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# Climate Resilient crops - Developing varieties that withstand drought and floods

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# Climate Resilient crops - Developing varieties that withstand drought and floods

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## Highlights

*Climate challenge mandates climate -resilient crops*

*Advanced Breeding (CRISPR, Genomic selection) is key.*

*Drought tolerance focuses on water management and root depth.*

*Flood tolerance uses the Sub1 gene and snorkeling mechanisms. Socioeconomic obstacles hinder the adoption of new crop varieties by farmers.*

*Harnessing genomic insights with immediate weather information for enhanced, adaptive outcomes.*

## Abstract

Climate change inhibits food production all over the world, which gives rise to climate-resilient crops. The United Nations is applying the climate–smart agriculture initiative to ensure food security. This project involves breeding climate-resilient crops or plant cultivars with enhanced resistance to unfavourable conditions like drought and flood. Climate-resilient crops ensure food security and regenerative practices. By using new and modern breeding techniques, we can make our crops tougher so they can deal with droughts and floods like molecular breeding, gene editing technology like CRISPR/Cas9.The rising intensity of extreme weather events, particularly droughts and floods, poses a severe threat to global food security, Smallholder farmers are being hit the hardest by the crisis.

**Keywords :** Climate-Resilient Crops, Drought Tolerance, Flood Tolerance, Food Security, Climate-Smart Agriculture, Genomics-Assisted Breeding, CRISPR/Cas9-Genome Editing, High-Throughput Phenotyping, Speed Breeding

## Introduction

Climate-resilient crops are essential defences for an agricultural system perpetually exposed to the threats of the climate crisis. Unpredictable rain, long dry periods, and sudden big floods are now common, making it hard for people to earn a living and putting our national food supply at risk. The diversity in temperature and precipitation is expected to profoundly decrease yields of staples like irrigated rice, wheat, and maize in the coming years without aggressive action to develop crops that can withstand climate change, such as climate-resilient crops. We now have resilient varieties that are specifically developed to keep producing high yields in the face of environmental hardship, and have become an urgent necessity. As Razzaq et al. (2021) emphasise, the goal is to create "climate-ready" crops that can ensure productivity in the face of these challenges, focusing on varieties that withstand the twin, contrasting threats of water scarcity and water excess.

## Climate Resilient Crops

Climate Resilient Agriculture (CRA), as defined by the FAO, relies on the agricultural system's ability to anticipate, adapt, absorb, and recover from climate-related impacts. Climate-ready varieties are indispensable, built with a mix of characteristics that provide defence against extremes in heat and moisture and improve how well they utilise available water and soil nutrients. These crops are crucial factors that control how secure our food and nutrition will be particularly in developing nations.

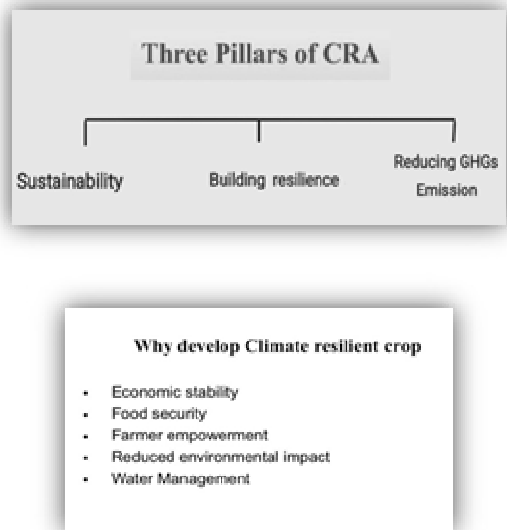



**Fig. 01**

Climate-resilient crops comprise specialised cultivars developed through targeted breeding or precise genetic engineering to exhibit superior performance and robust viability in the face of adverse meteorological variability.

We need resilient crops to maintain steady harvests. These plants are resilient to weather-related problems and pests due to innate characteristics that enable them to withstand climate-related stressors, including drought and flooding. Resilience models can be found in naturally robust organisms. The promotion of traditional crops that are naturally tolerant of heat and drought, such as sorghum and pearl millet, is a strategic adaptation in dryland farming.

### Breeding Technology

The development of climate-resilient varieties has been significantly increased by modern next-generation breeding strategies that enhance conventional methods.

- Crop domestication - it is an ancient process, the foundational human effort of genetically shaping wild species to enhance agronomic traits (e.g., maximizing yield, developing resilient crops). It helps in providing a genetic bank.

- Conventional breeding - a time-consuming, primary technique for mobilising native germplasm, it involves harnessing the genetic resources of wild species and landraces to carry out conventional hybridisation. Hence, bringing back stress-tolerant alleles to a variety.

- Genomics-Assisted Breeding (GAB) - it is an crucial platform for Hastening the selection process of climate-resilient traits, fundamentally reducing the time required to develop new stress-tolerant crop lines. Leveraging Pan genome-derived data, GAB exploits the crop's entire genetic range to swiftly identify and deploy valuable stress-resilient alleles.

### Key tools of GAB encourage resilience traits:

- Marker-Assisted Selection (MAS) and Marker-Assisted Backcrossing (MABC) - Rapidly trace and integrate specific desirable alleles, such as the Sub1 submergence gene, into superior, high-performing lines.

- Genomic Selection - it helps in governs multi-gene traits.

- CRISPR/Cas systems (Genome editing) - The technology is then applied to carry out targeted modifications, upgrading or implementing stronger resistance traits with the highest degree of precision. It offers exceptional precision for precise genetic editing, bypassing the slow, and chance outcomes of random crossing. It helps in maximizing or integrating superior resilience traits—such as better water retention or disease defence. As a result, greatly hastening the engineering of new attributes. This is the crucial step for testing the genetic modifications in practice.

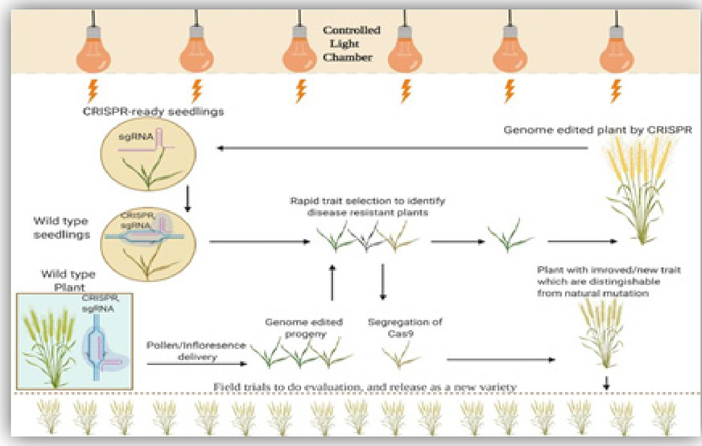



**Fig. 02**

- High-Throughput Phenotyping (HTP) uses automated cameras and sensors to quickly measure and observe thousands of new plant lines under stress (like simulated drought or flood). We then feed the huge amounts of data generated into AI and Machine Learning systems, which quickly and objectively choose the plants that truly perform best under those climate-stressed conditions.

- Speed breeding - The crucial concluding step for significantly expediting the breeding process. This enables researchers to rapidly climate resilient traits through generations, substantially reducing the duration required to finalize and market the new drought- and flood-resilient varieties for prompt distribution to cultivators.

The National Agricultural Research System (NARS) reported developing 2661 climate-resilient varieties across various crops between 2014 and 2024, demonstrating the output of these efforts.

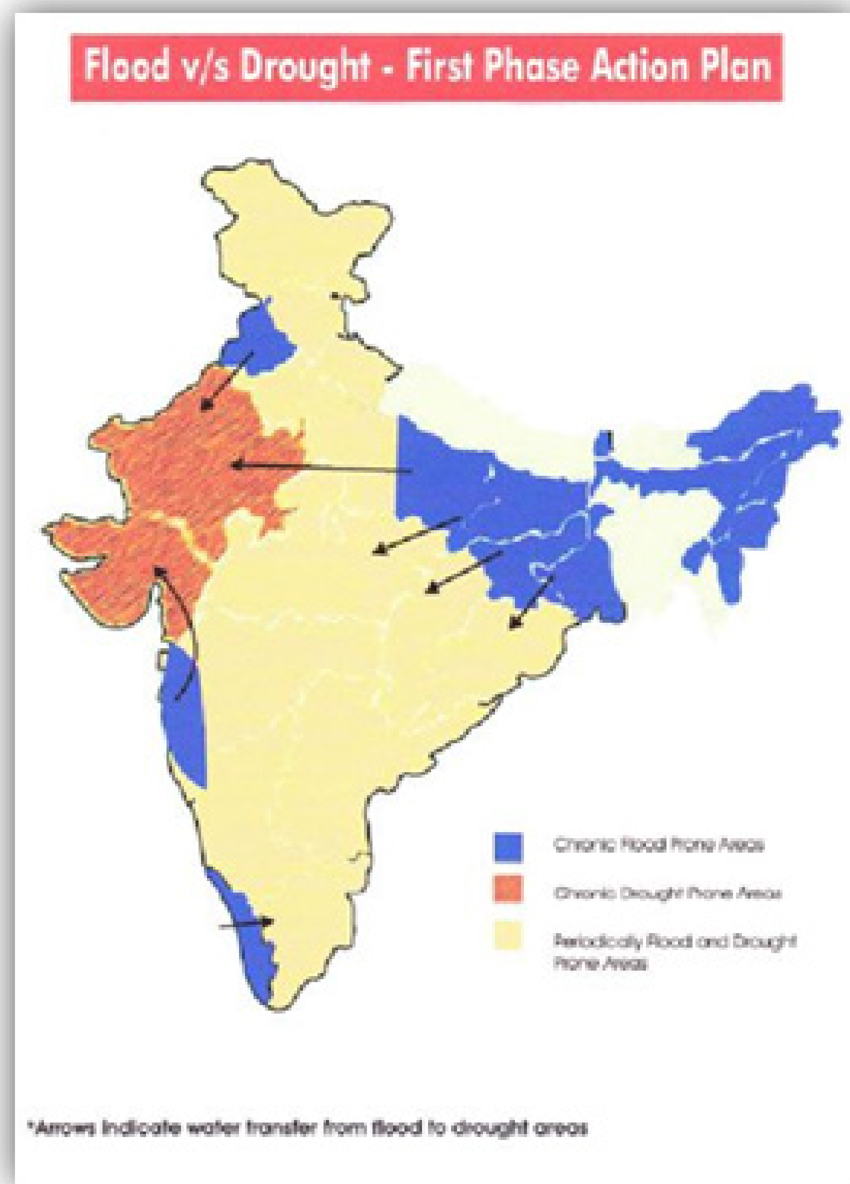
## Designing Crops to Withstand Water Extremes:

In developing climate-resilient cultivars, we tackle drought and flood using distinctly separate, focused methods.

- For drought tolerance is simply developing crops that are really good at saving and managing water. We must structurally engineer the plant by refining its Root System Architecture (RSA)—meaning we aim for deeper, more vigorous root growth to access water in the subsoil. This must be simultaneously matched with maximizing its Water-Use Efficiency (WUE), which is the photosynthetic ability to efficiently capture carbon while minimizing water transpiration from the canopy. Because drought tolerance isn't controlled by just one simple switch but is instead a complex trait orchestrated by many genes working together, we use Genomic Selection. This powerful method acts as a sophisticated predictor, allowing us to quickly forecast and select the plants most likely to perform well during a severe drought. We then validate these predictions using High-Throughput Phenotyping (HTP)—that is our fast, automated testing system. We specifically measure things like how hot the leaves get and how the plants manage their tiny pores (stomata function) to scientifically prove that the selected lines are genuinely water-efficient and capable of high yields.

- For flood strategy focuses entirely on how the plant stays alive when it's underwater and starved of oxygen. Plants have two main, brilliant ways to cope:

1. Snorkelling: They create internal air tubes (called parenchyma) to move precious oxygen from the leaves down to the roots.
2. Resting (Quiescence): They just stop all growth and go into an energy-saving mode until the floodwaters disappear. This "stop-growing" trick is thanks to specific genes, like the Sub1 gene in rice.




Since these survival tricks require the plant to turn its internal systems on and off (like flipping a metabolic switch), we use the advanced CRISPR/Cas gene-editing tools. This allows us to precisely adjust the plant's internal workings so it can produce and save the maximum amount of energy needed to survive the time it spends completely underwater.

## Example of climate resilient varieties:

| Crop | Variety | Stress Trait |
|---|---|---|
| Rice | Swarna Sub1 | Flood/Submergence |
| | Samba-Sub1 /Bahadur Sub-1/CR-1009 Sub1 | Flood tolerant |
| | Sahbhagi Dhan | Drought (rainfed upland) |
| | DRR Dhan / IR64-DRT | Drought tolerant |
| Pearl millet | HHB-226, RHB-177 | Drought (terminal drought) |
| | HHB 67 improved, GHB 757, GHB 719, Dhanshakti, HHB-234, Mandor Bajra Composite 2, Pusa Composite 443 | Drought/flood (flood perhaps less, but mainly drought / limited moisture) tolerant varieties |
| Sorghum | CSH-24 MF | Drought tolerant hybrid |
| Pigeon pea | ICPL-88039 | Drought escape (short duration) |
| Groundnut | Vijetha(R-2001-2), JL-501, CO series, ICGV-91114, Kadiri 6 | Drought/Rainfed suitability |
| | Ajaya, Girnar 1, TAG-24, Kadiri 6, ICGV 91114 | Drought tolerant |
| Cotton | LRA 5166 | Drought tolerant |
| Sugarcane | Co 0118 (Karan-2) | Drought and water logging tolerance |
| | Co 98014 (Karan-1) | Drought and water logging tolerance |
| | Co Pant 90223 | Drought and water logging tolerance |
| Wheat | PBW 527, HI 1531, HI 8627, HD 2888, HPW 349, PBW 644, WH 1080, HD 3043, PBW 396, K 9465, K 8962, MP 3288, HD 4672, NIAW 1415, HD 2987 | Flood and drought resistant seeds |
| Maize | Pusa Hybrid Makka 1, HM 4, Pusa Hybrid Makka 5, DHM 121, Buland | Flood and drought tolerant |
| Barley | RD 2660, K 603 | Flood and drought tolerant |
| Chickpea | Vijay, Vikas, RSG-14, RSG-888, ICCV 10 | Drought tolerant |
| Soybean | NRC 7, JS 95-60 | Flood / drought tolerant |
| Jute | JBO 1 (Sudhangsu), JRO 204, JRO 524, JRC 80 | Flood / drought tolerant |
| Mung | Pusa-0672 | Drought/rainfed suitability |

## Challenges in Development and Adoption:

Even with scientific progress, major problems are slowing down the widespread success of climate-ready crops.

The challenge of multi-gene traits under varied conditions. The inherent difficulty in breeding for resilience is exacerbated by the fact that field-grown crops must contend with simultaneous or sequential multiple abiotic and biotic stressors (e.g., drought, heat, and pathogen pressure). Engineering integrated tolerance to these complex, combined stress profiles remain a highly challenging objective.

Social and financial obstacles to implementation: Adoption of new resilient crops by small-scale producers is constrained by socio-economic barriers—not scientific limits, as Acevedo et al. (2020) highlighted. The success of a new variety depends on practical factors like seed availability, affordability, and market demand, as well as alignment with local preferences for taste and cooking quality, making successful integration a complex financial and cultural challenge.

Deficiencies in governance and physical structure: The successful scaling of resilient crops is hindered by deficiencies in governance and physical structure. Low overall agricultural productivity and the over-reliance on subsidized groundwater actually undermine sustainable efforts. Critically, a lack of policy recognition and initiative from local governance (Panchayat) levels can severely impede the ground-level implementation and widespread adoption of these advanced varieties.

## Future prospects

The future direction demands a holistic, evidence-based, and producer-oriented strategy.

Systemic technological convergence: The future relies on better science that translates quickly into better tools for farmers. We are going to keep using advanced methods (like studying all a plant's genes and proteins—what we call "Omics") to perfectly understand how it deals with drought and flood. The truly critical advance is getting this scientific insight to the farmer instantly. They may make fast decisions about important operations like planting or irrigation based on the immediate climate hazards thanks to mobile programs like "Meghdoot" and "Mausam," which send highly precise, real-time weather predictions straight to their phones.

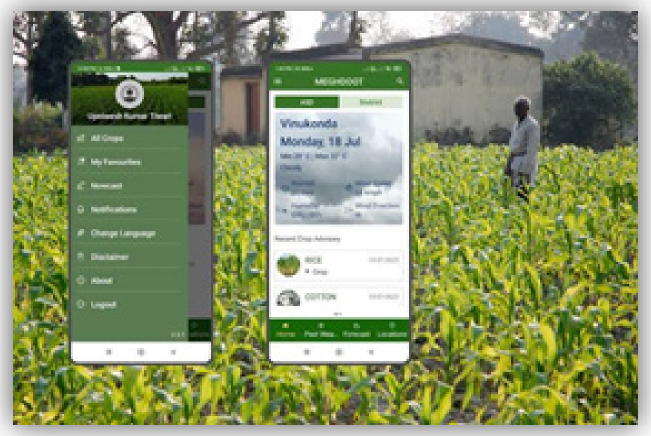


Fig 04

Resilient farming practices: True resilience demands shifts in overall farm management and responsible resource stewardship. Key goals include encouraging crop diversification—planting a greater variety of crops to improve ecosystem adaptation—and widely expanding micro-irrigation methods, such as drip systems, to significantly conserve water. Furthermore, promoting practices like organic farming contributes to the wider climate effort by reducing the agricultural sector's overall contribution to greenhouse gas emissions.

Progress in cultivar improvement: We have to keep getting better at breeding. This means constantly using our advanced tools like CRISPR and Speed Breeding. These strategies are necessary to create crops that are not only strong enough to survive drought and flood but are also much smarter about how they use every drop of water and every bit of nutrient available to them.

## Conclusion

Facing a climate where water extremes—sudden drought followed by severe flood—are the new normal, our success in farming now depends entirely on how fast we can get these scientifically engineered, tough crops into the ground.

The objective is straightforward: developing cultivars capable of enduring both extremes is essential. The good news is that science is ready. We use powerful tools like Genomic Selection to predict which plants will survive drought, and the precise CRISPR system to build in flood survival tricks, like the famous Sub1 gene in rice. This gives us the necessary genetic capability. However, the final success of these tough, new varieties depends entirely on getting them out of the research lab and into the fields. This means we have to fix the real-world money and political problems (socio-economic and policy barriers) that hold farmers back. The only way forward is through a complete, integrated effort: connecting sustained public funding, providing farmers with instant, accurate advice through mobile apps (like 'Mausam'), and setting up fair, accessible seed markets. This holistic approach is our best—and perhaps only—plan to stabilize food production and keep the world fed despite the chaotic challenges of a volatile climate.

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