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Advances in Plant Breeding for Climate-Resilient Crops

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INTRODUCTION

Climate change has emerged as the single largest threat to global food security. Rising temperatures, erratic rainfall, prolonged droughts, sudden floods, and the spread of new pests and diseases are squeezing the productivity of the world's major staple crops. According to the Intergovernmental Panel on Climate Change (IPCC, 2022), every additional degree of warming could reduce global yields of wheat, rice, maize, and soybean by 3–7 percent. For a planet projected to host nearly 10 billion people by 2050, this is a sobering arithmetic.

Plant breeding — the science of selecting and combining superior plants to develop better varieties — has always been agriculture's answer to changing environments. Today, breeders are equipped with a powerful new toolbox that blends classical selection with genomics, gene editing, high-throughput phenotyping, and artificial intelligence. The collective aim is to deliver climate-resilient crops that can tolerate drought, heat, flooding, salinity, and emerging biotic stresses while sustaining yield and nutrition. Varghese (2024) notes that climate-smart breeding is no longer a future ambition but an operational reality in most major crops.

From Conventional Selection to Genomic Breeding

Conventional breeding — crossing parents with desirable traits and selecting the best offspring — has produced landmark varieties such as the semi-dwarf wheats and rices of the Green Revolution. However, conventional cycles typically take 8–12 years, which is too slow for a rapidly shifting climate. Marker-assisted selection (MAS) and, more recently, genomic selection (GS) now allow breeders to predict the performance of seedlings using DNA information alone, dramatically shortening selection cycles. Crossa et al. (2017) demonstrated that GS can double the rate of genetic gain for grain yield under drought in maize and wheat compared with phenotypic selection.

High-density single-nucleotide polymorphism (SNP) arrays and low-cost sequencing have made it economical to genotype thousands of breeding lines. Coupled with environmental data, these genomic predictions help identify lines suited to specific climatic niches — a strategy called envirotyping. The Drought Tolerant Maize for Africa (DTMA) initiative used these tools to release more than 200 drought-tolerant hybrids and open-pollinated varieties across sub-Saharan Africa, benefiting an estimated 8 million households (Cairns & Prasanna, 2018).



Figure 1: Drought-tolerant maize lines under evaluation at a CIMMYT field trial in Kiboko, Kenya. Source: CIMMYT (CC BY-NC-SA 2.0).

CRISPR and Precision Genome Editing

The arrival of CRISPR-Cas9 has revolutionised plant breeding. By delivering a guide RNA and the Cas9 enzyme into a plant cell, scientists can introduce precise, predictable changes at specific locations in the genome (Figure 2). Unlike transgenic technology, many CRISPR edits do not introduce foreign DNA, which is helping to ease regulatory and consumer acceptance hurdles in countries such as the United States, Japan, India, and Argentina (Zhang et al., 2023).

Recent breakthroughs include CRISPR-edited rice with enhanced drought and salinity tolerance through modification of the OsERA1 and OsRR22 genes; potato lines with edited CBP80 that maintain tuber yield under water deficit (González et al., 2025); and tomato varieties with improved heat tolerance produced by knocking out negative regulators of flowering. By stacking edits at multiple loci, breeders can now combine drought tolerance, disease resistance, and improved nutrition in a single variety within two to three years.

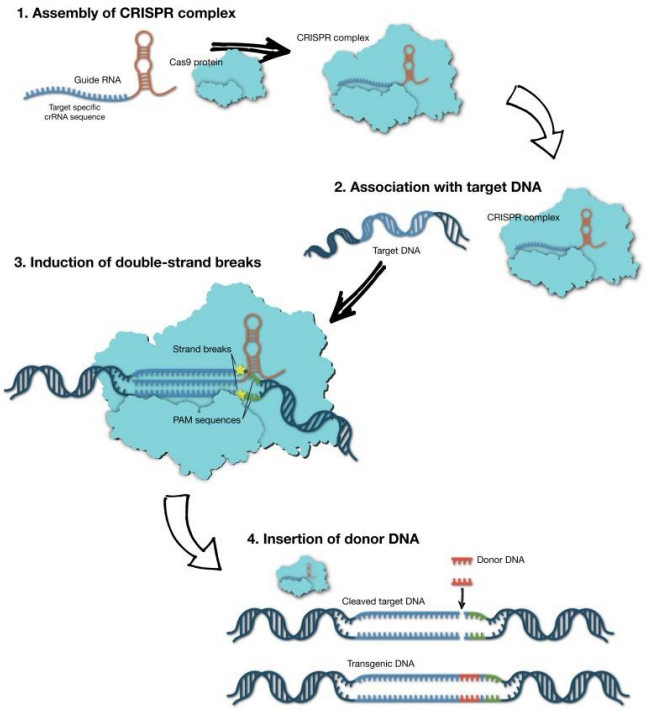


Figure 2: Mechanism of CRISPR/Cas9 genome editing: complex assembly, target recognition, double-strand break, and template-guided repair.

Tapping Wild Relatives and Speed Breeding

Crop wild relatives (CWRs) are reservoirs of stress-tolerance genes that were left behind during domestication. Pre-breeding programmes are systematically transferring these alleles into cultivated germplasm. Notable success stories include Sub1A, a gene from an Indian landrace that confers 14–17 days of submergence tolerance in rice, and which now powers the popular Swarna-Sub1, IR64-Sub1, and BR11-Sub1 varieties grown by over 6 million farmers in flood-prone Asia (Bailey-Serres et al., 2019).



Figure 3: Swarna-Sub1 rice variety on display at an IRRI demonstration plot in India; the Sub1A gene allows the crop to survive complete flooding for up to two weeks.

Watson et al. (2018) introduced speed breeding, in which extended photoperiods (22 hours of light) in glasshouses or growth chambers compress generation times. Up to six generations of wheat, barley, chickpea, and canola can now be raised in a year. When combined with genomic selection and doubled-haploid technology, speed breeding has cut variety-development cycles from a decade to as little as four years.



Figure 4: A speed-breeding glasshouse fitted with high-intensity LED lighting at the John Innes Centre, enabling up to six generations of wheat per year.

Phenomics, Artificial Intelligence, and Climate Modelling

Selecting for climate resilience demands accurate measurement of crop performance under stress. Field phenomics platforms — drones, robotic ground vehicles, hyperspectral cameras, and Internet-of-Things sensors — are being deployed to capture thousands of plant traits non-destructively. Machine-learning models then link these traits to genomic data and weather records, helping breeders predict which lines will thrive in 2050 climates. Reynolds et al. (2021) argue that this fusion of genomics, phenomics, and AI is the bedrock of next-generation breeding.

CONCLUSION

The challenge of feeding a warming planet is daunting, but plant breeding science is rising to meet it. Genomic selection, CRISPR-based gene editing, harnessing of crop wild relatives, speed breeding, and AI-driven phenomics together offer a credible pathway to deliver crops that can withstand the climate of the coming decades. Yet technology alone is not enough. Sustained public investment, enabling biosafety and seed-system policies, farmer participation, and equitable access to improved varieties — especially for smallholders in the Global South — will determine whether these innovations translate into food on the plate. As Mehta (2024) observes, the next generation of climate-resilient crops will be built not only in laboratories and breeding fields but also in partnerships among scientists, farmers, policymakers, and consumers.

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