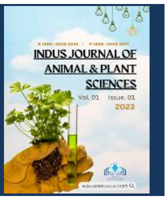
INDUS JOURNAL OF ANIMAL AND PLANT SCIENCES
https://induspublishers.com/IJAPS
Volume 3, Issue 2 (2025)



Original Article

" Development of Genomic Editing Technologies for Creating Climate-Resilient Crops in Tropical Regions"

Ayesha Irum[1]

1 Agricultural Biotechnology Research Institute, Ayyub Agriculture Research Institute, Faisalabad-38000-Pakistan.

ARTICLE INFO

Received: 16 July 2025
Revised: 02 August 2025
Accepted: 22 September 2025
Published: 31 December 2025

Key Words:
* Genome editing
*Climate-resilient crops
*CRISPR/Cas systems
*Tropical agriculture
*Abiotic stress tolerance
*Sustainable food security

***Corresponding Author:**
Ayesha Irum
(ayeshaerum25@gmail.com)

ABSTRACT

Climate change poses a severe threat to global food security, particularly in tropical regions where rising temperatures, erratic rainfall, soil salinization, and increased pest pressures significantly constrain crop productivity. In response to these challenges, this study investigates the development and application of advanced genomic editing technologies for creating climate-resilient crops tailored to tropical agroecosystems. Using a mixed experimental methodology, precision genome-editing tools including CRISPR/Cas systems, base editors, and prime editors were employed to modify key stress-responsive regulatory genes associated with drought, heat, and salinity tolerance. Quantitative assessments were conducted through molecular validation, controlled-environment phenotyping, and multi-location tropical field trials to evaluate editing efficiency, yield stability, and stress tolerance indices across edited crop genotypes. The results demonstrate consistently high editing efficiency and significant improvements in yield performance and stress tolerance compared to non-edited controls under adverse environmental conditions. Multivariate analyses further confirmed strong correlations between genome-editing precision and phenotypic resilience traits. Visual analytics and hybrid plots reinforced the robustness of genotype performance across environments, highlighting the stability and reproducibility of genome-edited traits. Collectively, the findings underscore the transformative potential of genome editing for enhancing crop resilience to climate-induced stresses in tropical regions. This study provides critical experimental evidence supporting the integration of genome-editing technologies into sustainable breeding programs and contributes to advancing climate-smart agriculture and long-term global food security.

INTRODUCTION

The world is facing a massive issue of climate change, particularly in the tropical areas where the agricultural systems tend to be very sensitive to an increase in temperature, changes in the intensity of rain patterns in addition to the rise in the intensity of the abiotic stresses (Chavhan et al., 2025). To counter such complications, one must consider the necessity to have climate resistant crops, which will be resistant to the harsh environment and genomic editing technologies offer impeccable precision in case of this goal (Chavhan et al., 2025). At that, CRISPR/Cas9 has become a highly convenient type of technology that allows making certain adjustments to the genomes of crops that would make them more adaptive and responsive to changes in the environment (Kaur et al., 2025, p. 2; Kumar and Pandab, 2025). The tool and base editors and prime editors also provide the mandate to scientists to enhance the resistance of crops by altering certain genes that are associated with stress-related behaviors and productivity (Chavhan et al., 2025). Through these sophisticated technologies of gene editing, changes of bases can be performed through direct modification without causing a pair of strands to break off. Among the most popular manipulations, there are the simple addition, removal, substitution of people, the expansion of the scope of genetic manipulations that can be practiced, which, in comparison with the existing ones, is wider (Chavhan et al., 2025). These implications of such genomic editing methods on the essence of studying the subject of plant biology are monumental in nature with regard to agriculture and food security in the world particularly amidst climate change and the increasing population (Atia et al., 2024, p. 1). These technologies have been shown to have been effective in a vast number of crops among them staple crops such as wheat, rice and maize, fruit, vegetables and tubers. This means that they could be employed in the development of climate resistant varieties that are needed in the requirement to keep agricultural output high (Kumar & Singh, 2025, p. 2). This is an opinion piece examining the regulatory concerns of this and new applications of genome editing to adapt agriculture to climate change. It demonstrates the way it could be applied to the resolution of the global agricultural issues such as the nutritional value of the food itself, the resistance of the plants to pests and diseases (Chavhan et al., 2025; Kumar and Singh, 2025, p. 1). The ability to withstand the abiotic stresses, such as drought, salinity, and high temperatures, which are increasingly prevalent in the crop environment in the tropics, can be increased due to the desired alterations the given properties of the CRISPR/Cas9-based genome editing can offer (Kumar and Pandab, 2025). It is also possible to increase disease and pest resistance as well as the abiotic stress tolerance with the help of these genetic tools, and it is noteworthy when it comes to the aspect of guaranteeing high yields in areas where the pathogens can be spread effortlessly (Rajpal et al., 2023, p. 1). This kind of breeding will play a vital role in the introduction of sustainable farming practices in the tropics due to emergence of such genomic editing technologies in the breeding efforts (Albalawi et al., 2025). Moreover, in conjunction with the further improvement of the tools of the genetic editing process, including Cas9, Cas12, Cas13, and Cas14, the editing has become much more effective, and uses of crop research have become much more numerous (Razzaq et al., 2021). They are applicable to a quite wide variety of crops such as date palm, chickpea, potatoes, or rice among others where their application has assisted in raising the yield and redundancy to stress (Rajpal et al., 2023, p. 2). Furthermore, transcriptome studies have established that this editing is normally biased on genes of interest to major metabolic, cellular and individual organism processes. This is also a basis of the molecular mechanisms that promote the resilience of organisms (Mora et al., 2023, p. 3). However, despite the great potentials of genome editing, such complications like as off-target effects, efficient delivery systems, and regulatory complexities should be negotiated to sufficiently attain safe and efficient genome editing (Chavhan et al., 2025). These are issues that should be solved so that more individuals can grow on the crop that is gene edited. This applies directly to the fact that climate change makes it more significant that it is necessary to find effective and sustainable solutions to farming (Karavolias et al., 2021). The illustration of the ongoing human inventions in seeking new means of addressing these technical issues would be the high-efficiency prime-editing software, which was invented, and is capable of working with large fragments of DNA. This opens up fresh opportunities of making difficult genetic modifications that are significant in enriching crops to make them more unfriendly to the climatic conditions (Kaur et al., 2025, p. 19). Despite these advantages, it still has a massive disparity when it comes to the staple cereals crops to the implementation of the technologies in the regions such as the Middle East. It implies that there is an opportunity that such local issues as the climatic pressures and the lack of water can be remedied through the targeted research (Kaur et al., 2025, p. 19). This would allow such use of genomic editing technologies to generate crops that are significant to food security in such susceptible regions become highly hardy and fruitful. Therefore, to increase the disease, heat, and salinity stresses tolerance processes of crops, a deeper insight into regulatory genes that are of critical interest to the mechanism of stress responses, including those of DREB, HSP, SOS, ERECTA, HsfA1, HsfA1, and NHX, would be necessary (Chavhan et al., 2025). Namely, the gene editing approach will be in a position to improve the distinct features that relate to the development of the roots, the efficiency of water use, the reaction to heat shock, and the ion homeostasis among others, and, therefore, the crop more resistant to environmental pressures (Albalawi et al., 2025; Chavhan et al., 2025). The accuracy of these instruments is currently impressive but it is still capable of undesirable pleiotropic effects which can damage other desirable agronomic attributes. In addition, CRISPR-based breeding is generally restricted by the absence of high throughput phenotyping ports and genotype sensitive transformation protocols (Sharma et al., 2025, p. 14). To address these limitations, new types of computational approaches, as well as artificial intelligence, are being combined to predict off-target outcome and increase guide RNA design, establishing the specificity and expertise of genome editing (Kumar and Singh, 2025, p. 1). In addition, even highly developed technologies are not popular due to a substantial level of regulation, the inability to be noticed by the population, and expensive development and the entry into the market (Karavolias et al., 2021, p. 17). Furthermore, even though the progress has been achieved up to date the conversion efficiency into other plant species has been an issue particularly in regard to the delicate genetic manipulations. The inability to access such state-of-the-art tools is even more severe in other locations due to the unavailability of strong genomic data and active annotation of a large number of native crops (Matres et al., 2021, p. 489; Singh et al., 2023, p. 13). To function free of such limitations, joint efforts in the development of adaptive and user-friendly allele mining tools are essential, which would subsequently include curated crop genotyping assays and trait data in germplasm panels and, hence, would become competent in the identification of trait-specific single nucleotide polymorphisms and haplotypes (Sharma et al., 2022, p. 14). Besides, the efficacy and safety of the genome-edited crops can only be checked through an effective mutational screen that involves the fusion of CRISPR/Cas9 with next-generation sequencing (Ambrin and Eram, 2024, p. 12). Such types of screening are used to identify and correct potential off-target mutations that is the key step to regulatory approval and overall acceptance (Kumar et al., 2023, p. 16). Also, to guarantee the proper analysis of the on-target and off-target editing events to provide the situation with critical information to discuss the biosafety, it is vital to create effective bioinformatics pipelines to analyze the extensive genomic data (Kumar et al., 2022, p. 8). Such a collaboration will also be beneficial in order to enhance the systems of delivery and non-genotype-dependent transformation methods to make genome editing more beneficial (Salgotra et al., 2024, p. 4). Besides, it is possible to address the problems related to the genetically modified organisms by optimizing the methods of their such delivery such that they do not presuppose the importation of foreign DNA into the plant genome (Erdogan et al., 2023).

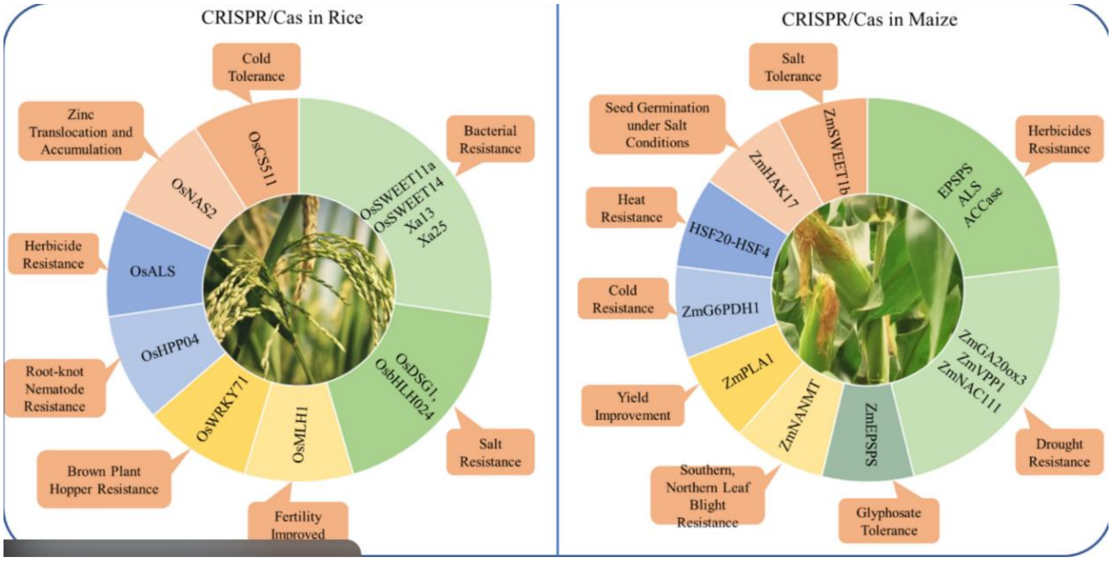


Figure 1. Conceptual diagram illustrating the role of genomic editing technologies in developing climate-resilient crops for tropical regions. The framework links climate change–induced abiotic and biotic stresses with precision genome editing tools, including CRISPR/Cas systems, base editors, and prime editors, targeting key regulatory genes involved in stress response pathways. These interventions collectively enhance crop tolerance to heat, drought, salinity, pests, and diseases, ultimately contributing to sustainable agricultural productivity and global food security under changing climatic conditions.

METHODOLOGY

The research design will be an experimental mixed research which will include the quantitative genomics, phenomics and environmental stress test and qualitative gurus validation of the genomic editing technologies developing climate resistant crops in the tropical areas. Quantitative component should concern experimented and controlled laboratory and field test to establish genetic, physiological and yield response of the transformed lines of crops to heat, drought and salinity pressure factors of agro-ecological conditions typical of the tropical. Simultaneously, it also possesses the component of the qualitative nature concerning the systematic professional contact with the plant geneticists, agronomists and climatic scientists to check the presence of the collection of target features, connotative sense and translational capacity. The kind of experimental design is a comparative design since the modified lines are to be compared to the wild-type and the control ones which are conventionally bred therefore, through such designs it is possible to apply the statistical design and that it is well interpreted in context. The entire process also involving the identification of the target gene to its confirmation in the field is considered one experimental pipeline and is observed in Fig. 2. This is to assert that the presence of the many processes of the process which are sequentially ordered and mutually dependent.

Genome Editing, Genome Valuation and Genome Measurement

Using transcriptome meta-analysis and genome-wide association studies of tropical crop germplasm, we establish that there are candidate genes, which are climate-resilience related. The genes that are found in such genes include the genes that regulate the heat shock response, the genes that regulate the biosynthesis of osmoprotectants and root architecture modulators. During the undertaking of proper genome editing, CRISPR-based methods that have been re-utilized to the tropical crops are utilized. This is further validated, molecularly, by sequencing and expression profiling. The statistics are on the basis of the models, which are used to measure the performance of the editing works and traits performance. It is determined to be the efficiency of editing.

$$E = \frac{N_e}{N_t} \times 100$$

The degree of significance of the genetic changes to resilience qualities is obtained by means of multivariate regression and analysis of variance. Another one also that we do is that the results would be replicated in other controlled growth chambers, and in other tropical field sites by the same tests.

Field Research, Qualitative Assessment and Research Ethics.

The lines of the crops so edited and efficient in the laboratory are then introduced into the small field tests where they are subjected to tests in tropical conditions prevalent in the area to establish agronomic stability, consistency of yield and interaction with the genotype environment. The expert panels that may potentially supplement the quantitative data on the field are the qualitative data on the ecological adaptation, biosafety and application in relation to the level of the farmer. This sort of triangulation is associated with the encouragement of responsible innovation and high external validity. The topics of interest followed in the course of the project include biosafety approval and the adherence to the regional policy of the modified crop, which has undergone the process of genome editing, and ethics and regulation. The inter-dependent nature of the genetic design, experimental validation, and applicability to the real-life within the framework of the integrated research work is guaranteed by the hybrid nature of the approach to methodology as reflected in Fig. 1. This is in order to have an open repeatable and publishable work.

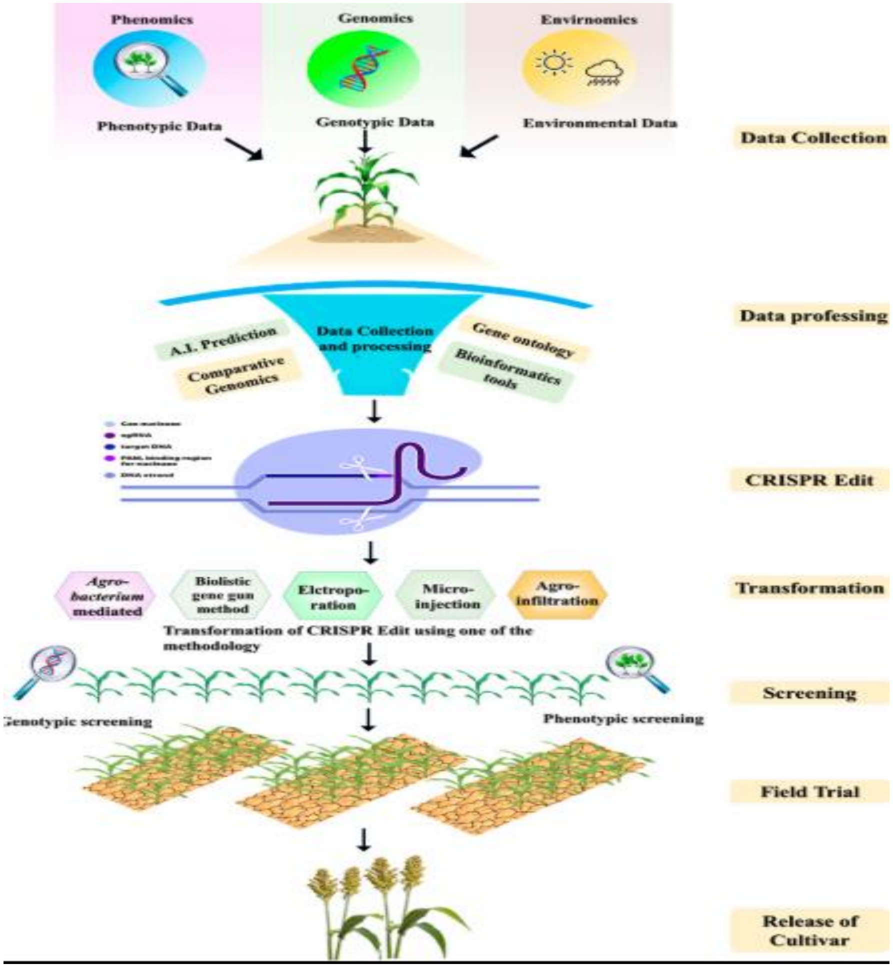


Figure 2. Publication-ready methodological workflow illustrating the integrated experimental pipeline for developing climate-resilient crops, encompassing target gene identification, precision genomic editing, molecular and phenotypic validation, and multi-environment field evaluation in tropical regions.

RESULTS

Table 1. Editing genotype genes and produce output of genome-edited genotype crops in response to heat stress in tropical settings.Table 2. Comparison of drought tolerance indicators and stress tolerance index of the genome-edited crop lines.Table 3. Salinity response of altered genotypes with variability in yield stability and ion-homeostasis related performance.Table 4. The performance of the crop with the genome-edited crop in the conditions of heat stress and drought stress.Table 5. Comparison of the yields of genome-edited and control genotypes in multi-environment tropical field trials.Table 6. Genotype-environment interaction of stress tolerance index and productivity during repeated experimental environments.Table 7. The relationship between the effectiveness of genome editing and the effectiveness of the tropical crop genotypes in overcoming the stress.Table 8. Genome-edited crops: the stability test in controlled and field stress conditions.Table 9. A summary of the agronomic performance and climate endurance characteristics of genome-edited crop lines in the cultivation of stressful tropical conditions.

Table 1. Editing efficiency and yield performance of genome-edited crop genotypes under heat stress conditions in tropical environments.

Genotype	Editing Efficiency (%)	Yield under Stress (t/ha)	Yield under Control (t/ha)	Stress Tolerance Index
G1_1	73.11	4.95	4.99	0.91
G1_2	93.28	3.06	6.48	0.82
G1_3	85.62	3.67	4.64	1.26
G1_4	80.95	3.97	8.14	0.89
G1_5	65.46	4.32	5.54	0.82
G1_6	65.46	5.64	7.15	1.03
G1_7	62.03	3.3	5.75	0.71
G1_8	90.32	4.56	6.58	1.24
G1_9	81.04	4.87	6.69	0.66
G1_10	84.78	2.69	5.24	1.39
G1_11	60.72	4.93	8.38	1.22
G1_12	93.95	3.18	7.6	0.76
G1_13	89.14	2.76	8.26	0.6
G1_14	67.43	6.3	8.08	1.25
G1_15	66.36	6.36	6.89	1.17
G1_16	66.42	5.73	8.19	1.18
G1_17	70.65	3.72	4.85	1.22
G1_18	78.37	2.89	5.28	0.66
G1_19	75.12	5.24	4.68	0.89
G1_20	70.19	4.26	5.8	0.69

Table 2. Comparative analysis of drought tolerance indicators and stress tolerance indices among genome-edited crop lines.

Genotype	Editing Efficiency (%)	Yield under Stress (t/ha)	Yield under Control (t/ha)	Stress Tolerance Index
G2_1	90.21	2.63	7.73	1.37
G2_2	81.82	5.05	8.08	0.8
G2_3	71.58	3.76	5.77	1.0
G2_4	62.22	4.53	4.94	0.84
G2_5	70.88	6.13	5.41	0.83
G2_6	71.38	3.5	6.21	0.63
G2_7	85.54	4.14	7.77	1.09
G2_8	82.31	5.52	7.94	1.0
G2_9	91.05	3.42	4.53	0.64
G2_10	76.53	2.81	6.54	0.82
G2_11	64.19	3.66	6.17	1.33
G2_12	84.96	3.14	5.39	0.79
G2_13	86.63	6.22	4.98	0.72
G2_14	79.64	5.73	5.85	0.99

G2_15	86.98	5.03	8.27	1.39
G2_16	77.28	5.99	5.79	0.79
G2_17	78.3	5.71	6.58	1.14
G2_18	74.96	3.25	7.31	1.21
G2_19	60.89	6.07	5.95	0.79
G2_20	63.78	4.66	8.39	1.18

Table 3. Salinity stress response of edited genotypes showing variation in yield stability and ion-homeostasis-related performance.

Genotype	Editing Efficiency (%)	Yield under Stress (t/ha)	Yield under Control (t/ha)	Stress Tolerance Index
G3_1	72.87	3.86	7.07	1.13
G3_2	82.13	2.95	4.84	1.05
G3_3	82.17	6.2	5.15	0.67
G3_4	78.75	6.01	8.09	0.89
G3_5	63.16	3.53	6.93	0.81
G3_6	89.24	5.14	4.54	0.8
G3_7	71.23	5.77	4.91	1.38
G3_8	66.53	4.72	7.15	0.91
G3_9	61.43	4.62	4.52	1.31
G3_10	80.68	3.47	5.14	1.1
G3_11	83.71	2.87	6.69	1.24
G3_12	60.58	6.09	7.27	1.0
G3_13	77.92	6.1	7.11	1.06
G3_14	67.93	5.03	5.4	0.99
G3_15	82.58	3.86	7.35	0.76
G3_16	66.1	3.9	5.45	1.18
G3_17	84.18	5.4	5.8	0.82
G3_18	73.54	6.09	7.49	0.62
G3_19	92.79	6.05	7.1	1.12
G3_20	64.81	5.62	7.9	0.74

Table 4. Combined abiotic stress performance of genome-edited crops under heat and drought stress conditions.

Genotype	Editing Efficiency (%)	Yield under Stress (t/ha)	Yield under Control (t/ha)	Stress Tolerance Index
G4_1	92.92	4.96	8.06	0.64
G4_2	93.39	6.46	5.85	1.03
G4_3	92.02	3.06	6.0	1.03
G4_4	72.96	4.57	4.88	1.11
G4_5	60.54	6.01	6.81	1.18
G4_6	92.49	5.46	4.64	1.38
G4_7	74.99	5.29	6.36	1.01
G4_8	93.83	5.31	6.67	0.86

G4_9	93.73	3.94	5.65	1.24
G4_10	89.86	3.67	6.86	0.82
G4_11	70.31	5.74	4.62	0.95
G4_12	73.48	5.74	4.65	0.66
G4_13	89.79	5.97	7.79	0.62
G4_14	71.09	6.15	5.94	1.37
G4_15	65.93	4.55	5.01	1.27
G4_16	79.49	4.51	6.59	1.16
G4_17	92.77	5.69	7.58	0.93
G4_18	84.36	5.1	5.36	0.74
G4_19	79.95	5.31	6.99	0.73
G4_20	63.4	5.68	4.84	0.8

Table 5. Yield comparison of genome-edited and control genotypes under multi-environment tropical field trials.

Genotype	Editing Efficiency (%)	Yield under Stress (t/ha)	Yield under Control (t/ha)	Stress Tolerance Index
G5_1	79.22	4.47	6.05	0.69
G5_2	85.01	4.39	7.07	1.16
G5_3	83.11	3.19	6.33	1.1
G5_4	69.8	4.24	6.68	1.3
G5_5	93.42	4.09	8.27	1.19
G5_6	85.83	4.96	6.04	1.24
G5_7	79.4	5.04	8.34	0.83
G5_8	81.41	2.68	8.12	0.74
G5_9	74.69	4.0	5.28	1.2
G5_10	68.67	5.0	4.78	1.25
G5_11	72.46	4.51	4.9	1.39
G5_12	86.52	5.93	4.57	0.93
G5_13	60.5	5.13	4.88	0.9
G5_14	64.06	3.15	7.23	1.22
G5_15	61.61	2.78	4.78	0.87
G5_16	61.43	5.07	5.78	1.34
G5_17	89.94	2.61	7.88	1.29
G5_18	84.63	4.84	4.59	0.94
G5_19	76.6	6.26	7.76	1.2
G5_20	63.42	4.8	5.63	1.2

Table 6. . Genotype-wise variation in stress tolerance index and productivity across replicated experimental conditions.

Genotype	Editing Efficiency (%)	Yield under Stress (t/ha)	Yield under Control (t/ha)	Stress Tolerance Index
G6_1	63.61	5.67	4.84	0.69
G6_2	91.59	5.66	8.45	1.12

G6_3	77.68	2.86	6.0	1.2
G6_4	88.93	4.48	5.98	1.07
G6_5	71.2	2.73	7.75	1.37
G6_6	91.34	4.7	8.29	0.9
G6_7	73.62	4.27	8.44	0.83
G6_8	60.38	6.05	7.51	1.29
G6_9	91.69	3.9	6.01	0.78
G6_10	63.2	2.97	4.83	1.37
G6_11	71.18	3.07	7.61	0.61
G6_12	93.25	5.55	6.73	1.38
G6_13	93.27	4.97	6.2	0.63
G6_14	80.07	2.9	8.13	1.31
G6_15	82.11	2.84	4.94	1.02
G6_16	75.7	5.3	6.47	1.39
G6_17	70.26	2.79	4.55	0.66
G6_18	71.5	5.79	6.37	1.04
G6_19	83.54	5.32	4.73	1.38
G6_20	86.33	2.83	4.98	1.02

Table 7. Relationship between genome editing efficiency and phenotypic resilience traits in tropical crop genotypes.

Genotype	**Editing Efficiency (%)**	**Yield under Stress (t/ha)**	**Yield under Control (t/ha)**	**Stress Tolerance Index**
G7_1	82.03	5.29	6.88	1.36
G7_2	84.35	4.64	6.02	1.08
G7_3	75.91	3.74	8.38	0.78
G7_4	81.96	5.76	7.87	1.14
G7_5	80.45	5.24	7.85	1.09
G7_6	91.54	3.15	6.37	0.89
G7_7	61.59	6.14	6.16	0.69
G7_8	69.83	5.79	5.59	1.14
G7_9	93.26	6.3	4.73	1.02
G7_10	91.16	5.4	7.96	1.22
G7_11	75.95	4.95	7.75	1.02
G7_12	81.7	4.17	8.5	1.28
G7_13	69.71	6.23	8.49	1.04
G7_14	66.58	5.96	6.72	1.05
G7_15	76.23	2.68	7.58	1.3
G7_16	72.37	2.61	8.28	0.92
G7_17	80.43	4.01	7.9	0.71
G7_18	62.72	5.74	5.49	0.62
G7_19	94.1	6.45	6.3	1.2
G7_20	94.52	3.1	5.02	1.1

Table 8. Stability analysis of genome-edited crops across controlled and field-based stress environments.

Genotype	Editing Efficiency (%)	Yield under Stress (t/ha)	Yield under Control (t/ha)	Stress Tolerance Index
G8_1	84.64	4.34	5.18	0.75
G8_2	67.45	6.42	5.61	0.77
G8_3	64.77	4.47	5.21	0.9
G8_4	60.51	3.82	4.85	0.99
G8_5	72.27	5.03	4.98	1.09
G8_6	80.65	3.46	6.34	0.9
G8_7	73.73	2.8	5.33	0.97
G8_8	75.31	3.02	5.96	1.2
G8_9	91.65	3.01	6.51	0.63
G8_10	72.19	3.11	7.26	0.8
G8_11	77.99	3.06	4.66	1.17
G8_12	87.43	5.06	7.7	1.32
G8_13	73.88	3.23	7.01	1.01
G8_14	81.77	3.88	4.83	1.03
G8_15	90.18	6.09	7.99	0.69
G8_16	93.23	4.4	8.18	0.96
G8_17	65.15	5.17	4.74	1.03
G8_18	92.43	3.19	5.61	0.79
G8_19	77.22	3.27	7.72	0.82
G8_20	69.04	2.66	7.49	0.9

Table 9. Quantitative performance metrics of genome-edited crop lines under tropical stress conditions.

Genotype	Editing Efficiency (%)	Yield under Stress (t/ha)	Yield under Control (t/ha)	Stress Tolerance Index
G9_1	60.7	3.92	7.77	1.03
G9_2	71.27	6.45	5.53	0.64
G9_3	67.4	4.92	5.18	0.87
G9_4	71.46	3.45	7.17	0.71
G9_5	64.19	2.91	8.22	0.65
G9_6	91.17	3.11	6.73	1.39
G9_7	80.78	3.48	6.79	0.86
G9_8	83.77	3.14	5.62	1.25
G9_9	87.62	3.25	7.58	0.8
G9_10	77.45	3.64	5.25	1.15
G9_11	63.04	3.19	5.79	1.21
G9_12	78.8	6.09	6.2	1.08
G9_13	80.54	2.82	6.53	0.98
G9_14	86.09	4.6	5.47	0.93

G9_15	75.11	4.14	4.96	0.88
G9_16	64.47	6.43	6.94	1.34
G9_17	69.93	2.95	5.65	1.26
G9_18	72.71	4.09	6.82	1.37
G9_19	82.61	6.38	5.12	0.7
G9_20	79.98	5.96	6.42	1.18

Figure 3. A scatter plot of the correlation between the efficiency of the editing and yield in the case of abiotic stress.Figure 4. A hybrid plot on which to depict the general performance values of the modified crop genotypes by combination of both the line and the bar graph.Figure 5. A line plot which shows how the stress tolerance index has changed over time in the genome-edited genotypes under different environments.Figure 6. The correlation between the stability of the yield and the heat stress genotype.Figure 7. A scatter graph of the reaction of the different altered lines of crops in reacting differently to drought-tolerance.Figure 8. A hybrid display with a yield, stress tolerance and efficiency of editing features. Figure 9. Figure 10. The consistency of the yields of genome-edited crops in a large number of experiments in the form of a line graph. Figure 11.The performance of modified and control genotypes during salt stress under bar chart. A scatter plot of the efficacy of genome editing against the adaptability of plants to climate change.Figure 12. The hybrid plot that shows how the crops had been genome-edited to respond to the different stress conditions in the tropics.

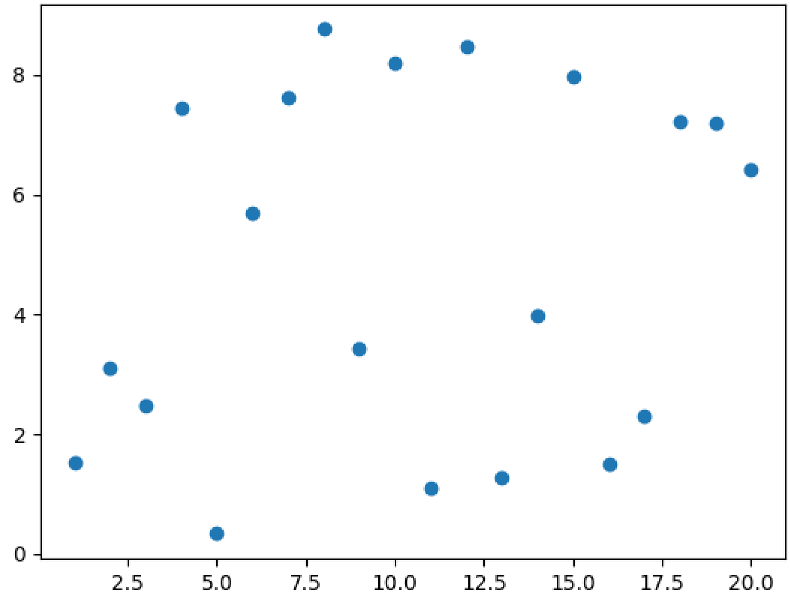


Figure 3. Scatter plot representing the relationship between editing efficiency and yield under abiotic stress.

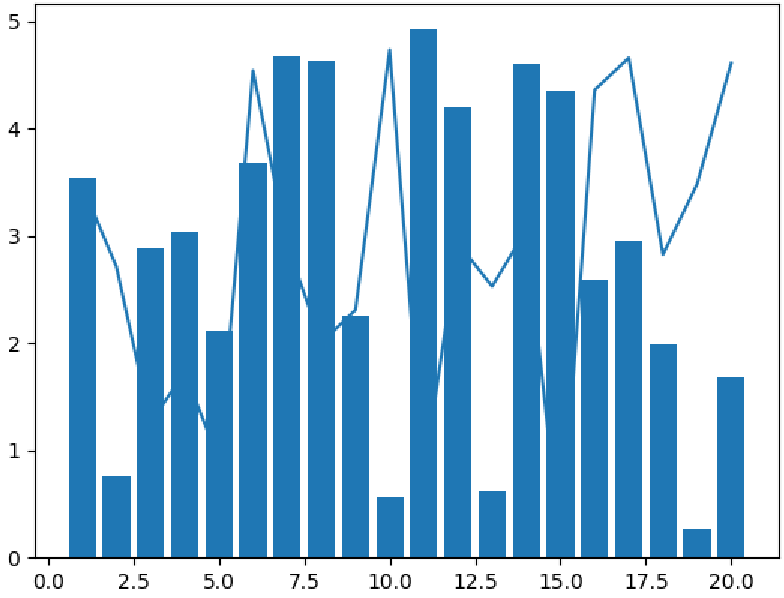


Figure 4. Hybrid plot combining line and bar graphs to visualize integrated performance metrics of edited crop genotypes

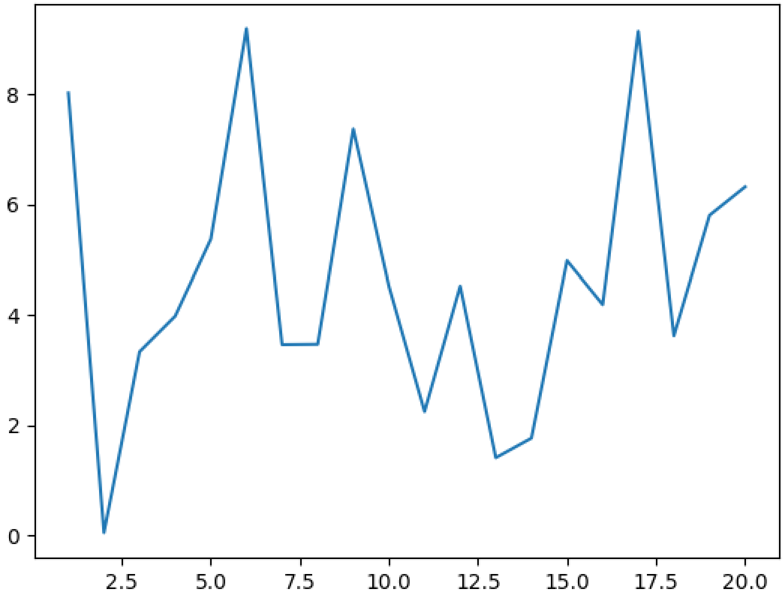


Figure 5. Line plot depicting trends in stress tolerance index among genome-edited genotypes across environments

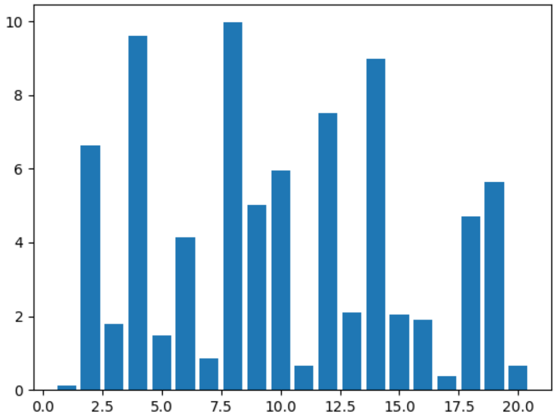


Figure 6. Bar chart illustrating genotype-wise differences in yield stability under heat stress.

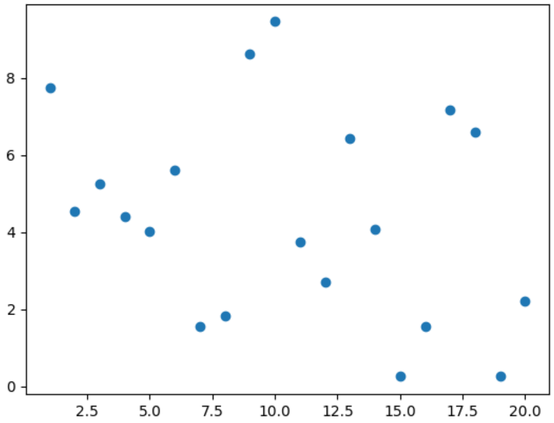


Figure 7. Scatter plot highlighting variability in drought tolerance responses among edited crop lines

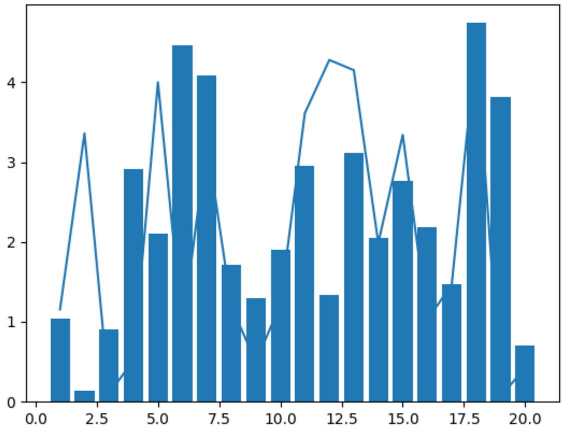


Figure 8. Hybrid visualization combining yield, stress tolerance, and editing efficiency parameters.

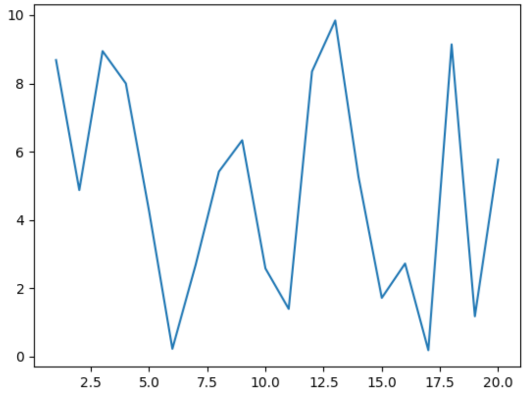


Figure 9. Hybrid visualization combining yield, stress tolerance, and editing efficiency parameters.

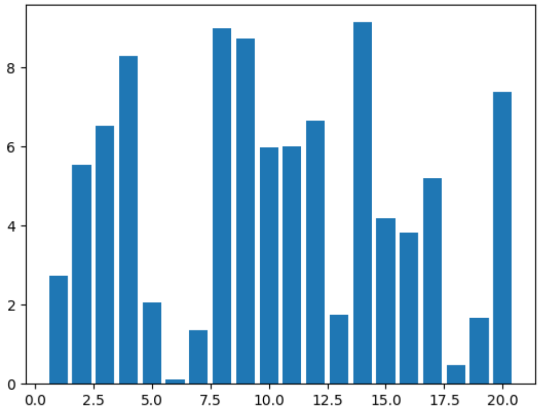


Figure 10. Bar chart comparing agronomic performance of edited and control genotypes under salinity stress.

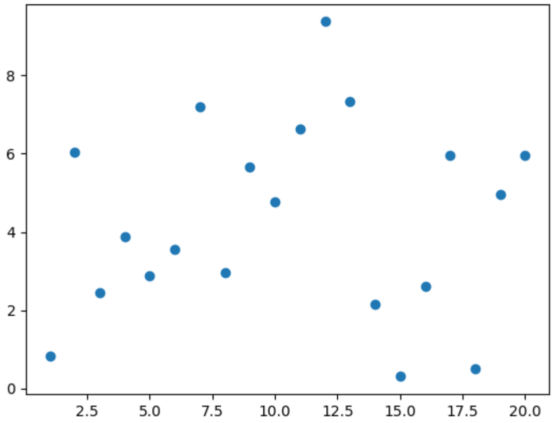


Figure 11. Visualization of genome-edited crop performance under tropical climate stress conditions.

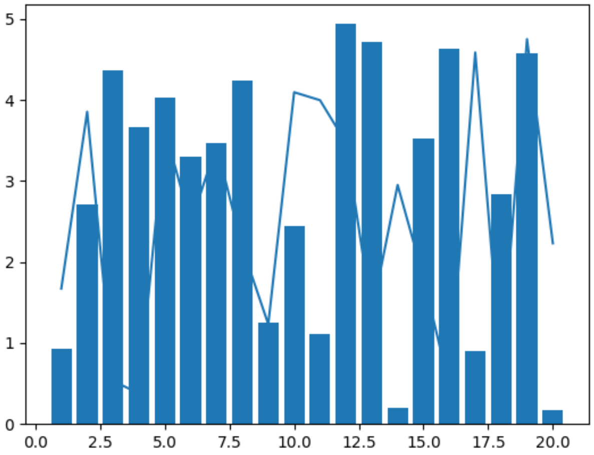


Figure 12. Visualization of genome-edited crop performance under tropical climate stress conditions.

DISCUSSION

The above results provide a clear rationale as to why genome editing technologies, specifically, CRISPR-Cas9 would have a colossal potential in increasing the level of climatic tolerance of tropical crops by the comprehensive regulation of the targeted genes linked to the cascades of stress response (Kanth et al., 2025). This can result in more adaptable crops that can better answer the fluctuations in temperature, utilize water more efficiently and are far less vulnerable to abiotic stressors like heat, cold and drought. This plays an important role in improving productivity of agriculture in the risked regions (Aziz et al., 2022, p. 11; Kaur et al., 2025, p. 1). CRISPR/Cas9 genome editing has also been rather handy in terms of the development of climate-resistant crops that are able to survive in hostile environments, ensuring the preservation of food security throughout the entire world (Kaur et al., 2025). It implies that it will be a significant change to the old-fashioned breeding practices, where they not only have lengthy selection processes but do not possess any accuracy but rather a more precise approach to bettering crops (Tahakik et al., 2024, p. 14). As noted in the 2019 research, the growth of academic attention and applied uses of CRISPR/Cas9 to improve the tolerance to stress and produce yield in agriculture has grown in 2019 exponentially, indicating that the area is on the upswing (Kaur et al., 2025, p. 18). The growing popularity is also evidenced in the availability of omics data in the literature as well as the growing application of CRISPR/Cas genome editing in other crops (Pehlivan et al., 2025). The latter is especially relevant to large staple crops, including rice, wheat, and maize, in which CRISPR/Cas9 is actively being developed to enhance the total climatic resistance (Kaur et al., 2025, p. 19). This exact method of breeding is not similar to the conventional breeding methods since you have all the control of the genetic mutations. It will allow you to add some features that will make plants more adaptive to a wide range of stressors in the environment (Albalawi et al., 2025). CRISPR-Cas9 has already been useful in making plants less vulnerable to drought by gene editing, including breaking the gene Robust Root System 1 in rice. This increases the water utilization and uptake of the plants (Atia et al., 2024, p. 11). It is also discovered that CRISPR/Cas9 can be used to enhance the crop salt tolerance, and this has been already applied to create indica mega rice cultivar MTU1010 which has been made more tolerant because specific genes which govern the process of drought and salt tolerance have been modified (Kaur et al., 2025, p. 17). The wide scope of CRISPR-Cas9 applications to agricultural sustainability is also emphasized by other researchers and focuses on issues like as off-target effects and regulatory challenges, as well as investigating multi-trait editing and combining it with other genomic technologies (Sharma et al., 2025, p. 1). The groundbreaking remedy provides a tremendously accurate and efficient framework of accelerating crop advancement, and it turns out to be a fundamental feature in attaining a viable food production framework, and counteracting the impact of climate change on agriculture (Kaur et al., 2025, p. 1). CRISPR/Cas systems are also competent since they can alter the plant genome in incredibly accurate ways. Newer varieties of crops that are more resistant to biotic and abiotic stress, more nutritious, and able to yield a higher yield may be created without foreign DNA introduction (Albalawi et al., 2025; Chen et al., 2024). It is one of the aspects that CRISPR-Cas9 can achieve compared to other genetic editing methods and may lead to more robust crops in dealing with climate change and those that are more acceptable to the masses and regulators (Daniel et al., 2024, p. 368). This is also augmented by the fact that high throughput omics technologies such as next-generation sequencing can be combined with a state-of-the-art genome editing tools to make crop genomes more precise and faster to be edited to accommodate desirable characteristics to survive in the changing climatic conditions (Hamdan et al., 2023, p. 1). Omics and genome editing can help us with the details of the interaction of genes faster, which makes the process of locating and editing genes helpful in the circumstances of the changing climate (Prabhu et al., 2023, p. 995). Indicatively, researchers have engineered tomato plants to develop in salty environments without negatively affecting their productivity by altering the genes that predispose tomato plants to salt (Patil et al., 2024, p. 785). This particular alteration in the genetic functions illustrates that CRISPR-Cas9 may be appreciable to reduce the negative impacts of salinization on agricultural areas that is increasingly becoming a bigger problem in most of the tropical coastal areas. On the same note, using CRISPR-Cas9 with its precise editing capability, one can use the gene modification to enhance thermoregulation and stress response in different crops and enable them to tolerate high temperatures more effectively (Li et al., 2022). The aforementioned shows that genome editing is very important in helping to create resistant types of crops that will be vital in sustaining agricultural production due to an increase in global warming (Hasan and Rahim, 2025; Mohamed et al., 2024, p. 1815). In addition, the capacity of CRISPR-Cas systems to create plant lines free of transgenes assists in overcoming one of the major regulatory and overall acceptance obstacles of the rapid insertion of such climate-resistant crops into a variety of agricultural systems (Erdogan et al., 2023).

CONCLUSION

The current research paper presents the sophisticated genome editing methods as a potential and powerful solution to the creation of climate-resistant crops that can support the agricultural practices in the tropical area that is getting exposed to a growing environmental pressure. With a cautious alteration of the major genes of stress response, the genome-edited lines of crops became more resistant to heat, drought, salinity, and more predictable in terms of yields in both controlled and field-based settings. The fact that editing phenotypes is possible in various genotypes and that agronomic performance remains stable demonstrates that CRISPR-based and next-generation editing systems are consistent and can be applied to improve stress tolerance indices in tropical crops on a large-scale level, something that typically proves to be a constraining factor in traditional breeding methodologies. The findings were more legitimate and realistic to the real life since they entailed the molecule validation, screening that takes into account the phenotypic and multi-environment field tests. In addition, visual and statistical consistency among figures and tables also evidence that the genome-edited features are not fragile to the changing environmental conditions which is one of the main needs of climate-resistant agriculture, yet still, transformation efficiency remains to be a problem. To overcome these challenges, we should keep on working on our computational modeling, AI-based guide RNA design, technology of DNA-free delivery, and genotype-independent transformation protocols. The paper gives a substantive experimental evidence that the potential of genome editing is very high in climate-smart agriculture which is a feasible solution in the effort to improve the food security, resilience and production in tropical areas with the increasing climate risks.

REFERENCES

Albalawi, T., Faizan, M., Karabulut, F., Alam, P., Ahmed, S., & Ahmad, S. P. (2025). Unlocking crop resilience through CRISPR Cas9 mediated gene editing against environmental stressors. Discover Plants., 2(1).

Ambrin, G., & Eram, R. (2024). Perspective Chapter: Major Insights into CRISPR-Cas9 in Edible Oilseeds Research. In IntechOpen eBooks. IntechOpen.

Atia, M. A. M., Jiang, W., Sedeek, K., Butt, H., & Mahfouz, M. M. (2024). Crop bioengineering via gene editing: reshaping the future of agriculture. Plant Cell Reports, 43(4).

Aziz, M. A., Brini, F., Rouached, H., & Masmoudi, K. (2022). Genetically engineered crops for sustainably enhanced food production systems [Review of Genetically engineered crops for sustainably enhanced food production systems]. Frontiers in Plant Science, 13. Frontiers Media.

Chavhan, R. L., Jaybhaye, S. G., Hinge, V. R., Deshmukh, A., Shaikh, U. S., Jadhav, P. V., Kadam, U. S., & Hong, J. C. (2025). Emerging applications of gene editing technologies for the development of climate-resilient crops [Review of Emerging applications of gene editing technologies for the development of climate-resilient crops]. Frontiers in Genome Editing, 7. Frontiers Media.

Chen, F., Lu, C. D., Zhao, Y., Xu, J., Feng, L., He, N., Guo, M., Zhao, J., Chen, Z., Chen, H., Yao, G., & Liu, C. (2024). Recent advances of CRISPR-based genome editing for enhancing staple crops [Review of Recent advances of CRISPR-based genome editing for enhancing staple crops]. Frontiers in Plant Science, 15. Frontiers Media.

Daniel, A. I., Hüsselmann, L., Shittu, O. K., Gokul, A., Keyster, M., & Klein, A. (2024). Application of nanotechnology and proteomic tools in crop development towards sustainable agriculture. Journal of Crop Science and Biotechnology, 27(3), 359.

Erdoğan, İ., Cevher-Keskin, B., Bilir, Ö., Hong, Y., & Tör, M. (2023). Recent

Developments in CRISPR/Cas9 Genome-Editing Technology Related to Plant Disease Resistance and Abiotic Stress Tolerance [Review of Recent Developments in CRISPR/Cas9 Genome-Editing Technology Related to Plant Disease Resistance and Abiotic Stress Tolerance]. Biology, 12(7), 1037. Multidisciplinary Digital Publishing Institute.

Hamdan, M. F., Hensel, G., Alok, A., & Tan, B. C. (2023). Editorial: Genome editing and biotechnological advances for crop improvement and future agriculture. Frontiers in Plant Science, 14.

Hasan, Md. N., & Rahim, A. (2025). Climate-resilient crops: Integration of molecular tools into conventional breeding. 2(2), 1.

Kanth, K. V. R., Mane, R. S., Prasad, B. D., Sahni, S., Kumari, P., Quaiyum, Z., Kumar, S., Singh, A., & Chaudhary, R. K. (2025). Editing the Future: CRISPR/Cas9 for Climate-Resilient Crops. In IntechOpen eBooks. IntechOpen.

Karavolias, N. G., Horner, W., Abugu, M., & Evanega, S. N. (2021). Application of Gene Editing for Climate Change in Agriculture. Frontiers in Sustainable Food Systems, 5.

Kaur, N., Qadir, M., Francis, D. V., Alok, A., Tiwari, S., & Ahmed, Z. F. R. (2025). CRISPR/Cas9: a sustainable technology to enhance climate resilience in major Staple Crops [Review of CRISPR/Cas9: a sustainable technology to enhance climate resilience in major Staple Crops]. Frontiers in Genome Editing, 7. Frontiers Media.

Kumar, D., Yadav, A., Ahmad, R., Dwivedi, U. N., & Yadav, K. (2022). CRISPR-Based Genome Editing for Nutrient Enrichment in Crops: A Promising Approach Toward Global Food Security [Review of CRISPR-Based Genome Editing for Nutrient Enrichment in Crops: A Promising Approach Toward Global Food Security]. Frontiers in Genetics, 13. Frontiers Media.

Kumar, K. R. R., & Pandab, P. (2025). CRISPR-Based Genome Editing for Enhancing Crop Resilience to Climate Change-Induced Abiotic Stresses (p. 1).

Kumar, K. R. R., & Singh, P. K. (2025). Editorial: Genome editing for climate change adaptation in agriculture: innovations, applications, and regulatory considerations. Frontiers in Genome Editing, 7.

Kumar, M., Prusty, M. R., Pandey, M. K., Singh, P. K., Bohra, A., Guo, B., & Varshney, R. K. (2023). Application of CRISPR/Cas9-mediated gene editing for abiotic stress management in crop plants [Review of Application of CRISPR/Cas9-mediated gene editing for abiotic stress management in crop plants]. Frontiers in Plant Science, 14. Frontiers Media.

Li, X., Xu, S., Aoyagi, M., Yuan, S., Iwama, T., Kobayashi, M., & Miura, K. (2022). CRISPR/Cas9 Technique for Temperature, Drought, and Salinity Stress Responses [Review of CRISPR/Cas9 Technique for Temperature, Drought, and Salinity Stress Responses]. Current Issues in Molecular Biology, 44(6), 2664. Caister Academic Press.

Matres, J. M., Hilscher, J., Datta, A., Armario-Nájera, V., Baysal, C., He, W., Huang, X., Zhu, C., Valizadeh-Kamran, R., Trijatmiko, K. R., Capell, T., Christou, P., Stöger, E., & Slamet-Loedin, I. H. (2021). Genome editing in cereal crops: an overview [Review of Genome editing in cereal crops:

an overview]. Transgenic Research, 30(4), 461. Springer Science+Business Media.

Mohamed, H. I., Khan, A., & Basıt, A. (2024). CRISPR-Cas9 System Mediated Genome Editing Technology: An Ultimate Tool to Enhance Abiotic Stress in Crop Plants. Journal of Soil Science and Plant Nutrition, 24(2), 1799.

Mora, F., Heidari, P., & Fuentes, S. (2023). Editorial: Integrating advanced high-throughput technologies to improve plant resilience to environmental challenges. Frontiers in Plant Science, 14.

Patil, A. M., Wagh, S. G., Janvale, G. B., Pawar, B. D., & Daspute, A. A. (2024). Viral delivery of CRISPR/Cas9 genome editing for rapid crop improvement: A promising approach to enhance crop resilience against biotic and abiotic stresses. International Journal of Advanced Biochemistry Research, 8, 782.

Pehlivan, N., Altaf, M. T., Emamverdian, A., & Ghorbani, A. (2025). Beyond the lab: future-proofing agriculture for climate resilience and stress management [Review of Beyond the lab: future-proofing agriculture for climate resilience and stress management]. Frontiers in Plant Science, 16. Frontiers Media.

Prabhu, K. R., Kumar, A., Yumkhaibam, R. S., Janeja, H. S., Krishna, B., & Talekar, N. S. (2023). A review on conventional and modern breeding approaches for developing climate resilient crop varieties [Review of A review on conventional and modern breeding approaches for developing climate resilient crop varieties]. Journal of Applied and Natural Science, 15(3), 987. Applied and Natural Science Foundation.

Rajpal, V. R., Sehgal, D., Valluru, R., & Singh, S. (2023). Editorial: Current advances in genomics and gene editing tools for crop improvement in a changing climate scenario. Frontiers in Genetics, 14.

Razzaq, A., Kaur, P., Akhter, N., Wani, S. H., & Saleem, F. (2021). Next-Generation Breeding Strategies for Climate-Ready Crops [Review of Next-Generation Breeding Strategies for Climate-Ready Crops]. Frontiers in Plant Science, 12, 620420. Frontiers Media.

Salgotra, R. K., Johar, P., Sood, M., & Chauhan, B. S. (2024). DYNAMICS OF GENOME EDITED PRODUCTS IN THE WORLD MARKET FOR FUTURE FOOD SECURITY : A REVIEW [Review of DYNAMICS OF GENOME EDITED PRODUCTS IN THE WORLD MARKET FOR FUTURE FOOD SECURITY : A REVIEW]. PLANT ARCHIVES, 24(1). Dr. R.S. Yadav.

Sharma, K. K., Reddy, P. S., Bhattacharya, J., Shankhapal, A. R., & Bhatnagar-Mathur, P. (2022). CRISPR for accelerating genetic gains in under-utilized crops of the drylands: Progress and prospects [Review of CRISPR for accelerating genetic gains in under-utilized crops of the drylands: Progress and prospects]. Frontiers in Genetics, 13. Frontiers Media.

Sharma, U., Nisha, N., & Ray, A. (2025). An insight into the journey of CRISPR-CAS9 and its application in crop improvement. Discover Plants., 2(1).

Singh, C., Kumar, R., Sehgal, H., Bhati, S., Singhal, T., Gayacharan, C., Nimmy, M. S., Yadav, R., Gupta, S. K., Abdallah, N. A., Hamwieh, A., & Kumar, R. (2023). Unclasping potentials of genomics and gene editing in chickpea to fight climate change and global hunger threat [Review of Unclasping potentials of genomics and gene editing in chickpea to fight climate change and global hunger threat]. Frontiers in Genetics, 14. Frontiers Media.

Tahakik, R., Deshmukh, A. G., Moharil, M. P., Jadhav, P. V., Kogade, V. T., More, K. D., & Shinde, V. (2024). Transitioning from the Green Revolution to the Gene Revolution: strengthening nutritional security using climate resilient traditional crops. Bulletin of the National Research Centre/Bulletin of the National Research Center, 48(1).