

Editorial

Harnessing Gene-editing Technology for Sustainable Crop Protection

Gene-editing technology, involving intentional modification of an organism's DNA to achieve specific traits or characteristics has emerged as a ground breaking tool in the realm of agriculture that offers unprecedented possibilities for sustainable crop protection. This revolutionary approach allows scientists to precisely modify the genetic makeup of crops, enhancing their resistance to pests and diseases while minimizing the need for chemical interventions. Harnessing gene-editing technology holds immense promise for addressing the challenges posed by conventional crop protection methods, paving the way for a more sustainable and environment friendly agricultural future. The most widely used technique for genome editing is CRISPR-Cas9, which stands for Clustered Regularly Interspaced Short Palindromic Repeats and CRISPR-associated protein 9. This system allows scientists to precisely target and edit specific genes, making it a powerful tool for genetic modification.

Disease resistance is a crucial trait for crops, as pathogens, such as bacteria, viruses, fungi, and pests, pose significant threats to global food production system. Traditional breeding methods have been employed to develop disease-resistant crops, but these approaches often lack precision and efficiency. Genome editing, particularly CRISPR-Cas9, offers a more targeted, precise and rapid method to introduce resistance traits into crops. Unlike traditional breeding methods, which rely on the introduction of entire genes and can result in unintended genetic changes, gene-editing enables targeted modifications at the molecular level. This precision allows researchers to enhance specific traits associated with pest and disease resistance, ensuring that only the desired genetic alterations are made. By doing so, gene-editing minimizes the risk of unintended consequences and accelerates the development of resilient crops, offers a sustainable and environmentally friendly alternative to chemical pesticides and fungicides, and reduces reliance on synthetic inputs and minimizes adverse impacts on human health and the environment. Furthermore, CRISPR can be used to develop durable resistance against evolving pathogens and pests by targeting multiple genes or employing strategies such as gene stacking and RNA interference. This could significantly mitigate yield losses and economic damage caused by crop diseases and pest infestations, thereby improving overall agricultural productivity and sustainability.

As mentioned, genome editing has emerged as a pivotal tool in advancing pathogen-resistant crops across diverse plant species. In the realm of crop enhancement, specific genes have been targeted using genome editing techniques to bolster resistance. Notable instances include achieving broad-spectrum resistance to bacterial blight in rice through modifications to the SWEET14 gene, developing powdery mildew-resistant wheat varieties via alterations to the TaMLO gene, and enhancing tomato plants' resistance to bacterial wilt by focusing on the Pto gene. Similarly, maize plants were fortified against *Fusarium verticillioides* through edits to the ZmLOX10 gene, while soybean plants gained resistance to soybean mosaic virus by targeting the eIF4E gene. Additionally, potato plants were engineered for late blight resistance via the Rpi-vnt1.1 gene, and apple trees achieved improved fire blight resistance through genome editing of the MdDIPM1 gene. In another suite of applications, grapevine plants were fortified against powdery mildew by editing the VvMLO7 gene, banana plants gained resistance to Panama disease through edits to the MaWRKY gene, and cotton plants achieved enhanced resistance to *Verticillium* wilt by modifying the GhMCK2 gene. Collectively, these examples underscore the transformative potential of genome editing in developing pathogen-resistant crops, contributing significantly to sustainable agriculture and diminishing reliance on chemical pesticides.

Besides the most promising applications of CRISPR in crop improvement is the development of genetically modified (GM) crops with enhanced nutritional content in terms of fortified crops with essential vitamins, minerals, and other beneficial compounds. Scientists have successfully used CRISPR to increase the iron and zinc content in rice, addressing micronutrient deficiencies prevalent in many developing countries. Similarly, CRISPR can be employed to enhance the levels of essential amino acids, antioxidants, and vitamins in various staple crops, thereby improving the nutritional quality of food and promoting human health. Another significant area of focus for CRISPR-mediated crop improvement is the enhancement of yield and productivity. By targeting genes involved in plant growth, development, and stress responses, researchers can engineer crops with improved vigor, biomass accumulation, and yield potential. For instance, CRISPR can be used to modify genes associated with flowering time, plant architecture, root development, and photosynthetic efficiency, thereby optimizing crop performance under different environmental conditions. By conferring resilience to various stressors, CRISPR-edited crops can maintain productivity and ensure food security in the face of changing climatic conditions and emerging agricultural challenges.

Furthermore, CRISPR holds immense promise for accelerating the breeding process and developing new crop varieties with desired traits. Traditional breeding methods often involve time-consuming and labor-intensive processes, coupled with genetic bottlenecks and limitations in genetic diversity. In contrast, CRISPR enables rapid and targeted modification of specific genes without the need for lengthy backcrossing or selection cycles. This allows breeders to bypass natural constraints and introduce valuable traits directly into elite cultivars, expediting the development of improved crop varieties with enhanced agronomic performance and market appeal. Moreover, CRISPR-based gene editing offers greater precision and efficiency compared to conventional transgenic approaches, minimizing unintended genetic alterations and regulatory concerns associated with GM crops.

CRISPR technology holds promise for unlocking the genetic potential of wild and underutilized crop species, expanding the genetic diversity available for crop improvement. By precisely editing the genomes of non-domesticated plants, researchers can introduce novel traits, improve agronomic performance, and broaden the genetic base of cultivated crops. This not only enhances resilience to environmental stresses and biotic threats but also facilitates the domestication of new crops with desirable attributes such as drought tolerance, nutrient efficiency, and adaptability to marginal lands. Furthermore, CRISPR-mediated gene editing offers opportunities for the development of tailor-made crops optimized for specific agro-ecological regions and production systems, catering to diverse consumer preferences and market demands.

The environmental impact of traditional crop protection, often reliant on chemical pesticides, has raised concerns about soil and water contamination, as well as harm to non-target organisms. Gene-editing provides a sustainable alternative by reducing the dependence on such chemicals. Genome-edited crops have the potential to reduce the need for chemical fertilizers and pesticides, making farming more environmentally sustainable, and contribute to enhanced climate resilience and reduced agri-food waste, leading to a more sustainable agricultural system. Moreover, the efficiency and speed of gene-editing technologies contribute to faster crop development cycles. This rapid turnaround allows for the timely response to emerging threats and changing environmental conditions. Scientists can swiftly adapt crops to evolving challenges, ensuring food security in the face of a dynamic and unpredictable climate.

While genome editing holds immense promise for enhancing disease resistance in crops, several challenges and ethical considerations need to be addressed. One significant concern is the potential off-target effects, where unintended changes to the genome may occur. Continuous advancements in CRISPR-Cas9 technology, along with rigorous testing and validation procedures, aim to minimize off-target effects and ensure the safety of edited crops. Regulatory frameworks also play a crucial

role in the acceptance and deployment of genome-edited crops. Different countries have varying regulations regarding genetically modified organisms (GMOs), and establishing clear guidelines for the approval and commercialization of genome-edited crops is essential to their widespread adoption. In conclusion, CRISPR-Cas9 technology represents a game-changing tool for crop improvement with far-reaching implications for global agriculture and food security. By harnessing the power of precision genome editing, researchers can develop crops with enhanced nutritional quality, increased yield potential, improved resilience to stresses, and enhanced resistance to diseases and pests. Furthermore, CRISPR offers opportunities for accelerating the breeding process, expanding the genetic diversity of cultivated crops, and unlocking the genetic potential of wild and underutilized species. As we continue to explore and refine the applications of CRISPR in crop improvement, the future holds immense promise for sustainable, resilient, and nutritious agriculture to meet the challenges of a growing global population and changing climate.

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