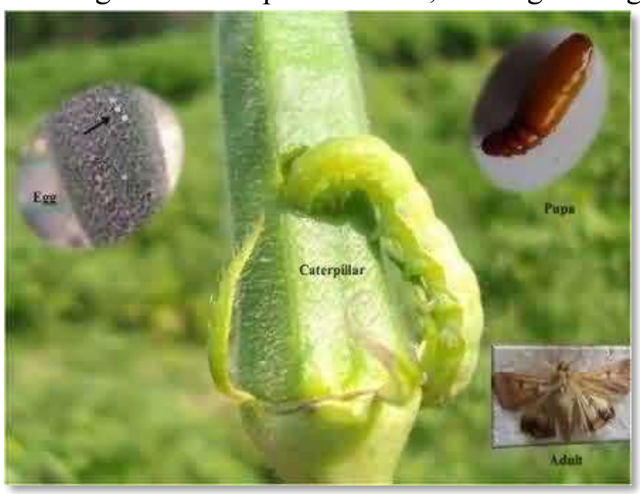
Okra (*Abelmoschus esculentus*), commonly known as lady's finger or bhindi, is one of the most important vegetable crops cultivated across tropical and subtropical regions of the world. It is valued for its tender green pods, which are rich in vitamins A, B, and C, calcium, and other essential nutrients. Okra plays a significant role in the income of small and marginal farmers.



However, its production is frequently affected by various insect pests that infest the crop at different growth stages, leading to severe yield losses and poor-quality fruits. More than seventy insect species have been recorded on okra, but only a few are considered major due to their frequent occurrence and destructive nature. Key pests include jassids, fruit and shoot borers, whiteflies, and aphids.

Understanding their life cycle, mode of damage, and effective management techniques is crucial for successful Integrated Pest Management (IPM).

1. Jassid (*Amrasca biguttula biguttula*)

Jassid is one of the most prevalent sucking pests of okra. Both nymphs and adults feed on the lower leaf surface, causing curling, yellowing, and drying of leaf margins. Severe attack results in "hopper burn," ultimately reducing photosynthesis and yield.

Life Cycle

- Eggs are laid along the veins on the underside of leaves.
- Eggs hatch in 5–10 days, releasing pale green nymphs.
- Nymphs pass through five instars before becoming adults.
- Entire life cycle completes in 2–3 weeks, favored by hot and dry weather.

Damage Symptoms

- Leaves turn pale and curl upward.
- Severe infestation gives the plant a scorched appearance and stunts growth.

2. Fruit and Shoot Borer (*Earias vittella* and *Earias insulana*)

This pest is the most destructive on okra, damaging both vegetative and reproductive stages. Larvae bore into tender shoots and fruits, resulting in wilting and malformed fruits.

Life Cycle

- Eggs are laid singly on tender shoots, flower buds, or fruits.
- Eggs hatch in 3–4 days.
- Newly hatched larvae bore into shoots, later infesting fruits.
- Larval stage lasts 8–10 days, followed by pupation inside the fruit or soil.
- Adults emerge in 7–10 days, completing the cycle in 20–25 days.

Damage Symptoms

- Infested shoots wilt and droop (dead hearts).
- Fruits have small boreholes plugged with frass, making them unmarketable.

3. Whitefly (*Bemisia tabaci*)

Whitefly is a major pest and an important vector of Yellow Vein Mosaic Virus (YVMV). Both nymphs and adults suck sap from leaves, causing chlorosis and curling.

Life Cycle

- Females lay 80–100 eggs on the underside of leaves.
- Eggs hatch in 3–5 days.
- Nymphal period lasts 10–15 days, followed by a pupal stage.
- Adults emerge in 20–25 days.
- Warm, humid weather favors rapid buildup.

Damage Symptoms

- Leaves turn yellow and become sticky due to honeydew.
- Sooty mold develops, hindering photosynthesis.
- Virus-infected plants show characteristic yellow vein patterns with poor fruit development.

4. Aphid (*Aphis gossypii*)

Aphids are soft-bodied insects that form colonies on tender shoots, leaves, and flowers. They suck plant sap and transmit viral diseases.

Life Cycle

- Reproduce mainly parthenogenetically.
- Nymphs mature into adults in 7–10 days.
- Several overlapping generations occur during warm, humid conditions.

Damage Symptoms

- Leaves curl and become distorted.
- Honeydew leads to sooty mold development.
- Heavy infestation causes stunted plants and reduced fruiting.

Integrated Pest Management (IPM) Strategies

1. Cultural Control

- Remove infested plant residues and weeds.
- Follow crop rotation and use pest-tolerant varieties.

2. Mechanical Control

- Regularly collect and destroy infested shoots and fruits.

3. Biological Control

- Encourage beneficial insects such as:
  - *Trichogramma chilonis*
  - *Chrysoperla carnea*
  - *Coccinella septempunctata* (ladybird beetle)
  - Parasitoid wasps

4. Botanical Control

- Apply neem oil (3%) or azadirachtin-based formulations.

5. Chemical Control

- Apply insecticides only when pest populations exceed ETL.
- Recommended options include:
  - Imidacloprid @ 0.3 ml/L
  - Spinosad @ 0.5 ml/L
- Use chemicals judiciously to avoid resistance and residue issues.

Conclusion

Okra cultivation faces significant challenges due to major insect pests such as jassids, fruit and shoot borers, whiteflies, and aphids. Each pest has a unique life cycle that favors rapid multiplication under tropical conditions. Understanding their biology is essential for effective and timely management.

Adopting Integrated Pest Management (IPM) — combining cultural, biological, botanical, and minimal chemical methods — ensures sustainable pest control. This approach reduces pesticide dependence, protects beneficial insects, and enhances long-term okra productivity.

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Improving Nutrient-Use Efficiency: Modern and Conventional Breeding Perspectives

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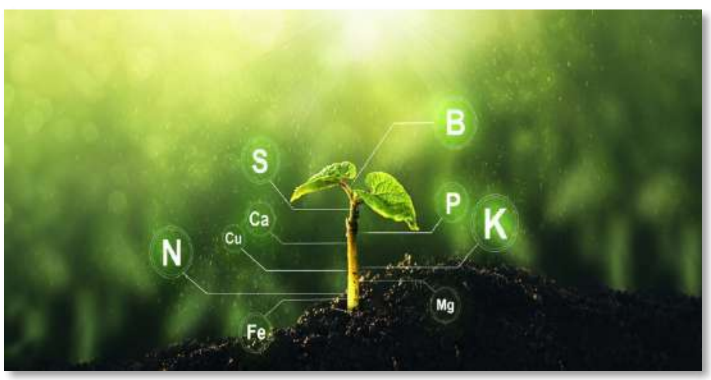
Since the beginning of crop domestication, humans have continuously improved crops to meet changing food and environmental demands. In the present era, agriculture faces increasing pressures from climate change, soil nutrient depletion, and rising global food needs. Enhancing nutrient-use efficiency (NuUE) has therefore become a critical target in crop improvement. Conventional breeding remains central to this goal through the selection of genotypes with superior nutrient uptake and the utilization of both cultivated and wild species to improve nutrient acquisition and assimilation. Mutation breeding has also contributed by generating novel traits and enabling the identification of nutrient-efficient lines.



The discovery of nutrient-related genes and QTLs through genetic mapping has further illuminated the molecular basis of nutrient absorption, transport, and utilization. However, the complex physiological and biochemical pathways underlying NuUE often limit the effectiveness of conventional breeding alone. Modern biotechnological tools—molecular markers, genomic selection, and genome editing techniques such as CRISPR–Cas—offer precise and accelerated avenues for improving NuUE. These methods facilitate targeted modification of key pathways and nutrient-responsive genes. Integrating traditional breeding with advanced biotechnologies provides a pathway to developing high-yielding varieties that require fewer fertilizers, ultimately contributing to a more sustainable and environmentally friendly agricultural system.

Agriculture in the 21st century faces three critical challenges. First, the global population is expected to reach 10 billion by 2050, placing immense pressure on global food production systems. Second, climate change—marked by rising temperatures, irregular rainfall, and frequent extreme weather events—threatens crop productivity and agroecosystem stability. Third, widespread micronutrient deficiencies or "hidden hunger" persist among populations dependent on staple crops lacking essential minerals.

Plants require mineral nutrients to support growth, metabolism, and stress tolerance. Macronutrients such as nitrogen, phosphorus, and potassium are particularly vital for yield, quality, and vigour. However, nutrient acquisition and utilization efficiency are often limited by environmental and physiological constraints. A large proportion of applied fertilizers is lost through leaching, volatilization, and runoff, contributing to soil degradation, water pollution, and higher production costs.

Improving nutrient-use efficiency (NuUE) is therefore a priority for modern agriculture. As nutrient uptake and utilization are under strong genetic control, plant breeding presents a powerful strategy for enhancing NuUE. Nutrient-efficient varieties can reduce fertilizer requirements, minimize nutrient losses, lower input costs, and enhance performance under nutrient-deficient conditions. Thus, breeding for improved NuUE is essential for meeting future food demands while ensuring environmental sustainability.

Conventional Approaches to Improve Nutrient-Use Efficiency

Conventional strategies for enhancing NuUE rely primarily on traditional breeding and agronomic practices. Classical plant breeding focuses on selecting and crossing genotypes with superior nutrient uptake, efficient root systems, and improved nutrient assimilation. As the root system is the primary organ responsible for acquiring water and nutrients from the soil (Ramakrishna et al., 2019), improving root architecture has become central to NuUE enhancement.

Several studies report strong associations between nitrogen uptake and root traits such as rooting depth, root hair length, root diameter, and cellular structure (Wang et al., 2023). For example, increased root length density significantly improved nitrogen and phosphorus assimilation in maize, contributing to a 22% increase in grain yield (Chen et al., 2022). In Brassica napus, Wang et al. (2014) developed an N-efficient line (D4-15) through hybridization, which showed improved yield performance compared to N-inefficient genotypes.

Mutation breeding is another conventional method for creating novel genetic variability. A notable example is the dominant male-sterile mutant Ms44 in maize (Fox et al., 2017), where a single amino acid substitution caused male sterility and reduced nitrogen allocation to tassels. This allowed greater nitrogen partitioning to ears, enhancing kernel number and increasing yield by 4–8.5% under low-nitrogen conditions.

Challenges of Conventional Breeding and Modern Solutions for Improving NuUE

Although conventional breeding has contributed significantly to NuUE improvement, it faces several limitations:

1. Slow and Labour-Intensive Processes

Repeated cycles of crossing and field evaluations delay the development of improved lines.

Modern Solution: Molecular markers, marker-assisted selection (MAS), and genomic selection (GS) accelerate breeding by enabling early and precise identification of NuUE-related genotypes.

2. Complex, polygenic nature of NuUE traits

NuUE traits are quantitative and environmentally influenced, making phenotypic selection difficult. **Modern Solution:** QTL mapping and marker-assisted backcrossing allow precise introgression of nutrient-efficiency QTLs.

3. Limited Genetic Variation Within Crop Gene Pools

Conventional breeding relies heavily on existing germplasm.

Modern solution: Genetic engineering and transgenic approaches enable the introduction of beneficial genes from diverse species, expanding the genetic base.

4. Difficulty Improving Complex Physiological Traits

Processes such as biological nitrogen fixation or modification of metabolic pathways are hard to manipulate using traditional methods.

Modern solution: Genome-editing tools (CRISPR/Cas, TALENs, ZFNs) enable precise gene modification without altering overall genomic integrity.

Genome-Based Strategies for Improving NuUE

Advances in molecular genetics have enabled the identification of genes and QTLs underlying key physiological traits. Linkage mapping and association mapping are the two primary methods used for dissecting quantitative traits.

- Genome-wide association studies (GWAS) scan the entire genome to identify marker–trait associations (Risch & Merikangas, 1996).
- Candidate-gene association mapping focuses on genes with known or suspected functions (Bangarwa et al., 2020).

These tools, along with genome sequencing and high-throughput genotyping, have greatly accelerated the identification of QTLs governing nutrient uptake and utilization.

Key QTL Discoveries in Rice

- **Nitrogen Use Efficiency:** 13 QTLs identified for NUE-related traits (Zhou et al., 2017; Obara et al., 2001).
- **Potassium-Use Efficiency:** Four QTLs discovered in IR64/Azucena cross affecting height, tillering, and biomass (Wu et al., 1998).
- **Phosphorus Uptake:** The major QTL Pup1 was fine-mapped (Wissuwa et al., 2002) and successfully introgressed into *Improved Samba Mahsuri* using MAS (Swamy et al., 2020), enhancing P-deficiency tolerance without compromising yield or quality.

Integrating these QTLs into breeding pipelines will accelerate the development of nutrient-efficient cultivars, especially for low-input farming systems.

Modern Biotechnological Approaches for Improving NuUE

Modern biotechnologies offer unmatched precision and speed in improving NuUE.

1. Genome Editing

CRISPR/Cas and related technologies enable targeted modification of genes involved in:

- nitrogen uptake and assimilation (e.g., NPF6.1, NPF4.5, AAP1, AAP5),
- regulation of nitrogen metabolism (GRF4, NLP1, MYB61),
- phosphorus uptake and signalling (PHT1–PHT5, PHR1, PHR2).

For example, modifying GS1.1 in wheat improved nitrogen-use efficiency (Wang et al., 2020).

2. Transgenic Approaches

Transgenic interventions introduce beneficial genes from unrelated species. Key examples include:

Table 1. Genetically modified crops with improved nutrient-use efficiency

Crop	Gene Overexpressed	Major Features	Reference
Arabidopsis, Rice, Tomato	AVP1/AVP1D	Enhanced root branching; increased P acquisition	Yang et al., 2014
Rice	OsNRT1.1B + OsNR2	Increased nitrate uptake and assimilation; improved tillering and yield	Gao et al., 2019
Maize	Raf2	Increased Rubisco content; improved carbon assimilation and stress resilience	Eshenour et al., 2024

These advancements expand the breeding landscape beyond the limitations of traditional gene pools.

Conclusion and Future Prospects

Improving nutrient-use efficiency is vital for increasing crop productivity while reducing environmental impacts. Advances in high-throughput phenotyping, genome mapping, and biotechnology have greatly enhanced the ability to identify and manipulate genes associated with NuUE. Root architecture traits, molecular markers, favourable QTLs, and genome-edited alleles offer promising avenues for developing climate-resilient, nutrient-efficient cultivars.

Future efforts should focus on multidisciplinary integration—combining phenomics, genomics, genome editing, and field-level validation—to develop varieties that perform consistently across diverse agroecosystems. Utilizing contrasting genotypes such as the N-efficient *B. napus* line D4-15 will aid in QTL discovery and the development of superior cultivars. Overall, a combination of conventional breeding, molecular tools, and biotechnology will be crucial for building a sustainable agricultural future.

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