

BIOTECHNOLOGY– A BOON OR A BUST

Abstract

With an increasing need for greater agricultural productivity and sustainability, biotechnology has emerged as a key instrument for revolutionizing crop development and management practices. Biotechnology offers creative ways to improve crop qualities, fend off illnesses and adjust to shifting climatic conditions by combining biological sciences with technological breakthroughs. It also reduces the need for chemical pesticides, promoting eco-friendly farming practices which is a major concern now- a- days. Through biotechnological interventions, one can introduce a gene of interest into an organism or it can cut an un wanted part or silence a gene to make it more advantageous for economical purpose. Different methods of biotechnology used for crop improvement and management includes genetic engineering, marked assisted selection, recombinant DNA technology and so on. In this exploration of biotechnology, we will delve into its remarkable achievements and its potentially troubling consequences.

Keywords: Biotechnology, Genetic engineering, Boon-Bust.

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I. INTRODUCTION

The pursuit of increased crop yield, adaptability and sustainability has been a persistent driving factor in the field of agricultural research. In order to accomplish these objectives, biotechnology, a multidisciplinary area that combines biology and technology, has become a game-changing tool. This introduction provides the foundation for numerous applications and outcomes of biotechnology in agriculture. Global food security has faced significant problems in recent decades as a result of population increase and changing climate conditions. While conventional breeding techniques are effective, they frequently have drawbacks in terms of accuracy, speed, and the capacity to handle complicated traits. In response to these difficulties, biotechnology has opened up novel opportunities for faster crop improvement, enabling the creation of crops that can flourish in various habitats, resist pests and diseases, and adjust to changing climatic circumstances.

Beyond genetic modification, biotechnology has aided the development of marker-assisted selection (MAS), a technique that makes it easier to identify desired qualities without the need for complete genetic change. This strategy speeds up the breeding process by enabling breeders to choose plants with desired features based on genetic markers linked to those qualities. Crop improvement consequently improves in efficacy, accuracy, and predictability. Modern agricultural practices now heavily rely on molecular breeding techniques, which involve locating and modifying particular genes linked to desirable features. A branch of science known as genetic engineering has made it possible to introduce particular genes into plants to impart features like herbicide tolerance, insect resistance, and increased nutritional value. This has accelerated the development of crops with distinctive and desirable characteristics in addition to broadening the range of features that can be manipulated.

1. Production and Productivity: Transgenic plant cultivars have previously proven to be effective in increasing yield and reducing expenses. The development of virus, insect and herbicide resistant plants resulted in yield increases of 5% to 10%, reduction in herbicide costs up to 40% and on pesticides costing \$60 to \$120 per acre (US dollars) in 1996 and 1997 respectively (James, 1998). However, despite how great they are, these productivity improvements are likely to have a limited influence on the world's food supply since the products that are now on the market are only appropriate for huge, mechanised farms that practise intensive agriculture. Majority of transgenic crops developed to far, particularly by the corporate sector, are intended to either lower production costs in agricultural regions with already high productivity levels or to raise the value of the finished product. Increasing productivity in developing nations, especially in areas of subsistence farming, where an increase in food production is urgently needed and where crop yields are significantly lower than those attained in other parts of the world, would be a more effective global strategy to ensure adequate levels of food production. Crop losses brought on by diseases, pests and deficient soils are exacerbated in developing nations in the tropics and subtropics by climate factors that favour insect pests and disease vector. It's feasible that plant biotechnology will help to solve many of these issues. Plant biotechnology has the significant benefit of frequently producing solutions for crop enhancement that may be used with a wide range of crops.

- 2. Abiotic Stress Management:** The main abiotic factors that impact the vegetative and reproductive stages of fruit development and production include high temperature, high light intensity, humidity, drought, frost, and salt. With the help of modified tomato plants carrying a DNA cassette containing an Arabidopsis C repeat/dehydration-responsive element binding factor 1 (CBF1) complementary DNA (cDNA) and a nos terminator, driven by a cauliflower mosaic virus 35S promoter, research on genetically altering various horticultural crops for improved abiotic stress tolerance has been investigated (Tsai-Hung et al., 2002). In comparison to wild-type plants, these transgenic tomato plants showed greater resistance to deficient water stress. In order to counteract the effects of stress, plants that are subjected to abiotic stress conditions create a number of pathogenesis-related proteins. Osmotin is one of these proteins that is crucially secreted under abiotic stress situations. When the tobacco osmotin gene was overexpressed in strawberry plants (*Fragaria x ananassa* Duch.), Husaini and Abdin (2008) discovered that the transgenic strawberry plants showed resistance to salt stress. In *Capsicum annuum*, the tobacco osmotin gene was expressed, and the transgenic chilli plants showed increased salt tolerance (Subramanyam et al., 2011).

II. BIOTIC STRESS MANAGEMENT

Up to 10%–16% of the world's yield is lost due to pathogens (Chakraborty and Newton, 2011). Transgenic technologies can help to reduce this loss. In conventional agriculture, crossbreeding is limited to members of the same species or eventually closely related species. Traditional breeders are unable to introduce this feature into new varieties if there is no biotic stress tolerance in this naturally occurring gene pool. As a result, it is vital to look for alternate sources of genes in microbial organisms or other plant species that are entirely unrelated to humans. Additionally, traditional procedures are resource- and time-intensive, and they depend on germplasm (Roy et al., 2011). Compared to 1996, when transgenic crops were only grown in 1.7 million hectares of land, herbicide, insect pest, and viral disease-resistant plants are now grown on more than 175.2 million ha worldwide (James, 2013).

- 1. Pest Management:** The Bt gene, a bioinsecticidal-endotoxin gene derived from *B. thuringiensis*, is now used to breed plants with insect pest resistance. The utilization of insect control protein genes from *B. thuringiensis* has advanced the creation of insect resistance in horticulture plants. Using Bt genes, insect resistance was first noted in tomatoes in 1987. *Spodoptera litura* and *Heliothis virescens* resistance was present in transgenic Bt tomato plants (Fischhoff et al., 1987). Technical and agronomic success allowed for large reductions in pesticide use while Colorado potato beetle-resistant potato cultivars were in commercial production for a number of years (Shelton et al., 2002). Cauliflower variety Pusa Snowball K-1 was changed by Chakrabarty et al. (2002) using a synthetic cry IAb gene during insect bioassays and the transgenic plants demonstrated the transgene's efficacy against diamondback moth (*Plutella xylostella*) larvae. In 2005, Paul et al. created transgenic cabbage (*Brassica oleracea* var. *capitata*) using a synthetic *B. thuringiensis* fusion gene that encoded a translational fusion product of cry1B and cry1Ab-endotoxins. They discovered that the transgenic plants were resistant to *P. xylostella*.

- 2. Disease Management:** Diseases brought on by various fungus, bacteria and viruses are one of the main factors restricting the output of crops. Due to the lack of resistance gene(s) in a given crop's gene pools, conventional breeding appears to have restricted applications. Crops may now be genetically engineered to withstand disease, which is advantageous in terms of both cost and effectiveness. The CP-mediated strategy to virus resistance engineering has been used in fruit crops to induce resistance to diseases such as PPV, citrus tristeza virus, grape fan leaf virus, etc. Tomato transgenic plants with an AC4 gene-RNAi construct were created by Praveen et al. (2010), and the transgenic plants were discovered to have tomato leaf curl virus activity suppressed. Crown gall disease resistance was discovered in transgenic tomato plants producing hairpin RNA (hpRNA) constructs against *Agrobacterium iaaM* and *ipt* oncogenes (Escobar et al., 2001). Transgenic tomato plants developed by Girhepuje and Shinde (2011) contain wheat endochitinase gene which impart resistance to *Fusarium oxysporum*.
- 3. Nutritional Value:** Since GM crops were first commercialised in the United States in 1996, one of the key promises of the biotechnology industry has been that a "second generation" of genetic alteration will deliver significant consumer advantages, such as by enhancing the nutritional content of meals. First-generation GM crops are intended for farmers by including genes for insect resistance and herbicide tolerance, which were marketed by biotechnology corporations as a means to reduce labour and input costs. With second-generation nutritionally improved genetically modified (GM) crops, the biotech sector now seeks to expand its market. It is claimed that these crops would reduce malnutrition and promote health. Many supporters of biotechnology even go so far as to assert that common diet-related disorders would be prevented by foods that will be available to customers.
- 4. Shelf-Life and Qualitative Traits:** It was discovered that storage and shelf-life of the produce are mostly impacted by excessive softness. Other objectives include increasing the amount of protein or vitamins. The function of specific activities in fruit softening during ripening has been examined using transgenic plants changed in the production of cell wall-modifying enzymes. Fruit ripening has been changed by changing the activity of cell wall enzymes including polygalacturonases, which are responsible for tissue softening and degradation. In order to slow down fruit ripening, ethylene's production has been suppressed in a number of methods. The extended shelf-life tomato (Flavr Savr), which was created by Calgene Inc. in the USA in 1994 using an antisense technique to suppress the polygalacturonase (PG) gene, was the first commercially successful transgenic plant. Later, new tomato cultivars with longer shelf lives were created by inhibiting two ethylene precursors and 1-aminocyclopropane-1-carboxylate (ACC) synthase or oxidase with antisense RNA. By controlling cytokinin production, it has been possible to delay leaf senescence in tobacco and petunia (Clark et al., 2003). With fruits accumulating greater amounts of the antioxidant lycopene, a CaMV35S- γ SpdSyn genotype showed a delayed crop maturity as measured by the proportion of ripening fruits on the vine. By using an RNAi technique to silence the expression of the mitochondrial APX gene, Zhang et al. (2011) created transgenic tomato plants and noticed enhanced vitamin C content in the transgenic tomato fruit.

5. Advantages

- Through biotechnology, one can make Genetic modification (GM) crops to confer desirable traits.
- Crop varieties were developed with enhanced disease resistance to various pathogens and pests thus, making us rely less on harmful chemical pesticides.
- Adverse environmental stress like drought, salinity and extreme temperatures may reduce the yield to a large extent that can be combated by biotechnological tools. Stress related genes were identified and made to express more during adverse environmental conditions to tolerate the stress within plants.
- Various breeding methods consume lot of time for identifying desirable traits among them. But, by using Marker-assisted selection (MAS), the traits can be identified at molecular level and it may accelerate the development of crop varieties.
- Viral diseases form more devastating that brings more yield loss. It can be controlled by biotechnology by inserting genes that confer resistance to viruses.
- Targeted breeding programs can be taken up by identifying the genes responsible for traits and can facilitate the breeding of crops with improved characteristics.
- One can stake the multiple desired genes in an organism and maximize the potential benefits from single crop variety by gene pyramiding techniques of biotechnology.
- New advances of biotechnology provide arena to improved phytoremediation by genetically engineering a crop to absorb and accumulate pollutants from environment.

However, as we venture deeper into the realm of biotechnology, ethical dilemmas and potential pitfalls loom large. Potential health risks, such as the possible toxic effects or allergenicity of substances produced in the plant, the introduction of antibiotic resistance genes into the gut microbiome of humans and animals, and environmental risks such as vertical gene transfer and horizontal gene transfer, possible unintended effects on nontarget organisms, the possibility of resistance building up in pests, weed resistance to herbicides.

Sometimes there is a chance that genes from GM crops could spread to their wild counterparts in conventional or organic crops, gene flow in GM crops is not desirable. Gene flow has occasionally resulted in significant economic losses, resulting in zero tolerances for admixtures, none of which posed a threat to the safety of food or the environment. However, for consistent selling of agricultural commodities, a thorough understanding and control of gene flow as well as realistic thresholds are needed to prevent market disruptions and related economic losses (Chandler and Dunwell, 2008).

Apart from these, many social and health issues arise due to use of GM crops. The exploitation of GM crops could be restrained due to following reasons:

- The ability of these crops to spread resistant genes to wild varieties of microbes and the intestinal flora, thereby boosting antibiotic drug resistance (Lack, 2002),
- The potential transfer of antibiotic, insecticidal genes into pathogenic microbes, which would make them immune system resistant and could cause pandemic diseases, and other potential health risks are major concerns with GM foods.

III. BIOSAFETY ISSUES

Key act controlling the biosafety issues of genetically modified crops is Environmental Protection Act (EPA). It is an umbrella legislation set in place by the ministry of the environment, forests, and climate change that offers a comprehensive framework for preserving and enhancing the environment. The authorities that comes under EPA are:

1. Recombinant DNA Advisory Committee (RDAC)
2. Institutional Biosafety Committee (IBSC)
3. Genetic Engineering Appraisal Committee (GEAC)
4. Review Committee on Genetic Manipulation (RCGM)
5. State Biotechnology Coordination Committee (SBCC)
6. District Level Committee (DLC)

The Rules under EPA Includes;

- No GMO substances or cells may be imported, transported, stored, processed, used, or sold without the consent of the GEAC.
- Use of pathogenic organisms, GMOs, or cells for research purposes must be permitted in labs or inside lab areas under EPA notifications from MoEF & CC.
- Anyone using or operating a GMO for scale-up or pilot operations must receive GEAC approval.
- Release of GMOs, whether thoughtful or not, is prohibited without proper approval.
- The approval for GMOs is valid for 4 years with a renewable period of 2 more years.

IV. FUTURE PROSPECTUS

The future of biotechnology in agriculture holds immense potential to revolutionize the way we produce food, address environmental challenges, and enhance global food security. As technology continues to advance, several key areas are expected to drive the future thrust of biotechnology in agriculture. Genome editing technologies like CRISPR-Cas9 will accelerate the development of crops with precise and beneficial traits. Scientists can edit genes responsible for disease resistance, stress tolerance, and nutritional content, reducing the reliance on chemical inputs and creating crops better suited for changing climates. The thrust will be more on successful integration of biotechnology with data analytics, remote sensing, and AI-driven decision support systems will enable farmers to optimize resource allocation, improve crop monitoring, and enhance yields while minimizing environmental impact.

V. CONCLUSION

Ultimately, the fusion of biotechnology and agriculture holds the promise of feeding a growing global population while treading lightly on the Earth's resources. It is a story of innovation, adaptability, and collaboration—a story that propels us towards a more sustainable, resilient, and nourished world. As scientists, policymakers, farmers, and consumers continue to engage with the possibilities and challenges of biotechnology in agriculture, the realization of its potential hinges on responsible stewardship, transparent dialogue, and a shared commitment to shaping an agricultural landscape that benefits both present and future generations. As we weigh the scales between boon and bust, it becomes

clear that the trajectory of biotechnology rests not just in the hands of scientists and policymakers, but in the collective consciousness of society at large.

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