

PROSPECTS AND CHALLENGES OF GENOME EDITING TECHNOLOGY IN AGRICULTURE: A REVIEW

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ABSTRACT

Genome-editing technologies, especially the CRISPR-Cas system, have revolutionized genetics, molecular biology, and biotechnology by executing precise DNA modification. Compared with earlier genome editing methods like zinc finger nucleases and transcription activator-like effector nucleases, CRISPR-Cas9 offers unmatched efficiency and ease of use. Applications of this technology reach from gene therapy to agricultural applications and fundamental research. Enhancements in specificity and reduction of off-target effects from recent advancements such as prime editing have rendered CRISPR-Cas9 an indispensable tool for genetic engineering in this era. CRISPR-Cas technology can enhance crop yield, disease resistance, and stress tolerance through site-directed mutagenesis in agricultural settings. Unlike conventional biotechnology techniques, CRISPR does not require the introduction of exogenous DNA, thus rendering genome-edited crops more palatable in the eyes of regulatory bodies and consumers. However, there are impediments to commercialization due to a wide variety of regulatory frameworks and acceptance modal values. Considering factors such as lower research expenses and shortened breeding processes, the importance of genome editing is emphasized for global food security. However, technical issues, particularly optimization for tropical crops, and fears regarding off-target effects have hindered the uptake of genome editing. Ethical issues and regulatory hurdles concerning biodiversity, food safety, and ecological risks remain some of the unapproachable hurdles. Public engagement is the only road to set the record straight on misconceptions and earn acceptance for genome editing technology to meet the food needs of the world.

Keywords: Genome editing technology, CRISPR-Cas, Biotechnology, Genetic engineering, Agriculture.

INTRODUCTION

Genome editing technology has revolutionized the field of genetics, molecular biology, and biotechnology enabling accurate modifications to DNA sequences across a range of organisms. Among the more prominent technologies are those related to the CRISPR-Cas system, whose efficiency, versatility, and relative ease of application are better compared to earlier genome editing technologies such as zinc finger nucleases and transcription activator-like effector nucleases (Maeder and Gersbach, 2016; Knott and Doudna, 2018; Chadwick and Musunuru, 2017).

The CRISPR-Cas9 system enabled the advancement of gene therapy, agriculture, and fundamental research and it has become the backbone of modern genetic engineering. The CRISPR-Cas9 system confers specificity on the Cas9 nucleate to genomic locations using guide RNA, which binds to the Cas9. The double-strand breaks inflicted by Cas9 on target DNA can then be repaired by non-homologous end joining (NHEJ) or homologous recombination (HR), enabling targeted knocking out of genes or precise editing of genes (Yamaguchi *et al.*, 2020; Gao *et al.*, 2022). Further advancements such as prime editing, which gives all twelve base-to-base conversions by specifically avoiding double-strand break creation, are new updates to the genome-editing revolution that aims at reducing off-target effects while enhancing specificity (Lu *et al.*, 2022). This is significant in therapeutic contexts, where the chance of unwanted mutations is quite a serious risk (Doudna, 2020).

Genome editing technologies can find useful applications, but with ethical considerations come the remaining key aspects to be considered while developing and implementing such technologies. The germline editing field raises the questions of possible unintended consequences of heritable genetic changes (Nguyen *et al.*, 2020; Collier, 2019). Hence, serious discussion is currently being implemented

by members of the scientific community to formulate more rational use guidelines for these powerful technologies (Doudna, 2020; Collier, 2019).

PROSPECTS

The scope of genome editing technologies in agriculture, especially through the CRISPR-Cas system, has been acknowledged as revolutionary for crop improvement. With this technology, plant genomes can be engineered precisely to introduce favourable traits, such as high yield, disease resistance, and improved stress tolerance. The ability to direct changes in the genetic mechanism of the crops positions CRISPR-Cas as a leading tool in modern agricultural practices (Godswill *et al.*, 2023; Hua *et al.*, 2019). The advent of genome-editing technologies has brought a major revolution in the agricultural ecosystem. CRISPR tools are more efficient and accurate than traditional GM methods. Unlike GMO techniques, which often introduce a foreign DNA part, CRISPR editing occurs in the existing DNA sequence leading to a possible market and regulatory acceptance of genome-edited crops (Cui and Shoemaker, 2018; Keiper and Atanassova, 2022). It increases the production of genes that are specific for biotic resistance and reduces abiotic stresses, which is also in line with consumers seeking transparency and sustainability in food production (Waghmode, 2024; Hamdan *et al.*, 2022).

Integrating genome editing into agriculture is not without challenges. Regulatory frameworks are one of the barriers to these technologies: since a particular state takes a liking to genome-edited crops, another state is hell-bent on overtaxing its bureaucracy to create regulations against them much as it would against GMOs, thus making commercialization unfeasible (Hundleby and Harwood, 2018; Turnbull *et al.*, 2021). Still, the general public plays a crucial role in the acceptance of genome-edited crops. It has been reasoned that consumer attitudes towards genetically engineered foods could affect the marketability potentials of genome-edited products, focusing on working out communication strategies to address public concerns (Cui and Shoemaker, 2018; Keiper and Atanassova, 2022; Kalaitzandonakes *et al.*, 2022). The economic considerations related to genome editing in agriculture are also relevant. It has the potential to lower R and D costs and quicken breeding, which is important to secure global food requirements due to rising population and climate change pressures (Kalaitzandonakes *et al.*, 2022; Matres *et al.*, 2021). While genome editing continues to advance, it is equally paramount that all stakeholders, policymakers, scientists, and farmers, seize this opportunity to forge an environment conducive to innovation with safety and public confidence put first (Evanega, 2024; Menz *et al.*, 2020). Genomic editing techniques might have commercialized agriculture profoundly, especially CRISPR/Cas9 technology regarding modifications in the genome of plants and animals. However, some impediments confront such initiatives, such as technical limitations, ethical quandaries, regulatory impediments, and societal resistance.

CHALLENGES

The most important challenges are the scientific and technical challenges, among which include the optimization of genome editing procedures for different crops will be the priority, especially in the tropics. Studies show that although CRISPR/Cas9 has the potential to improve crops against pests and abiotic stress, the transformation protocols available do not enable such feats to be easily applied by the suggested research or practitioners from these regions (Haque *et al.*, 2018). Besides, other safety and efficacy risks and challenges include off-target effects that cause the genome editing to alter unintended sites of the genome within the edited organisms ("CRISPR/Cas9: A Potential Tool for Genomes Editing", 2024).

Ethical questions regarding the manipulation of genetic materials raise concerns about biodiversity, food safety, and unintended ecological consequences (Ayanoğlu *et al.*, 2020). More or less, regulatory regimes differ from country to country, and some countries offer extremely strict regulation on GMOs, which can encompass any crops and livestock subjected to genome editing. For example, an important ruling by the Court of Justice of the European Union classifying gene-edited crops under the same regulations as "conventional GMOs" is presumed to block their commercial utilization and acceptance (Bishop and Eenennaam, 2020). This regulatory climate is adding another layer of complexity to developments and applications of technologies of genome editing. Concerned stakeholders must navigate through narrow channels of many more legal and ethical matters.

The success of genome editing technologies depends heavily on public acceptability and perception, which is influenced by perceived dangers, advantages, and ethical issues (Uchiyama *et al.*, 2018).

An open discussion with the public to address concerns and misconceptions about genome editing is an indispensable step in orchestrating acceptance and support for biotechnology in agriculture (Helliwell et al., 2019). It may help cancel out some of the scepticism around its use if genome editing is framed as a viable instrument for sustainable agriculture and food security (Helliwell et al., 2019; Kayode, 2024).

CONCLUSION

In conclusion, the possibilities of genome editing technology in agriculture are bright for its contribution extensively to the resilience of crops and social productivity. However, realizing these benefits will call for addressing regulatory hurdles of perception and socio-economics, allowing full exploitation of this cutting-edge technology. Genome editing technologies bear great prospects for changing agriculture by increasing the resilience of crops and the productive capacity of livestock; their deployment is obstructed by several challenges. To realize the full benefits of these innovations in agriculture, technical constraints, ethical issues, regulatory frameworks, and public acceptance must be addressed.

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