

CRISPR revolution transforming crop traits through precision molecular breeding.

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Introduction

In some countries, CRISPR-edited crops are treated similarly to GMOs, while others differentiate based on the absence of foreign DNA. The ethical debate centers on transparency, ecological impact, and equitable access to technology. Public engagement and clear regulatory frameworks are essential to ensure responsible deployment and societal acceptance. The global agricultural landscape is undergoing a seismic shift, driven by the urgent need to feed a growing population amidst climate change, diminishing arable land, and evolving pest and disease pressures. Traditional breeding methods, while foundational, are often slow and imprecise. Enter CRISPR/Cas a revolutionary genome editing tool that has redefined the possibilities of plant molecular breeding. With its precision, efficiency, and versatility, CRISPR is transforming how we develop crops with enhanced traits, from yield and nutrition to stress resistance [1, 2].

CRISPR is not just enhancing existing crops it's enabling the domestication of wild species. By editing domestication-related genes, researchers have transformed wild tomatoes into cultivars with desirable traits like compact growth and high yield. Moreover, CRISPR facilitates rapid breeding cycles through techniques like haploid induction and apomixis, allowing breeders to fix traits in fewer generations. Despite its promise, CRISPR faces regulatory hurdles. CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) paired with the Cas9 enzyme is a gene-editing system derived from bacterial immune mechanisms. It allows scientists to target specific DNA sequences and make precise edits insertions, deletions, or substitutions without introducing

foreign DNA. This precision makes CRISPR a game-changer in plant biotechnology, enabling trait improvement without the drawbacks of traditional transgenic approaches [3, 4].

Traditional breeding relies on crossing and selection, often taking years to achieve desired traits. Moreover, it can introduce unwanted genetic material, known as linkage drag. CRISPR circumvents these issues by directly editing genes associated with specific traits, drastically reducing breeding time and increasing accuracy. For example, researchers have used CRISPR to modify flowering time in wheat, improve drought tolerance in maize, and enhance grain size in rice all within a few generations [5, 6].

Yield is a complex trait influenced by multiple genes and environmental factors. CRISPR enables multiplex editing simultaneous modification of several genes to optimize yield-related pathways. In rice, editing genes like GS3 and GW2 has led to increased grain size and weight. Beyond yield, CRISPR is being used to improve nutritional quality. Golden Rice, engineered to produce beta-carotene, has been further refined using CRISPR to enhance vitamin A content without affecting other agronomic traits [7, 8].

Crop losses due to pests and diseases remain a major challenge. CRISPR offers a sustainable solution by enabling the development of disease-resistant varieties. For instance, tomatoes have been edited to resist Tomato Yellow Leaf Curl Virus (TYLCV), and bananas have been engineered to withstand Panama disease. Unlike chemical pesticides, CRISPR-based resistance is environmentally friendly and can be tailored to specific pathogens, reducing off-target effects and ecological disruption. Climate change is

intensifying abiotic stresses like drought, salinity, and heat. CRISPR is helping develop crops that can thrive under these conditions. In soybeans, genes regulating salt tolerance have been edited to improve performance in saline soils. Similarly, maize varieties with enhanced root architecture have shown improved drought resilience [9, 10].

Conclusion

CRISPR/Cas has ushered in a new era of precision molecular breeding, offering solutions to some of agriculture's most pressing challenges. From boosting yields and nutrition to enhancing resilience and sustainability, CRISPR is not just a tool it's a revolution. As we navigate the complexities of food security and climate change, embracing this technology responsibly will be key to cultivating a more resilient and equitable agricultural future. The future of CRISPR in agriculture is bright. Advances in base editing and prime editing are expanding the toolkit, allowing even more precise modifications. Integration with AI and machine learning is streamlining target identification and trait prediction. As the technology matures, CRISPR could enable personalized agriculture tailoring crops to specific environments, consumer preferences, and nutritional needs.

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