



ISSN:2583-9071

VOLUME 4, ISSUE 4 | APRIL 2026

A STEP TOWARDS AGRICULTURE

Agri Roots

e-Magazine

BIOFORTIFICATION

A sustainable solution to **Malnutrition**



“Sustainable path to fight
Malnutrition”

APRIL 2026

WWW.AGRIROOTSMAGAZINE.IN



“BIOFORTIFICATION
NOURISHES CROPS TO
NOURISH PEOPLE,
OFFERING A
SUSTAINABLE PATH TO
FIGHT MALNUTRITION
AND BUILD HEALTHIER
FUTURES.”

TABLE OF CONTENT

COVER STORY

EDITORIAL AND REVIEWER BOARD

EDITOR'S NOTE

NEW RELEASES

BIOFORTIFICATION: A SUSTAINABLE SOLUTION TO MALNUTRITION 01

Authors: G Prameela , Mala Dasari Pavan

BIOCHEMICAL RESPONSES OF PLANTS TO CLIMATE CHANGE-INDUCED ABIOTIC STRESS 02

Authors: Priya Pandey, Kirti Vardhan Pandey, Sheetanu Singh, Garima Dixit

AGRIPRENEURSHIP AND FARMERS: TRANSFORMING AGRICULTURE INTO A RURAL ENTERPRISE 03

Authors: Foram joshi

CROP DIVERSIFICATION: A SOLUTION TO DECLINING GROUNDWATER IN PUNJAB 04

Authors: Ms. Loveleen Gill, Mr. Arundeeep Singh

SEED DETERIORATION: PHYSIOLOGICAL AND BIOLOGICAL CHANGES 05

Authors: Subhali Sukanya Patel, Soubhagya Behera

**MONSOON MAGIC: RAINY SEASON
FLOWERING ANNUALS FOR VIBRANT
GARDENS**

06

Authors: M. Priyanka

**SEED STORAGE: SCIENTIFIC PRINCIPLES
AND MODERN APPROACHES FOR
PRESERVING SEED QUALITY**

07

Authors: Swagatika Behera, Soubhagya Behera

MEET *the* EDITORIAL BOARD



Dr. Deepak Kumar

Founder & Editor-in-Chief

Assistant Professor, School of
Agriculture & Environmental
Sciences, Shobhit Deemed to-be
University, Meerut (Uttar Pradesh),
India



Dr. Vipin Kumar

Editor

Professor, College of
Horticulture, Sardar
Vallabhbhai Patel University of
Agriculture & Technology,
Meerut (Uttar Pradesh), India



Dr. B.S. Tomar

Editor

Head, Professor And Principal
Scientist Division Of Vegetable
Science, ICAR – Indian
Agricultural Research Institute,
New Delhi, India



Dr. Moolchand Singh

Editor

Principal Scientist, Division Of
Plant Quarantine ICAR-NBPGR
(Ministry Of Agriculture &
Farmers Welfare, Govt. Of India)
IARI Campus (New Delhi), India



Dr. Ravindra Kumar
Editor

Senior Scientist, Plant Pathology, Crop Protection Division, ICAR- Indian Institute Of Wheat And Barley Research, Karnal (Haryana), India



Dr. Dilpreet Talwar
Editor

Extension Scientist (Vegetable), College Of Horticulture And Forestry, Punjab Agricultural University, Ludhiana (Punjab) India



Dr. Pankaj Kumar Kannaujia
Editor

Scientist (Senior Scale), Horticulture, Division Of Plant Exploration And Germplasm Collection, ICAR- NBPGR (New Delhi), India



Dr. Vineet Kumar
Editor

Assistant Professor, Department Of Soil Science, Galgotias University, Greater Noida (Uttar Pradesh) , India

MEET *the* REVIEWER BOARD



**Dr. Khushboo
Kathayat
Reviewer**

Assistant Professor,
Department of Horticulture,
College of Agriculture, Lovely
Professional University,
Phagwara (Punjab), India



**Dr. Pratima Gupta
Reviewer**

Subject Matter Specialist, KVK,
Nagina, Sardar Vallabhbhai
Patel University of Agriculture
and Technology, Meerut (Uttar
Pradesh), India



**Dr. Souhardo
Reviewer**

Subject Matter Specialist, KVK,
Ujhani, Sardar Vallabhbhai
Patel University of Agriculture
and Technology, Meerut (Uttar
Pradesh), India



**Dr. Pankaj Kumar
Reviewer**

Subject Matter Specialist, KVK,
Chandausi, Sardar Vallabhbhai
Patel University of Agriculture
and Technology, Meerut (Uttar
Pradesh), India



Dr. Aman Deep Ranga
Reviewer

Ph.D., Dr. YS Parmar University of
Horticulture and Forestry, Solan,
Himachal Pradesh, India



Dr. Sudhir Kumar
Reviewer

Assistant Professor,
Department of Food
Technology, School of
Advanced Agriculture Sciences
& Technology, CSJMU, Kanpur



Dr. Gaurav Tripathi
Reviewer

PDF, Geo-Informatics,
Department of Civil
Engineering, Indian Institute of
Technology, Bombay (India)



Dr. Navdeep Singh
Reviewer

Ph.D., Horticulture (Vegetable
Science), Punjab Agricultural
University, Ludhiana (Punjab),
India



from the editor

Malnutrition remains one of the most persistent global challenges, particularly in developing nations where diets are often dominated by staple crops lacking essential micronutrients. In this context, biofortification has emerged as a promising, sustainable, and cost-effective strategy to enhance the nutritional quality of food crops. By improving the concentration and bioavailability of vital nutrients such as iron, zinc, and provitamin A through conventional breeding, modern biotechnology, or agronomic practices, biofortification directly addresses “hidden hunger” at its source.

Unlike supplementation and food fortification, which require continuous investment and infrastructure, biofortified crops offer a long-term solution by embedding nutrition within the seed itself. This approach is especially beneficial for rural and resource-poor populations with limited access to diverse diets and healthcare systems. Furthermore, biofortification aligns well with climate-resilient agriculture, as many improved varieties are also bred for higher yield, stress tolerance, and adaptability.

As global efforts intensify to achieve nutritional security and sustainable development goals, biofortification stands out as an innovative intersection of agriculture and public health. Continued research, policy support, and farmer awareness will be crucial to fully realize its potential in combating malnutrition worldwide.

Dr. Deepak Kumar
FOUNDER & EDITOR

BIOFORTIFICATION

A sustainable solution to **Malnutrition**

EXPLORING
KNOWLEDGE
&
DISCOVERING
AGRICULTURE



AGRI ROOTS E-MAGAZINE

Biofortification: A Sustainable Solution To Malnutrition

ARTICLE ID: 0350

G Prameela¹, Mala Dasari Pavan^{2*}

¹Department of Agronomy, OUAT, BBSR, Odisha-751003

²Department of Vegetable Science, IGKV, Raipur, Chhattisgarh-492012

Introduction: The Global Challenge of Hidden Hunger

Malnutrition continues to be a significant global public health concern, especially micronutrient deficiencies, or "hidden hunger." It is thought to impact almost 2 billion people globally and cause over 800,000 deaths annually, with developing nations bearing the brunt of the burden due to limited access to a variety of nutrient-rich foods. Staple cereals make up to 60% of

daily caloric consumption in many of these areas, but they frequently lack important vitamins and minerals like iron, zinc, and vitamin A, which can result in deficiencies that affect immunity, growth, cognitive development, and general health. Biofortification, which increases the micronutrient content of staple crops through plant breeding, agronomic techniques, or biotechnology, has emerged as a sustainable and economical solution to this problem. Biofortification

provides a long-term solution to eliminate hidden hunger and promote nutritional security, especially among vulnerable populations in developing nations,

by enhancing the nutrient profile of regularly consumed foods (Vanguri *et al.*,2025).

What Is Biofortification? Concept and Methods

Biofortification is a long-term method for improving the nutritional content of staple crops by increasing levels of important vitamins and minerals. This can be accomplished via three

primary techniques: conventional breeding, which taps into natural genetic diversity from wild relatives and landraces (e.g., wild emmer wheat exhibits iron concentrations of 15-109 mg/kg, and the 'Lal Gotal' landrace achieves 100.45 ppm); agronomic biofortification, which involves mineral fertilizer applications that pose environmental concerns and limit long-term viability; and advanced biotechnological tools like transgenics, marker-assis



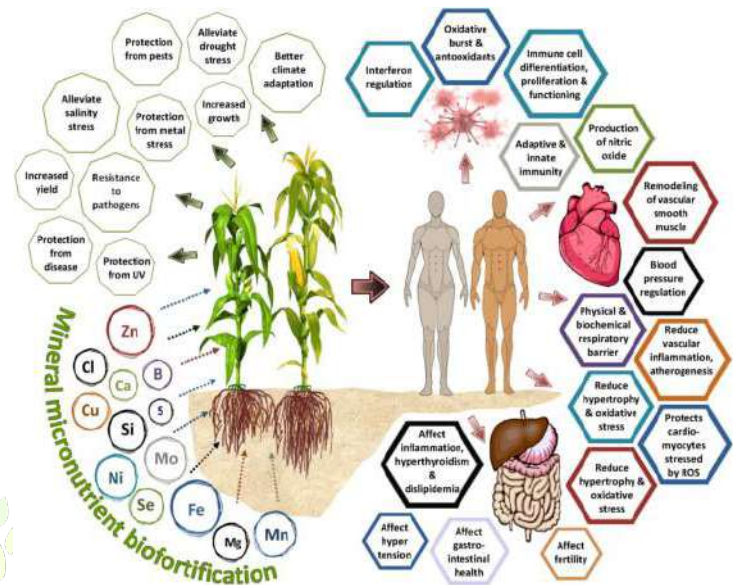
Biotechnology has led to developments such as Golden Rice, supplemented with β -carotene to alleviate vitamin A deficiencies, and maize variants with provitamin A concentration ranging from 0.24 to 8.80 μg per gram. These techniques have successfully increased zinc in wheat (up to 118 mg/kg in wild *Triticum dicoccoides*), iron in rice (6.2-71.6 ppm in brown rice lines), and provitamin A in sorghum and maize. Combining these measures boosts the nutrient density of ordinary crops, giving an affordable, long-term solution to hidden hunger, particularly in rural regions without access to supplements or fortified items (Sen *et al.*,2024).

Biofortified Crops and Their Nutritional Benefits

Biofortified crops are intended to supplement basic foods with vital vitamins and minerals, thereby alleviating hidden hunger and micronutrient shortages. Pearl millet biofortified with iron and zinc has shown remarkable improvements. The combined application of $\text{ZnSO}_4 @ 25 \text{ kg/ha}$ (soil) and FeSO_4 foliar spray (0.5% at tillering stage) produced the tallest plants (192.92 cm), highest grain yield (2422.25 kg/ha), stover yield (6669.26 kg/ha), and biological yield (9091.51 kg/ha), as well as maximum net returns ($\text{₹}54,707.5/\text{ha}$) and a benefit-cost ratio of 1.65. Similarly, zinc-rich wheat lines have been reported with grain Zn levels up to 118 mg/kg, and vitamin A-rich sweet potato and Golden Rice enriched with β -carotene supply important nutrients to people lacking access to supplementation. These biofortified crops not only boost growth and production but also improve human health by reducing iron-deficiency anaemia, zinc-related stunting and vitamin A deficiency, making

them a long-term and cost-effective solution to malnutrition (Yadav *et al.*,2025).

Influence of Micronutrient Biofortification on Human Health and Immunity



(Sen *et al.*,2024)

Advantages of Biofortification for Sustainable Agriculture

Biofortification offers considerable benefits for sustainable farming as an economical, long-term solution to hidden hunger, particularly in countries with high zinc and iron deficits, such as India, where 47% of soils are zinc-deficient, and 13% are iron-deficient. In contrast to supplemental or artificial food fortification, it improves dietary nutrition effortlessly since staple foods such as rice, wheat, maize, and pearl millet naturally absorb extra micronutrients during cultivation without affecting consumer habits. Bacteria such as *Bacillus altitudinis* and *Pseudomonas putida* increase nutrient solubilization, siderophore production, and root absorption, resulting in elevated Fe and Zn levels in grains. This strategy benefits farmers by increasing yields and soil health, consumers

by addressing micronutrient shortages that affect over two billion people worldwide, and food security by making calorie-dense staples nutritionally balanced. Biofortification improves agricultural resilience and addresses malnutrition by reducing reliance on synthetic fertilisers and utilising microbial mechanisms (Nazma *et al.*,2025).

Conclusion: Biofortification For A Healthier Future

Biofortification is a long-term, cost-effective solution to "hidden hunger," which affects more than 2 billion people worldwide due to iron, zinc, and vitamin A deficiencies. Rice, the major food for more than half of the world's population, loses significant amounts of iron and zinc during milling, emphasising the need for biofortified strains to improve nutritional quality. To date, 37 such rice cultivars enriched with iron, zinc,

protein, or provitamin A have been released globally (16 in India and 21 elsewhere), meeting national standards of more than 10 mg/kg iron, 24 mg/kg zinc, and 10% protein in polished grains. These types contribute to the prevention of anaemia, the reduction of child mortality, and the protection of maternal health, all while promoting the Sustainable Development Goals. However, widespread use necessitates increased consumer education, continued research on nutritional genetics and bioavailability, and strong regulations to integrate them into conventional agriculture. Addressing the shortfall, where ordinary rice, such as Swarna, provides only 2-3 mg iron and 7-8 mg zinc daily, vs the recommended 15 mg each, biofortification improves healthful eating and long-term health for vulnerable people (Vanguri *et al.*,2025).

References

1. Nazma, S., Hemalatha, M., & Sudha, T. (2025). Biofortification of Iron and Zinc in Field Crops Through Plant Microbe Interaction: A Review. *Agricultural Reviews*, 46(3), 393-400.
2. Sen, H., Kumar, A., & Janeja, H. S. (2024). Biofortification of major crops through conventional and modern biotechnological approaches to fight hidden hunger: an overview. *Journal of Advances in Biology & Biotechnology*, 27(7), 96-113.
3. Vanguri, P. R. (2025). Biofortification-Based Genetic Improvement of Rice for Nutritional Quality Enhancement to Combat Hidden Hunger. *Journal of Advances in Biology & Biotechnology*, 28(12), 1242-1262.
4. Yadav, S. K., Choudhary, B. L., Singh, H., Choudhary, A. L., & Chanda, D.(2025). Impact of Biofortification with Application of FeSO₄ and ZnSO₄ on Growth, Yield, and Economics of Pearl Millet (*Pennisetum glaucum* L.).

Biochemical Responses of Plants to Climate Change-Induced Abiotic Stress

ARTICLE ID: 0351

Priya Pandey¹, Kirti Vardhan Pandey¹, Sheetanu Singh¹, Garima Dixit¹

¹Research Scholar, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India

Climate change has emerged as a major global challenge affecting agricultural productivity and plant survival. Rising temperatures, irregular rainfall, drought, salinity, and extreme environmental conditions impose abiotic stress on plants. These stresses disrupt cellular homeostasis and metabolic processes, leading to reduced growth and yield. Plants respond through complex biochemical and molecular mechanisms, including the production of reactive oxygen species (ROS), activation of antioxidant systems, accumulation of osmolytes, and synthesis of stress-related proteins. This article discusses the biochemical responses of plants to climate change-induced abiotic stress and highlights their importance in developing stress-tolerant crops.

Climate change has intensified abiotic stresses such as drought, heat, salinity, and flooding, significantly affecting plant growth and productivity. These stresses often occur simultaneously and lead to severe physiological and biochemical disturbances.

Abiotic stress influences plant metabolism at multiple levels, including gene expression, enzyme activity, and cellular structure. Plants, being sessile organisms, have evolved sophisticated biochemical strategies to perceive stress signals and respond effectively.

Major Abiotic Stresses Induced by Climate Change

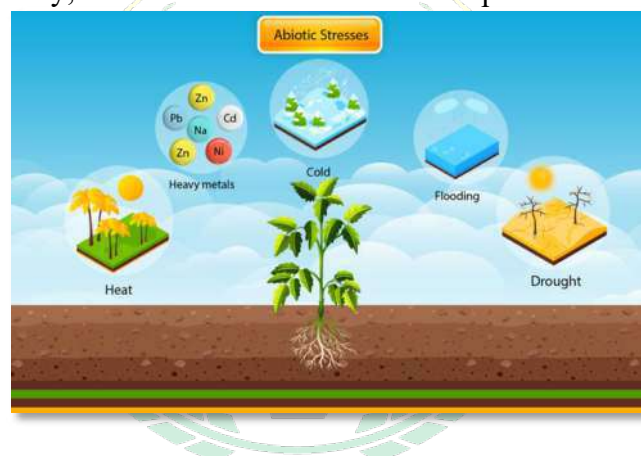
The major abiotic stresses associated with climate change include:

- Drought stress – due to irregular rainfall
- Heat stress – increased global temperature
- Salinity stress – soil degradation and irrigation issues
- Cold stress – unexpected temperature fluctuations
- These stresses can reduce crop productivity by more than 50% in severe conditions.

Generation of Reactive Oxygen Species (ROS)

One of the earliest biochemical responses to abiotic stress is the production of reactive oxygen species (ROS) such as:

- Superoxide radical (O_2^-)



- Hydrogen peroxide (H₂O₂)
- Hydroxyl radical (OH)

Under normal conditions, ROS are produced as by-products of metabolic pathways. However, under stress, their production increases drastically, leading to oxidative stress.

Excess ROS can cause:

- Lipid peroxidation
- Protein degradation
- DNA damage
- Membrane disruption

Despite their harmful effects, ROS also act as signaling molecules that trigger stress-response pathways.

Antioxidant Defense System

Enzymatic Antioxidants

- Superoxide dismutase (SOD)
- Catalase (CAT)
- Peroxidase (POD)
- Ascorbate peroxidase (APX)

These enzymes convert harmful ROS into less toxic molecules.

Non-Enzymatic Antioxidants

- Ascorbic acid (Vitamin C)
- Glutathione
- Carotenoids
- Flavonoids

These molecules scavenge free radicals and protect cellular components.

The balance between ROS production and antioxidant activity is crucial for plant survival under stress.

Osmolyte Accumulation and Osmoregulation

Plants accumulate osmolytes (compatible solutes) to maintain cellular water balance under stress conditions.

Key osmolytes include:

- Proline
- Glycine betaine
- Soluble sugars

These compounds help in:

- Osmotic adjustment
- Stabilization of proteins and membranes
- Protection against dehydration

Proline is especially important as it acts as:

- Osmoprotectant
- ROS scavenger
- Energy source and signaling molecule

Accumulation of osmolytes is a key adaptive mechanism during drought and salinity stress.

Secondary Metabolites and Stress Response

Plants produce secondary metabolites such as phenolics and polyphenols under stress conditions.

Functions:

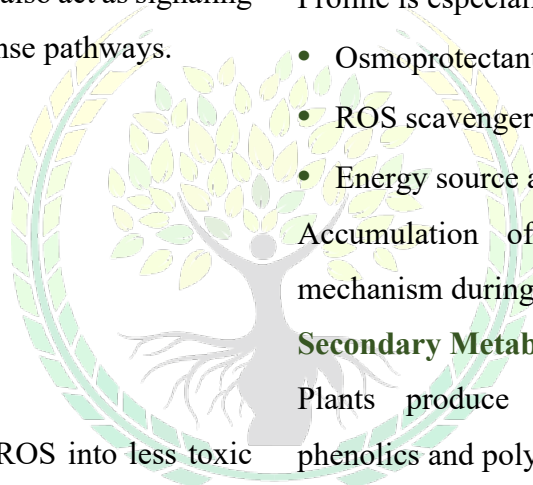
- Antioxidant activity
- Protection against oxidative damage
- Regulation of stress signaling pathways

The phenylpropanoid pathway plays a major role in producing these compounds, enhancing stress tolerance.

Stress Proteins and Molecular Responses

Plants synthesize special proteins under stress, including:

- Heat shock proteins (HSPs) – protect proteins from denaturation



- Late embryogenesis abundant (LEA) proteins – prevent dehydration damage
- Stress-responsive enzymes

These proteins help maintain cellular integrity and ensure survival under extreme conditions.

Signal Transduction Mechanisms

Plants perceive environmental stress through receptors and transmit signals via:

- Calcium ions (Ca²⁺)
- Hormones (ABA – abscisic acid)
- ROS signaling

These signals activate gene expression and biochemical pathways that enhance stress tolerance.

Impact on Photosynthesis and Metabolism

Abiotic stress affects photosynthesis by:

- Damaging chlorophyll
- Disrupting electron transport chain
- Reducing CO₂ fixation

References

1. Zhang, Y., Chen, K., Zhao, H., & Li, X. (2023). Plants' response to abiotic stress: Mechanisms and strategies. *International Journal of Molecular Sciences*, 24(5), 4567. <https://doi.org/10.3390/ijms24054567>
2. Zulfiqar, F., & Ashraf, M. (2023). Proline alleviates abiotic stress-induced oxidative stress in plants. *Journal of Plant Growth Regulation*, 42(3), 1456–1472. <https://doi.org/10.1007/s00344-022-10839-3>
3. Mishra, N. M., Singh, R., & Kumar, A. (2023). Antioxidative defense mechanisms in plants under abiotic stress conditions. *Frontiers in Plant Science*, 14, 1110622.
4. Renzetti, M., Rossi, F., & Bianchi, G. (2024). Role of proline and reactive oxygen species in plant stress responses. *Plant Physiology and Biochemistry*, 198, 108107. <https://doi.org/10.1016/j.plaphy.2023.108107>
5. Rao, M. J., Xu, Y., Tang, X., & Huang, Y. (2025). Role of polyphenols in plant abiotic stress tolerance. *Plant Physiology Reports*, 30(1), 15–28. <https://doi.org/10.1007/s40502-024-00789-5>

This results in decreased energy production and plant growth.

Strategies to Improve Stress Tolerance

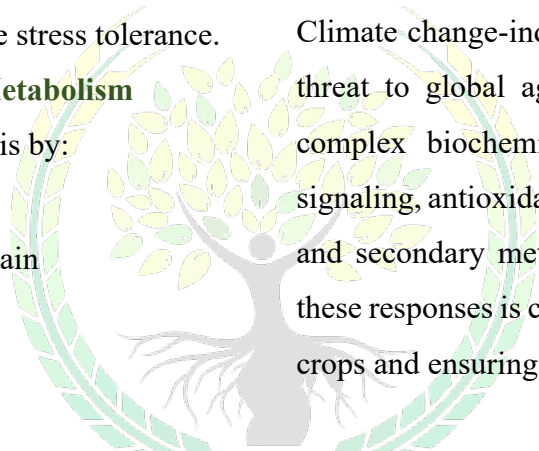
Understanding biochemical responses helps in developing strategies such as:

- Genetic engineering of stress-resistant crops
- Use of biostimulants and plant hormones
- Breeding for enhanced antioxidant capacity
- Application of osmoprotectants

These approaches are essential for sustainable agriculture under climate change conditions.

Conclusion

Climate change-induced abiotic stress poses a serious threat to global agriculture. Plants respond through complex biochemical mechanisms, including ROS signaling, antioxidant defense, osmolyte accumulation, and secondary metabolite production. Understanding these responses is crucial for developing stress-tolerant crops and ensuring food security in the future.



Agripreneurship And Farmers: Transforming Agriculture Into A Rural Enterprise

ARTICLE ID: 0352

Foram joshi

Senior Research Assistant, Community Radio Station, ASPEE College of Nutrition and Community Science, Sardarkrushinagr Dantiwada Agricultural University, 385506, Gujarat

Agriculture has historically served as the backbone of rural livelihoods in India, supporting millions of smallholder farmers and contributing significantly to national food security.

However, the agricultural sector is currently undergoing a significant transformation driven by rapid technological advancement, changing consumer preferences, expanding markets, and increasing climate variability.

Traditional farming systems that once focused primarily on crop production are now evolving toward more diversified and market-oriented agricultural enterprises.

In this changing environment, the concept of agripreneurship has gained increasing attention among policymakers, researchers, and development practitioners. Agripreneurship refers to the application of entrepreneurial principles in agriculture and allied sectors, where farmers engage in innovative activities such as value addition, agro-processing, agri-services, and agricultural marketing (Swain & Padhy, 2021).

In India, smallholder farmers often face challenges such as fragmented landholdings, fluctuating market prices, rising input costs, and climate uncertainties.

Agripreneurship offers a promising pathway to address these challenges by enabling farmers to diversify income sources, increase value addition, and create new employment opportunities in rural areas (Food and Agriculture

Organization, 2023).

Extension education and institutional support systems play a crucial role in facilitating this transformation. Agricultural extension services provide farmers with technical knowledge, entrepreneurial skills, and market information required to develop sustainable agricultural enterprises (Indian Council of Agricultural Research, 2022). Through training programs, demonstrations, and advisory services, extension institutions help farmers identify opportunities within the agricultural sector and convert them into profitable ventures.



Agripreneurship: A New Dimension of Farming

Agripreneurship represents a shift from traditional farming toward enterprise-based agriculture. Instead of focusing solely on production, farmers adopt innovative approaches that combine production with processing, marketing, and service provision.

Modern agripreneurs identify opportunities across the agricultural value chain. They explore new markets, adopt improved technologies, and develop innovative products that meet changing consumer demands. This transformation has been supported by various government initiatives, institutional programs, and entrepreneurial training efforts aimed at strengthening rural enterprises (Government of India, 2024).

Several institutions such as Krishi Vigyan Kendras (KVKs) under the Indian Council of Agricultural Research have expanded their activities to include entrepreneurship development, value addition, and agribusiness training (ICAR, 2022). These initiatives encourage farmers to think beyond conventional production systems and develop enterprises that generate higher income and employment.

Emerging Opportunities for Agripreneurs

The agricultural sector offers a wide range of opportunities for entrepreneurial activities. Advances in technology, growing demand for processed food, and expanding supply chains have opened new avenues for farmers to diversify their livelihoods (NABARD, 2023).

Table 1: Major Agripreneurship Opportunities in Indian Agriculture

Agripreneurship Area	Enterprise Opportunities	Potential Benefits
Agro-processing	Pickles, jams, dairy products, millet snacks	Value addition and higher market price
Organic farming	Organic vegetables, grains, spices	Premium market demand
Seed production	Certified seeds and planting materials	High profitability and stable demand
Agri-tourism	Farm stays, rural tourism activities	Additional income from visitors
Custom hiring centers	Tractor, harvester, drone services	Service income and mechanization support
Agri-input supply	Fertilizers, pesticides, farm tools	Business opportunities in rural markets

These enterprises allow farmers to diversify income sources and reduce dependence on traditional crop production.

Role of Extension Education in Promoting Agripreneurship

Extension education plays a pivotal role in transforming farmers into successful agripreneurs.

Extension professionals act as facilitators who connect farmers with research institutions, financial organizations, and markets (ICAR, 2022).

Training programs organized by extension agencies focus on several important areas:

- Skill development in agro-processing and value addition.
- Entrepreneurship development and business planning.
- Marketing strategies and digital agriculture tools.
- Financial literacy and access to credit

Through these programs, farmers acquire the managerial and technical skills necessary for running agricultural enterprises.

Organizations such as National Bank for Agriculture and Rural Development also support agripreneurship by promoting Farmer Producer Organizations (FPOs) and providing financial assistance to farmer collectives (NABARD, 2023). These institutions strengthen farmers' ability to access markets, technology, and financial services.

Real Indian Agripreneur Case Examples

Across India, several farmers have successfully transformed their agricultural activities into profitable enterprises through innovation and entrepreneurship.

1. Mansukhbhai Prajapati – Clay Entrepreneurship

Mansukhbhai Prajapati from Gujarat transformed traditional pottery into an innovative enterprise by developing the “Mitticool” refrigerator made from clay. His work demonstrates how indigenous knowledge can be converted into a sustainable business model (NABARD, 2023).

2. Rajkumari Devi – Mushroom Enterprise

Rajkumari Devi established a successful mushroom cultivation and processing enterprise. Through training and value addition activities, she has created employment opportunities and contributed to rural development (FAO, 2023).

3. Harishchandra Patil – Banana Value Chain

Harishchandra Patil adopted innovative banana cultivation and marketing practices in Maharashtra. By integrating production with value addition and market linkages, he significantly enhanced farm income (Swain & Padhy, 2021).

These examples highlight the transformative potential of agripreneurship in rural India.

Challenges in Agripreneurship Development

- Despite its potential, agripreneurship development faces several constraints in rural areas.
- Limited access to credit remains a major barrier for farmers who wish to establish enterprises. Many smallholders lack the collateral required to obtain institutional loans (NABARD, 2023).
- Infrastructure limitations such as inadequate storage, processing facilities, and transportation systems also restrict the growth of rural enterprises (Government of India, 2024).
- Additionally, farmers often lack managerial and entrepreneurial skills required to run successful enterprises. Extension services must therefore focus on capacity building and skill development to address these gaps (ICAR, 2022).

The Way Forward

Strengthening agripreneurship requires a comprehensive approach that integrates training,

institutional support, and market development. Extension systems must expand their focus to include entrepreneurship development and value chain integration (FAO, 2023).

Promoting farmer collectives, expanding digital extension platforms, and improving access to finance can significantly enhance the growth of agricultural enterprises. Encouraging youth participation in agripreneurship can also contribute to rural transformation (Government of India, 2024).

Conclusion

Agripreneurship is emerging as a transformative force in Indian agriculture, offering new opportunities for farmers to enhance income and build resilient

livelihoods. The integration of entrepreneurial approaches with agricultural practices enables farmers to participate more effectively in value chains and market systems.

Extension education plays a crucial role in this transformation by providing knowledge, skills, and institutional linkages. As demonstrated by successful agripreneurs across India, innovation and access to support systems can significantly improve economic outcomes for rural communities. With sustained efforts from extension institutions, policymakers, and financial organizations, agripreneurship can become a key driver of rural development and agricultural modernization in India.

References

1. Food and Agriculture Organization. (2023). *The status of women in agrifood systems*. FAO.
2. Government of India. (2024). *Formation and promotion of 10,000 Farmer Producer Organizations*. Ministry of Agriculture and Farmers' Welfare.
3. Indian Council of Agricultural Research. (2022). *Agricultural extension approaches for rural development*. ICAR.
4. NABARD. (2023). *Farmer Producer Organizations in India: Opportunities and challenges*. National Bank for Agriculture and Rural Development.
5. Swain, S., & Padhy, S. (2021). Agripreneurship development in India: Opportunities and challenges. *Indian Journal of Extension Education*, 57(3), 12–18.

Crop Diversification: A Solution to Declining Groundwater in Punjab

ARTICLE ID: 0353

Ms. Loveleen Gill¹, Mr. Arundeeep Singh²

¹Assistant Professor, Department of Agriculture, Sri Guru Granth Sahib World University, Sri Fatehgarh Sahib, Punjab

²M.Sc. (Agronomy), Mata Gujri College, Sri Fatehgarh Sahib, Punjab

Punjab has historically been regarded as the “food bowl of India” due to its significant contribution to national food security. The Green Revolution of the 1960s marked a turning point in the state’s agriculture, introducing high-yielding varieties, expanded irrigation systems, and modern farming techniques. These advancements significantly increased wheat and rice production.

However, continuous dependence on the wheat–rice cropping system has led to serious environmental concerns, particularly groundwater depletion. In recent years, crop diversification has gained importance as a sustainable approach to conserve water resources while ensuring farm profitability and productivity.

Groundwater Crisis in Punjab

Groundwater forms the backbone of irrigation in Punjab, with farmers heavily relying on tube wells. Excessive extraction, particularly for water-intensive

crops like rice, has caused a rapid decline in groundwater levels.

Punjab withdraws approximately 33.8 billion cubic metres of groundwater annually, whereas recharge is only about 20.6 billion cubic metres, indicating severe overexploitation.

In many parts of central Punjab, groundwater levels have declined from about 10 metres during the early

Green Revolution period to 40–50 metres today. More than three-fourths of the blocks in Punjab are now classified as overexploited.

This decline has increased irrigation costs and poses a serious threat to long-term agricultural sustainability and rural livelihoods.

The Wheat–Rice Cropping System and Water Use

The wheat–rice cropping system dominates Punjab agriculture. Rice, in particular, is highly water-intensive, requiring continuous irrigation.

- Water requirement of rice: 2,500–5,500 litres/kg



- In Punjab: 3,800–4,000 litres/kg
- Maize (alternative crop): 600–700 litres/kg

Rice cultivation involves standing water conditions, leading to excessive groundwater extraction. Currently, paddy covers more than 30 lakh hectares in Punjab.

Despite environmental concerns, farmers prefer rice due to assured procurement at Minimum Support Price (MSP), established markets, and strong policy support.

Status of Crop Diversification in Punjab

Table 1: Cropping Pattern Trends in Punjab (%)

Year	Paddy (%)	Wheat (%)	Other Crops (%)
1980	45	40	15
2002	60	35	5
2024	65–70	30–32	3–5

The declining share of diversified crops highlights increasing monoculture and environmental stress.

Benefits of Crop Diversification

A. Groundwater Conservation

Shifting from paddy to less water-intensive crops reduces irrigation demand and allows groundwater recharge.

B. Improved Soil Health

Crop rotation improves soil fertility, reduces nutrient depletion, and lowers dependence on chemical inputs.

C. Economic Opportunities

Diversification enables cultivation of high-value crops like fruits, vegetables, and oilseeds, increasing farmers' income.

D. Climate Resilience

Diverse cropping systems enhance resilience to climate variability, reducing the risk of crop failure.

Challenges to Adoption

1. Bias in MSP and Procurement

Assured procurement of wheat and rice discourages diversification.

2. Uncertain Market Conditions

Alternative crops lack stable markets and price assurance.

3. Lack of Infrastructure

Inadequate storage, processing, and transport facilities hinder diversification.

4. Risk-Averse Farming Practices

Farmers prefer familiar crops with assured returns.

5. Policy Constraints

Existing policies prioritize rice production, limiting diversification incentives.

Government Initiatives and Their Limitations

Several initiatives have been introduced to promote diversification, including incentives for maize and horticulture promotion. However, their impact has been limited due to weaker incentives compared to paddy, poor implementation, and lack of coordination among agencies.

As a result, the area under paddy cultivation continues to increase.

Policy Recommendations

1. Reform Procurement Policies

Extend MSP and assured procurement to maize, pulses, and oilseeds.

2. Rationalize Subsidies

Restructure subsidies like free electricity to encourage efficient water use.

3. Promote Water-Saving Technologies

Encourage drip irrigation, sprinkler systems, and direct-seeded rice.

4. Develop Infrastructure

Invest in storage, processing, and marketing systems.

5. Enhance Extension Services

Provide training, awareness, and technical support to farmers.

6. Encourage Private Sector Participation

Promote agro-industries and contract farming.

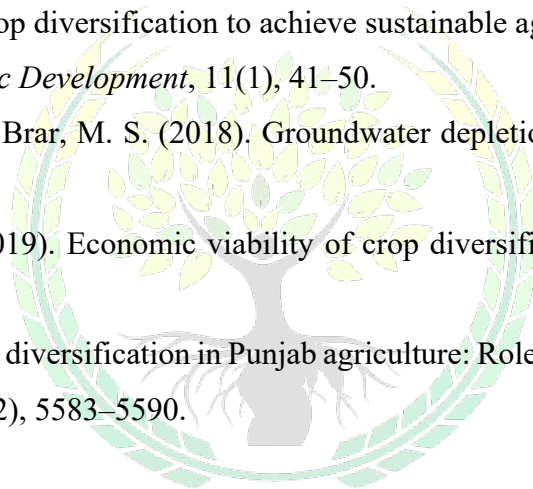
Conclusion

Punjab's groundwater crisis is a result of unsustainable agricultural practices, particularly the dominance of the wheat-rice system. Crop diversification offers a practical and sustainable solution to balance environmental conservation with farm profitability.

However, its success depends on strong policy support, market assurance, infrastructure development, and farmer-centric incentives. Effective implementation can ensure long-term agricultural sustainability while conserving Punjab's critical groundwater resources.

References

1. Kaur, I. (2020). Need of crop diversification to achieve sustainable agriculture in Punjab: A brief review. *Indian Journal of Economic Development*, 11(1), 41–50.
2. Kaur, S., Aggarwal, R., & Brar, M. S. (2018). Groundwater depletion in Punjab. *Encyclopaedia of Soil Science*, 3, 1–16.
3. Kumar, R., & Sangeet. (2019). Economic viability of crop diversification in Punjab. *Journal of Krishi Vigyan*, 8(1), 55–62.
4. Singh, S. (2014). Crisis and diversification in Punjab agriculture: Role of state and agribusiness. *Economic and Political Weekly*, 39(52), 5583–5590.



Seed Deterioration: Physiological and Biological Changes

ARTICLE ID: 0354

Subhali Sukanya Patel and Soubhagya Behera

Department of Seed Science and Technology, College of Agriculture, OUAT, Bhubaneswar, Odisha, India –
751003

Seeds are living entities that gradually lose viability and vigour due to an inherent ageing process known as deterioration. This paper describes the physiological, biochemical, and environmental factors responsible for the decline in seed quality from harvest through storage to germination. External factors such as field weathering, mechanical injury, and improper storage conditions (high temperature and humidity) accelerate deterioration. Internally, processes such as membrane degradation, enzyme inactivation, depletion of food reserves, accumulation of toxic metabolites, reactive oxygen species (ROS) damage, and genetic abnormalities impair seed performance. These changes result in reduced germination, weak seedlings, and lower crop productivity. Understanding these mechanisms helps in improving storage technologies and seed handling practices. Studies, including those from ICAR-Indian Agricultural Research Institute, indicate that maintaining low temperature and moisture conditions and minimizing physical damage can

significantly extend seed longevity. Therefore, preserving seed quality is essential for sustainable agriculture, stable crop production, and global food security.



High seed quality is essential for meeting the increasing demands of modern agriculture. Seed deterioration refers to a series of time-dependent physiological and biochemical changes that reduce seed viability and

vigour, ultimately affecting crop establishment and yield. These changes increase the susceptibility of seeds to environmental stresses and lead to a gradual loss of their survival potential (Kapoor et al., 2011).

Although some seeds exhibit extended longevity, all seeds eventually deteriorate. Understanding when and how deterioration occurs is crucial for improving agricultural productivity, conservation strategies, and seed storage practices. Major factors influencing seed deterioration include temperature, relative humidity, seed moisture content, and biotic factors such as fungi and insects.

Seed deterioration begins during seed development on the mother plant and continues through harvest, storage, and germination. It involves complex cellular, metabolic, and biochemical alterations, including lipid peroxidation, membrane damage, DNA degradation, and reduced synthesis of RNA and proteins.

Types of Seed Deterioration

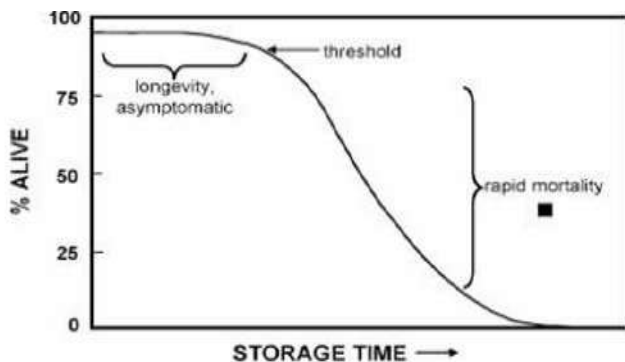
Seed deterioration can be broadly classified into:

1. Field weathering
2. Harvest and post-harvest deterioration
3. Storage deterioration

Field weathering occurs due to prolonged exposure of mature seeds to high temperature and humidity before harvest, leading to loss of quality. Khatun et al. (2009) reported that delayed harvesting may cause hardening and discoloration in pulse seeds.

Improper harvesting and handling practices cause mechanical damage, which facilitates pathogen entry and reduces seed storability.

Storage conditions play a critical role in determining seed longevity. High temperature and moisture accelerate deterioration, whereas cool and dry conditions help maintain seed viability.



Physiological and Biochemical changes during deterioration

Physiological and Biochemical Changes During Seed Deterioration

1. Membrane Degradation

Loss of membrane integrity is one of the earliest signs of seed deterioration. Increased membrane permeability leads to leakage of cellular constituents, reducing seed viability and vigour. Disruption of cellular membranes such as the plasmalemma, tonoplast, and endoplasmic reticulum impairs normal cellular functioning.

2. Enzyme Alterations

Seed ageing leads to a decline in the activity of important enzymes such as amylase, protease, lipase, catalase, peroxidase, and dehydrogenase. Reduced activity of antioxidant enzymes like catalase and peroxidase results in increased sensitivity to oxidative stress caused by reactive oxygen species.

3. Changes in Chemical Constituents

Deteriorated seeds exhibit a decrease in proteins, lipids, and total sugars, along with an increase in free fatty acids and reducing sugars. Structural carbohydrates and protective oligosaccharides decline, affecting membrane stability (Verma and Dubey, 2003).

4. Reduced Metabolic Activity

High moisture conditions accelerate the degradation of nucleic acids during storage, thereby limiting nucleotide synthesis and reducing metabolic efficiency.

5. Free Radical Damage

Reactive oxygen species (ROS) accumulate during seed ageing and cause oxidative damage to lipids,

proteins, and nucleic acids. This results in structural and functional impairment of cellular components.

6. Chromosomal Aberrations

Seed ageing induces genetic damage, including chromosomal breaks, fusions, bridges, and mutations, which negatively affect seed viability and seedling development.

7. Lipid Peroxidation

Lipid peroxidation is a major cause of seed deterioration, particularly in oilseeds. Accumulation of malondialdehyde (MDA), a by-product of lipid oxidation, is associated with reduced seed viability (Kibinza et al., 2006). Free fatty acids disrupt mitochondrial membranes and reduce energy production, while free radicals damage DNA, proteins, and enzymes (Ghassemi-Golezani et al., 2010).

Other Changes Associated with Seed Deterioration

- Breakdown of cellular structure
- Decline in ATP levels

References

1. Balešević-Tubić, S., Tatić, M., Đorđević, V., Nikolić, Z., & Đukić, V. (2010). Seed viability of oil crops depending on storage conditions. *Helia*, 33(52), 153–160.
2. Ghassemi-Golezani, K., Bakhshy, J., Yaeghoob, R. A. E., & Hosseinzadeh-Mahootchy, A. (2010). Seed vigor and field performance of winter oilseed rape (*Brassica napus* L.) cultivars. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 38(3), 146–150.
3. Kapoor, N., Arya, A., Siddiqui, M. A., Kumar, H., & Amir, A. (2011). Physiological and biochemical changes during seed deterioration in aged seeds of rice (*Oryza sativa* L.). *American Journal of Plant Physiology*, 6(1), 28–35.
4. Khatun, A., Kabir, G., & Bhuiyan, M. A. H. (2009). Effect of harvesting stages on the seed quality of lentil (*Lens culinaris* L.) during storage. *Bangladesh Journal of Agricultural Research*, 34(4), 565–576.
5. Kibinza, S., Vinel, D., Côme, D., Bailly, C., & Corbineau, F. (2006). Sunflower seed deterioration as related to moisture content during ageing, energy metabolism, and active oxygen species scavenging. *Physiologia Plantarum*, 128(3), 496–506.

- Reduction in sugar content
- Ribosome disintegration
- Enzyme inactivation (amylase, dehydrogenase, oxidases, phospholipase)
- Activation of hydrolytic enzymes
- Starvation of meristematic cells
- Increased leachate and free fatty acid content
- Reduced respiration rate

Conclusion

Seed deterioration is a natural and inevitable process that begins at seed formation and continues until germination. Environmental conditions, storage practices, and internal biochemical changes collectively determine the rate of deterioration. Adoption of improved storage techniques and careful handling can significantly slow down this process and maintain seed quality. Ensuring high seed viability and vigour is essential for sustainable agricultural production and food security.

Monsoon Magic: Rainy Season Flowering Annuals for Vibrant Gardens

ARTICLE ID: 0355

M. Priyanka

PhD Scholar, SKLTGHU, Mulugu

The arrival of the monsoon transforms landscapes into lush, green environments.

Although excessive rainfall can adversely affect many plant species, several flowering annuals perform exceptionally well under such conditions. These plants are generally sown before or at the onset of the monsoon and complete their life cycle within a single season, providing rapid and vibrant floral displays. In addition to their ornamental value, they contribute significantly to pollinator support and ecological sustainability.

Why Choose Rainy Season Annuals?

Rainy season annuals are well adapted to monsoon conditions and possess the ability to withstand:

- High moisture and humidity
- Intermittent sunlight and cloudy weather
- Rapid growth and flowering cycles

These characteristics ensure continuous garden color and vitality during periods when many other plants fail to perform.

Popular Rainy Season Flowering Annuals

1. Balsam (*Impatiens balsamina*)

Commonly known as “Touch-me-not,” balsam produces attractive single or double flowers in shades of pink, red, violet, and white. It thrives in moist soils and partial shade.



2. Marigold (*Tagetes* spp.)

A widely cultivated and versatile annual, marigold bears profuse blooms in yellow, orange, and red. It also functions as a natural pest repellent.

3. Zinnia (*Zinnia elegans*)

Zinnias are fast-growing annuals with brightly colored flowers. They perform well under rainy conditions with proper drainage and attract pollinators.

4. Cosmos (*Cosmos bipinnatus*)

Cosmos produces delicate, daisy-like flowers and adds elegance to gardens with its tall, airy growth habit.

5. Celosia (*Celosia argentea*)

Also known as cockscomb or wool flower, celosia is valued for its unique feathery or crested blooms and adaptability to humid climates.

6. *Gomphrena* (*Gomphrena globosa*)

Globe amaranth produces round, long-lasting flowers and performs well even under erratic rainfall conditions.

7. *Amaranthus* (*Amaranthus* spp.)

Grown for ornamental foliage and flowers, amaranthus adds height and striking color to gardens.

8. *Portulaca* (*Portulaca grandiflora*)

A low-growing plant known as moss rose, it produces vibrant flowers and thrives in well-drained soils.

9. *Cleome* (*Cleome gynandra*)

A tall annual with spider-like flowers, cleome adds vertical interest to landscapes.

10. *China Aster* (*Callistephus chinensis*)

A popular ornamental species producing colorful blooms, widely used for bedding and cut flowers.

Cultivation Practices for Rainy Season Annuals

1. Sowing Time

Seeds are typically sown during May–June to coincide with the onset of the monsoon. Early sowing ensures better vegetative growth and extended flowering duration.

2. Soil and Drainage

- Well-drained loamy soil is ideal
- Raised beds help prevent waterlogging
- Organic matter improves soil aeration and structure

3. Nutrient Management

- Application of farmyard manure (FYM) or compost as basal dose
- Balanced NPK fertilization
- Foliar feeding to enhance flowering

4. Plant Protection

High humidity during the monsoon favors fungal diseases. Preventive measures include:

- Adequate plant spacing
- Timely fungicidal application
- Removal of infected plant parts

5. Maintenance Practices

- Regular weeding
- Staking for tall plants
- Pinching to promote branching and increased flowering

Importance in Floriculture and Landscaping

Rainy season annuals play a crucial role in:

- Public gardens and parks
- Roadside landscaping
- Home and terrace gardening
- Cut flower production (e.g., zinnia, cosmos, China aster)

Their short duration and high ornamental value make them economically viable for seasonal flower production.

Recent Trends and Research

Recent studies have focused on:

- Optimization of planting dates for improved growth and flowering
- Promotion of climate-resilient ornamental species
- Development of pollinator-friendly gardens using species such as zinnia, cosmos, and gomphrena
- Adoption of sustainable practices including organic inputs and efficient water management

Monsoon flowering plants also contribute to biodiversity conservation, particularly in ecologically sensitive regions such as the Western Ghats.

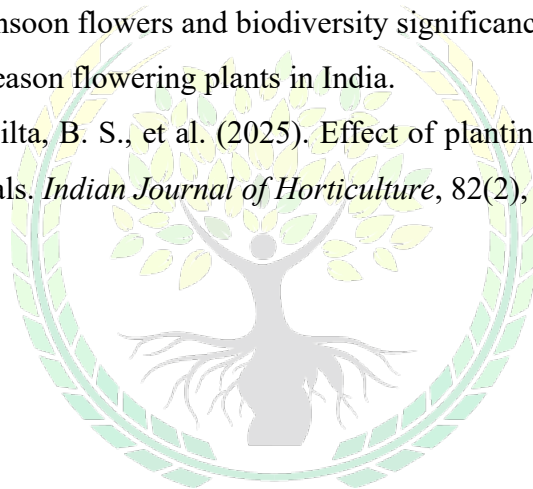
Conclusion

Rainy season flowering annuals provide an excellent opportunity to maintain vibrant and productive gardens during the monsoon. Their adaptability, ease of cultivation, and ecological benefits make them

indispensable in modern floriculture and landscaping. With appropriate species selection and management practices, growers can achieve abundant flowering even under challenging weather conditions.

References

1. Agriculture Institute (2024). Best rainy season annuals for vibrant gardens.
2. Malakar, M., et al. (2023). Advances in ornamental crop production and management. *Frontiers in Plant Science*.
3. Nguyen, T., & Ha, S. (2024). Climate-resilient approaches in ornamental horticulture. *Horticulturae*.
4. Rashed, N. M., et al. (2024). Advances in floriculture and seasonal crop management. *Frontiers in Plant Science*.
5. Times of India (2025). Monsoon flowers and biodiversity significance in India.
6. Ugao (2024). Top rainy season flowering plants in India.
7. Vijay, J., Baweja, H. S., Dilta, B. S., et al. (2025). Effect of planting dates on growth and flowering of selected rainy season annuals. *Indian Journal of Horticulture*, 82(2), 223–228.



Seed Storage: Scientific Principles and Modern Approaches for Preserving Seed Quality

ARTICLE ID: 0356

Swagatika Behera*, Soubhagya Behera

Department of Seed Science and Technology, College of Agriculture, OUAT, Bhubaneswar, Odisha, India-751003

www.agrirootsmagazine.in

ISSN: 2583-9071

Seed storage is a critical component of agricultural sustainability, food security, and genetic resource conservation. Seeds are living biological entities that undergo physiological aging after harvest, leading to gradual loss of viability and vigor. Proper storage conditions can significantly slow deterioration and extend seed longevity. This article examines the scientific foundations of seed storage, including the effects of moisture content, temperature, relative humidity, and oxygen concentration. It also discusses intrinsic and extrinsic factors influencing seed longevity, traditional and modern storage methods, and technological advancements such as hermetic storage and controlled atmosphere systems. The importance of monitoring seed quality through germination testing and moisture assessment is emphasized. Effective seed storage strategies reduce economic losses, ensure uniform crop establishment, and contribute to long-term conservation of plant genetic resources. Continued



research and innovation in storage technologies remain essential for sustaining agricultural productivity and preserving biodiversity in the face of climate variability and global food demand.

1. Introduction

Seeds serve as the primary means of propagation for most agricultural crops and represent the foundation of global food systems. Beyond their role in crop production, seeds carry genetic information essential for plant breeding, biodiversity conservation, and adaptation to environmental change. Although seeds appear dormant after harvest, they remain biologically active and gradually deteriorate over time. This deterioration reduces germination capacity, seedling vigor, and overall crop performance. Seed storage refers to the scientific management of environmental conditions to preserve seed viability and vigor from harvest until planting. The primary objective of storage is to slow metabolic and biochemical processes that lead to aging. According to Harrington's storage principles, seed longevity is

strongly influenced by moisture content and temperature, and small reductions in either factor can significantly extend storage life (Harrington, 1972). Understanding these principles is crucial for farmers, seed producers, researchers, and gene banks responsible for maintaining planting material.

This paper explores the physiological basis of seed deterioration, key determinants of seed longevity, storage methods for different durations, technological innovations, and the broader significance of proper seed storage in agricultural sustainability.

2. Physiological Basis of Seed Deterioration

Seed deterioration is an inevitable and irreversible process that begins at physiological maturity. Although deterioration cannot be completely prevented, it can be slowed under optimal storage conditions.

2.1 Metabolic Activity and Respiration

Even in a quiescent state, seeds maintain a low level of metabolic activity. Respiration continues at a reduced rate, consuming stored carbohydrates, proteins, and lipids. High moisture and temperature accelerate respiration, leading to depletion of food reserves and accumulation of toxic by-products (Copeland & McDonald, 2001).

2.2 Membrane Degradation

One of the earliest signs of seed aging is the disruption of cellular membranes. Oxidative stress causes lipid peroxidation, which damages membrane integrity and reduces cellular compartmentalization. This results in leakage of solutes during germination and reduced seedling vigor (Bewley et al., 2013).

2.3 Enzyme and DNA Damage

Enzymes required for germination gradually lose functionality due to structural degradation. Additionally, oxidative damage can affect nucleic acids, impairing genetic stability. Prolonged exposure to unfavorable storage conditions accelerates these changes, leading to loss of viability.

3. Factors Influencing Seed Longevity

Seed longevity depends on both internal (intrinsic) and external (extrinsic) factors.

3.1 Intrinsic Factors

3.1.1 Species and Genetic Composition

Different species exhibit varying storage behaviors. Orthodox seeds, such as cereals and legumes, tolerate drying and low temperatures, making them suitable for long-term storage. In contrast, recalcitrant seeds (e.g., many tropical tree species) are sensitive to desiccation and cannot survive extended storage under conventional conditions (Roberts, 1973).

3.1.2 Seed Composition

Seeds rich in oils generally deteriorate faster than starchy seeds due to lipid oxidation. Oilseed crops such as soybean and groundnut are more prone to rancidity and membrane damage during storage.

3.1.3 Maturity at Harvest

Seeds harvested at physiological maturity exhibit maximum vigor and storage potential. Immature or over-mature seeds often show reduced longevity.

3.1.4 Initial Seed Quality

Seed lots with high germination percentages and minimal mechanical damage have greater storage life. Mechanical injuries increase susceptibility to moisture absorption and microbial infection.

3.2 Extrinsic Factors

3.2.1 Moisture Content

Moisture content is the most critical determinant of seed longevity. High seed moisture increases respiration and fungal growth. Harrington (1972) suggested that within safe biological limits, for every 1% decrease in seed moisture content, storage life approximately doubles.

For most orthodox seeds, safe moisture levels range between 8% and 12%, depending on species.

3.2.2 Temperature

Temperature significantly affects biochemical reactions. Higher temperatures accelerate deterioration, while lower temperatures slow metabolic processes. Harrington's rule also states that for every 5°C decrease in storage temperature, seed life span may double, provided moisture is controlled.

3.2.3 Relative Humidity

Seeds are hygroscopic, meaning they exchange moisture with the surrounding environment. High relative humidity results in increased seed moisture content. Therefore, maintaining low and stable humidity is essential for preserving quality.

3.2.4 Oxygen Concentration

Oxygen supports respiration and oxidative reactions. Reduced oxygen environments, such as vacuum or controlled atmosphere storage, slow deterioration by limiting oxidative damage.

3.2.5 Storage Duration

The length of storage directly affects viability. Even under ideal conditions, seeds eventually lose germination capacity. Regular monitoring is necessary to determine appropriate storage periods.

4. Methods of Seed Storage

Storage practices vary according to duration, purpose, and available infrastructure.

4.1 Short-Term Storage

Short-term storage typically lasts up to one year and is common among farmers. Seeds are stored in:

- Cloth or jute bags
- Plastic containers
- Metal bins
- Earthen pots

These methods are economical but provide limited environmental control. Protection from moisture and pests is often inadequate.

4.2 Medium-Term Storage

Medium-term storage extends from one to three years. Improved facilities may include ventilated warehouses and moisture-proof containers. Use of desiccants and insect control measures enhances effectiveness.

4.3 Long-Term Storage

Long-term storage is essential for seed banks and breeding programs. Facilities maintain controlled temperature and humidity conditions.

4.3.1 Cold Storage

Seeds are stored at temperatures between 0°C and 10°C with low humidity. Cold storage reduces metabolic activity and extends viability.

4.3.2 Deep-Freezing and Gene Banks

For genetic conservation, seeds are stored at -18°C or lower. Under these conditions, metabolic processes are greatly minimized, allowing preservation for decades (FAO, 2014).

5. Modern Technological Advancements

5.1 Hermetic Storage

Hermetic storage uses airtight containers to prevent moisture exchange and limit oxygen availability. This method reduces insect infestation and fungal growth without chemical treatments.

5.2 Vacuum Sealing

Vacuum packaging removes air, lowering oxygen concentration and reducing oxidative damage.

5.3 Controlled Atmosphere Storage

This technique regulates oxygen and carbon dioxide levels to slow respiration and microbial growth. It is particularly useful for high-value seed lots.

5.4 Cryopreservation

For recalcitrant seeds that cannot tolerate drying, cryopreservation of embryos or tissues in liquid nitrogen offers a promising conservation method.

6. Monitoring and Quality Assessment

Effective seed storage requires periodic monitoring.

6.1 Germination Testing

Standard germination tests evaluate the percentage of seeds capable of producing normal seedlings under favorable conditions. Declining germination indicates the need for regeneration or replacement.

6.2 Moisture Testing

Moisture meters and oven-drying methods are used to determine seed moisture content. Maintaining optimal levels prevents rapid deterioration.

6.3 Seed Vigor Testing

Vigor tests assess the potential for rapid and uniform emergence under diverse conditions. These tests provide early indications of declining quality.

7. Importance of Proper Seed Storage

7.1 Agricultural Productivity

High-quality seeds ensure uniform crop establishment and optimal yield. Poor storage results in weak seedlings, uneven stands, and reduced productivity.

7.2 Economic Benefits

Preventing post-harvest seed losses protects farmers' investments and reduces the need for frequent seed replacement.

7.3 Food Security

Reliable seed supply supports consistent food production, which is essential for growing populations.

7.4 Conservation of Genetic Resources

Seed banks play a crucial role in preserving plant genetic diversity for future breeding programs and ecological restoration efforts.

8. Challenges in Seed Storage

Despite technological advancements, several challenges remain:

- Climate variability affecting storage environments
- Limited infrastructure in developing regions
- High costs of controlled storage facilities
- Storage difficulties for recalcitrant seeds

Addressing these challenges requires research, policy support, and capacity building.

9. Conclusion

Seed storage is a scientifically managed process aimed at preserving viability, vigor, and genetic integrity. Moisture content and temperature are the most critical factors influencing longevity, while intrinsic characteristics such as species type and seed composition also play significant roles. Traditional storage methods remain important for small-scale farmers, but modern technologies such as hermetic storage, controlled atmosphere systems, and

cryopreservation have greatly enhanced long-term conservation.

Effective storage practices ensure agricultural sustainability, economic stability, and food security.

Continued innovation and improved infrastructure are essential to meet future global demands and safeguard plant genetic resources for generations to come.

References

1. Ali, M., Rahman, M., Wadud, M. A., Fahim, A. H., & Nahar, M. (2018). Effect of seed moisture content and storage container on seed viability and vigour of soybean. *Bangladesh Agronomy Journal*, 21(1), 131–141. <https://doi.org/10.3329/baj.v21i1.39392>
2. Agrawal, P. K. (2025). Identification of suitable seed storage places in India on the basis of temperature and relative humidity conditions. *Seed Research*, 43(2), 80–84. <https://doi.org/10.56093/sr.v43i2.163114>
3. Bewley, J. D., Bradford, K. J., Hilhorst, H. W. M., & Nonogaki, H. (2013). *Seeds: Physiology of development, germination and dormancy* (3rd ed.). Springer.
4. Copeland, L. O., & McDonald, M. B. (2001). *Principles of seed science and technology* (4th ed.). Kluwer Academic Publishers.
5. Ellis, R. H., Hong, T. D., & Roberts, E. H. (1991). Seed moisture content, storage, viability and vigour. *Seed Science Research*, 1(4), 275–279. <https://doi.org/10.1017/S0960258500001008>
6. Food and Agriculture Organization. (2014). *Genebank standards for plant genetic resources for food and agriculture*. FAO.

