



Climate-Resilient Seed Production in India: Strategies for Sustainable Agriculture

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Abstract

Climate change poses a significant threat to seed production systems in India by affecting seed yield, quality, genetic integrity, and availability. Increasing temperatures, erratic monsoon behaviour, drought, heat waves, and high humidity have intensified abiotic stresses during critical stages of seed development. Climate-resilient seed production has therefore become a strategic priority for sustaining agricultural productivity and ensuring national food security. This article examines the impact of climate change on seed production in India and highlights key strategies, including climate-adaptive breeding, region-specific seed production practices, seed enhancement technologies, and institutional support mechanisms. Strengthening climate resilience in seed systems is essential to maintain seed quality and productivity under changing climatic conditions.

Keywords: Climate change, seed quality, stress tolerance, seed priming, Indian agriculture

Introduction

Seed is the most fundamental agricultural input, determining crop establishment, yield potential, and adaptability to environmental stress. In India, where agriculture supports a large proportion of the population, reliable seed production systems are critical for food and livelihood security. However, climate change has emerged as a major constraint to seed production, with rising temperatures, altered rainfall patterns, and frequent extreme weather events affecting seed crops across diverse agro-ecological regions. Seed crops are particularly sensitive to climatic stress during flowering, pollination, and seed filling stages, resulting in poor seed set, reduced vigour, and compromised genetic purity. Consequently, developing climate-resilient seed production systems has become essential for sustaining agricultural productivity under future climatic scenarios (Hampton *et al.*, 2016).

Impact of Climate Change on Seed Production in India



Climate change influences seed production at multiple stages, from flowering to post-harvest storage. Elevated temperatures reduce pollen viability and fertilization efficiency, leading to lower seed yield and poor seed quality. Drought and moisture stress during reproductive stages reduce seed size, vigour, and germination capacity, while high temperature and humidity during maturation and storage accelerate seed deterioration. In India, these effects are region-specific. Terminal heat stress in the Indo-Gangetic plains affects wheat and mustard seed production, erratic rainfall in central India disrupts pulse seed crops, and high humidity in southern and coastal regions increases disease pressure during seed development and storage. In hill regions, temperature fluctuations disturb flowering synchrony in temperate crops. These challenges highlight the vulnerability of Indian seed production systems to climate variability (Hampton *et al.*, 2016).

Strategies for Climate-Resilient Seed Production

Climate-Adaptive Breeding

Breeding stress-tolerant varieties is a sustainable and long-term approach to enhancing climate resilience in seed production. In India, ICAR and State Agricultural Universities have developed drought-tolerant, heat-tolerant, and early-maturing varieties in crops such as rice, wheat, and pulses to cope with climatic stress. Modern breeding programmes increasingly integrate conventional breeding with molecular markers, genomic selection, and advanced phenotyping tools to improve tolerance to heat, drought, and salinity while ensuring stability of reproductive traits. Such varieties help maintain seed yield, quality, and genetic integrity under adverse climatic conditions.

Adaptive Seed Production Practices

Improved agronomic management plays a vital role in reducing climate-related risks in seed production. Adjustment of sowing dates helps avoid exposure of sensitive reproductive stages to extreme temperatures or moisture stress. Shifting seed production to climatically suitable regions, improving irrigation efficiency, and adopting soil moisture conservation practices further enhance resilience. In India, high-altitude regions such as Himachal Pradesh and Uttarakhand are increasingly used for vegetable and temperate crop seed production due to favourable climatic conditions. Protected cultivation systems, including shade nets and polyhouses, also contribute to stabilizing seed yield and quality under variable climates.

Seed Enhancement and Priming Technologies

Seed enhancement technologies, particularly seed priming, have emerged as effective tools for improving seed performance under climatic stress. Techniques such as hydropriming, osmopriming, biopriming, nutrient priming, and Nano priming improve germination, seedling vigour, and early crop establishment under drought and heat stress conditions. Primed seeds exhibit enhanced metabolic activity, improved antioxidant defence mechanisms, and



better osmotic regulation, enabling seedlings to tolerate adverse environments. Recent advances in nanopriming allow precise delivery of beneficial compounds, offering significant potential for climate-resilient seed production in India (Gohari *et al.*, 2025).

Seed Quality and Genetic Integrity

Maintaining seed quality and genetic purity under climate stress is a major challenge, particularly in hybrid seed production systems. Elevated temperatures can disrupt male sterility systems and flowering synchrony, increasing the risk of genetic contamination. Stress during seed maturation reduces seed vigour and storage life. Therefore, climate-resilient seed production must incorporate strict field inspections, controlled pollination, scientific harvesting, and improved post-harvest handling and storage practices to preserve seed quality and varietal purity (Hampton *et al.*, 2016).

Institutional Support and Seed Systems in India

Strong institutional support is essential for climate adaptation in seed production. India's seed sector is supported by policies such as the National Seed Policy, seed village programmes, community-based seed production initiatives, and public-private partnerships. ICAR institutes, State Agricultural Universities, and Krishi Vigyan Kendras play a crucial role in developing climate-resilient varieties, training farmers in seed production practices, and promoting seed enhancement technologies. Strengthening both formal and informal seed systems ensures timely availability of quality seed in climate-vulnerable regions.

Conclusion

Climate-resilient seed production is central to sustaining Indian agriculture under changing climatic conditions. Integrating climate-adaptive breeding, region-specific seed production practices, seed enhancement technologies, and robust institutional support can safeguard seed quality, productivity, and availability. Strengthening resilience within seed systems will enhance the adaptive capacity of Indian farmers, stabilise crop yields, and contribute significantly to long-term food and nutritional security.

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