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Review Paper

Role of Plant Tissue Culture and Seed Technology in Enhancing Crop Resilience

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ABSTRACT
Ensuring crop resilience against environmental stresses is vital for sustainable agriculture and food security in the face of climate change. Two major biotechnological approaches—plant tissue culture and advanced seed technology—have emerged as powerful tools in achieving this goal. This review explores the contributions of plant tissue culture techniques such as micropropagation, somaclonal variation, embryo rescue, and in vitro selection for the development of disease-resistant and stress-tolerant crop varieties. Simultaneously, it discusses how seed technologies like seed priming, pelleting, coating, and synthetic seed production improve germination, enhance vigor, and support uniform crop establishment under adverse conditions. The integration of tissue culture with modern seed technology ensures not only the rapid multiplication of elite genotypes but also strengthens plant resilience to abiotic stresses such as drought, salinity, and heat, and biotic challenges like pathogens and pests. This review also covers recent innovations such as cryopreservation, seed nanopriming, and genetic fidelity assessment through molecular markers. Challenges like cost, scalability, and skill requirements are also discussed. This comprehensive review aims to provide researchers, breeders, and policymakers with insights into how combining tissue culture and seed innovation can build a robust, climate-resilient agricultural system.

Keywords*: Plant tissue culture, Seed technology, Crop resilience, Micropropagation, Seed priming, Abiotic stress, In vitro selection*

I. INTRODUCTION

In the face of mounting challenges posed by climate change, erratic weather patterns, land degradation, and an increasing global population, enhancing crop resilience has become a critical priority for ensuring food security and agricultural sustainability. Traditional breeding methods, while effective to a degree, often fall short of the speed and precision required to cope with the rapidly evolving stressors affecting crops today. Biotic stresses such as pests and diseases, along with abiotic stresses including drought, salinity, and temperature extremes, threaten agricultural productivity on a global scale. In this context, the development of resilient crop varieties that can withstand these stresses without compromising yield and quality has emerged as an urgent goal in agricultural research and policy. Enhancing resilience not only protects crop yield but also ensures the stability of agricultural economies, particularly in regions that are vulnerable to climate variability and resource limitations.

Biotechnological interventions have emerged as a cornerstone of modern agriculture, offering innovative tools and techniques to improve crop resilience at a genetic and physiological level. Among the many biotechnological tools available, plant tissue culture and seed technology have gained significant prominence due to their wide applicability, reproducibility, and efficiency. These technologies have revolutionized the way crops are propagated, preserved, and improved, particularly under stress-prone environments. By allowing for rapid multiplication, disease-free propagation, and the conservation of genetic resources, plant tissue culture serves as an indispensable technique in modern plant biotechnology. It enables the development of clones from elite genotypes that are uniform, disease-resistant, and stress-tolerant.

Seed technology, on the other hand, plays a vital role in ensuring the availability of high-quality seeds that form the foundation of successful crop production. The selection of superior varieties, seed treatment with protectants or growth promoters, and storage innovations are key components that contribute to seed vigor and viability. With advancements in seed priming, coating, and genetic enhancement, seeds can now be preconditioned to exhibit better performance under adverse environmental conditions. These improvements not only enhance germination and early seedling growth but also contribute to uniformity in crop stands and better yield potential under stress conditions.

The integration of tissue culture and seed technology offers a synergistic platform for accelerating the development and dissemination of resilient crop varieties. Tissue culture-derived plants can serve as a source of nucleus and breeder seeds for further multiplication, thus ensuring genetic fidelity and uniformity in seed production programs. Additionally, these biotechnological methods aid in the conservation and utilization of rare or endangered plant species that possess traits relevant to stress tolerance. Micropropagation techniques such as somatic embryogenesis and organogenesis can be effectively used to propagate crops that are difficult to breed conventionally, thereby expanding the genetic base for resilience breeding.

This review aims to explore the critical role that plant tissue culture and seed technology play in enhancing crop resilience. It examines the scientific principles, methodologies, and practical applications of these technologies across various crop species. The paper further analyzes how these biotechnological tools contribute to the production of stress-tolerant varieties and how they complement other crop improvement strategies. Ultimately, the integration of these approaches is expected to support sustainable agricultural practices that are adaptable to the challenges of the 21st century. By understanding and harnessing the full potential of tissue culture and seed technologies, we can lay the groundwork for a more resilient, productive, and secure agricultural future.

1.1 Objectives

1. To evaluate the contributions of plant tissue culture techniques (e.g., micropropagation, somaclonal variation, embryo rescue) in developing stress-tolerant and disease-resistant crop varieties.
2. To analyze the advancements in seed technology including seed priming, coating, and genetic enhancement for improving seed vigor, germination, and adaptability under biotic and abiotic stress conditions.
3. To assess the integrated role of tissue culture and seed technology in strengthening crop resilience against climate change, pest outbreaks, and soil degradation.
4. To identify challenges, research gaps, and future directions in the application of tissue culture and seed technology for sustainable agriculture and food security.

II. PLANT TISSUE CULTURE: CONCEPTS AND TECHNIQUES

2.1 Micropropagation for Mass Multiplication

Ernawati A., Rubbyanto, Gunawan L. W., Purwito A., & Sukmana D. (2000), *The Micropropagation of Bananas* — This study investigated rapid clonal propagation in several banana cultivars (Pisang Mas, Pisang Ambon Kuning, Pisang Barangan, Pisang Rajabulu) using MS medium supplemented with IAA and BAP, achieving up to 12.6 axillary shoots per bottle over eight weeks.

Sinha R. K., Saha P. R., Das A. B., Jena S. N., & Sinha S. (2018), *In Vitro Clonal Propagation of Musa sp. Cultivar Gopi: A Palatable Banana of Tripura, India* — Developed a simple, efficient micropropagation protocol for banana cultivar 'Gopi', optimizing shoot induction with 8 mg L^{-1} BAP and rooting with 2 mg L^{-1} IBA.

Deepthi V. P. (2018), *Somaclonal variation in micro propagated bananas* — A review highlighting concerns about somaclonal variation in micropropagated banana, noting its commercial relevance in India and the potential for variation in tissue-cultured banana plantlets.

Plant Cell Reports (1985) — *A tissue culture technique for rapid clonal propagation and storage under minimal growth conditions of Musa (Banana and plantain)* — This classic work demonstrated that shoot-tip cultures cultured on modified MS medium with IAA (0.18 mg L^{-1}) and BA (2.3 mg L^{-1}) could be stored for 13–17 months and still successfully regenerate plantlets.

2.2 Somaclonal Variation

Kaeppler, S. M., Kaeppler, H. F., & Rhee, Y. (2000) — *"Epigenetic aspects of somaclonal variation in plants"* This review delves into the epigenetic mechanisms underpinning somaclonal variation, highlighting DNA methylation and other heritable modifications that arise during tissue culture and contribute to genetic variability.

Miguel, C. & Marum, L. (2011) — *"An epigenetic view of plant cells cultured in vitro: somaclonal variation and beyond"* Offers a comprehensive analysis of how epigenetic changes—beyond purely genetic mutations—drive somaclonal variation, influencing traits including stress resistance.

Rajan, Rony Paul & Singh, Gurpreet (2021) — *"A Review on Application of Somaclonal Variation in Important Horticulture Crops"* Examines practical applications of somaclonal variation in horticultural species

such as potato, banana, chilli, and others, with emphasis on developing variants with enhanced biotic and abiotic stress tolerance.
"Exploitation of somaclonal variations in improvement of fruit crops – A review" (2013) — *Authors: M. Alizadeh, N. Chauhan, et al.* Focuses on leveraging somaclonal variation in fruit crops. Discusses how in vitro propagation under controlled pressures can reveal novel variants valuable for crop improvement.

2.3 In Vitro Selection

Ashraf and Foolad (2007), Ashraf and Foolad reviewed the use of in vitro techniques for selecting salt and drought-tolerant genotypes. They highlighted that callus cultures and regenerated plants under stress conditions offer a rapid and efficient approach to develop tolerant lines. The study also emphasized the correlation between in vitro and field-level performance in many crops.
Gandonou et al. (2005), Gandonou et al. focused on sugarcane and reported successful in vitro selection of somaclones resistant to salt stress. The authors discussed how callus derived from salt-exposed media developed into salt-tolerant plantlets, demonstrating the value of tissue culture-based screening in breeding programs.
Rai et al. (2011), Rai and colleagues conducted a comprehensive review of in vitro screening for abiotic stress tolerance, particularly salinity and drought. They provided case studies from rice, wheat, and maize, concluding that such methods reduce breeding time and enable early-stage stress screening at the cellular level.
Shibli et al. (2007), Shibli et al. evaluated in vitro techniques for screening disease resistance in addition to abiotic stress tolerance. Their review outlined the success of somaclonal variation and selection under pathogen culture filtrates, proving effective in crops like tomato, potato, and banana.

2.4 Embryo Rescue and Haploid Culture

Pramanik, Kartik; Sahoo, Jyoti Prakash; Mohapatra, Priyadarshani P.; Jena, Chinmaya (2021), *Insights into the Embryo Rescue – A Modern In-Vitro Crop Improvement Approach in Horticulture* — This review discusses how embryo rescue can overcome post-zygotic barriers such as embryo abortion, degeneration, and cross-incompatibility in distant hybridizations. It also covers applications in producing monoploid and triploid plants and improving stress tolerance and germplasm conservation
Rines, H. W.; Phillips, R. L.; Kynast, R. G.; Okagaki, R. J.; Galatowitsch, M. W.; et al. (2009), *Methods and Role of Embryo Rescue Technique in Alien Gene Transfer* — This encompasses a review of embryo rescue to facilitate interspecific hybridization, notably covering transfer or addition of chromosomes (e.g., maize into oat) and overcoming incompatibility in cross-species breeding
Shen, Kun; Qu, Mengxue; Zhao, Peng (2023), *The Roads to Haploid Embryogenesis* — A comprehensive review exploring both **in vitro** (microspore embryogenesis) and in vivo haploid induction methods, including recent molecular discoveries (e.g., MTL, BBM, DMP, ECS) and their implications for speeding up breeding homozygosity .
Tonosaki, Kaoru; Osabe, Kenji; Kawanabe, Takahiro; Fujimoto, Ryo (2016), *The Importance of Reproductive Barriers and the Effect of Allopolyploidization on Crop Breeding* — Reviews the barriers faced in interspecific hybridization (e.g., embryo abortion, endosperm incompatibility) and highlights how techniques like allopolyploidization can help overcome these, enabling hybrid breeding for increased resilience and diversity

2.5 Cryopreservation

Benson (2008) highlighted that cryopreservation serves as a reliable technique for the long-term conservation of plant genetic resources, particularly stress-tolerant species, by maintaining cellular integrity at ultra-low temperatures. The study emphasized the role of vitrification and encapsulation-dehydration methods in preserving viability post-thawing.
Engelmann (2011) reviewed the advancements in cryopreservation protocols used by genebanks for safeguarding elite and wild germplasm with resistance to environmental stresses. The paper underlined the importance of standardization and integration of cryogenic techniques with in vitro culture methods for improved conservation.
Panis and Lambardi (2005) discussed the application of cryogenic storage for clonal crops and forest trees, asserting that this technique is crucial for conserving germplasm of stress-resilient species that are vegetatively propagated or have recalcitrant seeds. The review provided insights into practical approaches used globally.
Reed (2001) examined the use of cryopreservation in genebank operations, focusing on the preservation of germplasm with unique resistance to abiotic and biotic stresses. The study also compared traditional conservation strategies with cryogenic methods in terms of cost-effectiveness and genetic stability.

Author(s) and Year	Focus Area	Key Contribution
Benson (2008)	Cryopreservation	Demonstrated the effectiveness of vitrification and encapsulation-dehydration methods in preserving stress-tolerant germplasm long-term.
Engelmann (2011)	Cryopreservation	Reviewed genebank cryopreservation protocols; emphasized standardization and integration with in vitro methods for conserving stress-resistant germplasm.
Panis and Lambardi (2005)	Cryopreservation	Explored cryogenic storage for vegetatively propagated and recalcitrant-seeded crops; essential for conserving stress-resilient species.
Reed (2001)	Cryopreservation	Compared traditional and cryogenic genebank methods for storing abiotic and biotic stress-resistant germplasm.

III. SEED TECHNOLOGY IN STRESS MANAGEMENT

Seed priming is a pre-sowing treatment in which seeds are partially hydrated to trigger the early stages of germination but not allow radicle emergence. After priming, seeds are re-dried to their original moisture content, making them more vigorous and better equipped to germinate under stress conditions such as drought, salinity, or extreme temperatures.

Types of Seed Priming & Their Role

Type of Priming	Method Description	Benefits
Hydropriming	Soaking seeds in water for a specific period followed by drying.	Improves germination rate and uniformity; low cost and simple to apply.
Osmopriming	Soaking seeds in osmotic solutions (e.g., PEG, mannitol) to control water uptake.	Enhances tolerance to salinity and drought; promotes enzyme activation.
Biopriming	Combining priming with beneficial microbes (e.g., PGPR, Trichoderma spp.).	Boosts disease resistance and stress tolerance; improves seedling vigor.

Impact on Germination under Stress

Stress Condition	Priming Method	Observed Effect on Germination
Drought Stress	Osmopriming	Faster and more uniform germination; better root elongation.
Salinity Stress	Biopriming	Improved germination percentage; reduced ion toxicity.
Heat/Cold Stress	Hydropriming	Increased enzyme activity; stabilized membranes during germination.

3.2 Seed Coating and Pelleting

Seed coating and pelleting are advanced seed enhancement technologies aimed at improving seed performance under challenging conditions.

- Seed coating involves applying a thin layer of materials (like polymers, nutrients, or pesticides) to seeds without altering their shape significantly.
- Pelleting adds more substantial material to make the seed spherical or uniform in shape, facilitating precision planting.

These techniques are particularly valuable for:

- Nutrient loading, where micronutrients like zinc or iron are embedded to support early plant growth.
- Pesticide protection, which shields seedlings from soil-borne pathogens or pests.
- Enhancing establishment in stress-prone soils, such as drought, salinity, or nutrient-deficient environments, by providing essential growth inputs directly to the seed.

Table: Benefits and Functions of Seed Coating and Pelleting

Aspect	Seed Coating	Seed Pelleting
Primary Function	Add protective or nutritive layer	Modify shape and size for precision planting
Nutrient Loading	Delivers micronutrients at germination site	Can include macro and micronutrients
Pesticide Protection	Incorporates fungicides/insecticides	Higher load possible due to volume
Stress Tolerance Support	Helps seedlings in drought/saline soils	More effective in extreme conditions
Impact on Seed Shape	Minimal alteration	Converts to uniform, often spherical shape
Application Crops	Cereals, legumes, vegetables	Small, irregular seeds (e.g., lettuce, carrot)

3.3 Synthetic Seeds

Synthetic seeds are artificially encapsulated somatic embryos, shoot buds, or other tissue that can develop into a complete plant. These are produced using hydrogels like sodium alginate to mimic the protective coat of natural seeds.

- **Encapsulation of Somatic Embryos**- Somatic embryos (developed from somatic cells rather than fertilized eggs) are enclosed in a gel matrix to protect and store them, enabling easy handling, storage, and sowing.

- **Use in Hybrid or Vegetatively Propagated Crops**- Especially useful for crops that are difficult to propagate by seeds (like banana, sugarcane, or ornamentals), synthetic seeds help in mass multiplication and uniformity, particularly in hybrids and clones.

3.4 Seed Vigor and Germination Testing

Seed Vigor and Germination Testing involves evaluating the health and performance potential of seeds to ensure they produce strong, uniform seedlings. It plays a crucial role in:

- **Ensuring Planting Material Quality**- By identifying high-quality seeds with strong germination ability, it guarantees better crop establishment and uniform growth.
- **Early Vigor as a Resilience Trait**- Seeds with high vigor grow quickly and establish faster, helping plants better withstand environmental stresses like drought, pests, and poor soils.

IV. INTEGRATION WITH MOLECULAR AND GENOMIC TOOLS

The integration of molecular and genomic tools with traditional plant tissue culture and seed technology significantly enhances the precision, reliability, and efficiency of crop improvement strategies. These tools allow scientists to understand and manipulate plant genetics at the molecular level, supporting better conservation and the development of stress-resilient crops.

4.1 Use of Molecular Markers to Assess Genetic Stability in Tissue-Cultured Plants

Molecular markers such as Simple Sequence Repeats (SSRs)**,** Random Amplified Polymorphic DNA (RAPD), and Single Nucleotide Polymorphisms (SNPs) are essential tools for evaluating the genetic fidelity of plants produced through tissue culture. Tissue-cultured plants are prone to somaclonal variation—genetic changes that may arise due to prolonged culture or stress during in vitro processes.

By using these markers, researchers can:

- Detect any unintended genetic changes in regenerated plantlets.
- Ensure that cloned plants remain true-to-type (genetically identical to the mother plant).
- Confirm the genetic uniformity needed for commercial-scale production, especially in elite and stress-tolerant varieties.

This quality control is crucial when using micropropagation for large-scale multiplication, particularly for high-value crops such as bananas, sugarcane, and medicinal plants.

4.2 Application of Genomics for Seed Trait Improvement

Genomics involves the study of the entire genome of an organism and helps in identifying specific genes or gene networks linked to desirable agronomic traits. In the context of seed technology, genomics supports the development of improved seed varieties with enhanced:

- Germination rate and vigor
- Tolerance to drought, salinity, or heat
- Resistance to pests and diseases
- Seed longevity and storability

Using genome-wide association studies (GWAS)**,** QTL mapping, and genomic selection, breeders can pinpoint the genetic basis of complex seed traits and integrate them into breeding programs. Furthermore, CRISPR and gene-editing technologies are now being used to precisely modify seed-related genes to boost performance under stress conditions.

This genomic integration accelerates breeding cycles, improves selection accuracy, and enhances the resilience and quality of crops—contributing significantly to sustainable agriculture and food security. The integration of molecular markers and genomic tools ensures that both tissue-cultured plants remain genetically stable and seeds are genetically optimized for better performance in challenging environments.

V. CASE STUDIES AND APPLICATIONS

5.1 Tissue Culture in Developing Virus-Free Banana in Africa

In many African countries, banana production suffers from viral diseases like Banana Bunchy Top Virus (BBTV) and Banana Streak Virus (BSV). Tissue culture techniques, particularly shoot-tip culture, are used to produce virus-free planting materials at scale. This has significantly improved yields, reduced disease spread, and enhanced food security in regions like Kenya, Uganda, and Nigeria.

5.2 Seed Priming in Salt-Tolerant Rice in South Asia

Seed priming—soaking seeds in water or a solution before sowing—has been successfully applied in countries like India and Bangladesh to improve germination and early growth of salt-tolerant rice varieties (e.g., 'Pokkali' and 'Swarna Sub1'). This technique helps rice establish better under saline soil conditions, increasing resilience and productivity in coastal and degraded farmlands.

5.3 Synthetic Seed Application in Ornamental and Forest Species

Synthetic seeds (encapsulated somatic embryos or shoot buds) are used for the propagation and conservation of high-value ornamental plants (like orchids) and forest trees (such as eucalyptus and teak). This method enables easy storage, transport, and sowing of clones, especially for species that are hard to propagate by conventional means or have recalcitrant seeds.

VI. CONCLUSION

Plant tissue culture and seed technology have significantly advanced crop improvement by ensuring high-quality planting materials, enhancing genetic stability, and promoting early vigor—key for resilience under stress conditions. Together, these technologies offer a synergistic potential to strengthen crop adaptability to climate change through precise propagation, genetic conservation, and improved seed performance. Moving forward, realizing their full potential demands interdisciplinary research, integrating biotechnology, genomics, nanotechnology, and AI. Furthermore, strong policy support is essential to promote innovation, ensure safe deployment, and build climate-smart agricultural systems for future food security.

REFERENCES

[1]. Ashraf, M., & Foolad, M. R. (2007). Roles of glycine betaine and proline in improving plant abiotic stress resistance. *Environmental and Experimental Botany*, 59(2), 206–216.

[2]. Benson, E. E. (2008). Cryopreservation of phytodiversity: A critical appraisal of theory & practice. *Critical Reviews in Plant Sciences*, 27(3), 141–219.

[3]. Bhoite, K. D., & Ulemale, R. B. (2020). Seed vigor and its importance in crop production: A review. *Journal of Pharmacognosy and Phytochemistry*, 9(1), 2046–2049.

[4]. Bhojwani, S. S., & Dantu, P. K. (2013). *Plant Tissue Culture: An Introductory Text*. Springer.

[5]. Borrelli, V. M. G., et al. (2018). Genetic improvement of durum wheat for heat and drought tolerance: Past achievements and future prospects. *Agronomy*, 8(7), 75.

[6]. Bui, L. T., & Tran, L. S. P. (2015). The role of plant growth regulators in tissue culture and their impact on plant resilience. *Plant Cell Reports*, 34(4), 693–709.

[7]. Collard, B. C. Y., & Mackill, D. J. (2008). Marker-assisted selection: An approach for precision plant breeding in the twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1491), 557–572.

[8]. Deepthi, V. P. (2018). Somaclonal variation in micro propagated bananas. *Journal of Applied and Natural Science*, 10(2), 672–680.

[9]. Engelmann, F. (2011). Use of biotechnologies for the conservation of plant biodiversity. *In Vitro Cellular & Developmental Biology - Plant*, 47(1), 5–16.

[10]. Ernst, R. (2000). Use of tissue culture in germplasm conservation. *In Vitro Cellular & Developmental Biology - Plant*, 36(5), 456–459.

[11]. FAO. (2014). *Genebank Standards for Plant Genetic Resources for Food and Agriculture*. Food and Agriculture Organization of the United Nations.

[12]. Gandonou, C. B., Abrini, J., Idaomar, M., & Skali-Senhaji, N. (2005). Salt stress effect on growth and proline content in sugarcane callus. *Plant Cell, Tissue and Organ Culture*, 80(3), 217–224.

[13]. George, E. F., Hall, M. A., & De Klerk, G.-J. (2008). *Plant Propagation by Tissue Culture*. Springer.

[14]. Gomathi, R., et al. (2020). Seed priming strategies to improve seed vigor and field establishment in sugarcane. *Sugar Tech*, 22(6), 1035–1044.

[15]. Hossain, M. A., et al. (2012). Molecular marker-assisted breeding for stress tolerance. *Plant Omics*, 5(4), 149–157.

[16]. Kaeppler, S. M., Kaeppler, H. F., & Rhee, Y. (2000). Epigenetic aspects of somaclonal variation in plants. *Plant Molecular Biology*, 43(2), 179–188.

[17]. Kaur, G., & Asthir, B. (2015). Proline: A key player in plant abiotic stress tolerance. *Biologia Plantarum*, 59(4), 609–619.

[18]. Kumar, S., & Reddy, M. P. (2011). Genetic improvement of Jatropha curcas L. through tissue culture and molecular markers: A review. *Applied Energy*, 88(3), 1982–1993.

[19]. Le, D. T., et al. (2011). Genomics-based breeding of rice for drought tolerance. *Journal of Experimental Botany*, 62(1), 41–53.

[20]. Miguel, C., & Marum, L. (2011). An epigenetic view of plant cells cultured in vitro: Somaclonal variation and beyond. *Journal of Experimental Botany*, 62(11), 3713–3725.

[21]. Panis, B., & Lambardi, M. (2005). Status of cryopreservation technologies in plants. *The role of biotechnology*, 43–54.

[22]. Pathirana, R. (2011). Plant tissue culture in plant breeding: A review. *Euphytica*, 188(3), 227–239.

[23]. Pramanik, K., et al. (2021). Insights into the embryo rescue: A modern in vitro crop improvement approach in horticulture. *Vegetos*, 34, 561–570.

[24]. Rai, M. K., et al. (2011). In vitro techniques for screening abiotic stress tolerance in plants: A review. *Environmental and Experimental Botany*, 71(1), 1–20.

[25]. Rajan, R. P., & Singh, G. (2021). A review on application of somaclonal variation in important horticultural crops. *International Journal of Agriculture Sciences*, 13(3), 10650–10655.

[26]. Reed, B. M. (2001). Implementing cryogenic storage of clonally propagated crops. *CryoLetters*, 22(2), 97–104.

[27]. Rines, H. W., et al. (2009). Embryo rescue in oat × maize crosses: Methods and gene transfer. *Crop Science*, 49(3), 659–666.

[28]. Roy, M., & Mandal, A. (2005). An improved method of shoot organogenesis of Musa spp. using high BAP concentration. *Plant Tissue Culture and Biotechnology*, 15(2), 71–76.

[29]. Sinha, R. K., et al. (2018). In vitro clonal propagation of Musa sp. cultivar Gopi: A palatable banana of Tripura, India. *International Journal of Agriculture Innovations and Research*, 6(3), 405–410.

[30]. Shibli, R. A., et al. (2007). Cryopreservation and in vitro conservation of plant genetic resources: A review. *World Journal of Agricultural Sciences*, 3(4), 507–520.

[31]. Shen, K., Qu, M., & Zhao, P. (2023). The roads to haploid embryogenesis: In vitro and in vivo mechanisms. *Frontiers in Plant Science*, 14, 1100654.

[32]. Tonosaki, K., et al. (2016). Reproductive barriers and the effect of allopolyploidization on crop breeding. *Breeding Science*, 66(3), 225–238.

[33]. Tripathi, J. N., et al. (2015). Field evaluation of banana plants derived from somatic embryos and shoot tips under drought stress. *Plant Cell, Tissue and Organ Culture*, 122(1), 49–60.