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Transgenic Crops as Novel Allies for Human Health Promotion

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ABSTRACT

Crops are essential in human diets, offering vitamins, minerals, dietary fiber, and phytochemicals associated with reduced risks of chronic diseases such as cardiovascular disorders, diabetes, and certain cancers. However, vegetable cultivation faces significant biotic stresses from pathogens, insect pests, and weeds, leading to high reliance on agro chemicals. Transgenic Crops expressing traits like virus resistance and insecticidal proteins (e.g., Bacillus thuringiensis toxins) have been developed to mitigate pest damage and reduce pesticide use. Ongoing genetic engineering focuses on enhancing host plant resistance to pathogens and insects, conferring herbicide tolerance, delaying fruit ripening for extended shelf-life, improving nutritional quality, inducing parthenocarpy for seedless fruits, and increasing sweetness. Transgenic breeding contributes to integrated pest management by reducing pesticide applications and minimizing residue levels, thereby improving food safety and environmental sustainability. Additionally, herbicide-tolerant crops support conservation tillage practices, helping to reduce soil erosion and conserve fuel through decreased mechanical cultivation. Never the less, market acceptance of transgenic Crops varies, requiring clear evidence of safety and benefits to both growers and consumers to ensure successful adoption.

Key Words: Transgenic Crops, Biotic Stress Management, Integrated Pest Management, Genetic Engineering, Herbicide Tolerance

Introduction

Transgenic Crop are revolutionizing modern agriculture and nutrition by enabling precise genetic improvements that go far beyond what conventional breeding can achieve. (1) Through genetic engineering, specific genes responsible for disease resistance, pest tolerance, and abiotic stress resilience—such as drought, salinity, or extreme temperatures—can be introduced into vegetable crops, ensuring stable yields and reduced crop losses. (2)

This reduces dependency on chemical pesticides and herbicides, promoting safer and more sustainable farming practices. Moreover, transgenic technologies are being used to enhance the nutritional profile of vegetables, such as increasing levels of essential vitamins, minerals, antioxidants, and beneficial phytochemicals. Examples include tomatoes enriched with folate, carrots with higher calcium, and lettuce fortified with zinc or resveratrol, all of which help address global health issues like micronutrient deficiencies, osteoporosis, and chronic diseases. Furthermore, traits like delayed ripening, improved texture, and longer shelf-life in transgenic vegetables reduce postharvest losses and enhance marketability and transport quality, benefiting farmers and consumers alike. Transgenic approaches also enable the development of seedless fruits, better taste, and more uniform produce.

Overall, transgenic vegetables represent a powerful solution to ensure food and nutritional security, improve economic viability for farmers, and meet the growing demands of a changing global climate and population. (3)

Transgenic Crops Tomato

Tomato is a key vegetable affected by various stresses, prompting biotechnological solutions to enhance yield and quality. The first transgenic tomato, Flavr Savr™, delayed ripening using an antisense polygalacturonase gene but failed commercially due to poor cultivar traits. Subsequent research targeted ethylene biosynthesis genes, like ACC synthase and oxidase, to better control ripening. Anti-ripening genes (rin and nor) have improved shelf-life in many cultivars. For disease resistance, coat protein genes from viruses such as tobacco mosaic virus, alfalfa mosaic virus, and cucumber mosaic virus have been inserted into tomatoes, effectively reducing viral infections and improving plant health and productivity. (1,2)

Cassava

Cassava, crucial in tropical diets and industries, has benefited from transgenic advancements. Early genetic engineering reduced cyanide content, improving food safety for communities reliant on cassava as a staple. Transgenic approaches have also enhanced virus resistance, nutritional quality, and storage root shelf-life. Innovations include using the *ipt* gene driven by a leaf-senescence promoter to extend leaf life and boost drought tolerance, and expression of cold-resistance genes regulated by low-temperature inducible promoters. However, some virus-resistant cassava lines lost resistance in field conditions, indicating challenges remain. Nonetheless, transgenic cassava holds significant promise for food security and industrial applications. (4)

Potatoes

Transgenic potatoes have been developed for improved stress tolerance and industrial use. Introducing tomato Cu,Zn-SOD genes made potatoes tolerant to paraquat herbicide, while producing fructans boosted drought tolerance. Genetic engineering has modified starch biosynthesis by targeting enzymes like ADP glucose pyrophosphorylase (ADPGP Pase), leading to tubers with higher starch content or altered starch properties beneficial for food and industrial applications. For instance, potatoes expressing E. coli glgC16 gene showed increased starch, while antisense technology reduced amylose content, producing amylose-free cultivars with better gel stability and clarity. Genetic engineering also holds potential to enhance potato protein quality by improving essential amino acid composition . (5, 6)

Egg Plant

Eggplant suffers severe yield losses—up to 65%—from the fruit and shoot borer (ESFB), whose larvae damage shoots and fruits, making them unmarketable. Conventional insecticides are ineffective as larvae hide inside plant tissues. To combat this, Bt eggplant was developed by Mahyco and Monsanto, incorporating the cry1Ac gene from *Bacillus thuringiensis*. This transgenic eggplant showed up to 98–100% ESFB mortality. Additionally, the cry1Aa3 gene was successfully introduced into eggplant cv. Kashi Taru, producing plants with high levels of insecticidal proteins in shoots and fruits. Bt eggplants reduce pesticide reliance, promoting safer environments and healthier, marketable crops. (7)

Summer Squash

Transgenic summer squash (*Cucurbita pepo*) has been successfully developed for resistance against major viral diseases. The variety ZW-20 expresses coat protein genes from Zucchini yellow mosaic virus (ZYMV) and Watermelon mosaic virus (WMV), granting robust resistance to both single and mixed infections. Field trials confirmed these transgenic plants maintained high protection under diverse conditions. Notably, transgenic summer squash became the first disease- resistant genetically modified crop to gain exemption status in the U.S. This innovation reduces crop losses, lowers dependence on chemical controls, and ensures healthier produce, making virus- resistant squash a valuable advancement for sustainable horticultural production. (8)

Peppers (Capsicum sp.)

Peppers are vital as vegetables and spices but face challenges due to limited genetic resources and interspecies breeding barriers. Genetic engineering provides solutions, enabling the introduction of traits like virus and fungal resistance. For instance, Kim et al. transferred satellite RNA resistance against cucumber mosaic virus into hot pepper cv. Golden Tower. However, transgene stability varies due to factors like insertion sites, copy numbers, and transformation methods. Ribosome inactivating proteins (RIPs) are being explored for fungal resistance because of their cytotoxic action on pathogens. Overall, transgenic technology offers promising avenues for improving pepper crop resilience and quality. (8)

Pea

Transgenic pea development has mainly targeted disease resistance to enhance crop health and yield. Genetic engineering enables the introduction of resistance genes against significant pathogens, helping protect pea crops from yield losses. Although numerous research reports exist, most remain in experimental stages without widespread commercial application. Challenges such as stable gene expression, regulatory approval, and public acceptance have slowed the commercial rollout of transgenic peas. Nevertheless, the technology holds strong potential to improve pea cultivation by offering protection against diseases and possibly enhancing nutritional traits, thus contributing to sustainable agriculture and food security in the future. (9)

Carrot

Carrot, a biennial crop rich in carotene, has seen significant advances through genetic engineering. Overexpression of its BADH gene increased glycine betaine levels, enabling growth in saline soils. Researchers like Wally et al. introduced genes such as OsPOC1, OsPrx114, and AtNPR1 to enhance disease resistance, with OsPrx114 notably improving fungal defense. Additionally, carrots have been engineered to produce beneficial compounds, including human interferon alpha-2b, which holds therapeutic potential against viral diseases. These innovations highlight the diverse applications of transgenic technology in carrot breeding for stress tolerance, disease resistance, and production of pharmaceutical compounds. (10,11)

Onion

Transgenic onion plants have been developed with an antisense version of the bulb alliinase gene under CaMV35S promoter control to reduce alliinase activity, responsible for the pungent flavor and tear-inducing effect. Biochemical analyses revealed significantly lowered enzyme activity in some transgenic lines, confirmed by reduced alliinase transcript levels through multiplex RT-PCR. However, variability existed, possibly due to gene silencing, environmental effects, or chimeric plant development. Further molecular fingerprinting aims to match these transgenic plants to clones and progeny for phenotypic assessment. This research opens possibilities for creating milder-flavored onions with reduced pungency and better consumer acceptance. (12)

Garlic

Garlic, propagated vegetatively without seeds, poses challenges for breeding resistance to diseases like white rot. Genetic engineering offers a solution, with early transformations achieved via Agrobacterium tumefaciens and biolistic methods. Park et al. produced herbicide-resistant garlic, while Lagunes-Fortiz introduced chitinase and glucanase genes from tobacco to combat fungal pathogens. Transgenic plants showed reduced mycelial invasion by *Sclerotium cepivorum*, though not complete resistance, indicating delayed fungal progression. Optimized culture media enabled effective plant regeneration. These advances mark the first successful introduction of fungal resistance genes into garlic, representing progress in improving yield, disease resistance, and garlic quality through biotechnology. (13,14)

Sweet Potato

Sweet potato, the world's seventh most important food crop, has benefited from advances in genetic transformation using Agrobacterium tumefaciens. This technology enables the introduction of genes conferring resistance to viral diseases, pests, and environmental stresses like drought and salinity. Transgenic sweet potato varieties are being developed to improve storage root quality, enhance nutritional content such as increased levels of β-carotene, and extend shelf-life. Research also focuses on producing sweet potato plants with higher yields and resistance to weevils, major pests affecting the crop. These genetic improvements hold great potential for enhancing food security and nutrition, especially in developing regions. (15) Genetically modified plants produce vaccine antigens in edible components like banana, potato, lettuce, and tobacco

Soya Bean

Soyabean Caterpillars often feed on soybean leaves, leading to significant crop damage and yield loss. To protect soybean plants from such insect pests, scientists can introduce specific insecticidal genes into the soybean genome. One of the most widely used genes for this purpose is the cry gene, derived from the bacterium Bacillus thuringiensis (Bt). The Bt cry gene produces Cry proteins, which are toxic to certain caterpillar species but safe for plants, humans, and most other organisms. By introducing the Bt cry gene into soybean, the plants can produce these protective proteins in their leaves, preventing caterpillars from feeding and thereby reducing crop damage without harming the soybean plants themselves.

Transgenic Plants and Edible Vaccines

Plant-based systems are increasingly used to produce foreign proteins, including vaccines and therapeutics. They offer advantages like cost-effectiveness, safety, and scalability. Protein expression in plants can be achieved through stable or transient methods, each with unique benefits.

Systems for expressing foreign proteins in plants

Two major strategies have been investigated for transgene expression in plants aimed at vaccine production: stable genomic integration and transient expression using viral vectors. In the stable integration approach, foreign DNA is permanently inserted into the plant genome through methods such as *Agrobacterium tumefaciens*-mediated transformation or direct techniques like microprojectile bombardment. This method offers the advantage of generating large numbers of transgenic plants through either vegetative propagation or sexual reproduction. It also enables the co-expression of multiple genes, which is particularly useful for developing multicomponent vaccines. Additionally, the use of specific regulatory sequences can allow for targeted expression in particular plant tissues or organs. On the other hand, transient expression involves the introduction of viral vectors into individual host plants, which can be more labor-intensive to initiate. However, this method typically results in much higher yields of recombinant proteins within a shorter timeframe, making it suitable for rapid protein production. (16, 17)

Stable genomic transformation using genes encoding foreign antigens

Streptococcus mutans spaA protein The first report of the concept of using a plant expression system for the production of an edible vac- cine appeared in a patent application published under the International Patent Cooperation TreatylO. It described a means to express a surface protein (spaA) from S. ~zlrtunr in tobacco plants to a level of approximately 0.02% of the total leaf protein; the gene had been stably inserted by Agrobacteritrm-mediated transformation. Data were presented on the oral immunogenicity of spaA produced in Escherichia coli, which stimulated the production of S-IgA in saliva. (18,19)

Techniques for Creating Transgenic Crops

To develop genetically edited plants, scientists first identify and select target genes and design an appropriate editing system. A DNA vector is then constructed and introduced into the plant genome using different transformation techniques. One common method is Agrobacterium-mediated transformation, where bacteria are first genetically modified to carry the desired DNA. These bacteria are then used to infect plant tissues, allowing the new genes to integrate into the plant cells during co-cultivation. Alternatively, the biolistic method involves preparing DNA-coated tiny particles, which are physically shot into plant tissues using a gene gun. After transformation, plant cells are grown in tissue culture, where they undergo stages like shoot induction, shoot elongation, and rooting. Throughout this process, marker genes help identify successfully edited plants, ultimately producing stable, genetically modified plants. (20)

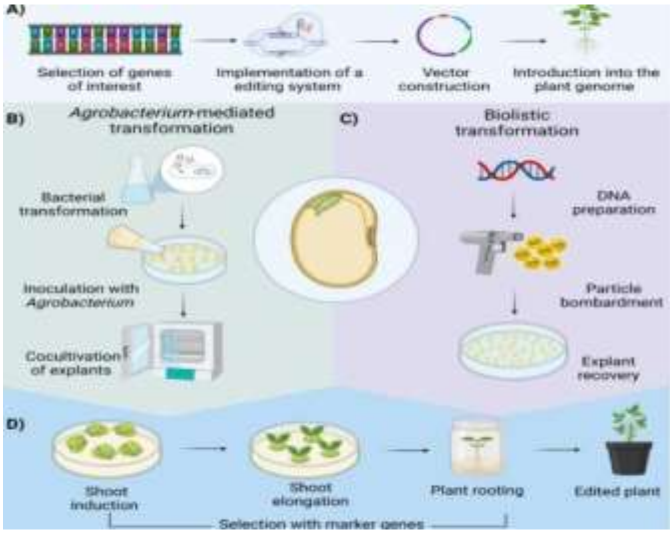

Fig 1- Techniques for Creating Transgenic Crops

Advancement and Disadvantages Advantages

Genetically modified (GM) technology has been widely used to develop crop plants with improved traits such as pest resistance, virus tolerance, and herbicide tolerance. These developments, mainly seen in countries like the USA and Canada, have helped farmers by increasing yield and reducing costs. While consumer benefits have been limited, such as lower prices due to easier production, new GM crops with enhanced nutritional value are expected to be introduced in the next 5–10 years. (20)

Disadvantages

The use of transgenic crops has raised concerns mainly in two areas: human health and environmental impact. Health concerns include potential allergic reactions and the risk of antibiotic resistance due to genes used in GM crops. People are also uneasy about consuming DNA from sources like bacteria or viruses. Environmental concerns involve the unintended harm to non- targe`t species, such as monarch butterfly larvae, which may die after consuming pollen from GM corn that contains bacterial toxins dispersed by wind. (21)

Current Challenges

One of the major technical hurdles impeding the advance of plant genetic engineering and biotechnology is the fact that the expression or manipulation of multiple genes in plants is still difficult to achieve. Although a small proportion of commercial genetically modified (GM) crops present ‘stacked’ or ‘pyramided’ traits, only a handful of products have been developed by introducing three or more novel genes. On the research front, a variety of conventional and more novel methods have been employed to introduce multiple genes into plants, but all techniques suffer from certain drawbacks. (21)

Conclusion

In the future, researchers hope to be able to provide vaccinations and medicines in GM foods, which can provide medications to people in developing countries more easily. Medications incorporated into food are easier to transport and store than conventional medicine. The advancements made with transgenic plants have and will continue to have a great impact on the lives of many. Transgenic plants offer a new approach to producing and administering human antibodies. The use of genetic engineering for the production of bio pharmaceuticals like erythropoietin to treat anemia and insulin to treat diabetes are well known. Future generations of GM plants are intended to be suitable for harsh environments and for the Enhancement of Nutrient content, production of pharmaceutical agents and production of Bioenergy and Biofuels.

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