



## Climate-Smart Seed Systems: Tools for Adapting to Extreme Weather Conditions

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Climate change poses a serious threat to global agriculture by increasing the frequency and intensity of extreme weather events such as droughts, floods, and heat stress. Climate-smart seed systems (CSSS) form a core component of climate-smart agriculture (CSA) by ensuring the development, availability, and adoption of resilient crop varieties. This paper reviews the concept, components, tools, and institutional mechanisms of climate-smart seed systems, highlighting their role in enhancing agricultural resilience, food security, and sustainability. Emphasis is placed on breeding for climate resilience, farmer-managed seed systems, digital decision-support tools, and community seed banks. Case studies and examples from India and other developing regions illustrate the practical relevance of climate-smart seed systems in adapting to climate variability.

**Keywords:** Climate-smart agriculture; climate-resilient seeds; seed systems; high-throughput breeding; extreme weather; food security

### Introduction

Climate-smart agriculture (CSA) aims to transform agri-food systems to sustainably increase productivity, enhance resilience to climate change, and reduce greenhouse gas emissions. Among the pillars of CSA, climate-smart seed systems play a crucial role by providing farmers with access to seeds that are tolerant to biotic and abiotic stresses. As climate change accelerates, strengthening seed systems becomes essential to ensure stable crop production and livelihood security, particularly for smallholder farmers.

### Climate-Smart Seed Systems: Concept and Importance

Climate-smart seed systems focus on the development, production, distribution, and conservation of seeds that can withstand climate-induced stresses such as drought, heat, salinity, flooding, pests, and diseases. These systems reduce farmers' vulnerability to climate shocks, minimize yield losses, and promote long-term sustainability by lowering dependence on external inputs. By conserving genetic diversity and promoting locally adapted varieties, climate-smart seed systems contribute to resilient and inclusive agricultural development.

### Components of Climate-Smart Seed Systems

#### Breeding for Climate Resilience

Breeding programs emphasize traits such as drought tolerance, early maturity, heat tolerance, pest and disease resistance, and flood tolerance. Examples include drought-tolerant rice varieties (Sahbhagi Dhan, Vandana), salt-tolerant cultivars (CSR 56, CSR 60), submergence-tolerant rice (Swarna Sub1), heat-tolerant wheat (WH 1124, DBW 173), drought-tolerant maize (DL 708), and inherently resilient millets.

## Seed Production, Storage, and Quality Control

Decentralized seed production, climate-proof storage facilities, and strengthened certification systems ensure timely availability of quality seeds. Community seed banks and farmer-led seed hubs play an important role in conserving locally adapted varieties and maintaining seed quality under changing climatic conditions.

## Seed Dissemination and Institutional Support

Efficient dissemination mechanisms involving agro-dealers, cooperatives, and digital platforms improve farmers' access to climate-resilient seeds. Policy and institutional support through public-private partnerships, subsidies, and legal frameworks is critical for scaling climate-smart seed systems.

## Farmer-Managed and Participatory Seed Systems

Farmer-managed seed systems enable farmers to select, save, and exchange seeds adapted to local agro-climatic conditions. Participatory plant breeding (PPB) actively involves farmers, researchers, and other stakeholders in varietal development, ensuring that new varieties meet farmers' preferences while enhancing genetic diversity and resilience. Successful examples include farmer-selected maize varieties such as GDRM-187 in India.

## Decision-Support and Digital Tools

Digital decision-support tools strengthen climate-smart seed systems by integrating climate, crop, and management data. Tools such as DSSAT (Decision Support System for Agrotechnology Transfer) assist in assessing climate change impacts and optimizing crop management, while models like PRISM support early warning and planning. Digital platforms such as SeedSAGE and SeedTracker enhance seed system analysis, certification, traceability, and access to climate-resilient seeds.

## Community Seed Banks and Biodiversity Conservation

Community seed banks (CSBs) conserve plant genetic resources, promote seed sovereignty, and enhance farmers' adaptive capacity. Initiatives such as Navdanya and Sahaja Samrudha in India demonstrate the role of CSBs in preserving agro-biodiversity, sharing indigenous knowledge, and supporting climate-resilient farming systems.

## Case Study: Scaling Up Climate-Smart Crop Systems

A FAO-led project (2021) in Sri Lanka and Zambia under the "Save and Grow" initiative highlights the integration of climate-smart crops and mechanization. The project focused on optimizing water, labour, and machinery use while assessing climate change impacts on major crops including rice, maize, green gram, onion, chilli, and potato, thereby strengthening the evidence base for CSA.

## Opportunities, Innovations, and Challenges

Emerging innovations such as genomic tools, CRISPR/Cas-based breeding, digital seed systems, and agroecological approaches offer significant opportunities for strengthening climate-smart seed systems. However, challenges persist, including limited access to resilient varieties, weak extension services, inadequate regulatory frameworks, and fragmented seed supply chains. Addressing these constraints requires coordinated policy support, investment in research and extension, and integration of climate information with seed distribution planning.

## Conclusion

Climate-smart seed systems are essential for adapting agriculture to extreme weather conditions and ensuring food security under climate change. By integrating resilient breeding, farmer participation, digital tools, and supportive policies, these systems can enhance agricultural sustainability and resilience. Strengthening climate-smart seed systems should therefore be a priority for future crop improvement and climate adaptation strategies.

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