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Application and Prospect of Genetically Modified Technology in Agriculture

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Abstract This study focuses on exploring the application and prospects of genetically modified technology in the agricultural field. Starting from the definition and historical background of genetically modified technology, the challenges and needs faced by agriculture were analyzed. The basic principles and methods of genetically modified technology encompass basic knowledge such as DNA, genes, and genomes, as well as major technical means such as gene cloning and gene editing. The application of genetically modified technology in agriculture involves multiple fields, including the research and development of insect resistant and disease resistant crops, improving salt alkali tolerance and adaptability to adversity, and cultivating crops rich in nutrients. Transgenic technology increases production and has the effect of improving storage and transportation tolerance. This study analyzes the advantages of genetically modified technology in agriculture, such as increasing yield, reducing pesticide use, and conserving resources. It also explores related controversies, such as environmental risks and food safety. The future development of genetically modified technology requires special attention to the application of emerging gene editing technologies such as CRISPR-Cas9, as well as the trend of sustainable agriculture and ecological balance. We have a deep understanding of the application and advantages of genetically modified technology in agriculture, and have highlighted key issues and directions for future development. Our aim is to provide scientific basis for the research direction of genetically modified technology in the agricultural field.

Keywords Genetically modified technology; Agricultural applications; Advantages and controversies; Sustainable development; Gene editing techniques

Genetically modified technology, also known as genetic engineering technology, is a biotechnology that introduces exogenous genes into target organisms to alter their genetic characteristics (Ryding et al., 2001). This technology began to emerge in the early 1980s, bringing profound impacts to fields such as agriculture, medicine, and the environment. By introducing genes from different species, genetically modified technology has broken through the limitations of gene transmission between natural species, creating organisms that can resist diseases and pests, withstand adversity, and increase yield for humans. This has had a revolutionary impact on agricultural production methods and food supply chains.

With the continuous growth of global population, agricultural production is facing increasingly severe challenges. Traditional agricultural models are affected by various factors such as climate change, soil impoverishment, and invasion of diseases and pests. These issues not only limit crop growth and yield, but also pose a threat to crop quality and food safety. In addition, the reduction of arable land and the shortage of water resources have also made it difficult for traditional agriculture to meet the sustained growth of food demand.

This study aims to comprehensively explore the application and prospects of genetically modified technology in the agricultural field. Due to the challenges faced by traditional agriculture, we will focus more on issues such as climate change, pests and diseases, and resource shortages, thus highlighting the potential of genetically modified technology in addressing these issues. The specific application of genetically modified technology in agriculture cannot ignore the advantages and controversies it brings, balancing its positive impact and potential risks. This study will look forward to the future development of genetically modified technology, with special attention to emerging gene editing technologies and their applications in sustainable agriculture. By summarizing existing research and perspectives, we will emphasize the importance of genetically modified technology in addressing global agricultural challenges and promoting sustainable agricultural development.

1 Basic Principles and Methods of Genetically Modified Technology

1.1 Basic knowledge of DNA genes and genomes

As a cutting-edge field of modern biotechnology, the core of genetically modified technology lies in modifying the genome of organisms to achieve changes in specific traits (Prather et al., 2003). In this process, a deep understanding of the basic knowledge of DNA genes and genomes is crucial. DNA (deoxyribonucleic acid), as a carrier of genetic information, forms the basis of the genetic code with its double helix structure and base pairing rules. Genes are functional units on DNA that carry genetic information encoding biological traits and functions. The genome is a collection of all genes within an organism, which is the sum of the genetic characteristics of the organism and determines the external morphology, physiological function, and behavioral characteristics of an individual.

Genetically modified technology utilizes these characteristics of genes to achieve the introduction or modification of target characteristics. Taking golden flowers as an example, their petals contain purple pigment genes and yellow pigment genes. Through transgenic technology, the purple pigment gene can be isolated and cloned from purple plants, and then introduced into yellow golden flowers, causing changes in petal color. This process utilizes the characteristics of genes and achieves new flower color traits by altering the genome of golden flowers.

In genetically modified technology, understanding the composition and role of genes is crucial for the successful development of genetically modified crops. By cloning, editing, and integrating specific genes, scientists can introduce new traits into different organisms, thereby improving crop disease resistance, stress tolerance, and yield. Understanding the genome also helps scientists better understand the genetic mechanisms of organisms, thereby enabling more precise gene editing and regulation. Understanding the basic knowledge of DNA, genes, and genomes is the foundation for in-depth exploration of genetically modified technology, which provides strong theoretical and methodological support for scientists to develop new types of genetically modified crops and solve agricultural problems.

1.2 Main methods of genetically modified technology

Genetically modified technology is a method of introducing new genes or modifying existing genes in organisms to achieve specific goals of biological modification. Among them, gene cloning and gene editing are two main and critical methods, which have led to revolutionary changes in the fields of bioscience and agriculture.

Gene cloning is the process of replicating specific genes from one organism and introducing them into another, enabling the target organism to acquire certain traits or functions of the source organism. This process typically involves creating recombinant DNA and then inserting it into the host cell to express it in the host cell. Ultimately, the target organism will exhibit similar characteristics to the source organism. The Golden Rice Project is a typical gene cloning application. Scientists have identified the β- Introducing carotene synthesis genes into rice to produce more β- Carotenoids increase the nutritional value of rice. This method can help solve the problem of vitamin A deficiency in children in some developing countries.

Gene editing is a method of directly modifying the genome of an organism to achieve specific traits. CRISPR-Cas9 is a commonly used gene editing technique that allows scientists to accurately locate and edit gene sequences. This can include deleting harmful genes, inserting beneficial genes, or simply changing specific parts of genes. In the field of medicine, gene editing is used to treat hereditary diseases. For example, a disease called spinal muscular atrophy is caused by a lack of specific genes. Scientists use gene editing technology to insert normal gene sequences into patients' cells to restore normal protein production and alleviate disease symptoms.

2 Application of Genetically Modified Technology in Agriculture

The wide and diverse application of genetically modified technology is of great significance in addressing the many challenges faced by global agriculture. However, in practical applications, it is also necessary to balance technological progress with considerations such as food safety and environmental protection, in order to ensure that the application of genetically modified technology can have a positive impact in practice.

2.1 Development of insect and disease resistant crops

Agricultural production is often invaded by pests, causing huge agricultural losses and disrupting ecological balance. To address this challenge, genetically modified technology has emerged (He et al., 2022). By introducing insecticidal protein genes from bacteria into crops in the future, crops will produce these insecticidal proteins during their growth process, thereby exhibiting stronger resistance to pest infestation. This technology not only reduces the use of pesticides, reduces environmental pollution, but also improves the quality of agricultural products. For example, an insect resistant gene introduced into genetically modified maize comes from a bacterium called “Bacillus”, which enables maize to effectively resist the invasion of pests such as corn borers.

The infection of crops by viruses also causes huge agricultural losses. Genetically modified technology can quickly produce antiviral proteins in crops when threatened by viruses by introducing antiviral protein genes, thereby reducing the impact of virus damage. This method not only enhances the resistance of crops, but also helps to maintain the sustainable development of agriculture. For example, genetically modified watermelons have been endowed with antiviral protein genes, enabling them to resist the invasion of viruses such as cucumber mosaic virus.

2.2 Improving salt alkali resistance and adaptability to adversity

Globally, due to excessive cultivation and unreasonable irrigation, more and more farmland is being affected by salinization. Salinized land has become unsuitable for cultivation, severely limiting crop growth and yield. In order to solve this problem, genetically modified technology has been widely applied to improve the salt alkali tolerance and stress adaptability of plants. By introducing salt alkali tolerant genes, crops can survive and grow under these harsh environmental conditions.The introduction of salt alkali tolerant genes (betaine synthesis genes, HAL3 genes, etc.) into plants enables their expression to resist the effects of salt alkali environments. These genetically modified plants can grow and achieve high yields in soils with up to half the salt content of seawater.

The introduction of stress adaptation genes also enables crops to better cope with extreme temperatures, droughts, and other adverse environmental conditions. When genes related to stress adaptation are introduced into plants (such as drought, high salt, low temperature resistance genes), the expression of these genes enables plants to better adapt and grow normally when facing various stress conditions. These genetically modified plants have a higher survival rate and yield under adverse conditions compared to non genetically modified plants, thereby increasing crop yield and stability.

2.3 Cultivation of nutrient intensified crops

In some developing countries, a lack of sufficient vitamins and minerals in the diet leads to malnutrition and health problems. Genetically modified technology can be used to cultivate nutrient fortified crops that are rich in specific vitamins, minerals, or other nutrients. This method helps to alleviate malnutrition and improve people's health status. For example, the introduction of genetically modified rice β- The carotene synthesis gene causes it to produce carotene, thereby increasing the vitamin A content of rice and helping to alleviate the problem of vitamin A deficiency.

2.4 Increase production and storage and transportation resistance

Food security has always been the focus of global attention. Genetically modified technology can regulate the balance of plant hormones by introducing genes that promote growth. Introducing growth promoting genes can accelerate the crop growth cycle and increase yield. In addition, gene introduction that regulates hormone balance within crops can also improve crop yield and quality. This is crucial for meeting the growing population demand and food supply.

Grain storage is a key link in ensuring food supply, but due to the invasion of pests and molds, the process of grain storage often causes significant losses. Genetically modified technology can improve the storage tolerance of crops, making them more resistant to pests and mold during storage, thereby reducing food loss. For example, genetically modified maize not only exhibits insect resistance in the field by introducing insect resistant genes, but also maintains relatively low levels of pest damage under storage conditions.

3 Advantages and Controversies of Genetically Modified Technology in Agriculture

The advantages and controversies of genetically modified technology in agriculture coexist (Ubalua, 2009). Scientists and decision-makers need to weigh these factors and develop strict regulatory measures and reasonable decisions to ensure that the application of genetically modified technology can fully leverage its advantages while minimizing its potential risks and uncertainties.

3.1 Improving crop yield

On a global scale, food security has always been an important issue. The population is constantly increasing, and the demand for food is also constantly increasing. Genetically modified technology provides a possibility to meet the growing demand for food by introducing genes that promote growth, improving crop resistance, disease resistance, and stress adaptability, as well as increasing crop yield. For example, the development of genetically modified rice "Golden Rice" aims to increase the content of vitamin A in rice and reduce patients with vitamin A deficiency. The increase in yield of genetically modified rice and corn has played a positive role in alleviating hunger and improving global food supply.

3.2 Reducing pesticide use

Traditional agriculture often requires a large amount of pesticides to resist pests and diseases, but excessive use of pesticides may bring environmental pollution and ecological damage. Genetically modified technology can enable crops to have the ability to resist pests and viruses, thereby reducing the use of pesticides. This not only helps to protect farmland ecosystems, but also reduces the risk of farmers being exposed to harmful pesticides.

3.3 Saving farmland and water resources

With the increase of global population, arable land and water resources have become increasingly limited. Genetically modified technology can achieve more agricultural products under limited arable land and water resources by increasing crop yield and stress resistance. For example, genetically modified cotton increases yield while resisting pests, allowing farmers to obtain more cotton yield on limited farmland (Figure 1).

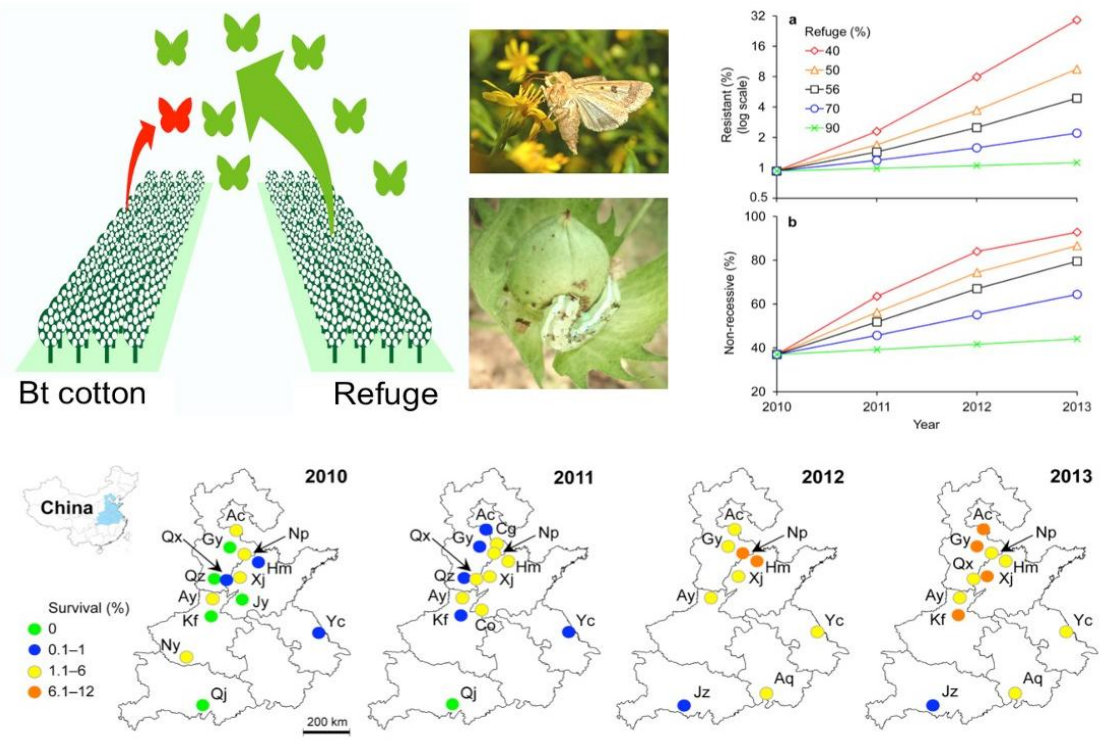


Figure 1 Data on transgenic cotton (Jin et al., 2015)

3.4 Environmental risks and ecological impacts

Although genetically modified crops can reduce the use of pesticides, their release in the natural environment may pose potential risks. For example, insect resistance genes in genetically modified crops may have an impact on non target insects, leading to the disruption of ecological balance. In addition, hybridization between genetically modified crops and wild relatives may lead to weed resistance, leading to the problem of super weeds and affecting the stability of ecosystems.

3.5 Food safety and human health issues

The food safety of genetically modified foods has sparked widespread controversy. Although most scientific studies believe that genetically modified foods are as safe as traditional foods, some people still worry that genetically modified foods may cause allergies or other adverse reactions. In addition, some people are concerned about the spread of antibiotic resistance genes that may exist in genetically modified crops, which may have an impact on human health and antibiotic treatment. In 1999, there was an outbreak in Europe regarding the possibility of allergies caused by genetically modified corn. Although subsequent research did not find conclusive evidence to support this view, this incident has raised public concerns about the health risks of genetically modified foods (Hefferon and Herring, 2017).

4 Prospects for the Development of Genetically Modified Technology

The future of genetically modified technology is full of hope, and the emergence of new gene editing technologies will further promote the accuracy and efficiency of crop improvement. At the same time, the development of eco-friendly crops will protect the balance and diversity of ecosystems while ensuring sustainable agricultural development. However, scientists, policy makers, and the public still need to work together to balance the relationship between technological development and ecological protection, ensuring that the application of genetically modified technology always conforms to the best interests of humanity and the Earth.

4.1 Application of new gene editing technology

With the continuous development of gene editing technology, especially the emergence of CRISPR-Cas9 technology, genetically modified technology is ushering in a new era. CRISPR-Cas9 technology has the characteristics of high efficiency and precision, which can more accurately edit the genome, achieve targeted modification, gene knockout, and other operations. The prospects of this technology are very broad, and it can be used to improve multiple aspects of crops, including yield, disease and pest resistance, stress tolerance, and so on. For example, using CRISPR-Cas9 technology, scientists have successfully developed wheat varieties with insect resistance, bringing revolutionary changes to traditional breeding.

The development of genome editing technology not only enables the editing of a single gene, but also allows for the simultaneous editing of multiple genes, thereby achieving more complex genetic regulation. This enables scientists to more finely adjust crop traits, such as increasing yield, improving quality, and increasing disease resistance. Through genome editing, more precise and rapid crop improvement can be achieved, further accelerating the cultivation of new varieties.

4.2 Sustainable agriculture and ecological balance

In the future, the development of genetically modified technology will pay more attention to the cultivation of eco-friendly crops. This means not only paying attention to crop yield and resistance, but also considering its interaction with the ecosystem. Scientists will pay more attention to how to reduce adverse environmental impacts, protect ecological diversity, and avoid unnecessary ecological risks in the process of crop improvement. For example, when developing insect resistant crops, in addition to considering insect resistance, the impact on non target insects will also be considered to maintain ecological balance.

When developing genetically modified crops, it is necessary to deeply consider their interaction with the natural environment. Improper introduction of genetically modified crops may disrupt ecosystem balance, affect biodiversity, and even lead to new ecological problems. Therefore, in the application process of genetically modified technology, it is necessary to establish a strict ecological risk assessment system to ensure that the

impact of introduced genetically modified crops on the ecosystem is within a controllable range. With the widespread planting of genetically modified corn, soybeans, and other crops, the number of pollinating insects has decreased, which may affect the pollination and ecological balance of other plants. This example reminds us to carefully consider the potential impact of genetically modified crops on ecosystem stability while developing them (Park et al., 2011).

5 Conclusion

Genetically modified technology, as an important technology in modern agriculture, provides new ways and solutions to address various challenges faced by agriculture. Through precise improvement of crop genes, genetically modified technology has a wide range of applications in agriculture, from improving insect resistance, disease resistance, and stress tolerance to improving yield and quality, and has achieved significant achievements. Genetically modified crops not only provide farmers with more stable harvests, but also help reduce pesticide use, save arable land and water resources, and promote the development of sustainable agriculture. These advantages not only have a positive impact on agricultural production, but also help alleviate global food shortages and improve the stability of food supply.

However, the application of genetically modified technology is not without controversy. The long-term effects and potential risks of genetically modified crops require more in-depth research and evaluation to ensure that the application of genetically modified technology does not have adverse effects on ecosystems and human health. The public's attitude and understanding towards genetically modified technology directly affect its legitimacy and sustainability of application. Therefore, it is necessary to establish more open and transparent communication channels, actively listen to the public's voices, and make decision-making more universal and scientific. While promoting the development of genetically modified technology, it is necessary to emphasize the cultivation of eco-friendly crops, pay attention to the balance between crops and ecosystems, and avoid potential ecological problems. The application of genetically modified technology must be carried out within a strict legal and ethical framework, ensuring compliance and legality in the application of technology, while protecting the rights and interests of farmers, consumers, and the ecological environment.

The application prospects of genetically modified technology in agriculture are broad, but it needs to be promoted on a scientific, safe, transparent, and sustainable basis. Through global cooperation and interdisciplinary research, we are confident in fully leveraging the advantages of genetically modified technology and making positive contributions to future agricultural development and food security.

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