THE AGRI PUBLICATION
THE FUTURE OF AGRICULTURE
Grow With Every Page
e-Magazine for Agricultural Articles
Volume 01 | Issue 06 | November 2026
Available online at https://agripublication.com/
UDYAM REGISTERED NUMBER UDYAM-MP-06-0043239
©Agri Publication ISSN (Online): 3139-6127
Scan to Visit Our Website
Article ID: AP-V01-I06-12

# CRISPR/CAS-MEDIATED GENOME EDITING IN MAIZE: ADVANCES, APPLICATIONS AND PROSPECTS FOR STRESS TOLERANCE

Published Online: 02 Nov 2026

**MOULI PAUL[1]***

[1] Ph.D. Scholar, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University, Imphal, Manipur, India.

**Corresponding Author's Email:** moulipaul2827@gmail.com

## ABSTRACT

Climate change has intensified the frequency and severity of abiotic stresses, including drought, heat, salinity and waterlogging, which significantly affect maize productivity. Developing stress-tolerant maize varieties is therefore essential for ensuring sustainable crop production and food security. Conventional breeding has contributed substantially to maize improvement, but the complex genetic regulation of stress tolerance often limits the speed and precision of genetic improvement. CRISPR/Cas-mediated genome editing has emerged as a promising biotechnology that enables targeted modification of genes associated with important agronomic and stress-responsive traits. Recent advances in CRISPR/Cas9, base editing, prime editing and multiplex genome editing have expanded opportunities for improving drought tolerance, heat resilience, salinity tolerance and overall crop adaptability. The integration of genome editing with molecular breeding, genomics and advanced phenotyping can accelerate the development of improved maize varieties. This article discusses the major advances, applications, challenges and future prospects of CRISPR/Cas-mediated genome editing for developing stress-resilient maize.

**Keywords:** CRISPR/Cas Genome Editing, Stress-Resilient Maize, Abiotic Stress Tolerance

## INTRODUCTION

Maize (*Zea mays L.*) is one of the most important cereal crops globally, serving as a major source of food, livestock feed and industrial raw material. However, its productivity is increasingly threatened by climate change and environmental variability. Rising temperatures, irregular rainfall, prolonged drought and increasing soil salinity adversely affect maize growth, reproductive development and grain yield. Among these constraints, drought and heat stress are particularly damaging because they frequently occur together during critical growth stages. Drought stress

ISSN (Online): 3139-6127

during flowering affects silk emergence, pollen viability and fertilisation, resulting in poor kernel formation. Similarly, high temperatures disturb photosynthesis, accelerate crop maturity and reduce grain-filling duration. Salinity stress restricts water and nutrient absorption and causes ionic imbalance, negatively affecting plant development. These challenges highlight the need for maize varieties capable of maintaining stable productivity under adverse environmental conditions. Conventional breeding and molecular selection have played important roles in developing improved maize varieties. However, the development of tolerance to multiple abiotic stresses is difficult because these traits are controlled by complex genetic networks involving several genes and physiological mechanisms. In this context, CRISPR/Cas-mediated genome editing offers a new dimension to crop improvement by allowing precise modification of specific genetic regions associated with stress responses. It has the potential to complement conventional breeding and accelerate the development of climate-resilient maize.

## 1. UNDERSTANDING CRISPR/CAS-MEDIATED GENOME EDITING

CRISPR stands for Clustered Regularly Interspaced Short Palindromic Repeats, while Cas refers to CRISPR-associated proteins that function as molecular tools for editing DNA. The CRISPR/Cas9 system is one of the most widely used genome-editing technologies because of its simplicity, flexibility and ability to target specific DNA sequences. The technology primarily involves two important components: a guide RNA (gRNA), which identifies the target DNA sequence, and the Cas9 enzyme, which acts as molecular scissors to cut the DNA at the selected location. The plant's natural DNA repair mechanisms then repair the break, potentially resulting in targeted genetic changes. These changes can disable undesirable genes, modify gene activity or introduce specific genetic variations.

Unlike conventional genetic modification, which may involve introducing foreign genetic material, genome editing can generate targeted changes within the plant's existing genome. However, whether a particular edited plant contains foreign DNA depends on the editing and transformation method used. In maize, CRISPR/Cas technology has become an important tool for functional genomics and crop improvement. It allows researchers to investigate the functions of stress-responsive genes and explore their potential for developing improved varieties (Jiang et al., 2022).

## 2. ADVANCES IN CRISPR/CAS TECHNOLOGY FOR MAIZE IMPROVEMENT

The development of genome-editing technologies has progressed beyond conventional CRISPR/Cas9 systems. Several advanced approaches are now expanding the possibilities of precise genetic improvement in maize.

- **CRISPR/Cas9:** This system enables targeted disruption or modification of specific genes. It is useful for understanding gene functions and modifying genetic components associated with stress tolerance, yield and other agronomic characteristics.
- **Base editing:** Base editors allow the conversion of one DNA nucleotide into another without introducing conventional double-strand DNA breaks. This technology provides opportunities for making precise genetic changes in genes associated with stress responses and plant development.
- **Prime editing:** Prime editing is a relatively advanced genome-editing approach that can introduce specific DNA substitutions, insertions and deletions. It offers greater flexibility for making precise genetic modifications, although its efficiency and practical application in maize still require further optimisation.
- **Multiplex genome editing:** This approach enables the simultaneous targeting of multiple genes using several guide RNAs. It is particularly important for improving complex traits such as drought and heat tolerance, which involve several interacting genetic pathways.

These technological developments are gradually transforming genome editing from a tool for studying individual genes into a broader strategy for precision crop improvement.

ISSN (Online): 3139-6127

## 3. APPLICATIONS OF CRISPR/CAS IN IMPROVING ABIOTIC STRESS TOLERANCE

### 3.1 Drought Tolerance

Drought is one of the most important environmental constraints affecting maize productivity, particularly in rainfed agricultural systems. Water deficiency reduces photosynthesis, restricts nutrient uptake and affects reproductive development. Improving drought tolerance requires genetic modifications that support better water-use efficiency, root development and reproductive stability. One important example is the modification of the ARGOS8 gene through CRISPR/Cas9-mediated regulatory engineering. Shi et al. (2017) demonstrated that replacing the native ARGOS8 promoter with a maize GOS2 promoter increased ARGOS8 expression and improved grain yield under flowering-stage drought conditions. This study provided an important demonstration of the potential of genome editing for improving an economically important maize trait. Other potential targets include genes involved in stomatal regulation, root architecture, abscisic acid signalling and osmotic adjustment. Their modification may help maize plants maintain water balance and physiological activity during prolonged drought.

### 3.2 Heat Stress Tolerance

Increasing temperatures during flowering and grain filling can seriously affect maize production. Heat stress reduces pollen viability, disrupts fertilisation and accelerates leaf senescence, ultimately reducing grain development. CRISPR/Cas technology provides opportunities to investigate and modify genes involved in heat-shock protein regulation, antioxidant defence and cellular protection. Heat-shock proteins play an important role in maintaining protein stability and protecting cellular functions under elevated temperatures. Genome editing of regulatory genes involved in heat-stress signalling may improve the ability of maize plants to maintain normal physiological activities under high-temperature conditions. However, developing varieties with stable reproductive performance under field-level heat stress remains an important research priority.

### 3.3 Salinity Tolerance

Soil salinity is another major constraint affecting crop productivity, particularly in irrigated and coastal agricultural regions. Excessive salt accumulation interferes with water uptake and causes toxic accumulation of sodium ions in plant tissues. CRISPR/Cas-mediated modification of genes involved in ion transport and cellular regulation offers opportunities to improve salinity tolerance. Genes associated with sodium and potassium transport, osmotic adjustment and antioxidant defence are important targets for investigation. The maize ZmHKT1 gene, which is associated with sodium transport, has been investigated in relation to salt tolerance. Genome-editing studies involving this gene have demonstrated the potential of modifying ion-transport mechanisms to improve plant responses to saline conditions. Further evaluation is necessary to determine the effects on whole-plant performance and grain yield under field conditions.

### 3.4 Waterlogging and Other Environmental Stresses

Waterlogging reduces oxygen availability in the root zone and affects root respiration, nutrient absorption and plant growth. CRISPR/Cas technology may help improve waterlogging tolerance by targeting genes involved in oxygen sensing, anaerobic metabolism and root adaptation. Similarly, genes associated with antioxidant defence, membrane stability and stress-responsive signalling pathways may provide opportunities for improving tolerance to multiple environmental stresses. Developing maize varieties capable of withstanding combinations of drought, heat, salinity and waterlogging will be particularly important for future climate-resilient agriculture.

## 4. INTEGRATION OF GENOME EDITING WITH MOLECULAR BREEDING AND GENOMICS

The successful development of stress-resilient maize requires the integration of genome editing with conventional breeding and modern molecular technologies. Genomics and genome-wide association studies help identify genes

ISSN (Online): 3139-6127

and genetic regions associated with desirable stress-related characteristics. These candidate genes can subsequently be investigated through functional validation and targeted genome editing. Molecular markers can be used to identify favourable genetic backgrounds, while genomic selection helps predict the breeding potential of different maize genotypes. Genome editing can then introduce targeted modifications in selected genetic regions without unnecessarily disturbing other desirable characteristics. Advanced phenotyping technologies, including drone-based imaging, remote sensing and thermal cameras, can provide valuable information about plant responses under different stress conditions. Artificial intelligence and machine learning can further support the analysis of genomic and phenotypic information, helping researchers identify promising genetic combinations. This integrated approach can improve breeding efficiency and reduce the time required to develop improved maize varieties with stable yield and better environmental adaptability.

## 5. CHALLENGES AND LIMITATIONS

Despite its considerable potential, CRISPR/Cas-mediated genome editing faces several technical and practical challenges. One major limitation is the complex genetic nature of abiotic stress tolerance. Since drought, heat and salinity responses involve multiple genes and physiological pathways, modification of a single gene may not provide sufficient tolerance under diverse environmental conditions. Another important challenge is the efficiency of genetic transformation and plant regeneration. Maize genotypes differ in their response to tissue culture and transformation procedures, making it difficult to apply genome editing uniformly across different genetic backgrounds. Unintended modifications, commonly referred to as off-target effects, must also be carefully evaluated. Furthermore, a genetic modification that improves stress tolerance may sometimes negatively influence plant growth, development or grain yield. Therefore, comprehensive molecular characterisation and multi-location field testing are essential. Regulatory frameworks, biosafety assessment, intellectual property considerations and public acceptance also influence the wider application of genome-edited crops. Addressing these issues through transparent research and appropriate evaluation will be important for the successful adoption of genome-editing technologies.

## 6. FUTURE PROSPECTS

The future of CRISPR/Cas-mediated maize improvement lies in developing more precise, efficient and reliable genome-editing strategies. Advanced technologies such as base editing, prime editing and multiplex genome editing offer opportunities to modify several important genes and regulatory elements simultaneously. Greater emphasis should be placed on identifying genetic resources from traditional maize landraces, wild relatives and diverse germplasm collections. These resources can provide valuable information about naturally occurring stress-tolerance mechanisms and help identify suitable candidate genes for genome editing. The integration of genome editing with speed breeding, genomic selection, artificial intelligence and high-throughput phenotyping may further accelerate the development of improved maize varieties. Future research should prioritise multiple-stress tolerance, stable grain yield, improved water-use efficiency and adaptability to different agro-climatic regions. Importantly, genome-edited varieties must undergo rigorous field evaluation to establish their agronomic performance, environmental safety and suitability for farmers. Strong collaboration among plant breeders, geneticists, biotechnologists and agricultural institutions will be essential for translating laboratory innovations into practical agricultural benefits.

## CONCLUSION

CRISPR/Cas-mediated genome editing represents a promising advancement in modern maize breeding, offering opportunities for precise genetic improvement and enhanced tolerance to abiotic stresses. Its applications in modifying genes associated with drought, heat and salinity responses demonstrate the potential of this technology to address important agricultural challenges. The integration of CRISPR/Cas with genomics, molecular breeding and advanced phenotyping can further improve the efficiency and accuracy of maize improvement programmes. Although technical limitations, field validation and regulatory considerations remain important challenges, continued research

ISSN (Online): 3139-6127

and technological advancement will strengthen the role of genome editing in crop improvement. Ultimately, the effective application of CRISPR/Cas technology can contribute to the development of high-yielding, stress-resilient maize varieties and support sustainable agricultural production under changing climatic conditions.

## REFERENCES

1. Shi, J., Gao, H., Wang, H., Lafitte, H. R., Archibald, R. L., Yang, M., Hakimi, S. M., Mo, H., and Habben, J. E. (2017). ARGOS8 variants generated by CRISPR-Cas9 improve maize grain yield under field drought stress conditions. *Plant Biotechnology Journal*, 15(2), 207–216.
2. Jiang, Y., Sun, K., and An, X. (2022). CRISPR/Cas system: Applications and prospects for maize improvement. *ACS Agricultural Science & Technology*, 2(2), 174–183.
3. Namata, M. J., Xu, J., Habyarimana, E., Palakolanu, S. R., Wang, L., and Li, J. (2025). Genome editing in maize and sorghum: A comprehensive review of CRISPR/Cas9 and emerging technologies. *The Plant Genome*, 18(2), e70038.
4. Mohamed, H. I., Khan, A., and Basit, 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, 1799–1822.