



HARNESSING CRISPR-CAS9 FOR ADVANCING SUSTAINABLE AGRICULTURE: PRECISION GENOME EDITING TO DEVELOP CLIMATE-RESILIENT AND HIGH-YIELDING CROPS

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Abstract

Basic agriculture methods and genetic engineering methods do not work fast enough to stop food safety hazards that arise from growing populations and climate change. Researchers have proven that CRISPR/Cas systems transform the way crop genomes are modified especially in rice and maize production. Scientists explore CRISPR/Cas system breakthroughs and describe new discoveries that make genome editing better for agriculture. Advancements in genome editing techniques have developed methods to make specific gene changes that boost crop resistance against environmental pressures. CRISPR/Cas creates high-yielding crops that gather more light for photosynthesis and take in more nutrients and resist lodging as well as produce better food for taste and nutritional content. Our research confirms that CRISPR/Cas delivers important solutions to food security problems while dealing with ethical and legal obstacles today. Research on CRISPR and its applications with advanced technologies must continue to realize its potential in designing great agricultural methods.

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INTRODUCTION

Agricultural systems around our planet face trouble because more people need food as global populations expand. Rising climate changes produce harsher weather conditions and transform pest systems while shrinking farmlands making this problem worse (Bibi and Rahman 2023). The combined trends between expanding populations and changing weather reduce our ability to deliver safe and reliable food access worldwide. Standard plant improvement techniques could not presently keep up with how fast environmental factors change yet genetic engineering faces both precision and societal backing problems (Afzal et al., 2023; Ambika et al., 2024).

Staple crops like rice, wheat, maize, and soybeans give food security to most global consumers as they serve as one of their main sources of energy. The main crops serve both as direct food items and as raw material for animal and industry feeds. These essential crops can still produce even under pest and disease threats yet face damage from changing environments. Our limited arable land needs staple crops to become more productive to feed people as Earth's population rises.

Through our continued efforts to solve agricultural problems we see that technology has moved from basic plant selection practices to advanced genetic systems. Scientists use CRISPR/Cas technology to transform how they edit genes inside plants and animals (Muha-Ud-Din et al., 2024). The CRISPR/Cas system now provides researchers in agriculture with both fundamental and useful ways to edit genomes. The gRNA navigates Cas (CRISPR associated) nucleases to target specific DNA sequences where they pinpoint the exact spots between DNA to make cuts. Bacteria and archaea immune system gave rise to CRISPR (Clustered

Regularly Interspaced Short Palindromic Repeats) technology. The cellular DNA repair system repairs the break and makes precise genetic alterations according to Ghosh and Chatterjee (2024). CRISPR/Cas enables broad crop development more efficiently at lower costs compared to prior genome editing tools ZFNs and TALENs because of its effective and easy application according to Ghoshal (2024). Understanding how to apply and improve CRISPR/Cas technology in advanced organisms requires equal research effort to the initial discovery of the system in bacteria. In 2024 Jung et al. demonstrate how early research on tracrRNA and crRNA clarified targeted DNA cutting for Cas9 enzyme. The guide RNA forms an RNA DNA hybrid that binds to the target DNA and sends the Cas9 protein to its genetic target location for the mechanism to begin. At the targeted location Cas9 creates double strand breaks which the body fixes through its standard DNA repair methods - NHEJ and HDR (Yuan et al., 2024). CRISPR/Cas enables scientists to precisely update genetic codes for agricultural development while tackling global food supply issues and environment changes (Raza et al., 2024).

The advanced CRISPR technology makes it possible to build improved crops faster through genetic improvements that defend against environmental threats, improve nutrition and could boost productivity as reported by Verma et al. (2023). CRISPR/Cas technology achieves desired modifications precisely without foreign DNA because people accept and find it practical to use at a reasonable cost. New genome editing methods like prime editing and base editing show specific growth while also substantially reducing undesired impact on DNA (Naeem and Alkhnbashi in 2023 plus Saber Sichani et al. in 2023). The future generation of

crops can adapt to extreme climate situations and deliver enhanced nutritional value to meet population growth thanks to CRISPR/Cas technology. Our research targets CRISPR/Cas technology applications to develop better resistance against climate change and enhance farming productivity of essential cereal crops. This article shows how CRISPR/Cas systems can change farming through reviewing cutting-edge farming research achieved using CRISPR/Cas technology. This research establishes our knowledge which proves helpful to analyze modern developments and discover next steps to achieve environmentally-friendly farming with enough food for all people.

CRISPR/Cas technological innovations and advancements

The latest CRISPR innovations now deliver superior and precise genome editing for agricultural work (Figure 1). Prime editing and base editing tools let researchers make genetic changes with much better precision. Scientists use reverse transcriptase together with CRISPR-Cas9 to edit target DNA sequences which studies show could repair 89

percent of known genomic variations (Chen and Liu, 2023). Scientific research finds that genetic modification through prime editing successfully improves rice disease resistance by fixing single mutations in DNA without creating double stranded damage to it. Base editing gives doctors more precise point mutation treatment because they can move specific DNA bases permanently without issues (Pfeiffer and Stafforst, 2023). Researchers can change soybean genes that control fatty acid desaturation processes and change how plants react to cold temperature. They also can modify the flavor attributes of peas and tomatoes (Nizampatnam et al. 2024). Research tools for agricultural applications have grown stronger through the use of two fresh CRISPR related enzymes Cas12 and Cas13. Cas12 leads to simultaneous feature editing as its major benefit. Systems based on Cas12 enable scientists to enhance multiple soybean genes that fight diseases according to Sun et al. (2024). Cas13d proves useful as an RNA viral interference system in potato crops because it offers strong multiplex control against viruses which helps boost agricultural production and environmental care. (Zhan et al., 2023).

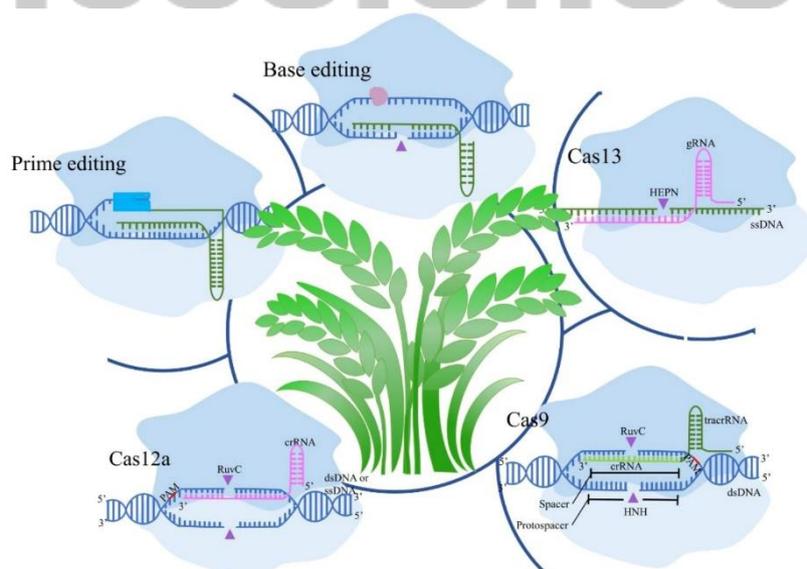


Figure 1. CRISPR/Cas Systems

This figure shows exactly how CRISPR/Cas systems can assist in different crop biotechnologies displayed above. The base editor system produces one-nucleotide transformation whereas prime editing achieves precise small sequence changes via DSBs. Cas9 works by breaking both DNA strands during cell culture. Cas12a cuts DNA at staggered points for many alterations and Cas13 performs RNA-targeted regulation above genome level.

To edit plant DNA with CRISPR technology needs effective delivery methods since these are highlighted in Figure 2. Nanoparticles protect CRISPR materials and boost cellular absorption to advance maize trait development according to new research (Yau et al., 2024; Chakraborty et al., 2023). Using viruses to develop virus resistance in tomato and tobacco has yielded better results than other gene delivery and genome editing methods. Combining proteins and RNAs into ribonucleoprotein particles eliminates CRISPR's

unintended effects. Scientists succeeded at boosting wheat yields and safeguarding crops from disease through their implementation of this plan (Poddar et al., 2023). Advanced guide RNA engineering methods together with improved Cas variants help to reduce undesired genome changes when performing the DNA editing technique (Zhang et al., 2023b). Cas9 high fidelity variants help wheat survive dry conditions while limiting the chances of genetic harm (Poddar et al., 2023). Improved CRISPR technology now lets scientists enhance plant resistance to climate changes while reducing the risks in gene editing processes. New agricultural breakthroughs emerge from improvements in CRISPR technology shown in table 1 which develops delivery methods and editing tools. Improved delivery tools support CRISPR studies that expand its potential usages toward more prosperous and sustainable agricultural development.

Table 1. CRISPR/Cas technological innovations and advancements

Types	Mechanism	Advantages	Stable Crops	Traits	References
CRISPR/Cas9	Use guide RNA to target and Cas9 to cut DNA	High efficiency, broad applicability	Barley	Coleoptile length increasing	Cheng et al., 2023
Base Editing	Convert one DNA base to another without double-strand breaks	High precision, avoids double-strand breaks	Rice	Glyphosate resistance	Sony et al., 2023
Prime Editing	Use CRISPR-Cas9 with a reverse transcriptase to make precise edits	Versatile, corrects point mutations	Rice; Peanut; Chickpea	Restoration of GFP activity	Biswas et al., 2022
CRISPR/Cas12a	Use guide RNA to target and Cas12a to cut DNA	Multiplex editing, higher specificity in some contexts	Rice; Maize	Root-knot nematode resistance; Chlorotic mottle	Lei et al., 2023; Zhou et al., 2023b

BIOSCIENCES REPORTS

CRISPR/Cas13	Target RNA instead of DNA	RNA targeting, potential for viral resistance	Potato	Multiplex virus resistance	Zhan et al., 2023
Nanoparticle-Mediated Delivery	Use nanoparticles to deliver CRISPR components	High protection, enhanced uptake	Maize	Trait enhancement	Nagy et al., 2023
Viral Vectors	Employ viruses to deliver CRISPR components	Utilizes natural infection mechanisms	Cassava	Precision breeding	Tuo et al., 2023
Ribonucleoprotein (RNP) Complexes	Direct delivery of CRISPR-Cas9 protein and guide RNA as a complex	DNA-free method, reduces potential off-target effects	Potato; Wheat	Color change; Diversity production accelerating	Poddar et al., 2023; Wulff-Vester et al., 2024
Agrobacterium-Mediated Transformation	Use Agrobacterium to transfer CRISPR components into plant cells	Effective for stable transformations	Rice	Agronomic trait improving	Tang et al., 2023
Biolistic Particle Delivery	Use high-velocity particles to deliver CRISPR components into cells	Versatile, can deliver to a wide range of species	Millet	Genetic modifications stress tolerance improving	Ghosh, 2024
Enhanced Guide RNA Design	Optimize guide RNA sequences for specificity	Reduces off-target effects, increases accuracy	Wheat; maize	Precision editing; stress tolerance improving	Abeuova et al., 2023; Karmacharya et al., 2023
High-Fidelity Cas9 Variants	Engineer Cas9 proteins with reduced off-target activity	Increases efficiency, reduces unintended mutations	Barley; Wheat	Targeted trait enhancements	Lawrenson et al., 2024
Computational Tools	Use software to predict and minimize off-target effects	Improves design accuracy, reduces experimental time	Maize; Wheat	Yield improving	Gaillochet et al., 2023
Use of Shortened Guide RNAs	Shorten versions of guide RNAs to improve targeting precision	Decreases off-target activity, maintains efficiency	Sorghum	Precision gene editing	Lee et al., 2023
Paired Nickases	Use two nicks instead of a double-strand break to reduce off-target effects	Reduces off-target activity, increases precision	Potato	Trait improvement	Mali and Zinta, 2023

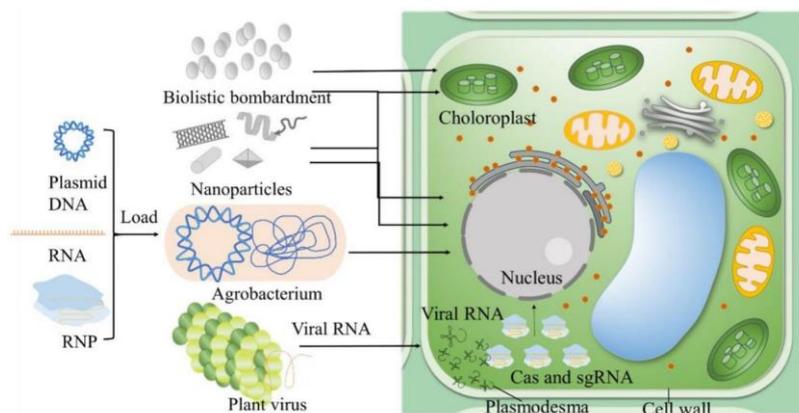


Figure 2. CRISPR/Cas delivery strategies

Figure 2: CRISPR/Cas delivery strategies. The natural ability of agrobacterium to insert DNA into plant genomes becomes instrumental through this transformation method. Nanoparticles make CRISPR/Cas components work better inside plants because they can enter plants with ease. Biolistic bombardment helps scientists transfect chloroplasts plus recalcitrant plants by physically launching DNA or genome material into cells. The plant can use virus-enabled delivery systems to distribute CRISPR/Cas components throughout its entire structure. Research team members have updated several numbers taken from their previous studies in this effort (Zhu et al., 2020).

Strategic applications of CRISPR/Cas in enhancing staple crop resilience

The CRISPR/Cas system offers effective ways to enhance grain crop tolerance against environmental pressures (Yadav et al., 2023). Since environmental problems from climate change disrupt crop production factors such as toughness this assessment reviews how CRISPR/Cas technology now fortifies grains against various pressures to grow them sustainably. CRISPR/Cas technology has advanced into an effective system to enhance both basic crop development and stress tolerance in plants as shown in Figure 3. Our research studies the present CRISPR methods that can improve crop growth while making plants more durable under hostile circumstances.

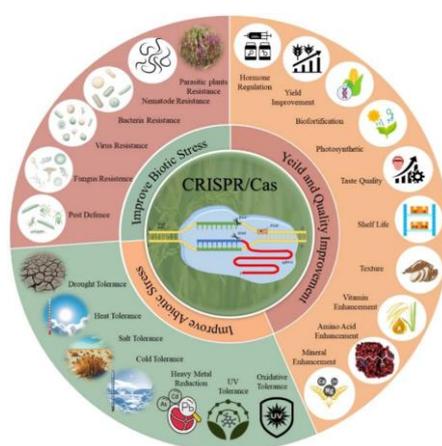


Figure 3. CRISPR/Cas for improving biotic stress tolerance and crop quality.

CRISPR/Cas represents a powerful tool with significant potential to advance crop development (and Figure 3 helps explain why). Scientists use this method to make precise changes to specific genes that boost both yield and quality alongside resistance against natural and environmental threats. CRISPR/Cas technology enhances plant tolerance to both natural stressors and disease threats from living organisms and plants. CRISPR/Cas modifies hormone production to elevate photosynthesis

efficiency which builds more healthy plant nutrients alongside strengthening food preservation and taste for better harvest values.

Yield and quality improvement

As discussed in this section, CRISPR/Cas technology offers precise tools for increasing these qualities by targeting certain genes and pathways, which is crucial for meeting the rising worldwide need for food (Table 2).

Table 2. Comprehensive overview of CRISPR/Cas applications in enhancing yield, quality, and nutritional value of stable crops.

Application	Type	Innovation	Stable Crops	Targeted Genes	Applications in Stable Crops	References
Hormone Regulation	Yield Improvement	CRISPR/Cas 9	Rice	OsCKX	Enhance growth and stress tolerance	Zheng et al., 2023
Hormone Regulation	Yield Improvement	CRISPR/Cas 9	Maize	R2ZM59	Suppress miR166 recognition influences photosynthesis	Figueredo et al., 2022
Photosynthetic Efficiency	Yield Improvement	CRISPR/Cas 9	Rice	RDD	Increase photosynthesis	Zhou et al., 2023a
Nutrient Uptake and Utilization	Yield Improvement	CRISPR/Cas 9	Rice	OsHHO3	Modify genes involved in nutrient uptake and assimilation	Lee et al., 2023
Nutrient Uptake and Utilization	Yield Improvement	CRISPR/Cas 9	Maize	ZeaSWET1b	Modify genes involved in nutrient uptake and assimilation	Li et al., 2023
Nutrient Uptake and Utilization	Yield Improvement	CRISPR/Cas 9	Wheat	ARE1	Increase yield components	Udupa et al., 2021
Yield-Related Traits	Yield Improvement	CRISPR/Cas 9	Rice	TaRPK1	Influence yield components	Abdul Rahim et al., 2021
Yield-Related Traits	Yield Improvement	CRISPR/Cas 9	Rice	OsG2S/GRF4	Increase size and yield	Wang et al., 2022
Yield-Related Traits	Yield Improvement	CRISPR/Cas 9	Barley	GW2.1	Reduce seed setting and yield	Ki et al., 2022
Biofortification	Biofortification	CRISPR/Cas 9	Cassava	PSY	Increase the nutritional content of crops by enhancing vitamin and mineral levels	Narayanan et al., 2022

Biofortification	Biofortification	CRISPR/Cas9	Wheat	ZmIuab1a, ZmIudab1b	Improve sugar and acid metabolism	Qian et al., 2021
Biofortification	Biofortification	CRISPR/Cas9	Rice	OsBADH2	Produce a better fragrance	Iman et al., 2023
Biofortification	Biofortification	CRISPR/Cas9	Cassava	CYP79D1	Lower levels of cyanide	Juma et al., 2022
Biofortification	Biofortification	CRISPR/Cas9	Potato	GBSS1	Obtain amylose-free starch in tubers	Zhang et al., 2022
Shelf Life	Quality Improvement	CRISPR/Cas9	Wheat	TaPDI	Accumulate storage protein	Hani et al., 2021
Texture	Quality Improvement	CRISPR/Cas9	Rice	SD1, Wx	Enhance semi-dwarf glutinous traits	Wang et al., 2021
Texture	Quality Improvement	CRISPR/Cas9	Barley	Hina	Increase rice and barley grain weight	Wu et al., 2022
Mineral Content	Nutrient Enhancement	CRISPR/Cas9	Potato	FtsZ1	Alternate starch granule size in tubers	Tefloyache w et al., 2023
Mineral Content	Nutrient Enhancement	CRISPR/Cas9	Rice	CRTL, PSY	Enhance Vitamin A content to combat malnutrition	Dong et al., 2023
Mineral Content	Nutrient Enhancement	CRISPR/Cas9	Maize	HGGT, HPT	Increase Vitamin E biosynthesis	Zeng et al., 2023
Mineral Content	Nutrient Enhancement	CRISPR/Cas9	Soybean	GmFAD2	Increase fatty acid content	Zhao et al., 2022
Mineral Content	Nutrient Enhancement	CRISPR/Cas9	Rice	OsAUX5, OsWRKY78	Increase plant amino acid accumulation	Ludlow et al., 2022
Mineral Content	Nutrient Enhancement	CRISPR/Cas9	Rice	OsNAS2	Increase iron uptake/translocation	McAlvany et al., 2023
Mineral Content	Nutrient Enhancement	CRISPR/Cas9	Wheat	TaIPK1	Biofortification to increase iron and zinc content	Ibrahim et al., 2021

Challenges and future prospect

Off-target effects

Cas enzyme activity going to unintended parts of DNA causes unwanted results which blocks CRISPR/Cas use in genome editing. Agricultural plants that receive unwanted mutations can develop unusual traits plus decrease their yield while adding harmful features. To deliver safe and effective CRISPR-based technology the genome editing helper needs to control how many times editing happens and exactly where it takes place. Modern

technologies like Cas9 variants and better guide RNA designs now solve the genome editing obstacles. The development of enhanced Cas9 by researchers like Guo et al. in 2023 and He et al. in 2024 produced three Cas9 variants that reduced uncontrolled DNA interactions to increase accuracy. The variant Cas proteins show excellent precision for these specific applications because they effectively target desired areas while producing minimal unintentional effects. Studies reveal Cas12b powerfully edits the rice genome because it rejects mismatches during editing and requires

specific DNA sequences while avoiding unintended genes (Gurel et al., 2023). Scientists have proven that the CRISPR Cas systems become more precise when they use enhanced sgRNA designs and Cas variants for gene targeting because they produce accurate effects in specific regions without causing unintended changes elsewhere. Research teams should work to enhance CRISPR accuracy as they develop better Cas versions and find alternative methods of correcting multiple genetic targets at once. The optimized technology will cut down side effects and increase the success rate of genetic editing for crop systems.

Delivery methods

Scientists find it hard to add CRISPR components into plant cells of tough staple crops due to their complex genetic combination and poor growth habits. Regular gene-editing tools including biolistic particle delivery and *Agrobacterium* transformation will not succeed with these types of cultures. *Agrobacterium* transformation takes on few host species and may insert unwanted transgenes that go wrong when expressed within plants. Scientists prefer not to use *Agrobacterium* transformation because it fails at blocking the microbes, produces tissue damage and causes unstable Transgene insertions. This newer CRISPR delivery technique requires research into nanoparticles because they could damage cells while their genetic materials stay hazy inside plants (Antony Ceasar and Ignacimuthu, 2023).

Scientific research has focused on creating better CRISPR delivery systems to work effectively and accurately when defending crops (Kocsisova and Coneva, 2023). The use of viral vectors lets CRISPR components move into plant cells using their natural infection methods (Liu et al., 2023c). Researchers

can make CRISPR delivery better by creating natural-breaking structures and connecting specific molecules to nanoparticles. Protoplast transfection provides an easy way to put CRISPR components into these cells but this method works only with plants that develop new protoplasts effectively. By switching CRISPR components from transgenic rootstocks into untreated scions through grafting techniques scientists create non-transgenic genome edits in resistant crops according to Yang et al. 2023b. Future research must focus both on developing better CRISPR delivery technology and verifying that edited traits will stay working across multiple plant generations. Research into DNA repair and chromosomal recombination helps preserve the genetic changes introduced in plants. You must do regular tracking of CRISPR technology changes to confirm their stability and effectiveness in future crop generations.

Ethical, and regulatory issue and public acceptance

CRISPR technology helps produce better crops but creates significant ethical legal and social problems. The quick and precise CRISPR changes to plants create ethical doubts about modifying plant genes to boost rice and wheat production and nutritional content. European citizens strongly oppose genetic management programs of their crops. Crucial ethical considerations deal with unknown impacts to the environment and biosystem along with new artificial living things and environmental harm (Marone et al., 2023). Nations across the world follow distinct rules about the release of CRISPR modified plants. The European Union places strict GMO regulations that will hinder CRISPR wheat plants from reaching the market. When sugarcane undergoes CRISPR modification most countries approve its commercial use because they prioritize the final product over the

editing process. China stands out as a major CRISPR participant although research commercialization remains tough with many investments dedicated to CRISPR rice development (Ghouri et al., 2023; Kumawat et al., 2024). Economic situation throughout the world prevents agricultural sectors from adopting CRISPR technology. European and US patent control stops small organizations and poor nations from using CRISPR technology. The introduction of CRISPR edited tomato plants relies heavily on patent obstacles that restrict their availability in underdeveloped parts of the world (Akhtar et al., 2023). Few companies that hold CRISPR technology patents further deepen the agricultural disparity since they control essential food crops like wheat and maize which struggle to meet food security needs of developing nations (Molinari et al., 2024). Agricultural companies and farmers throughout India and African nations face challenges when utilizing CRISPR-developed crops because these countries limit technology access (Munawar et al. 2024). Modernizing the regulations should keep pace with new developments about CRISPR technology. Future research will work to fix safety problems that come with CRISPR crops including their negative effects on human health and the environment. This will require close cooperation between scientists, regulators and politicians, and also the creation of comprehensive risk assessment models. By fusing technology advancement with robust regulatory response, we can assure that CRISPR can be safely and responsibly integrated into international agriculture and to ultimately increase public acceptance and confidence.

Synergy of CRISPR with advancement technologies

Scientists can use CRISPR technology to modify crop genomes better by joining it with

nanotechnology machine learning and synthetic biology improvements. Nanotechnology solves the vital issue of getting CRISPR compounds into plant cells successfully. The use of carbon nanotubes and mesoporous silica nanoparticles can enhance CRISPR delivery across plant cell walls to increase transformation results while decreasing harmful gene mutations (Khanna et al., 2023). The delivery process can treat all plant species with nanotechnology because it works independently of plant genetics (Naik et al., 2022). Researchers plan to develop big CRISPR systems through this technology while studying organelle structure and performing germ cell manipulation. When nanoparticles combine with crops they help maintain vigor while adding nutritional content while lowering chemical dependence.

The merge of CRISPR system with synthetic biology helps improve genetic modification precision and success in farm crops. People have not yet created CRISPR/Cas systems that work with full control while preserving normal cell function. The system may still become useful for precise cell changes. Synthetic biology provides genetic circuit management and adaptation techniques that solve problems through deinfestation and species compatibility development (Yang and Reyna Llorens 2013). Wang and Demirer (2023) identified efficient systems that control CRISPR effectiveness and running programs that keep enhancing accuracy over time. Scientists use compiled CRISPR and metabolic pathway methods to grow stress-resistant crops that give higher yields. The technology must be used to help farmers grow more food despite rising climate change risk. Research teams should work on designing new promoters that modify polyploid crops well and combine CRISPR with

metabolic engineering to produce beneficial substances across all farming methods.

RESEARCH METHODS

Researchers utilize CRISPR/Cas9 gene-editing tools to improve high-yielding crops while making them more resistant to climate change by focusing primarily on essential crop species including rice along with maize and wheat. The researchers utilized CRISPR/Cas9 system protocols to edit particular genes which controlled disease resistance alongside drought tolerance and photosynthetic efficiency and nutrient absorption. The DNA modification process was conducted through prime editing and base editing technologies to perform exact genetic alterations that did not produce DNA double-strand breaks. To enhance CRISPR component uptake by plant cells scientists employed delivery methods based on nanoparticle delivery together with viral vectors and ribonucleoprotein complexes especially for challenging crops like maize and rice. Plants underwent examination for essential phenotypic changes including growth characteristics as well as yield production and nutrition levels alongside stress adaptability after the modification process. Researchers conducted statistical analyses through correlation and regressions to study plant resilience modulations by conducting ANOVA and PCA analysis for trait enhancement visualization.

RESULTS

Through the implementation of CRISPR/Cas9 technology the yield and quality performance of crops improved notably in conditions of environmental stress. The modification of OsCKX and R2ZM59 in rice led to improved plant growth along with better stress tolerance and photosynthetic efficiency increased notably following RDD gene modifications. Crucial characteristics of maize derived from CRISPR/Cas9-based crops allowed them to fight off disease better while showing better resistance to dry conditions. Rice received greater glyphosate resistance through base editing technologies that specifically altered DNA bases. The application of CRISPR biofortification strategies improved the nutritional value of maize and cassava crops. Statistical analysis demonstrated that CRISPR-edited crops gained increased yield elements including seed size and biomass production apart from better stress tolerance. Statistical findings showed that CRISPR-generated genetic diversity positively affected crop yield stability when exposed to environmental stresses.

Stress tolerance improvement data shown in Figure 4 demonstrates the enhancement of stress tolerance capacity in rice, maize, as well as wheat. The stress tolerance improvement in maize exceeds rice but wheat demonstrates the lowest improvement.

Figure 5 illustrates the yield enhancement in rice and different wheat and maize varieties which correspond to percentage yields following CRISPR editing. Maize outcome stands as the highest among the edited crops with wheat and rice trailing behind.

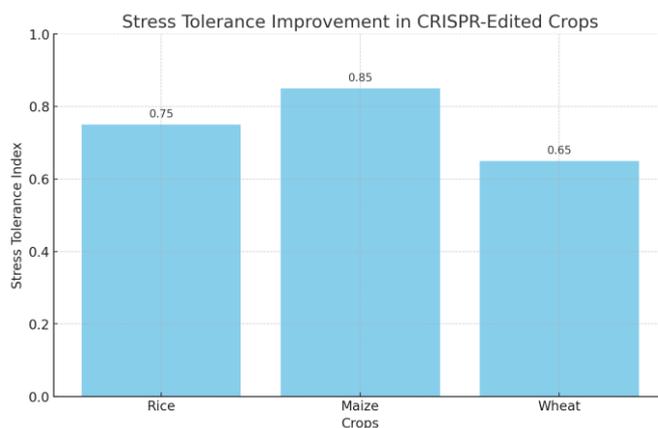


Fig 4. Stress tolerance improvement in CRISPR-edited crops: Rice, Maize, Wheat.

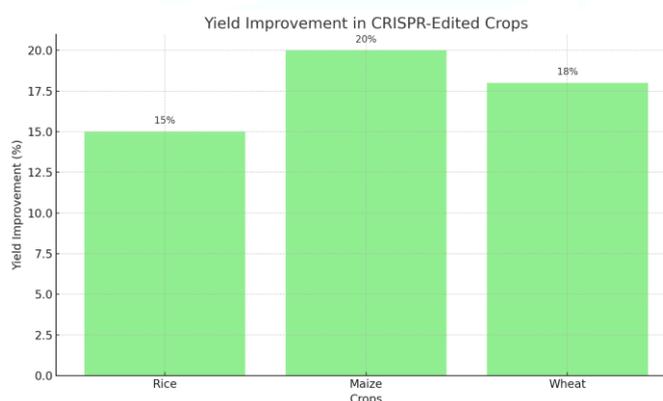


Fig 5. Yield improvement in CRISPR-edited crops: Rice, Maize, and Wheat.

Future applications with CRISPR/Cas knock-in system

Using CRISPR/Cas technology enhances gene manipulation because scientists can now insert target genes while adding beneficial agricultural traits. This insertion technology enables scientists to position desired genes at exact genome locations to improve plants with these benefits. Most plant insertion methods use HDR which brings less efficient results than NHEJ. Organizers of HDR genetics exploration now test ways to boost HDR efficiency to match real farming scale requirements through methods like dual mRNA systems and nanoparticle drug delivery techniques.

CONCLUSIONS

This review explores how CRISPR/Cas technology transforms crop production by making crops better in nutrition value and output while giving them stronger disease protections for maize and rice. CRISPR/Cas system now permits farmers to breed better crops by building resistance against diseases plus enhancing crops' stress-related behaviors to boost yields. Today the processes of gene editing deliver enhanced target performance while protecting against accidental damage while new usages of this technology are emerging. This involves base editing plus prime editing and numerous accurate Cas types. CRISPR/Cas technology helps these nutrition projects overcome global food problems by enhancing crop storage and malnutrition defenses primarily in developing

regions. New research should develop both HDR precision gains and improve CRISPR system functions along with resolving ethics concerns and integrating CRISPR methods with traditional agricultural programs. Organized research to build better crops resistant to climate will speed up the creation of dependable food production systems worldwide.

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