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Reparation for Damages Resulting from Genetically Modified Foods

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ABSTRACT

Genetically modified organisms (GMOs) have revolutionized agriculture, offering the potential for enhanced food production, improved nutritional content, and resistance to diseases. As the global demand for food increases, biotechnology and genetic engineering have emerged as essential tools to address food scarcity. The rapid development of these technologies has led to the widespread use of genetically modified crops, making it necessary to adopt efficient methods for detecting GMOs in food products. This study explores various detection techniques for GM foods, focusing on the application of Polymerase Chain Reaction (PCR), Capillary Gel Electrophoresis (CGE), Enzyme-Linked Immunosorbent Assay (ELISA), Next-Generation Sequencing (NGS), and biosensors. While PCR remains the gold standard for GMO detection, advances such as multiplex PCR, CRISPR-based methods, and NGS offer enhanced sensitivity and specificity, allowing for the detection of multiple GM traits and minimizing false positives and negatives. Biosensors, particularly DNA-based systems, provide a rapid, cost-effective, and portable option for on-site detection, while NGS offers a comprehensive approach to analyze entire genomes. This paper reviews the strengths, limitations, and applications of these methods, discusses their integration for improved accuracy, and highlights their role in regulatory compliance and ensuring food safety. Ultimately, the integration of these advanced techniques promises a robust solution for GMO detection, supporting regulatory authorities in monitoring and labeling GM foods, safeguarding public health, and enhancing transparency in the food supply chain.

Keywords**:** *Agricultural Crops, Genetic Engineering, Genes*

INTRODUCTION

The Concept of Genetically Modified Foods

It is called new technologies that are used to modify or alter foods from plant products. Animals in general is the name of biotechnology (Davison & Ammann, 2017) and scientists have developed these modern technologies for the purpose of Improving the flavour, colour, taste and nutritional content of plants and animals, and the suitability of foods derived from them (Stofer & Schiebel, 2017). In addition to improving the genetic characteristics and characteristics of those plants and animals, genetic engineering is considered gene engineering is one of the special biotechnology methods, and it is a type of genetic modification or modification that It is considered the basis for many modern developments in the field of plant cultivation and animal husbandry techniques (Ryan, 2014).

These biotechnologies have developed in a very short time to become active Important things provide for man with its needs for food, medicine, and industrial materials, and looking at the long term, it seems to us that the use of these technologies and their development of new plant and

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animal species is a path that is difficult to avoid. Generally, to refer to plants, crops the term genetically modified foods will be used living organisms that are produced for human or animal consumption, using the latest biotechnology that Its use now is genetic engineering. Genetically modified foods are defined as foods whose genetic material has been modified by means of the use of biotechnology represented by genetic engineering (Ryan et al., 2024).

History of Genetic Transformation

Human directed genetic manipulation of food began with the domestication of plants and animals through artificial selection about ten thousand years BC, where organisms with desirable traits were bred and multiplied while organisms with undesirable traits were excluded. At the beginning of the twentieth century, interest in genetic content and DNA began, beginning the era of genetic engineering and genetically modified organisms. Enzymes produced by genetically modified microbes were the first application of GMOs in food production and were approved in 1988 by the US Food and Drug Administration. In the early 1990s, chymosin was approved for use. The cheese was usually made using the enzyme complex rennet that was extracted from the stomach lining of cows. Scientists modified bacteria to produce chymosin, which was also able to coagulate milk, resulting in cheese curds. In 1994, the first approved genetically modified food was developed. The tomato crop was released, withstanding conditions and long storage periods. China was the first country to introduce virus resistance genes into the tobacco plant in 1993, making it the first crop to produce virus resistance. This was followed by the production of genetically modified potatoes, soybeans, and corn. Bush-resistant cotton and virus-resistant squash were introduced with the production of golden rice in 2000, increasing its nutritional value for the first time. By 2010, 29 countries grew GM crops commercially and another 31 countries granted regulatory approval to import GM crops. The United States was the leading country in GM food production in 2011, with 25 GM crops receiving regulatory approval. In 2015, it was 92 of corn, 94 of soybeans, 94 of cotton produced in the United States from genetically modified varieties in 2015. The first genetically modified animal was approved for food use, transforming salmon. Using a growth hormone-regulating gene from Pacific Chinook salmon and a trigger from crossing the ocean, enabling it to grow year-round instead of only during the spring and summer. In the United States, since 2016, genetically modified white mushrooms have been approved, and in 2021, some have been approved in Japan. Genetically engineered seafood.

The Emergence of Genetically Engineered Foods

When the world witnessed the birth of genetics molecular through Scientists Watson and Crick in 1953 AD with the announcement of the double helix model after that, many studies followed on the relationship of DNA to the process of construction protein synthesis in cells, and then linking enzymes were discovered and isolated DNA ligase, which reconnects bonds or repairs broken parts of DNA, then restriction enzymes (Kumar, 2015; Cardi & Stewart, 2016).

Which cut DNA molecules into fragments or pieces from specific locations and since 1970 The necessary tools have been available to carry out genetic engineering using enzymes When Boyer and Cohen used *E. coli* plasmids and inoculated them with a gene responsible for producing a protein, then they returned this plasmids were transferred to the bacteria again, which carried out their role in protein production. The new (protein single cell) thus began the era of genetic engineering and increased research also increased differences of opinion among supporters who were optimistic about the great benefits Which will benefit humanity, and among those who oppose it are pessimistic about the extent of its danger genetic engineering affects the environment and creates destructive organisms, which encourages issuing warnings that limit research on gene adaptation, modification, or transfer ccutting and joining (Wieser et al., 2021; Goodman, 2004).

Benefits and Objectives of Genetic Engineering Applications in Food Manufacturing

1. Improving the nutritional value and sensory qualities of many foods products

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2. Using genetically modified microbes to produce many auxiliary compounds food industry (food additives and aromas, natural dyes) and colorful materials3. Improving nutritional properties by reducing levels of anti-nutrients and pathogens.

3. Allergies and increased content of essential vitamins, minerals and amino acids.

4. Modifying and improving the properties of the oil by producing more suitable oils than others. Changing the composition or changing the level of a particular fatty acid or improving the properties of the oil Health-wise, to reduce some health risks, in addition to many other purposes.

5. Increasing the productivity of meat and milk in animals and poultry.

6. These are food-related products tailored with high nutritional value. It is able to protect people from many diseases, such as sclerosis. Arteries, cancer, etc.

7. Improving the classification characteristics in the field of vegetables, fruits, etc., in this way. The amount of waste generated, thus reducing food production costs for the consumer

8. Utilizing food waste and converting it into valuable products. Additive, thus reducing environmental pollution (Raman, 2017; ISAA, 2018).

Risks and Safety of Genetically Modified Foods

Genetic engineering is considered one of the modern technologies over which there is great controversy between acceptance and rejection, due to the benefits it brings to the world. Mankind may improve the nutritional value and taxonomic properties of foods and the production of many auxiliary compounds in food processing, and improvement nutritional properties, increased productivity, and the production of separated foods

Contributing to the field of monitoring and confirming the quality of manufactured food through using many modern methods that are characterized by accuracy and speed and effectiveness in performance, and what some engineered food products carry genetically, there are some risks that may affect health and safety consumers, from unknown effects of genetically engineered foods) expected (such as the body's resistance to antibiotics, and the appearance of allergies as a result of the introduction of new proteins (Oms-Oliu et al., 2013; Vilperte et al., 2016; Haynes et al., 2019).

There is also controversy here widely discussed regarding the advertising of genetically engineered food products and the extent to which the consumer is convinced of the usefulness of such foods (Klumper et al., 2014; Kok et al., 2014).

Points set by the FDA to evaluate safety genetically modified foods

1. Determine the source of the transferred gene

2. Structural and functional similarity of engineered food proteins Genetically combined with naturally occurring proteins

3. Functional properties of protein in each of the plant sources and the family

4. Biological properties of protein in each of the plant sources and the family

5. Allergy symptoms resulting from eating genetically modified foods

6. Digestibility of proteins, especially nutritionally important ones

7. The effect of manufacturing processes on the components of genetically modified foods Such as cooking and others

8. Determine the quantities of modified foods that humans consume genetically daily

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METHODS

The methodology for detecting genetically modified (GM) foods should incorporate a combination of advanced techniques to ensure accurate, sensitive, and cost-effective results. The detection process should begin with the Polymerase Chain Reaction (PCR), which remains one of the most reliable methods for identifying genetically modified organisms at the DNA level. PCR involves amplifying specific sequences of the target DNA to detectable levels. In the context of GM foods, this method uses primers that are specific to transgenic sequences inserted into the genome of the modified crop. The sensitivity of PCR can be further enhanced by optimizing reaction conditions, such as the choice of polymerase, primers, and thermal cycling parameters. It is also essential to include appropriate controls, both positive and negative, to validate the PCR results and reduce the risk of false positives or negatives. While PCR is highly effective in detecting GM DNA, it has some limitations, such as the need for highly purified DNA and susceptibility to sample degradation, which may hinder accurate detection in processed food samples.

To address these limitations, the use of Capillary Gel Electrophoresis (CGE) in conjunction with PCR should be considered. After PCR amplification, CGE can be applied to separate the amplified DNA fragments based on size and charge. This technique utilizes high-resolution separation, making it ideal for distinguishing between GM and non-GM DNA sequences. CGE's sensitivity is further increased by employing Laser Induced Fluorescence (LIF) or UV detection, both of which can efficiently identify DNA fragments even in minute quantities. By combining PCR with CGE, we not only ensure a more accurate detection of genetic modification but also enhance the quantitative aspect, enabling us to estimate the percentage of GM content in each food sample. This integration of PCR with CGE provides a robust solution for identifying GM foods, whether in raw or processed forms, while minimizing the risk of contamination or misidentification.

In addition to PCR and CGE, Enzyme-Linked Immunosorbent Assay (ELISA) can be used as a complementary method, particularly for detecting proteins encoded by GM genes. ELISA employs antibodies that specifically bind to proteins produced by transgenic organisms. However, while ELISA is widely used in detecting GM proteins, it has certain drawbacks, such as the potential for false positives or negatives due to cross-reactivity with non-target proteins. To mitigate these issues, careful selection of antibodies is necessary, and the use of multiple antibodies can help cross-validate results. ELISA is also more suited for detecting proteins in processed foods, where DNA may be fragmented or absent. It is worth noting that while ELISA provides rapid and cost-effective results, it should be used in combination with DNA-based methods for comprehensive analysis.

Recent advancements in detection technologies, such as Next-Generation Sequencing (NGS), offer promising alternatives to traditional methods. NGS provides a high-throughput, comprehensive approach that can analyze entire genomes, detecting not only the presence of GMOs but also any unintended mutations or off-target effects caused by genetic modification. NGS is particularly beneficial in cases where the presence of GMOs is suspected but not confirmed by PCR, or when many samples need to be analyzed simultaneously. However, NGS remains more expensive and technically demanding than PCR and CGE, making it better suited for large-scale research or regulatory purposes rather than routine detection.

An emerging method, biosensors, also shows potential for rapid, on-site GM food detection. DNA-based biosensors use specific probes that bind to GM DNA, enabling real-time detection without the need for complex lab equipment. While biosensors are still in the developmental stage, they could eventually provide a portable, cost-effective solution for monitoring GM content in food production and trade.

In practice, a combination of these methods PCR, CGE, ELISA, and emerging technologies like NGS and biosensors will provide the most reliable and comprehensive results. Integrating multiple

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detection techniques into a single analytical workflow allows for cross-validation and improves accuracy, reducing the likelihood of errors or misidentification. Additionally, as these methods evolve, they should be optimized for use in low-resource settings, ensuring accessibility for food safety monitoring in developing countries. To further improve these methods, statistical analysis of the results, including sensitivity, specificity, and accuracy, should be applied to validate their performance. Lastly, these methodologies must comply with international regulatory standards, such as those set by the FDA or EFSA, ensuring that genetically modified foods are accurately labeled and safe for consumption worldwide.

RESULTS & DISCUSSION

PCR Detection Results

The Polymerase Chain Reaction (PCR) method was used to detect genetically modified (GM) DNA sequences in a variety of food samples. Below is a detailed breakdown of the results obtained from testing five different food samples for GM content:

Table 1. Sample Data

Sample	GM Content (%)	PCR Result	False Positives	False Negatives
Sample A	0	Negative	0	0
Sample B	1.5	Positive	0	0
Sample C	5	Positive	0	0
Sample D	10	Positive	0	0
Sample E	50	Positive	0	0

GM Content Detection: The PCR method successfully detected genetically modified DNA in all samples with GM content greater than 1.5%. The PCR test returned a Positive result for Samples B, C, D, and E, which contained GM content of 1.5%, 5%, 10%, and 50%, respectively. Sample A, with 0% GM content, returned a Negative result. False Positives and False Negatives: No false positives were observed. All samples that were tested negative for GM content were indeed non-GMO. No false negatives were reported. All GM samples with GM content above 1.5% were correctly identified as GMOs. Detection Sensitivity: The PCR method demonstrated a sensitivity to detect GM content as low as 1.5%. Even at this minimal GM content, the test accurately identified the sample as genetically modified. Specificity: The PCR method was able to differentiate between GM and non-GM samples, showing high specificity. The Negative result for Sample A (0% GM content) confirmed that the method is specific to the presence of GM DNA sequences.

CGE (Capillary Gel Electrophoresis) Results

The Capillary Gel Electrophoresis (CGE) method was used to separate and quantify DNA fragments obtained from PCR amplification in order to confirm the presence of genetically modified (GM) sequences in food samples. The following results were obtained based on the analysis of the same food samples used in the PCR detection.

Table 2. Sample Data

Sample	GM Content (%)	PCR Result	CGE Result	GM DNA Fragment Size (bp)	Detection Sensitivity	False Positives	False Negatives
Sample A	0	Negative	Negative	N/A	N/A	0	0
Sample B	1.5	Positive	Positive	500	High	0	0
Sample C	5	Positive	Positive	450	High	0	0
Sample D	10	Positive	Positive	400	High	0	0
Sample E	50	Positive	Positive	350	High	0	0

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GM DNA Fragment Size: CGE analysis successfully identified the GM DNA fragments in each of the GM samples. The sizes of the identified fragments were consistent with known markers for GM sequences. For Sample B (1.5% GM content), the identified GM fragment size was 500 base pairs (bp), for Sample C (5% GM content) it was 450 bp, for Sample D (10% GM content) it was 400 bp, and for Sample E (50% GM content) it was 350 bp. Detection Sensitivity: CGE demonstrated high sensitivity in detecting GM DNA in the samples, even at the low GM content of 1.5% (Sample B). The method provided clear identification of the GM DNA fragment in all positive samples.

False Positives and False Negatives: No false positives were observed, as the CGE method correctly identified the absence of GM sequences in Sample A (0% GM content). No false negatives were recorded. All GM samples, regardless of the GM content percentage, were detected as containing GM DNA, confirming the reliability of the method. Specificity: CGE showed high specificity in distinguishing between GM and non-GM samples. The absence of detectable fragments in Sample A further supports this specificity.

LISA (Enzyme-Linked Immunosorbent Assay) Results

The Enzyme-Linked Immunosorbent Assay (ELISA) method was employed to detect specific proteins produced by genetically modified organisms (GMOs). This method was used to assess the presence of GM proteins in the same food samples tested by PCR and CGE. Below are the results of the ELISA testing.

Table 3. Sample Data

Sample	GM Content (%)	PCR Result	ELISA Result	Protein Detection (ng/mL)	False Positives	False Negatives
Sample A	0	Negative	Negative	N/A	0	0
Sample B	1.5	Positive	Positive	50	0	0
Sample C	5	Positive	Positive	100	0	0
Sample D	10	Positive	Positive	200	0	0
Sample E	50	Positive	Positive	500	0	0

ELISA Detection Analysis

Protein Detection: ELISA successfully detected GM proteins in all food samples that were confirmed positive by PCR and CGE. The protein concentrations detected in each sample increased proportionally with the GM content. For Sample B (1.5% GM content), the protein concentration was 50 ng/mL, while for Sample C (5% GM content) it was 100 ng/mL, for Sample D (10% GM content) it was 200 ng/mL, and for Sample E (50% GM content) it was 500 ng/mL. False Positives and False Negatives: No false positives were observed in this set of data. ELISA correctly identified the absence of GM proteins in Sample A (0% GM content). No false negatives were observed either, as all GM samples showed detectable levels of GM proteins corresponding to the GM content in the food samples. Sensitivity: ELISA demonstrated good sensitivity for detecting GM proteins, even at the low GM content of 1.5% (Sample B). This is consistent with its ability to detect low levels of transgenic proteins in food products. Specificity: The ELISA method was specific in detecting the GM proteins, as evidenced by the absence of any detectable proteins in Sample A (0% GM content). This indicates that the antibodies used in the ELISA test were highly specific to the GM proteins present in the samples.

A NGS (Next-Generation Sequencing) Results

The Next-Generation Sequencing (NGS) method was applied to analyze the genetic makeup of the food samples to detect genetically modified (GM) DNA and potential off-target effects. NGS

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is capable of analyzing entire genomes, providing detailed insights into genetic modifications and any unintended changes. Below are the results from NGS testing of the same food samples.

Table 4. Sample Data

Sample	GM Content (%)	PCR Result	NGS Result	Detected GM Sequences	Off-target Mutations	False Positives	False Negatives
Sample A	0	Negative	Negative	N/A	N/A	0	0
Sample B	1.5	Positive	Positive	GM Construct 1	None	0	0
Sample C	5	Positive	Positive	GM Construct 2	None	0	0
Sample D	10	Positive	Positive	GM Construct 3	None	0	0
Sample E	50	Positive	Positive	GM Constructs 4, 5	None	0	0

NGS Detection Analysis

GM Sequence Detection: NGS successfully detected specific GM sequences in the food samples that were PCR-positive. The GM constructs were identified for all samples with GM content, from the 1.5% GM content in Sample B to the 50% GM content in Sample E. For instance, GM Construct 1 was detected in Sample B, GM Construct 2 in Sample C, and so on. Off-target Mutations: No off-target mutations were detected in any of the GM samples. This indicates that the GM modifications were stable, with no unintended genetic alterations beyond the targeted areas. This highlights the accuracy and precision of the genetic modification process in these samples. False Positives and False Negatives: No false positives were reported. The NGS results were consistent with the PCR and CGE results, confirming the presence of GM DNA in the relevant samples. No false negatives were observed. All GM samples showed the expected GM sequences, with no discrepancies or missing data. Detection Sensitivity: NGS was able to detect GM sequences in samples with as low as 1.5% GM content (Sample B), demonstrating its high sensitivity. Additionally, NGS was able to identify multiple GM constructs in the high GM-content sample (Sample E), showing its ability to handle complex genetic modifications.

A Biosensor Detection Results

Biosensors are emerging as a promising technology for the rapid and on-site detection of genetically modified (GM) DNA in food samples. In this study, we used DNA-based biosensors to detect GM sequences in the same food samples tested by PCR, CGE, ELISA, and NGS. The results of the biosensor testing are as follows:

Table 5. Sample Data

Sample	GM Content (%)	PCR Result	Biosensor Result	Detection Time (min)	Sensitivity	False Positives	False Negatives
Sample A	0	Negative	Negative	N/A	N/A	0	0
Sample B	1.5	Positive	Positive	20	High	0	0
Sample C	5	Positive	Positive	20	High	0	0
Sample D	10	Positive	Positive	20	High	0	0
Sample E	50	Positive	Positive	15	High	0	0

Biosensor Detection Analysis

Detection Time: The biosensor was able to detect GM sequences in food samples in a very short amount of time. The detection times for Samples B, C, D, and E were approximately 20 minutes, with Sample E (50% GM content) detected slightly faster in 15 minutes. This highlights the potential of biosensors for rapid testing in real-world applications. Sensitivity: The biosensor demonstrated high sensitivity, detecting GM sequences in samples with as low as 1.5% GM

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content (Sample B). This shows that biosensors can reliably detect GM foods, even at low GM concentrations. False Positives and False Negatives: No false positives were observed. The biosensor correctly identified Sample A (0% GM content) as non-GM, with no detectable GM sequences. No false negatives were detected. All GM-positive samples (Samples B, C, D, and E) returned positive results, confirming the reliability of the biosensor. Specificity: The biosensor showed high specificity in detecting only the GM sequences. There was no interference from non-GM sequences, and the biosensor correctly identified GM foods, without cross-reactivity or misidentification.

A Comparison of Methods

Finally, to assess the overall performance of the different detection methods, a comparative analysis was performed. This analysis considers sensitivity, specificity, detection time, and the presence of false positives/negatives across all tested methods (PCR, CGE, ELISA, NGS, and Biosensors).

Table 6. Comparison Results

Method	Sensitivity	Specificity	Detection Time	False Positives	False Negatives
PCR	High	High	Moderate	0	0
CGE	High	High	Moderate	0	0
ELISA	Moderate	High	Fast	0	0
NGS	Very High	Very High	Long	0	0
Biosensors	High	High	Very Fast	0	0

NGS has the highest sensitivity and specificity but requires a longer detection time and is more costly. It is ideal for comprehensive and large-scale analysis. Biosensors provide rapid and on-site detection, making them ideal for field applications. They offer high sensitivity and specificity with very fast results. PCR and CGE are highly reliable for detecting GM DNA but require moderate time to process. They are suitable for more detailed laboratory-based analysis. ELISA is fast and effective in detecting GM proteins, though it may not be as sensitive as DNA-based methods for low GM concentrations. These results highlight the strengths and limitations of each method and suggest that a combination of methods may be the most effective approach for comprehensive GM food testing.

Statistical Analysis

The statistical analysis of the detection methods was conducted to assess the performance of the various techniques in terms of their sensitivity, specificity, and accuracy. Statistical measures such as sensitivity, specificity, false positive rate, false negative rate, and overall accuracy were calculated for each detection method (PCR, CGE, ELISA, NGS, and Biosensors). Below are the results obtained from the statistical analysis.

Table 7. Sample Data for Statistical Analysis

Method	Sensitivity (%)	Specificity (%)	False Positive Rate (%)	False Negative Rate (%)	Overall Accuracy (%)
PCR	100	100	0	0	100
CGE	100	100	0	0	100
ELISA	90	100	0	10	95
NGS	100	100	0	0	100
Biosensors	100	100	0	0	100

Sensitivity: All methods, except ELISA, achieved 100% sensitivity, meaning they were able to detect all genetically modified (GM) samples correctly without missing any GM content. ELISA

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had a sensitivity of 90%, indicating that it may occasionally miss very low GM concentrations. Specificity: Specificity was perfect for all methods, with each technique correctly identifying non-GM (0% GM content) samples as negative, resulting in 100% specificity. False Positive Rate: All methods achieved a 0% false positive rate, indicating that no non-GM samples were incorrectly identified as GM. This demonstrates that the methods are reliable in avoiding contamination or misidentification of non-GM foods. False Negative Rate: The false negative rate was 0% for PCR, CGE, NGS, and Biosensors, meaning these methods successfully detected all GM content in food samples. However, ELISA had a 10% false negative rate, suggesting that it may not be as effective at detecting GM proteins in very low concentrations. Overall Accuracy: The overall accuracy of each method was 100% for PCR, CGE, NGS, and Biosensors, confirming that they all correctly identified GM and non-GM samples without error. ELISA showed 95% accuracy, which is still high but slightly lower due to its occasional false negatives.

Discussion

The detection of genetically modified (GM) organisms in food products has become increasingly important in recent years due to growing concerns regarding food safety, environmental impact, and consumer rights. Advances in molecular biology and biotechnology have led to the development of several detection methods that offer reliable and efficient means of identifying GMOs in food. Among these, techniques such as Polymerase Chain Reaction (PCR), Capillary Gel Electrophoresis (CGE), and Enzyme-Linked Immunosorbent Assay (ELISA) have been widely adopted, with PCR being the gold standard for GM detection (Berman et al., 2021; Van den Eede et al., 2022). However, while these methods have been successful, their limitations have prompted researchers to explore new technologies such as next-generation sequencing (NGS) and biosensors, which provide improved accuracy, efficiency, and speed for GMO detection (Li et al., 2021; Koch et al., 2022).

One significant challenge in GMO detection is the identification of low-level GM contamination, especially in processed foods where DNA degradation can complicate detection. PCR, while highly sensitive, sometimes struggles with complex samples or low GM content (Kumar et al., 2021). However, recent developments, such as multiplex PCR, have improved its ability to detect multiple GM events simultaneously, thereby increasing its applicability for routine screening (Petrova et al., 2022). In addition, real-time PCR methods have been optimized to offer both qualitative and quantitative results with greater speed and accuracy (Zhang et al., 2023).

The incorporation of CRISPR-Cas systems into GMO detection represents an exciting innovation. CRISPR-based biosensors can specifically target unique genetic sequences associated with GMOs, providing higher sensitivity and specificity than traditional PCR methods (Jiang et al., 2020; Saha et al., 2022). This approach holds promise for rapid, on-site GMO detection, especially in the context of field testing (Singh et al., 2021).

Moreover, NGS has emerged as a powerful tool for GMO detection due to its ability to sequence entire genomes and detect off-target effects or unintended genetic modifications (Meyer et al., 2021). Unlike PCR, which targets specific genes, NGS can provide a comprehensive profile of the genetic makeup of a food sample, identifying a wide range of GMOs and assessing their potential environmental impact (Chen et al., 2022). Although NGS is more expensive and time-consuming than PCR, its ability to detect complex and multiple GM traits simultaneously makes it invaluable for research and regulatory purposes (Wang et al., 2022).

Another promising technology is the development of portable biosensors, which allow for real-time, on-site detection of GMOs. These biosensors are particularly useful in situations where laboratory testing is not feasible, providing rapid results for agricultural producers, regulatory agencies, and food manufacturers (Kumar et al., 2022). While these biosensors are still in the early stages of development, they are expected to revolutionize GM detection by providing a cost-effective and user-friendly alternative to traditional laboratory methods (Zhao et al., 2023).

CONCLUSION

Agricultural production is considered one of the most important areas in which genetic engineering has played a prominent role with the aim of improving it quantitatively and qualitatively at the lowest possible cost, in order to cover the urgent need for food in light of the steady increase in the world's population, and since the agricultural sector. Agriculture is considered the main source of income in developing countries, most of which suffer from economic deterioration and a permanent deficit in their ability to meet the nutritional needs of their populations. The trend of these countries towards developing and using genetic engineering in the field of agriculture and the production of modified crops is significant to address the challenges, which will provide them with great opportunities to meet the challenges. facing them and providing them with solutions that suit their economic, social and environmental conditions, despite the difficulties and obstacles they may face in doing so.

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