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Genetic Manipulation: A Tool for Food Security

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Abstract
Bob Fraley's pioneering use of *Agrobacterium tumefaciens* in the early 1980s marked the inception of plant genetic engineering igniting a revolution in agriculture. This groundbreaking technology has become a cornerstone of modern crop production facilitating the widespread cultivation of genetically modified (GM) crops worldwide and introducing new avenues for enhancing agricultural efficiency and sustainability. At its core genetic engineering entails the precise integration of foreign genes known as transgenes into plant genomes thereby conferring specific traits like herbicide tolerance, drought resistance and defense against pests and diseases. In contrast to conventional breeding methods which face limitations due to species barriers and the risk of undesirable trait transfer genetic engineering offers unmatched precision and flexibility. By bypassing the necessity for sexual reproduction it enables the introduction of traits from any organism into target plant species allowing breeders to incorporate desired characteristics without genetic encumbrances. The success of plant genetic engineering rests upon the totipotent nature of plant cells which enables the regeneration of entire plants from isolated cells containing the inserted transgene. This remarkable capability facilitates the seamless integration of foreign DNA into plant genomes ensuring the widespread dissemination of desired traits throughout the regenerated plants. In essence, plant genetic engineering stands as a transformative tool for agricultural advancement offering unprecedented opportunities to customize crop traits to address evolving needs and challenges ultimately fostering global food security and sustainability.

Keywords: Genetic engineering, sustainability, GM crops, food security.

Introduction
The dawn of genetically engineered plants emerged when Bob Fraley and his colleagues demonstrated the successful use of *Agrobacterium tumefaciens* to introduce recombinant DNA into plant cells during the early 1980's (Vasil, 2008a). This breakthrough paved the way for the routine development and cultivation of genetically modified (GM) crops worldwide. Through genetic engineering novel genes of economic significance can be incorporated into crop plants, facilitating their genetic enhancement. Genetic engineering involves the targeted insertion of foreign genes into an organism's genome. These genes, known as transgenes can be isolated from different species and introduced into another organism or they may be modified genes reinserted into the same species. The process of inserting transgenes into a plant is termed transformation wherein the inserted gene carries information that confers a specific trait to the organism. While traditional crop breeding

(plant breeding) remains an essential tool it has its limitations. Conventional genetic improvement relies on sexual mating between compatible plants restricting the introduction of new traits to those already present within the species. Additionally conventional breeding often results in the transfer of undesirable traits alongside the desired ones.

In contrast genetic engineering transcends these limitations. By directly transferring genes from one organism to another regardless of species barriers it enables the precise incorporation of desired traits into plants. This specificity allows for the addition of single or multiple traits without the need for sexual crossing. Genetic engineering offers a broad spectrum of beneficial traits spanning from herbicide and drought tolerance to resilience against viral, bacterial and fungal infections along with defense against herbivorous insects. Notably, these desirable traits can be sourced from any organism as long as the expression of the transferred gene(s) or transgene(s) aligns with the physiology of the host plant.

The feasibility of plant transformation is rooted in the totipotency of plant cells which enables the regeneration of an entire plant from a single isolated cell. Consequently, when a gene is introduced into a plant cell's genome the resulting regenerated plant will carry the gene in all of its cells. Genetic engineering offers a powerful tool for enhancing crop plants by overcoming the limitations of traditional breeding methods. By harnessing the totipotent nature of plant cells and enabling the precise transfer of genes it holds the potential to address agricultural challenges and contribute to global food security.

History

The history of plant genetic engineering unfolds through a series of transformative milestones and pivotal breakthroughs

Early Domestication: The origins of plant genetic engineering can be traced back to the early stages of scientific exploration of agriculture approximately 10,000 years ago. Early farmers initiated the practice of selectively breeding wild plants laying the groundwork for modern crop breeding methods.

Discovery of DNA: The groundbreaking revelation of the DNA structure by James Watson and Francis Crick in 1953 laid a cornerstone in genetics catalyzing further progress in genetic engineering.

Discovery of Restriction Enzymes: In the 1960’s scientists like Werner Arber and Hamilton Smith discovered restriction enzymes which enabled precise cutting of DNA at specific sequences. This breakthrough facilitated the manipulation of DNA molecules a crucial development in genetic engineering.

First Recombinant DNA Experiment: Paul Berg's successful conduct of the first recombinant DNA experiment in 1972 marked a significant milestone. By combining DNA from different sources Berg created hybrid molecules heralding a new era in genetic engineering research.

Development of Transgenic Plants: In 1983 researchers achieved a breakthrough by successfully transforming tobacco plants using *Agrobacterium tumefaciens*. This demonstrated the feasibility of introducing foreign genes into plant genomes paving the way for the creation of transgenic crops.

Creation of Herbicide-Resistant Crops: The year 1986 witnessed a milestone with the emergence of the initial genetically modified organisms significant strides were made in the realm of genetic engineering: a tobacco plant resistant to the herbicide glyphosate. This breakthrough laid the foundation for the subsequent development of herbicide-resistant crops like Roundup Ready soybeans.

Introduction of Bt Crops: The commercial introduction of genetically modified crops containing *Bacillus thuringiensis* (Bt) toxin in 1996 represented a notable milestone in the progression of biotechnology. These crops exhibited resistance to certain insect pests offering a sustainable pest control solution for farmers.

Expansion of Crop Traits: Over the ensuing decades genetic engineering techniques continued to evolve leading to the development of crops with enhanced traits such as resistance to drought and diseases and improved nutritional content.

Genome Editing Technologies: Recent breakthroughs in genome editing technologies like CRISPR-Cas9 have transformed the landscape of plant genetic engineering. These tools facilitate accurate modifications to the plant genome without the requirement of inserting foreign DNA thereby unlocking novel avenues for enhancing crops. Through these milestones plant genetic engineering has emerged as a powerful tool for addressing agricultural challenges and enhancing crop productivity, resilience and sustainability.

Difference between traditional and genetic engineering

Sl. No	Particulars	Traditional methods	Gene technology
1.	Sexual process	Yes	No
2.	Technical skill	Moderate	Very high
3.	Accuracy of method	Moderate	Very high
4.	Gene transfer between unrelated species	Not possible	Possible
5.	Bio ethical measures	Not required	Required
6.	Bio safety measures	Not required	Required
7.	Direct single gene transfer	Not possible	Possible
8.	Transgene	Not involved	Involved

Steps involved in genetic engineering

Plant genetic engineering is a meticulous process aimed at altering the genetic composition of plants to introduce novel traits or enhance existing ones. Below are the detailed steps involved in this transformative method:

1. **Identifying Desired Traits**: The journey commences with scientists identifying specific traits or characteristics they intend to introduce or modify within the plant. These traits encompass a wide range of possibilities including pest resistance, herbicide tolerance, improved nutritional content or heightened yield potential.
2. **Isolation of Genes**: After identifying the desired traits, scientists proceed to isolate the genes responsible for them. These genes can be obtained from various sources *viz.*, same plant species, closely related species or even disparate organisms such as bacteria or other plants.
3. **Gene Cloning**: Isolated genes undergo a meticulous cloning process wherein their DNA sequences are replicated. This commonly includes the insertion of the gene of interest into a vector such as a plasmid or viral genome which can autonomously replicate within bacteria.
4. **Transformation**: The cloned genes are subsequently introduced into plant cells through a procedure called transformation. Different methods are available for plant transformation such as *Agrobacterium*-mediated transformation and particle bombardment techniques like the gene gun method. Notably *Agrobacterium*-mediated transformation is commonly employed wherein the gene of interest is inserted into the Ti plasmid of *Agrobacterium tumefaciens* a soil bacterium proficient in transferring its DNA into plant cells.
5. **Regeneration of Transgenic Plants**: Post-transformation the plant cells containing the foreign genes necessitate regeneration into complete plants. This intricate process is typically accomplished through tissue culture techniques. These techniques involve culturing the transformed cells on a growth medium infused with specific hormones and nutrients conducive to shoot and root formation.

6. **Selection and Screening**: Following regeneration not all transformed cells will successfully integrate the foreign genes into their genome. To pinpoint the successfully transformed cells selectable markers like antibiotic or herbicide resistance genes are often co-introduced alongside the gene of interest. Cells that have successfully integrated the foreign genes will express the selectable marker enabling their selection and isolation from non-transformed cells.
7. **Confirmation of Transgene Integration**: After transgenic plants are regenerated molecular techniques like PCR (Polymerase Chain Reaction) and Southern blot analysis are utilized to verify the presence and integration of the foreign genes into the plant genome. These techniques are crucial in ensuring the successful accomplishment of the desired genetic modifications.
8. **Field Trials and Evaluation**: Transgenic plants that pass molecular confirmation undergo rigorous field trials to evaluate their performance under diverse environmental conditions. These trials encompass the assessment of various agronomic traits, yield potential and the expression of the desired traits under real-world field conditions.
9. **Regulatory Approval**: Before transgenic plants can be commercialized they undergo meticulous regulatory scrutiny to ensure their safety. Regulatory agencies such as the USDA, EPA, and FDA meticulously assess the risks and benefits of genetically modified plants before granting approval for cultivation and marketing.
10. **Commercialization and Deployment**: Upon obtaining regulatory approval transgenic plants are poised for commercialization and deployment in agricultural practices. This phase entails collaborative efforts with seed companies for large-scale manufacturing and dissemination of genetically modified seeds to farmers.
11. **Monitoring and Follow-Up**: Even after commercialization ongoing monitoring endeavors are indispensable to assess the environmental impact and long-term safety of genetically modified plants. These monitoring efforts encompass vigilant observation for potential gene transfer to wild relatives and impacts on non-target organisms and any unforeseen consequences stemming from the genetic modifications.

Through these meticulously orchestrated steps, plant genetic engineering has emerged as a groundbreaking tool revolutionizing agriculture offering innovative solutions to myriad challenges such as pest infestations, diseases and environmental stresses.

Principal of Genetic Engineering

Technique Involved in Genetic engineering: Genetic engineering involves crafting new combinations of heritable material by introducing externally produced nucleic acid molecules into vectors such as viruses, bacterial plasmids or other systems. This allows their integration into a host organism where they can replicate despite not occurring naturally. This process can achieve various types of genetic modifications including inserting foreign genes from one species into another altering existing genes to modify their products and manipulating gene expression to control translation frequency. Manipulating DNA in vitro relies on purified enzymes capable of cleaving, modifying and joining DNA molecules in specific ways. Enzymes ensure predictable manipulation of DNA unlike chemical methods. Each enzyme plays a crucial role in genetic engineering contributing to different stages of the process. Commonly used enzymes include restriction enzymes, nucleases, DNA ligase, kinase, phosphatase, reverse transcriptase, terminal deoxynucleotide transferase and RNaseP. These enzymes perform vital functions in DNA manipulation facilitating the creation of desired genetic modifications.

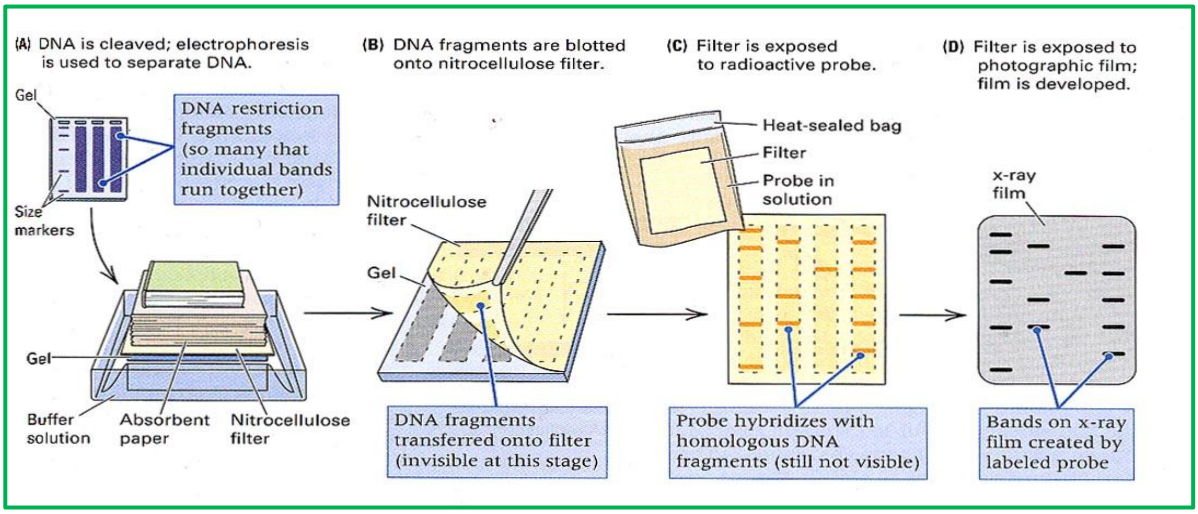
1) **Gene Cloning:** Gene cloning involves incorporating a particular segment of desired DNA into a host cell ensuring its replication and transmission to subsequent cell

generations during division. Below are the sequential steps in DNA cloning using plasmid DNA as a vector:

- **Isolation of DNA**: This involves obtaining the gene of interest and the vector (usually a plasmid) containing the cloning site.
- **Treatment with Restriction Enzymes and Ligation:** Both the plasmid DNA and the foreign DNA harboring the gene of interest undergo treatment with the same restriction enzyme to produce compatible ends. Subsequently these fragments are joined together using DNA ligase to create a recombinant DNA molecule.
- **Transformation:** The recombinant plasmid DNA is introduced into a suitable host cell typically *Escherichia coli bacteria* through a process known as transformation. During this process the host cells uptake the recombinant DNA.
- **Screening for Transformed Cells:** Transformed host cells harboring the recombinant plasmid DNA are identified by utilizing selectable markers such as antibiotic resistance genes present on the plasmid. Cells that have successfully integrated the recombinant DNA will survive in the presence of the selective agent.
- **Amplification and Purification of Recombinant Plasmid DNA:** Transformed cells containing the recombinant plasmid DNA are allowed to proliferate leading to the amplification of the inserted DNA. Subsequently, the recombinant plasmid DNA is isolated and purified from the bacterial cells for further analysis or downstream applications.

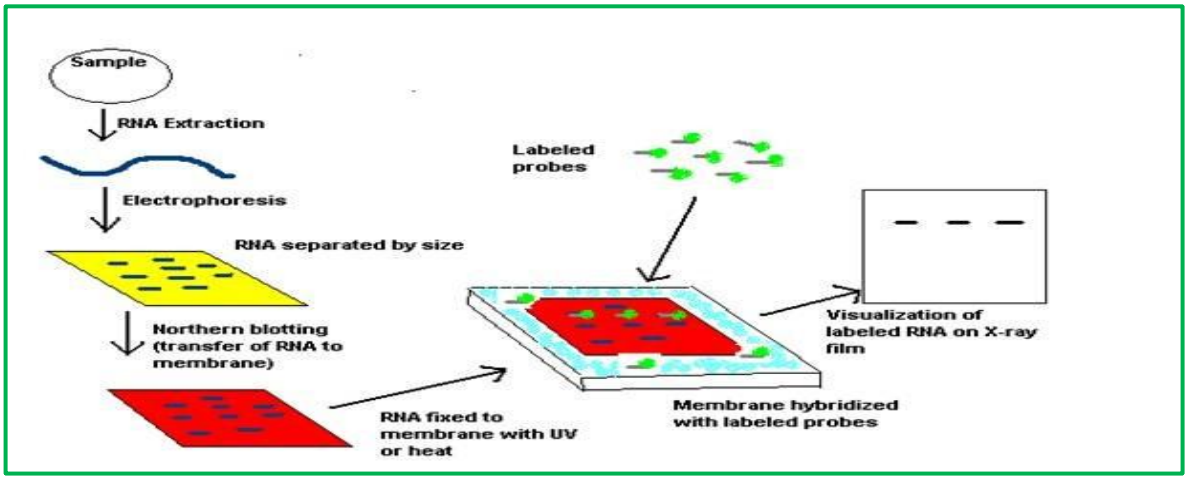
2) **Southern Blotting:** A Southern blot is a molecular biology technique utilized for detecting specific DNA sequences in DNA samples named after its inventor Edwin Southern. The method involves transferring electrophoresis-separated DNA fragments onto a membrane and detecting them through probe hybridization. Here are the steps involved:

- **DNA Fragmentation**: High-molecular-weight DNA strands are fragmented into smaller pieces using restriction endonucleases.
- **Electrophoresis**: The DNA fragments are separated based on their size using electrophoresis on an agarose gel.
- **Treatment for Large Fragments**: If some DNA fragments are larger than 15kb the gel may undergo treatment with acid (such as dilute HCl) to depurinate the DNA breaking it into smaller fragments for more efficient transfer.
- **Transfer to Membrane**: The DNA gel is transferred onto a nitrocellulose or nylon membrane. For alkaline transfer the gel is immersed in an alkaline solution to denature the double-stranded DNA, facilitating binding to the membrane. Pressure is applied to ensure even contact between the gel and membrane, and buffer transfer via capillary action moves the DNA onto the membrane.
- **Attachment to Membrane**: The transferred DNA is permanently affixed to the membrane by baking in an oven or exposure to ultraviolet radiation.
- **Hybridization with Probe:** The membrane is exposed to a hybridization probe which is a single DNA fragment with a specific sequence complementary to the target DNA. The probe is labeled with radioactivity, fluorescence or a chromogenic dye for detection. To enhance specificity, blocking agents and detergents are used to reduce non-specific binding.
- **Washing and Visualization**: Excess probe is removed from the membrane through washing and the hybridization pattern is visualized. Detection can be achieved through autoradiography or color development on the membrane depending on the type of probe utilized.



3) **Northern Blotting:** The Northern blot procedure closely resembles Southern blotting but with the key distinction of separating RNA instead of DNA through gel electrophoresis. Here are the steps involved:

- **RNA Separation**: Total RNA or mRNA is separated via gel electrophoresis typically on an agarose gel. Due to the diverse RNA molecules present the gel often exhibits a smear rather than discrete bands.
- **Transfer to Membrane:** The separated RNA is transferred to a specialized blotting paper usually nitrocellulose while retaining the same separation pattern as on the gel.
- **Probe Incubation**: The blot is incubated with a probe typically single-stranded DNA. The probe forms base pairs with its complementary RNA sequence creating a double-stranded RNA-DNA molecule. The probe is either radioactive or bound to an enzyme (e.g., alkaline phosphatase or horseradish peroxidase).
- **Detection:** The probe's location is revealed by incubating it with a colorless substrate that the attached enzyme converts into a colored product. This product can be directly visualized or emits light exposing X-ray film. If the probe was labeled with radioactivity it can directly expose X-ray film.



4) **Polymerase Chain Reaction:** Polymerase chain reaction (PCR) facilitates the swift amplification of a particular DNA segment devoid of vectors or host cells. This method involves mixing the template DNA with forward and reverse primers complementary to the template DNA ends alongside nucleotides and Taq polymerase obtained from the thermophilic bacterium *Thermus aquaticus* which remains stable at elevated temperatures. The PCR process encompasses three primary steps:

- **Denaturation**: The two nucleotide strands of the DNA molecule are separated.
- **Primer Annealing**: The forward and reverse primers attach to the single-stranded DNA.
- **Extension**: Nucleotides are added to the primers in the 5' to 3' direction crafting a double-stranded copy of the target DNA.

During each PCR cycle the DNA sequence between the primers undergoes exponential duplication commencing from 2 strands and escalating to 4, 8, 16 and so forth reaching approximately a million strands. This exponential amplification allows for the rapid generation of substantial quantities of a specific DNA sequence within a few hours. PCR operates with high efficiency with each cycle typically requiring only a few minutes. Repeated cycles can swiftly generate significant amounts of the target DNA sequence. However, PCR necessitates knowledge of the nucleotide sequence to be amplified and is highly susceptible to even minute contamination. Despite these considerations PCR stands as a potent tool in molecular biology and genetics empowering researchers to amplify and scrutinize specific DNA sequences with precision and efficacy.

Advanced PCR Techniques

a. **Reverse Transcription PCR (RT-PCR)**: This technique is valuable for studying gene expression or characterizing RNA transcripts. Unlike traditional PCR which begins with double-stranded DNA RT-PCR starts with mRNA. Reverse transcriptase enzyme and a reverse primer are used to convert the mRNA into single-stranded DNA. Then a forward primer is utilized to generate a double-stranded DNA template for PCR amplification. This technique allows researchers to analyze gene expression levels and study RNA molecules.

b. **Real-Time PCR (RT-PCR)**: It enables the quantification of DNA amplification in real-time. During the PCR process fluorescent-tagged oligonucleotides anneal to the DNA strands. As the DNA polymerase extends the primers it encounters the fluorescent-tagged probe leading to its degradation and a subsequent increase in fluorescence. This fluorescence intensity is measured by a fluorimeter providing real-time data on the progression of the PCR reaction.

c. **Overlapping PCR**: It is employed to introduce mutations at specific sites or join smaller DNA fragments into larger ones. This technique involves two stages:
   - In the first stage PCR amplifies the segments to be joined using overlapping primers designed to hybridize with each other.
   - In the second stage the products from the first stage are denatured and annealed together forming longer DNA fragments. Another PCR is then performed using end primers to amplify the final product.

d. **PCR-mediated DNA shuffling**: It is utilized in directed evolution experiments to create genetic diversity. This technique involves fragmenting parent genes with DNaseI followed by size fractionation and PCR amplification with cross-priming between overlapping fragments. The recombined full-length products are then amplified using terminal primers. Despite its efficiency DNA shuffling has limitations in generating diversity which can be addressed by techniques like RACHITT (Random Chimeragenesis on Transient Templates).

e. **Reverse PCR**: It is employed to explore unknown flanking regions of DNA sequences. In this technique a restriction enzyme site is "inserted" into the flanking regions by genomic cutting. The linear sequence is then ligated into a plasmid allowing for PCR amplification using primers from the known sequence. This method enables the amplification and characterization of unknown flanking regions surrounding a known sequence.

Applications of genetic engineering

1. Virus resistance

Virus	Transgenic product	Transformed plant	Origin of transgene
Potato virus X	Viral coat protein	Potato	PVX
Potato virus Y	Viral coat protein	Potato kufri jyothi	PVY
Tomato yellow leaf curl virus (TYLCV)	Viral coat protein	Tomato	TYLCV
	Cl-gene	Tomato	TYLCV
Tomato mosaic virus	Antisense RNA	Tomato	ToMV
Cucumber mosaic virus	Satellite RNA	Tomato	CMV

2. Fungal resistance

Disease	Casual organism	Gene transfered
Soft rot	*Erwinia caratovora*	Chitinase
Leaf spot	*Alternaria brassicae*	Thionin
Black rot	*Xanthomonas compestris*	Chitinase

3. Bacterial resistance

Crop	Transgenic product	Origin of transgene	Resistance against
Potato	Lysozyme	T4 bacteriphase	*Erwinia caratovora*
	Tachypelsin	Horseshoe crab	
	Pestate lyase	*Erwinia caratovora*	
	Glucose oxidase	*Aspergillus niger*	
Beans	Phaselotoxin insensitive OCTase	*Pseudomonas syringae var. phaseocola*	*Pseudomonas syringae var. phaseocola*

4. Bt genes transferred for insect resistance

Crop	Targeted insect	Organism of transgene	Transgenic product
Cabbage	DBM *Plutella xylostella*	*Bacillus thuringiensis*	*Cry 1 A*
Cabbage	*Pieries brassicae*	*Bacillus thuringiensis*	*Cry 1 A*
Corn	*Helicoverpa armigera*	*Bacillus thuringiensis*	*Cry 1 H*
Brinjal	*Leptinotarsa decimlineata*	*Bacillus thuringiensis*	*Cry 3 A*
Tomato	*Helicoverpa armigera*	*Bacillus thuringiensis*	*Cry 1 AB*

5. Synthetic Bt

Crop/pest	Variety	Gene
Tomato *Helicoverpa armigera*	Pusa ruby	*Gy 1 AC*
Brinjal *Leucinodes arbonaslis*	Pusa purple long	*Gy 1 Ab*

6. Post-harvest traits

Purpose	Targeted gene	Origin of transgene	Transferred plant
Ripening inhibitors	Antisense ACC oxidase	Tomato	Tomato
Improved shelf life	Antisense polygalacturonase	Tomato	Tomato
Fruit pigmentation	Phtoene synthase gene	Tomato	Tomato

7. **Genetic engineering for male sterility:** Male sterility serves as an economic facilitator for hybrid seed production. In crops such as okra where male sterility is absent in both cultivated and wild species it can be introduced from microorganisms through R-DNA Technology. This technique has already been successfully applied in Brassica and tomato.

Advantages

Plant genetic engineering stands as a transformative force in agriculture promising to bolster food security, enhance environmental sustainability and tackle pressing challenges. Key advantages include:

- **Increased Crop Yields**: Through genetic modifications plants can be tailored to resist pests withstand environmental stresses like drought, salinity or extreme temperatures leading to bountiful harvests to meet global food demands.
- **Improved Nutritional Quality**: Genetic enhancements allow crops to be enriched with vital nutrients addressing deficiencies and improving public health outcomes as seen in biofortified crops.
- **Pest and Disease Resistance**: Genetic engineering confers resistance to pests and diseases curbing reliance on chemical pesticides and fostering sustainable agricultural practices.
- **Herbicide Tolerance**: Modified crops tolerate specific herbicides enabling weed control without harming crops thus enhancing weed management and yield.
- **Environmental Sustainability:** Reduced dependence on chemical inputs in genetically engineered crops diminishes chemical runoff, erosion and biodiversity loss contributing to environmental preservation.
- **Climate Resilience**: Genetic modifications create crops resilient to climate change adapting to heat, altered precipitation and evolving pest patterns.
- **Reduced Food Waste**: Enhanced post-harvest traits in genetically engineered crops such as extended shelf life and resistance to bruising mitigate food waste and enhancing food security.
- **Development of Novel Traits:** Genetic engineering introduces novel traits beyond conventional breeding improving taste, texture, color and processing qualities.

Limitations

Despite the numerous advantages offered by plant genetic engineering it also brings forth several significant concerns that demand thoughtful consideration:

- **Environmental Risks**: The introduction of genetically modified crops carries the potential for unintended environmental consequences. This encompasses the accidental dissemination of modified genes to wild plant populations which could result in ecological disruptions and harm to biodiversity.
- **Development of Resistant Pests and Weeds:** Continuous reliance on genetically modified crops with resistance traits may result in the evolution of pest or weed populations that are resistant to these modifications. This could create novel challenges for managing pests and weeds effectively.
- **Gene Flow and Contamination**: Genes from genetically modified crops have the potential to spread to non-modified crops through mechanisms such as cross-pollination or seed dispersal. This raises concerns about the contamination of conventional or organic crops leading to apprehension among farmers and consumers.
- **Potential Health Risks**: Debates persist regarding the long-term health implications of consuming genetically modified crops. Worries encompass allergic reactions unintended alterations in nutritional content and other potential health effects.
- **Loss of Genetic Diversity:** The widespread adoption of a small selection of genetically modified crop varieties could lead to a decrease in genetic diversity within crop populations. This decrease in diversity could compromise their resilience to pests, diseases and environmental changes.
- **Corporate Control of Agriculture**: There are concerns surrounding the consolidation of intellectual property rights and seed patents in the possession of a few major

agrochemical corporations. This dominance raises worries about corporate influence over agriculture, farmer autonomy and access to seeds and genetic resources.

- **Ethical and Socioeconomic Issues:** Genetic engineering prompts ethical debates regarding the manipulation of living organisms and the commercialization of life itself. Moreover, it exacerbates existing socioeconomic disparities with access to genetically modified seeds and technologies often limited to large-scale commercial farmers disadvantaging smallholder farmers in developing countries.
- **Uncertain Regulatory Frameworks:** Variations in regulatory frameworks across different countries lead to inconsistencies in safety assessments and public perception regarding genetically modified crops. Uncertainty surrounding regulatory oversight complicates efforts to ensure transparency and accountability in the industry.

Conclusion

Plant biotechnology offers immense potential in addressing diverse agricultural and societal challenges. Genetic modification strategies are effectively deployed to combat yield losses caused by both biotic and abiotic stresses while also enriching the nutritional content of food crops with essential proteins, vitamins, minerals and other beneficial compounds. Furthermore initiatives are underway to extend the shelf life of fruits and vegetables thereby reducing post-harvest losses. Despite the increasing global cultivation of genetically modified (GM) crops no harmful effects have been documented even after extensive cultivation and consumption. Insect-resistant Bt crops and herbicide-tolerant GM crops currently in commercial use have proven advantageous to farmers enabling improved pest and weed management, higher yields and reduced reliance on chemical pesticides. Hence, it is evident that the sustainable integration of traditional agricultural practices with modern biotechnology is crucial for achieving food security for present and future generations. However it is essential to subject GM crops to thorough scrutiny over several generations under field conditions and rigorous biosafety assessments on a case-by-case basis before their commercial release. GM crops hold the potential to become indispensable in our lives and it is imperative to harness the vast capabilities of biotechnology for the betterment of humanity.

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