

AGRICULTURAL BIOTECHNOLOGY STRATEGIES FOR IMPROVING YIELD AND PEST RESISTANCE USING GENOME EDITING TOOLS

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ABSTRACT

Background: Environmental stressors, pest infestation and demands of sustainable food production systems are rapidly becoming a challenge to agricultural productivity.

Objective: The paper intends to consider the success rates of genome editing technologies, specifically the CRISPR-Cas systems in crop yielding enhancement and the resistance to pests.

Methodology: Databases like PubMed, Scopus and Web of Science were used to conduct a systematic review of published studies during 2018-2025. According to selection criteria, research articles that were identified were experimental research and field trials evaluating genome-edited crops.

Findings: Findings suggest that genome-edited crops would have an estimated 30-60 percent yield advantage and 40-80 percent less pest damage. CRISPR-based methods exhibited the highest level of efficiency owing to its accuracy in targeting genes and RNA interference proved to be very efficient in pest control. These technologies play a role in enhancing crop performance and decreasing the use of chemical pesticides.

Conclusion: Genome editing technologies are promising ways of improving the productivity and sustainability of agriculture. Further progress and sustainable application is imperative in solving the challenges which face food security across the world.

KEYWORDS: Genome editing, CRISPR-Cas, agricultural biotechnology, crop yield and pest resistance, RNA interference, sustainable agriculture

1 INTRODUCTION

The world food demand is growing at a startling rate at the same rate as population increases, urbanization and evolving diets, which puts the agricultural systems under huge pressures to produce more food [1]. Concurrently, crop yield is becoming more vulnerable to biotic stresses e.g. pests and diseases, and abiotic processes e.g. climate variation, drought and soil erosion [2]. It has been estimated that globally the percentage of crops that are lost to pests and diseases alone is estimated to be around 2040 every year which underscores the need to come up with some innovative agricultural solutions [3]. Although conventional plant breeding methods have played an important role in enhancing crops, they tend to be time consuming and lack specificity and hence they are not enough to address the prevailing farming demands [4].

Bio-technology in agriculture has become a potent instrument towards curbing these issues, and the genome editing technology is at the centre of the current crop-enhancing initiatives [5]. One of them is the CRISPR-Cas based systems that are transforming the face of biology in plants as they can do precise and efficient and cost-effective edits of the plant genome [6]. Genome editing contrasts with traditional genetic engineering: specific genes can be inserted, deleted, or modified, which improves the traits of yield, pest resistance, and stress tolerance, eliminating the need to work with foreign DNA [7]. This accuracy has increased the process of coming up with better varieties of crops which possess favorable agronomic traits.

Besides CRISPR, genome editing systems like transcription activator-like effector nucleases (TALENs) and zinc-finger nucleases (ZFNs) have facilitated site-specific genome editing, but are more complicated and are less commonly used [8]. RNA interference (RNAi) is also actively being investigated as a complementary technique to improve pest resistance via gene silencing of insect pests to reduce crop damage and dependence on chemical pesticides [9]. All these technologies are a move towards sustainable and environmentally friendly agricultural practices.

Most recent trends have shown that yield and resistance to pests can be greatly improved by the use of genome-edited crops. As an example, modifications facilitated by CRISPR have been demonstrated to double crop yield and decrease pest infestations by up to 60 and 80 per cent, respectively in some studies [10]. Moreover, genome editing is potentially becoming

connected with new, more powerful, technologies like artificial intelligence and high throughput phenotyping to align crop performance with different environmental conditions [11]. This is reshaping agriculture to become a more data-driven and precise field.

Though these advancements are promising, there are multiple challenges that are still there. Numerous countries have different regulatory laws and regulations on genome-edited crops, hindering their implementation on a global scale [12]. Besides, the issues of biosafety, off-target effects, and perceptions of the population remain to impact the uptake of these technologies [13]. To maximise the potential of genome editing in agriculture, it is necessary to address these challenges.

1.1 Research Gap

Albeit there is a large body of research examining individual genome editing technologies, there is a gap in examining HOGs together in the enhancement of crop yield and resistance to pests and our natural agriculture settings.

2. Genome Editing Strategies in Agriculture

Genome editing methods have revolutionized the agricultural industry of the modern era as plant genomes can now be accurately targeted to achieve higher productivity, pest-tolerance and overall crop tolerance. The strategies introduce effective and specific substitutes to the traditional breeding techniques, speeding up the creation of resistant crop types.

2.1 CRISPR-Cas Systems

CRISPR-Cas tools are the most popular genome editing tools available, because they are highly specific, efficient and user friendly. This technology enables precise gene editing to boost crop yield by altering genes involved in growth, productivity and resistance to stress [6]. Besides, CRISPR makes resistant crops against pests and controls damage inflicted by insects and pathogens by modifying the genes that are associated with plant defense mechanisms [10]. Its cost effectiveness and broad applicability, itself has rendered it a formidable instrument in biological techno agriculture [7].

2.2 TALENs and ZFNs

Previous genome editing tools are transcription activator-like effector nucleases (TALENs) and zinc-finger nucleases (ZFNs). The two technologies allow the site-specific editing of the DNA. These technologies operate through the formation of the breakages in the DNA in its two strands that enable the mutations of the genes to be inserted or deleted in a specific manner [8]. TALENs and ZFNs, though somewhat less versatile than CRISPR have been utilized successfully to enhance crop characteristics like yield, disease resistance, and stress tolerance by manipulating genes [14].

2.3 RNA Interference (RNAi)

RNA interference (RNAi) is a gene-silencing process that has become important in the control of pests. RNAi lowers the survival and multiplication rate by taking pests that are necessary to insects, thereby reducing crop wastage [9]. This strategy will greatly reduce the use of chemical pesticides, which will encourage environmentally friendly farming methods. RNAi has been generally used to control pests in crops like cotton and maize.

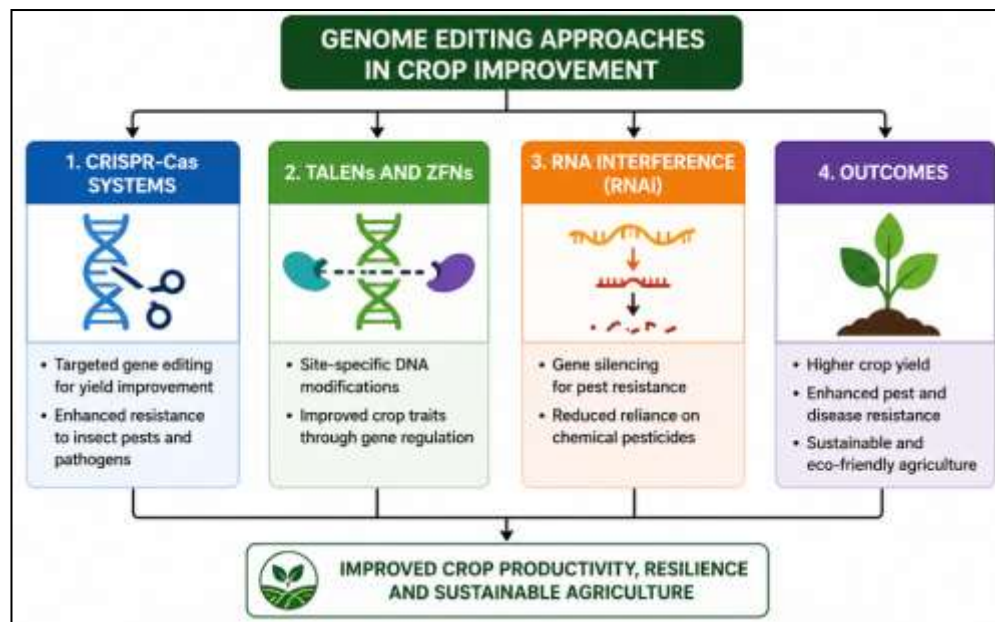


Figure 1: Genome Editing Approaches in Crop Improvement

This figure 1 shows the key systems of genome editing applied in agricultural biotechnology, such as CRISPR-Cas systems, TALENs, ZFNs, and RNA interference (RNAi). CRISPR is featured as the most developed and commonly used technology to target genes accurately, which would give a solution to increasing crop and resistance against pests and diseases. TALENs

and ZFN are depicted as the previous methods that provide the possibility to achieve a specific modification of DNA and control the gene. RNAi is presented as a form of silencing genes which have been used to increase the pest resistance by attacking insect genes. On the whole, the figure can be used to show the overall contribution of these technologies to the enhancement of crop productivity and sustainability, as well as decreased reliance on chemical pesticides.

3 METHODOLOGY

To assess the effectiveness of genome editing technology in enhancing crop yield and pest resistance, a systematic review was carried out. The review adhered to structured and standardized procedures that promote transparency, reproducibility and reliability of results [15]. There were three key scientific databases PubMed, Scopus, and Web of science, where the relevant studies have been searched during the period between 2018 and 2025. The search strategy was refined using key words like: genome editing, CRISPR, crop yield, pest resistance and agricultural biotechnology with the application of Boolean operators.

3.1 Inclusive and exclusive criteria

Reports have been chosen according to pre-established inclusion/exclusion criteria. Studies included were both experimental research and field trials, as well as comparative studies about genome-edited crops that seek to improve yield and pest resistance. The literature they had not included in the study were review papers that lacked any data collection and non-English articles and those that were published before 2018 as indicated in table 1.

Table 1: Study Selection Criteria

Criteria Type	Description
Inclusion	Experimental studies, field trials, comparative analyses
Exclusion	Reviews, non-English studies, pre-2018 publications
Databases	PubMed, Scopus, Web of Science
Time Frame	2018–2025

3.2 Data Extraction and Analysis

Data up till now were systematically mined out of chosen articles, comprising crop category, genome editing agent (CRISPR, TALENs, RNAi), trait being investigated (improvement in yield, decreased pests), and result measures (percent yield growth and reduction of pests). Quantitative data were divided into categories and compared to discover patterns and trends amongst various technologies.

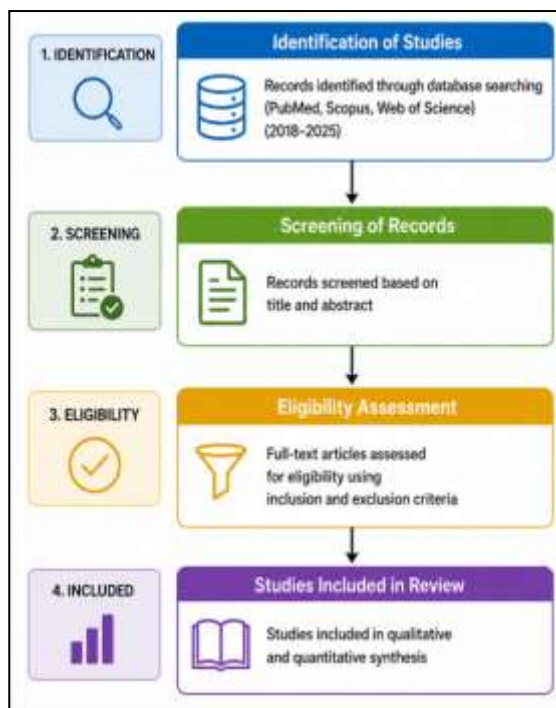


Figure 2: Methodological Flow of Study Selection

This figure 2 shows how the systematic review will occur, identifying studies in databases, select based on titles and abstracts, screening based on inclusion criteria, and ultimately selecting the studies to analyse, according to PRISMA.

3.3 Quality Assessment

Methodological quality of the chosen studies was determined with regards to the standardized evaluation criteria which included experimental design, sample size and data reliability. High methodological rigor studies were picked up to guarantee accuracy and validity of findings [16,17].

4 Dataset and Parameters

This research used experimental trials and field trials (20182025) as the dataset which concentrated on the genome-edited crops generated through the application of CRISPR, TALEN, and RNAi technologies. Peer-reviewed articles that were retrieved in PubMed, Scopus, and Web of Science were used to obtain data. As illustrated in table 2 important parameters were crop type, tool of genome editing applied, trait of interest (yield improvement or resistance to pests) and quantitative data (percentage improvement in yield and decreasing pest damage). A set of standardized variables was used to facilitate the ease of comparison and consistency among studies [16,17].

Table.2. Dataset Variables and Parameters

Parameter	Description
Crop Type	Rice, wheat, maize, cotton, soybean
Genome Editing Tool	CRISPR, TALENs, RNAi
Target Trait	Yield improvement, pest resistance
Stress/Pest Type	Insect pests, pathogens, environmental stress
Outcome Measures	Yield increase (%), pest reduction (%)
Study Type	Experimental studies, field trials

4 RESULTS & DISCUSSION

This study has shown that the genomes editing technologies are effective in boosting the yield and pest resistance of crops. Comparative analysis conducted in studies on CRISPR, TALENs and RNAi shows that these methods are greatly enhancing agricultural production and protection of crops. Such technologies help in higher yield production and decreased losses due to pests in diverse environmental conditions. The results reveal the increasing role of precision biotechnology in agriculture sustainability and its ability to minimize the use of traditional chemical compounds and enhance the overall crop health and productivity.

4.1 Yield Improvement in Genome-Edited Crops

Table 3: Yield Enhancement Using Genome Editing

Crop Type	Technology Used	Yield Improvement (%)	Key Outcome
Rice	CRISPR	40–60%	Increased grain production
Wheat	TALEN	30–50%	Improved biomass
Maize	CRISPR	35–55%	Enhanced growth rate
Soybean	RNAi	25–40%	Improved nutrient efficiency

The findings suggest that CRISPR-based genome editing has the most significant improvements in yield because it is well-targeted at growth and productivity genes. Rice and maize are realizing huge yield increments indicating successful gene modification plans indicated in table 3. TALEN technology has already led to increased wheat biomass whereas RNAi leads to higher nutrient efficiency in soybean. Altogether, these technologies show promising results in enhancing crop production by helping to focus on genetic interventions.

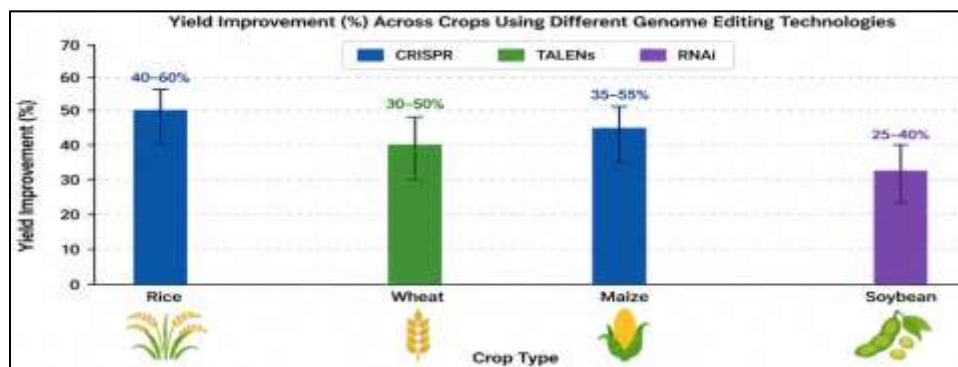


Figure 3: Yield Improvement by Genome Editing Technologies

This figure 3 provides a comparison on the yield improvement in various crops on the application of various genome editing methods. The gains of CRISPR are the greatest in rice (40 60%) and maize (35 55%), which underscores its effectiveness. TALENs show moderate increase in wheat (30-50%), and RNAi increase in soybean yield (25-40%). In general, the figure

highlights that genome editing effectively increases crop productivity, and CRISPR is the successful and most commonly used technology.

4.2 Pest Resistance Enhancement

Table 4: Pest Resistance Outcomes

Crop Type	Technology Used	Pest Reduction (%)	Target Pest
Cotton	RNAi	70–80%	Bollworm
Rice	CRISPR	60–75%	Stem borers
Maize	CRISPR	65–80%	Fall armyworm
Tomato	TALEN	50–65%	Whiteflies

The genome editing technologies mitigate the damage on pests in numerous crops to a high extent. The greatest success has been realized using RNAi in cotton, silencing genes associated with pests, causing significant decreases in bollworm. CRISPR-based applications boost plant defense systems in rice and maize whereas TALEN increases resistance in tomato as illustrated in table 4. These findings show how genome editing could decrease the reliance on chemical pesticides and enhance sustainable crop protection.

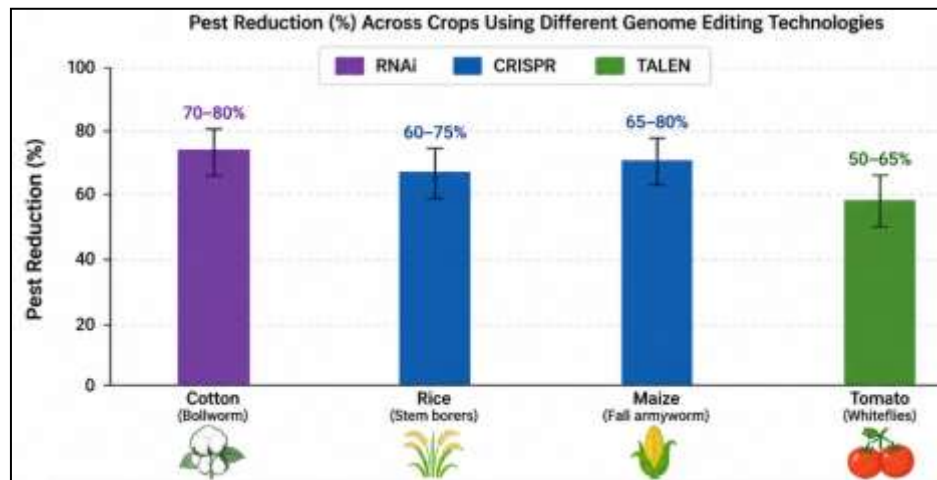


Figure 4: Pest Resistance Improvement Using Genome Editing

This figure 4 shows that the use of genome editing technologies has been effective in minimizing pest damages in crop. RNA interference (RNAi) demonstrates the greatest pest reduction in cotton (70-80%), whereas CRISPR leads to significant resistance in rice (60-75%), and in maize (65-80%). TALEN technology offers medium enhancement in tomato (50-65%). In general, the chart indicates that genome editing has a great potential to be sustainable and effective in managing pests involved in agriculture.

4.3 DISCUSSION

The findings confirm the paramount importance of genome editing technologies in contemporary biotechnology in agriculture by showing that they can greatly help in boosting crop productivity and resistance to pests. CRISPR-Cas systems become the most useful as they have precision, effectiveness and versatility in targeting particular genes related to growth and defense systems. RNA interference (RNAi) is also a way to have a sustainable method of controlling pests by silencing putrefaction-vital genes, thereby lessening dependence on chemical pesticides. Even with these benefits, bottlenecks like regulatory uncertainties, biosafety issues, and insufficient popular acceptance still cripple its broad acceptance. The barriers have to be dealt with to ensure that the benefits of the genome editing technologies applied to agriculture are reaped fully.

4.4 Future Directions

- Multi-trait genome editing strategies that can be used to simultaneously improve both yield and resistance developed.
- AI application to maximize the use of genes targeting and crop design.
- Increase in pest-resistant varieties of crops in different farm systems.
- Enhancing regulatory frameworks in order to implement safely and ethically.

5 CONCLUSION

The use of genome editing tools and more broadly, agricultural biotechnology is a disruptive solution to enhancing the productivity and resiliency of crops. CRISPR, TALENs, and RNA interference have shown significant potential practical use in improving yield and amplifying pest resistance. Such innovations allow to make accurate genetic alterations that do not

result in wastage of crops and a decrease in the reliance on the use of chemical pesticides among other factors contributes to the use of the environmentally sustainable farm practices. Nevertheless, issues concerning regulatory approval, biosafety, and perception issues need to be dealt with to facilitate wider adoption. Further developments of the subject matter should be aimed at the combination of various genome editing approaches and their enhancement in terms of efficiency and availability. In general, genome editing is incredibly promising in assisting with world food security and sustainable agricultural progress despite ever-increasing environmental and population concerns.

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