Volume 4, Issue 2
February I 2026

Agri Roots
e- Magazine

www.agrirootsmagazine.in

ISSN: 2583-9071

Role of GM and Genome-Edited Crops in Enhancing Stress Tolerance and Nutrient Use Efficiency

ARTICLE ID: 0335

Alka[1], Dr. Arunima Paliwal[2], Dr. Gargi Goswami[3], Shivam Singh[4], Diksha Negi[5]

[1]Ph.D. (Agronomy), Veer Chandra Singh Garhwali University of Horticulture and Forestry, College of Hill Agriculture, Chirbatiya, Uttarakhand, India

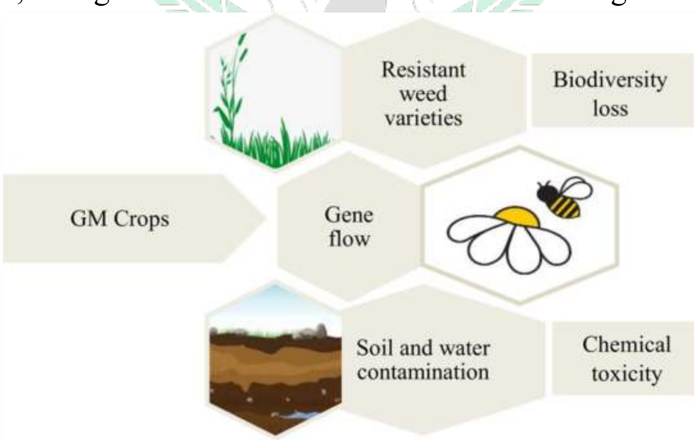
[2]Assistant Professor (Agronomy), College of Hill Agriculture, VCSGUUHF, Chirbatiya, Uttarakhand, India

[3]Assistant Professor (Agronomy), College of Horticulture, VCSGUUHF, Bharsar, Pauri Garhwal, Uttarakhand – 246123, India

[4]M.Sc. Ag. (Horticulture – Vegetable Science), SAAST, Chhatrapati Sahu Ji Maharaj University, Kanpur, Uttar Pradesh, India

[5]M.Sc. Ag. (Agronomy), College of Hill Agriculture, VCSGUUHF, Chirbatiya, Uttarakhand, India

Global agriculture faces increasing pressure from climate change, land degradation and rising food demand. Abiotic stresses such as drought, salinity and heat, along with inefficient nutrient utilization, significantly limit crop productivity. Conventional breeding approaches are often slow and constrained by genetic variability. Advances in genetic modification (GM) and genome editing technologies offer precise tools to improve stress tolerance and nutrient use efficiency (NtUE) in crops. This article reviews the role of GM and genome-edited crops in enhancing resilience to abiotic stresses and improving nutrient utilization. Mechanisms, case studies and future prospects are discussed, highlighting their potential contribution to sustainable agriculture and global food security.



Global agriculture faces unprecedented challenges from climate change, land degradation and a growing human population. Increased incidence of drought, salinity, heat stress and nutrient depletion are among the major constraints limiting crop productivity and food security. Traditional breeding methods have historically improved yield and stress tolerance traits, but they are relatively slow and limited by genetic variability within breeding populations.

Recent advances in biotechnology have paved the way for genetically modified (GM) and genome-edited crops, offering precise and robust solutions to enhance stress tolerance and nutrient use efficiency (NtUE). This article explores how these technologies contribute to sustainable crop improvement, examines specific examples, discusses mechanisms of action and considers broader implications for agriculture.

Genetic Modification and Genome Editing: Background

GM crops involve introducing foreign genetic material into a plant genome to confer desired traits such as insect resistance or herbicide tolerance. Examples include Bt cotton and herbicide-tolerant soybean.

Genome editing utilizes tools such as CRISPR/Cas9, TALENs and ZFNs to induce precise changes in native DNA without necessarily introducing foreign genes. These approaches enable gene knock-out, insertion or modification with high accuracy.

Unlike GM crops, genome-edited plants may be indistinguishable from naturally occurring variants except at the nucleotide level, allowing potential regulatory flexibility. Both technologies offer powerful avenues for improving stress tolerance and NtUE.

Enhancing Stress Tolerance

Understanding Stress Factors

Plants experience multiple abiotic stresses including drought, salinity, heat and cold. These stresses trigger ROS accumulation, cellular dehydration and hormonal imbalance. Improvement of stress tolerance focuses on genes involved in perception, signalling, osmotic regulation and antioxidant defence.

GM Approaches to Stress Tolerance

Transgenic strategies commonly introduce stress-responsive genes or transcription factors such as DREB**,** enhancing water-use efficiency and osmotic balance.

HB4 wheat, containing a sunflower gene, exhibits improved drought tolerance and biomass retention under water stress, providing yield stability in drought-prone environments.

Genome Editing for Stress Resilience

Genome editing modifies endogenous genes controlling stress responses. CRISPR-Cas9 mediated disruption of stress-sensitivity genes improves tolerance to drought, salinity and cold.

Edited rice MYB genes enhanced cold tolerance, while MAPK and ARF gene modifications improved heat and salinity tolerance. Kumar et al. (2024) reported that genome editing targets regulatory networks enabling superior abiotic stress resilience.

Mechanisms Underlying Stress Tolerance

- Regulation of stress signalling pathways
- Improved osmotic balance and water-use efficiency
- Enhanced antioxidant defence reducing oxidative damage

These mechanisms collectively support crop productivity under adverse environments.

Improving Nutrient Use Efficiency (NtUE)

Importance of NtUE

NtUE reflects a plant’s ability to acquire and utilize nutrients efficiently. Improved NtUE reduces fertilizer demand, lowers production costs and minimizes environmental pollution.

GM Approaches to NtUE

GM cereals have demonstrated higher nitrogen uptake efficiency and grain yield per unit nitrogen applied. Meta-analyses show improved NUpE in rice, maize and wheat without increased fertilizer input.

Genome Editing for Nutrient Efficiency

Genome editing targets nutrient transporters, root architecture genes and regulatory pathways to enhance uptake and utilization. Editing negative regulators of nutrient signalling offers promising strategies for low-input agriculture.

Biofortification and Dual Benefits

Genome editing supports biofortification (e.g., β-carotene enriched rice) and indirectly influences nutrient metabolism, linking human nutrition with crop efficiency.

Case Studies and Examples

Drought and Salt Tolerance

- CRISPR-edited rice (OsDREB1A) showed improved drought survival.
- Maize with modified ZmNHX1 exhibited enhanced salinity tolerance.

Enhanced NtUE

- GM cereals demonstrated significant improvements in nitrogen uptake efficiency.
- CRISPR targets regulating nutrient uptake show future potential under poor soil conditions.

Integration of Stress and NtUE Traits

Stress tolerance and nutrient efficiency share overlapping molecular pathways. Advanced genome editing allows multiplexed trait improvement, producing crops capable of maintaining productivity under combined stress and nutrient limitation.

Challenges and Considerations

Regulatory and Ethical Issues

Genome-edited crops may face relaxed regulations in some regions; however, biosafety and public acceptance remain crucial.

Environmental Concerns

Potential off-target effects and ecological impacts necessitate rigorous evaluation.

Socio-Economic Impacts

Equitable access, farmer training and intellectual property considerations must be addressed to ensure inclusive benefits.

Conclusion

GM and genome-edited crops are transformative technologies for modern agriculture. They enhance abiotic stress tolerance and nutrient use efficiency, reducing fertilizer dependency and environmental impact. Genome editing, particularly CRISPR-Cas systems, provides unprecedented precision and speed. As climate challenges intensify, these tools will play a vital role in sustainable crop production and global food security.

References

1. ACS Journal of Agricultural and Food Chemistry (2021). CRISPR-based crop improvements for stress tolerance.
2. Food Safety Institute (2025). Various types of genetically modified and genome-edited crops.

3. Frontiers in Genetics (2022). Genome editing targets for improving nutrient use efficiency and nutrient stress adaptation.
4. PMC (2022). Genome editing for enhanced nutrient content and stress adaptation.
5. Scientific Reports (2020). Genetically modified crops superior in nitrogen use efficiency.
6. Wikipedia (2024). HB4 wheat drought-tolerant genetically modified wheat.