
Breeding approach to develop climate resilient crops: current status and future prospects: A review

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Introduction

Climate-resilient breeding develops crops that can withstand climate change impacts like drought, heat, floods, and pests, ensuring food security by using advanced techniques (genomics, gene editing) alongside traditional methods (hybridization, selection) to identify and incorporate stress-tolerance genes, creating varieties with stable yields under harsh, erratic conditions, benefiting farmers and global food systems.

Key goals and characteristics

Stress Tolerance: Develops plants resistant to drought, heatwaves, waterlogging (floods), high salinity, and new pests/diseases.

Stable Yields: Maintains productivity even with unpredictable weather and extreme events.

Adaptability: Enables crops to thrive in diverse soils and challenging environments.

Examples & Impact:

Drought-Tolerant Maize: Widely adopted in Africa, improving yields in dry conditions.

Flood-Tolerant Rice: Showing promise in Southeast Asia, reducing crop loss.

Climate-Resilient Wheat: Focuses on early maturity and plant architecture for heat/drought areas.

Importance

Food Security: Secures food supply for growing populations facing climate threats.

Farmer Livelihoods: Protects farm income by preventing crop failure.

Sustainability: Reduces reliance on water and inputs, promoting sustainable agriculture. Climate-resilient wheat varieties are bred for heat/drought tolerance,

better yields under stress, and disease resistance, with key Indian examples including DBW187, DBW222 (Karan Narendra), DBW303, HD 3385, and WH1270, developed by ICAR-IIWBR for timely/late sowing, helping farmers adapt to rising temperatures and ensure food security. These varieties, along with others like PBW826 and HI 1633, focus on traits like better grain filling under heat, lodging resistance, and water efficiency, supported by government and research efforts for widespread adoption.

Key Heat-Tolerant Varieties (India)

DBW187 & DBW222 (Karan Narendra): Highly heat-tolerant, showing significant yield gains in warmer conditions, superior to older heat-tolerant types like HD-3086.

HD 3385: Specifically designed for terminal heat (late March spikes), suitable for both timely and late sowing.

DBW303, DBW327, WH1270, PBW872: Also developed for heat stress, often grown with adjusted planting times (mid-November) to avoid peak heat.

Other Resilient & High-Yielding Varieties

Narendra 09: Farmer-developed, high-yielding, water-efficient, thrives in diverse conditions.

HI 1633 (Pusa Wheat 1633): Recommended for better disease/yield.

PBW 826: A top high-yielding choice.

Muktinath 3170 & GW 451: Hard-grain varieties good for milling and processing.

Features of resilient wheat

Heat Tolerance: Ability to maintain yield during grain

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filling when temperatures rise (terminal heat).

Drought Resistance: Better performance in water-scarce regions.

Lodging Resistance: Stronger stems to prevent crop collapse, reducing yield loss.

Disease Tolerance: Resistance to common diseases like rust.

Strategies for resilience

Breeding: ICAR-IIWBR and international partners (CIMMYT) are developing new gene pools for diverse traits.

Sowing Times: Adjusting planting (e.g., mid-November) to align grain filling with cooler temperatures.

Resource Conservation: Using techniques like Zero Tillage (ZT) and Happy Seeder (HS) for better profitability and efficiency.

What is climate-resilient crop varieties?

Climate-resilient crop varieties are plants that are adapted to tolerate extreme weather conditions such as: Drought and Heat and Salinity and Flooding.

Pests and Diseases

These varieties are designed to grow and yield optimally despite environmental challenges, using advanced breeding techniques and biotechnology.

The Need for Climate-Resilient Crops

Erratic Weather Patterns: Unpredictable rainfall and temperature fluctuations threaten crop yields.

Increasing Soil Salinity: Rising sea levels and irrigation practices lead to saline soils, making it hard for conventional crops to grow.

Water Scarcity: Droughts are becoming more frequent, reducing water availability for crops.

Pest and Disease Outbreaks: Warmer temperatures can lead to new and more aggressive pests and diseases.

Examples of Climate-Resilient Crops

Drought-Tolerant Maize: Developed using selective breeding and genetic engineering, varieties like *Drought TEGO* in Africa provide stable yields under water-limited conditions.

Salt-Tolerant Rice: In coastal regions, rice varieties like *Swarna Sub1* can survive submergence and high salinity.

Heat-Tolerant Wheat: Researchers have developed wheat strains with a higher temperature threshold for germination and flowering.

Flood-Resistant Sorghum: Sorghum varieties bred to withstand waterlogged soils help mitigate yield losses in flood-prone regions.

Legume Varieties with Pest Resistance: Cowpeas and chickpeas are being developed with natural pest resistance to reduce chemical pesticide dependency.

Breeding Techniques Used

Conventional Breeding: Cross-breeding plants with desired traits over generations to develop climate-resilient varieties.

Marker-Assisted Selection (MAS): Using molecular markers to identify and select plants with stress-tolerant traits more efficiently.

Genetic Modification (GM): Introducing foreign genes into plants to provide resilience against drought, salinity, or pests.

CRISPR Gene Editing: Precise editing of plant DNA to improve resilience traits without introducing foreign genes.

Speed Breeding: Using controlled environments to accelerate the breeding process.

Benefits of Climate-Resilient Crops

Food Security: Ensures stable food production even under extreme conditions.

Reduced Dependency on Pesticides and Water: Enhanced resistance to pests and diseases reduces the need for chemical treatments, and drought tolerance reduces irrigation requirements.

Economic Stability for Farmers: Resilient varieties minimize crop losses and provide consistent incomes.

Biodiversity Preservation: Diverse crop varieties reduce the risk of monoculture-related vulnerabilities.

Challenges in Developing and Adopting Climate-Resilient Crops

Research and Development Costs: Developing new varieties takes time, money, and extensive research.

Regulatory and Ethical Concerns: Some stakeholders have concerns over the safety and environmental impact of genetically modified crops.

- Farmer Awareness and Training:** Adoption is slow due to limited knowledge or trust in new crop varieties.
- Market Access:** Small-scale farmers often lack access to improved seeds or financing options.
- Future Outlook and Innovations:** The future of climate-resilient agriculture lies in embracing technological innovations such as:
- AI and Big Data:** Using predictive analytics to identify traits that enhance climate resilience.
- Blockchain Technology:** Ensuring traceability and transparency in the seed supply chain.
- Agroecological Practices:** Integrating resilient crops with sustainable farming methods for holistic climate adaptation. The future of climate-resilient breeding is shifting from traditional selection to a highly integrated “smart breeding” framework. This approach combines genomic tools, artificial intelligence, and rapid generation advancement to develop crops that can withstand multiple simultaneous stresses like extreme heat, drought, and flooding.
- Key Technological Innovations:** The integration of these technologies aims to reduce breeding cycles from decades to just a few years:
- Precision Gene Editing (CRISPR/Cas):** Beyond simple gene knockouts, future applications focus on multiplex editing to target multiple genes at once for complex traits. It is also being used for *de novo* domestication, where wild relatives with natural resilience are rapidly “domesticated” by editing key yield-related genes while keeping their native stress tolerance.
- Next-Gen Artificial Intelligence (AI):** AI and machine learning are becoming central to analysing massive “multi-omics” datasets (genomics, phenomics, enviromics) to predict how specific genotypes will perform in future climate scenarios.
- Speed Breeding:** By manipulating light and temperature in controlled environments, breeders can now produce up to 6 generations per year for crops like wheat and barley, drastically accelerating the deployment of new varieties.
- High-Throughput Phenomics:** Using drones, sensors, and hyperspectral imaging, researchers can non-destructively monitor plant health and root architecture in real-time, allowing for the selection of superior traits that were previously invisible.
- Emerging Strategic Priorities** Future breeding efforts are expanding beyond single-crop yield to broader ecological resilience:
- Exploiting Crop Wild Relatives (CWRs):** Gene banks are being “mined” for lost genetic diversity. CWRs and underutilized “orphan crops” (e.g., millets, quinoa) are being prioritized for their inherent survival traits in harsh environments.
- Breeding for “Combined Stresses”:** Future varieties must handle dual threats, such as drought followed by heatwaves, which require a deeper understanding of complex molecular signaling pathways like ROS and calcium waves.
- The Holobiont Approach:** Breeding is moving toward a “holistic” view that includes the plant microbiome. Future strategies may involve selecting for plants that better recruit beneficial soil microbes to enhance nutrient uptake and stress tolerance.
- Climate Modeling Integration:** Incorporating predictive climate models directly into breeding programs helps identify the specific environmental stressors a region will face 20–30 years in the future.
- Current Challenges & Bottlenecks:** Despite technological promise, several hurdles remain for widespread adoption:
- Regulatory & Social Barriers:** Gene-edited crops face complex regulatory frameworks and varying levels of public acceptance across different countries.
- G x E Interactions:** The “Genotype x Environment” interaction remains a major challenge, as a variety that is resilient in one region may fail in another due to local soil or weather nuances.
- Data Standardization:** The explosion of “big data” from sensors and sequencing requires new standards to ensure information can be shared and used effectively by breeders worldwide.
- Government and Policy Support:** Governments and international organizations play a vital role in funding research, streamlining regulatory approvals, and creating incentives for farmers to adopt climate-resilient varieties. Initiatives like the Global Commission on Adaptation and CGIAR’s Climate Change Program are already driving innovation in this field.

Conclusion

Climate-resilient crop varieties offer a promising path toward a sustainable and food-secure future. By investing in research, raising awareness, and promoting equitable access to resilient seeds, we can empower farmers to adapt to changing climates and ensure agricultural stability for generations to come.

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