

Engineering Climate-Resilient Crops by Integrating Genomics, Omics, and Genome Editing

Vikram Singh gaur¹,
Ashutosh Singh², Sharwan
Kumar Shukla², Rakesh
Kumar², Rajesh Kumar
Singh², Chander Mohan³

¹College of Agriculture,
Balaghat, JNKVV, Jabalpur,
M.P., India

²RLB Central Agricultural
University, Jhansi, U.P., India

³ICAR–IIMR, Regional Maize
Station, Begusarai, Bihar, India



Open Access

*Corresponding Author

Chander Mohan*

Article History

Received: 03.06.2026

Revised: 08.06.2026

Accepted: 13.06.2026

This article is published under the
terms of the [Creative Commons
Attribution License 4.0](https://creativecommons.org/licenses/by/4.0/).

INTRODUCTION

Rising temperature, prolonged water deficit in the soil, soil salinity, erratic weather are the major cause of climate change. Most of the abiotic factors continuously threaten sustainable crop production across the world and influenced global food security. Human induces activities like destroy of natural habitat and biodiversity, industrialization and loss of natural resources are the major cause of global warming, drought, erratic rainfall (Toromade, et al., 2024). Several attempts have been made by researchers through conventional breeding approaches to improve crop cultivars sustain under diverse environmental conditions. Due to lack of the integration of genomic and biotechnological approaches in conventional breeding, past agricultural advancement limited by long developmental cycle and reduced precision in targeting genes associated with complex traits. Recent advancement of biotechnological tools and techniques like genetic engineering, genomic assisted breeding, omic technologies and genome editing and accelerates crop improvement strategy (Thingujam, et al., 2025). Thus, integration of these technologies in crop improvement is highly transformative and efficient for speed-up plant breeding strategy to develop climate resilient crop cultivars. Targeting sophisticated network of plant cellular defense mechanism to understand about molecular level stress-responsive systems inside the plants may provide robust platform for the development of tolerance in crop cultivars with ability to survive in diverse range of climatic conditions.

Most of the environmental stresses including heat and oxidative damages and disrupt protein folding significantly leading to loss of function due to aggregation. During oxidative stress, plant relies on molecular chaperons (heat-sock proteins) and their synthetic pathway that can assist stabilization and refolding of proteins damaged by oxidative stress. Further, these pathways not only preserve cellular mechanism but rapidly recover plants from heat and salinity stress.

In context to development of climate-resilient crop cultivars, genetic manipulation of chaperon synthetic pathway plays pivotal role (Reynolds, et al., 2012). Moreover, integration of omic technologies with genome editing and genetic engineering rapidly enhance crop resilience under accelerated climate change. Unfavourable environmental conditions including extreme temperature, prolonged water deficit condition, soil salinity and erratic rain pattern creating unpredictable pressure on global agricultural systems and food security may rapidly tackle employing integrated crop improvement strategy. Therefore, targeted manipulation of the cellular stress response systems of the plants including chaperon pathways, manipulation and other physiological and biochemical mechanism play

crucial role to develop resilience mechanism in plants under diverse environmental conditions.

Thus, simultaneous but stepwise integration holistic approaches such as genetic manipulation, genome editing and multi-omic analysis precise reprogramming of plant stress physiology and facilitate robust platform for the development of climate-resilience crop cultivars able to sustain productivity under extreme environmental conditions for proposing sustainable food security platform for the global population. In this article, authors has explore the various platforms provide strength to the engineering climate-resilient crops for global food security and sustainable agricultural development (Tester and Langridge, 2010).

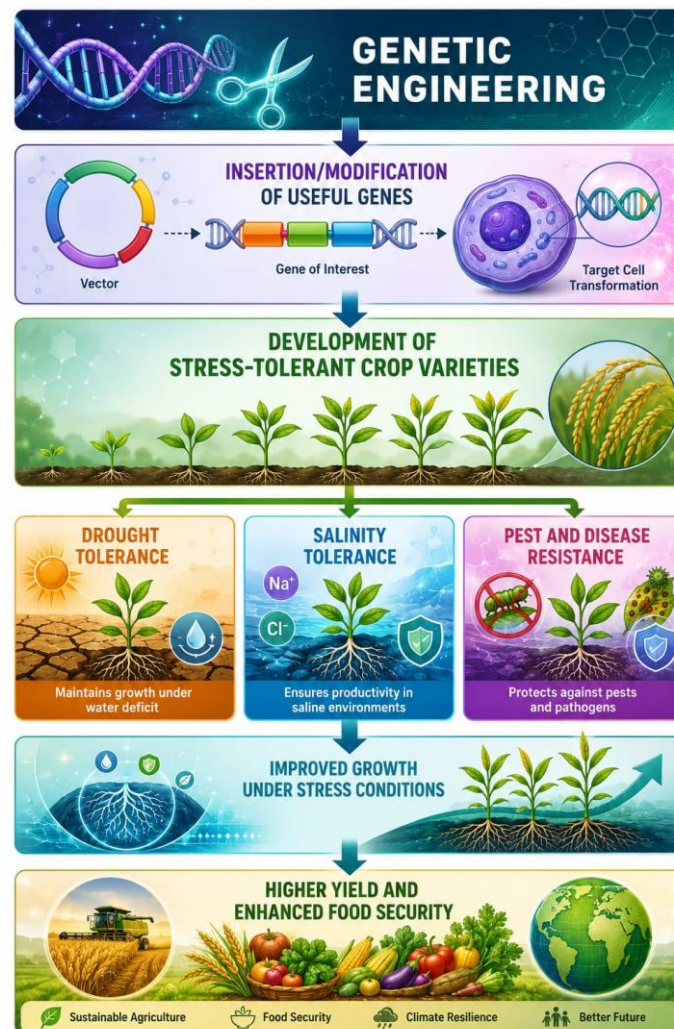


Figure-1: Plant Genetic Engineering to Enhance Climate-resilience in Crop

1. Role of Genetic Engineering in Crop Stress Adaptation

Continuous increase in the global temperature, prolonged drought, soil salinity and erratic rainfall patterns creating unpredictable pressure on global food security by reducing agricultural production (Toromade, et al., 2024). Recent advancement in plant genetic engineering transforms crop improvement strategy by enhancing crop resilience. Identification and strategic manipulation of cellular stress responsive system, particularly heat-shock protein associated pathways stabilize protein, prevent aggregation and maintain cellular homeostasis under adverse climatic conditions (Reynolds, et al., 2012). Engineering crops with modified chaperon pathways enable crops withstand extreme environmental stress may prove strength to the agricultural sustainability and global food security. By targeting heat-shock transcriptional factors like HsfA1 may activate the network associated with genes encoding the heat-shock protein and other protective cellular molecules. Rapid transcriptional change in genetically engineered plants accelerates protein folding, reduce cellular damage and improve resilience against abiotic factors like drought, heat and salinity. Employing such strategy, researchers can significantly prime plant in response to heat and drought stress and formulate strategy for the development of more climate-resilient crops.

2. Genomic-assisted Breeding to Enhance Crop-resilience

Integrating advance genomic-assisted breeding with bioinformatics and conventional breeding has been emerged as transformative approach of the development of climate-resilient crops. Such approaches enable the researchers to identify and select the genes associated with trait of interest like heat resistance, drought tolerance, salinity tolerance and improved nutrient efficiency (Lobell and Gourdj, 2012). Most of the genomic tools like marker-assisted selection, genomic selection, QTL mapping and genome-wide association studies accelerate conventional breeding strategies by allowing researchers to predict plant performance at juvenile stage. These technologies are easy, fast, cheap to detect with low cost and fortunately associated with conventional breeding while increasing precision of trait improvement (Desmae, et al., 2019). Most of the molecular markers and integrative genomic-assisted breeding also enable genomic exploitation of germplasm, landraces, and wild crop relatives may broadening the narrow genetic base of cultivated crops. In context to development of climate-resilient crops, several genes, QTLs and linked DNA markers have been identified and developed to enhance the crops withstand adverse environmental conditions (Aravind, et al., 2022). Introgression of these genes and QTLs into crop cultivars may provide strength to development of climate-resilient varieties for global food security and agricultural sustainability

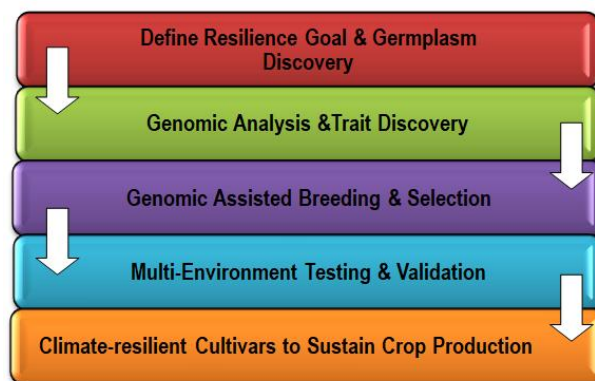


Figure-2: Genomic-assisted Breeding Approaches to Develop Climate-ready Crops

3. Genome Editing in Crop-Stress Interaction and resilience

Genome editing is another précised tools targeted the modification of plant genomes by addition/deletion/alteration of nucleotide sequences at various location of chromosome. Genome editing tools like TALENs, ZFNs and CRISPR/Cas9 transform plant genome by targeted modification (Carrijo, et al., 2021). Apart of these tools, CRISPR-based genome editing approaches can be used to fine-tune gene expression that ensuring stress tolerance mechanism without compromising plant growth and development. Genome editing tools allows researchers to regulate negatively expressed pathways associated with various

kinds of stresses (Zhang,, et al., 2014). In plants, transcriptional factors like WRKY acts as suppressors of the defense signaling have been targeted for modification employing genome editing tools. Modifying or altering these genes can accelerate protective pathways leading to increased tolerance against heat, drought and salinity. Collectively, genome editing approaches enable the multiple-trait improvement by regulating metabolic pathways. In many crops several transcriptional factors and stress-responsive pathways have been targeted for enhancement of stress tolerance, disease resistance as well as nutritional and yield attributing trait improvement.

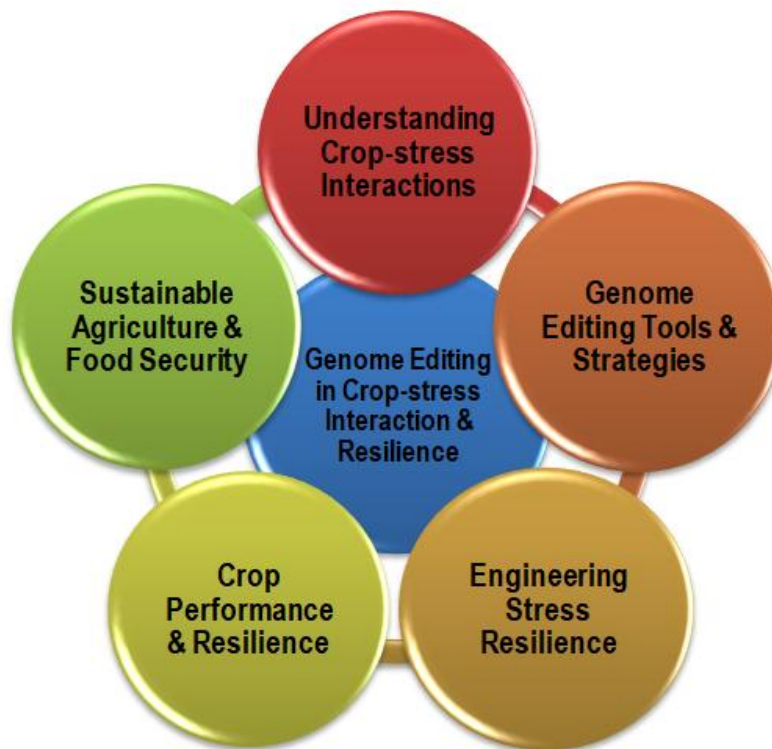


Figure-3: Genome Editing Tools Enhancing Stress-resilience

4. Omic Approaches in Plant Stress Resilience:

Multiplex omic approaches include genomics, transcriptomics, proteomics, metabolomics, ionomics, and phenomics. Together, these approaches enable to analyze complex traits and cellular signaling pathways. Integration of multi-omic approaches in crop improvement

rapidly transforming crop resilience in the era of climate change. Most of the environmental stresses such as heat and oxidative damage disrupt protein structure, leading to misfolding and aggregation of proteins affects cellular function. Heat-sock protein assisted pathways improvement significantly advances the tolerance m3chanism in plants under adverse

climatic conditions (Thingujam, et al., 2025). Osmotic adjustment, stomatal closure can also be improving employing omic approaches. Furthermore, transcriptomic studies enable strategic identification of stress-induced gene expression revealing the key regulation like heat shock transcriptional factors and downstream gene expression. Beyond the protein and gene regulation, some biochemical adjustment into accelerates increased accumulation of osmoprotectants like sugars, proline and antioxidants may also stabilize cellular structure and provide strength to mitigating oxidative damage. Thus, hormonal signaling networks play central role in

mitigating effect of heat and drought. Accumulation of other phytochemicals like abscisic acid and salicylic acid also play central role in mitigating the effect of stresses. Accumulation of abscisic acid in the plant regulates drought and salinity tolerance in the plants, whereas salicylic acid associated with pathogen resistance. Thus, integration of omic data with genomics enables crops improvement strategy to introgress traits linked with stress tolerance mechanism (Araus, et al., 2018). In future, such data-driven framework accelerates discovery of novel genes and traits in support to development of crops adapted to climatic challenges.

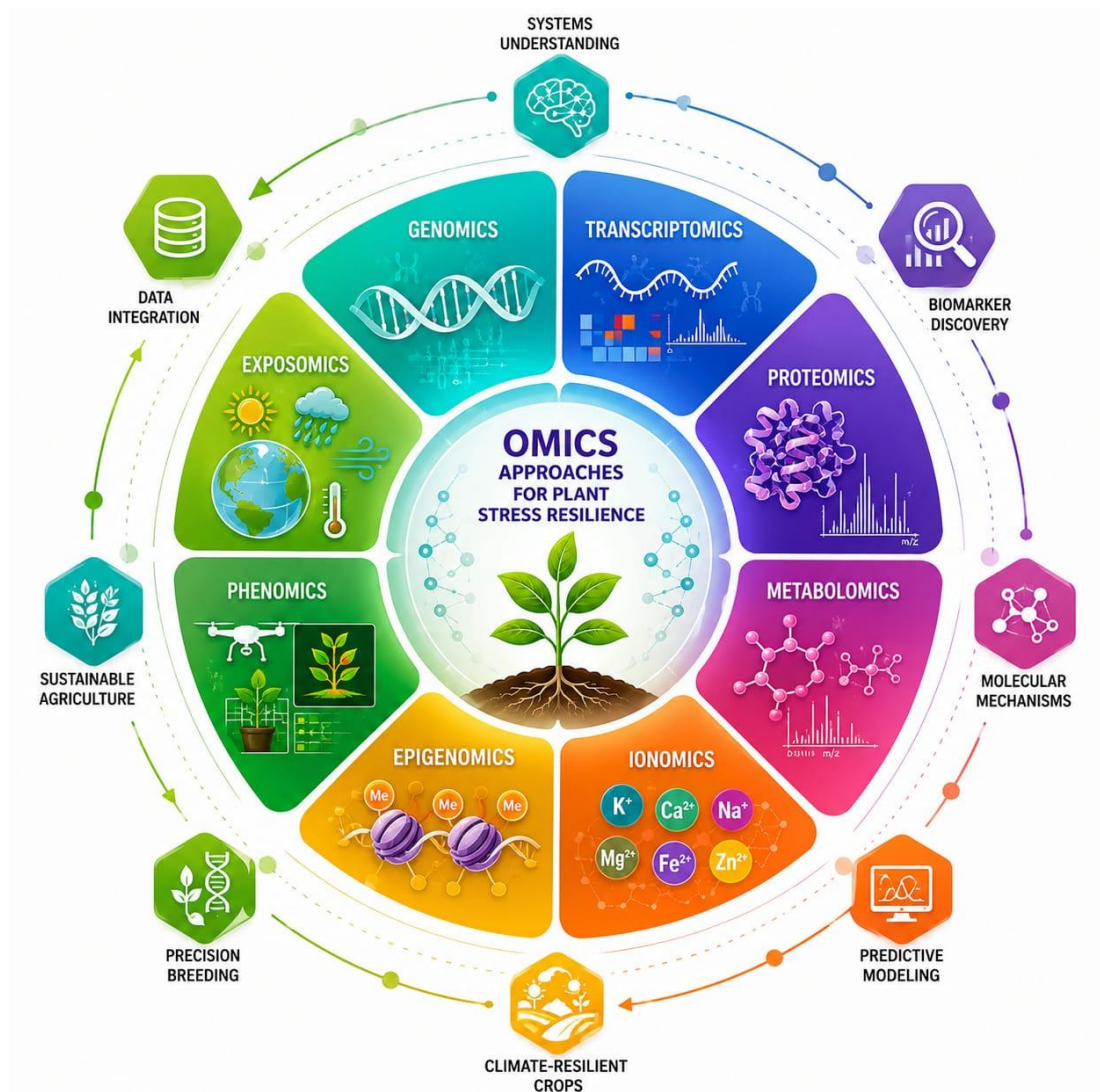


Figure-4: Multi-omic approaches to develop Climate-ready Crops

CONCLUSION AND FUTURE PERSPECTIVES

Integration of recent advancement in genetic manipulation of plants, multi-omic technologies, genome-wide association studies and genome editing tools offers robust network for enhancing resilience in crops under climate change. Using these tools and techniques, researchers are able to target most of physiological and biochemical mechanism including SHPs-mediated protein stabilization and stress-responsive pathways to reprogram research strategy. Precise genome editing or modification using CRISPR/Cas9 and manipulation of transcriptional factors like WRKY, HsfA1 have been successfully demonstrated to achieve durable resistance in plants against heat, drought and salinity stress. Further integration of multi-omic approaches enable more targeted and efficient crop improvement strategies. In future, multi-omic approaches, system biology and artificial intelligence will further enhance resilience for most of complicated traits of the plant.

REFERENCES

- Araus, J.L., Kefauver, S.C., Zaman-Allah, M., Olsen, M.S., Cairns, J.E. (2018). Translating High-Throughput Phenotyping into Genetic Gain. *Trends Plant Sci.* 23, 451–466.
- Aravind, B., Nayak, S.N., Choudhary, R.S., Gandhadmath, S.S., Prasad, P.V.V., Pandey, M.K., Bhat, R.S., Puppala, N., Latha, P., Sudhakar, P., Varshney, R.K. (2022). Integration of genomics approaches in abiotic stress tolerance in groundnut (*Arachis hypogaea* L.): an overview. *Springer Int. Pub.* pp. 149–197.
- Desmae, H., Janila, P., Okori, P., Pandey, M.K., Motagi, B.N., Monyo, E., Mponda, O., Okello, D., Sako, D., Echeckwu, C., Oteng-Frimpong, R., Miningou, A., Ojiewo, C., Varshney, R.K. (2019). Genetics, genomics and breeding of groundnut (*Arachis hypogaea* L.) *Plant Breed.*, 138, pp. 425–444.
- Carrijo, J., Illa-Berenguer, E., LaFayette, P., Torres, N., Aragao, F.J. L., Parrott, W., Vianna G.R. (2021). Two efficient CRISPR/Cas9 systems for gene editing in soybean. *Transgenic Res.*, 30, pp. 239–24.
- Lobell, D.B. and Gourdji, S.M. (2012). The influence of climate change on global crop productivity. *Plant Physiol.* 160, 1686–1697.
- Reynolds, M.P., Hellin, J., Govaerts, B., Kosina, P., Sonder, K., Hobbs, P., Braun, H. (2012). Global crop improvement networks to bridge technology gaps. *J. Exp. Bot.* 63, 1–12.
- Tester, M. and Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. *Science*, 327, 818–822.
- Thingujam, D., Gouli, S., Cooray, S.P., Chandran, K.B., Givens, S.B., Gandhimeyyan, R.V., Tan, Z., Wang, Y., Patam, K., Greer, S.A., Acharya, R., Moseley, D.O., Osman, N., Zhang, X., Brooker, M.E., Tagert, M.L., Schafer, M.J., Jeong, C., Hoffseth, K.F., Mukhtar, M.S. (2025). Climate-Resilient Crops: Integrating AI, Multi-Omics, and Advanced Phenotyping to Address Global Agricultural and Societal Challenges. *Plants*, 14(17), 2699.
- Toromade, A.S., Soyombo, D.A., Kupa, E., Ijomah, T.I. (2024). Reviewing the impact of climate change on global food security: Challenges and solutions. *Int. J. Appl. Res. Soc. Sci.*, 6, 1403–1416.
- Zhang, H., Zhang, J., Wei, P., Zhang, B., Gou, F., Feng, Z., Mao, Y., Yang, L., Zhang, H., Xu, N. (2014). The CRISPR/Cas9 System Produces Specific and Homozygous Targeted Gene Editing in Rice in One Generation. *Plant Biotechnol. J.* 12, 797–807.