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Role of Agricultural Biotechnology in Crop Improvement

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1. Introduction

Biotechnology can be defined as the use of scientific techniques to improve and alter plants, animals, and microorganisms. Biotechnology has revolutionized agriculture by providing innovative tools to address global challenges such as food security, climate change, and resource scarcity. With the global population projected to reach 10 billion by 2050, the demand for sustainable crop production has never been more urgent. Biotechnology, particularly through genetic engineering, proteomics, and nanotechnology, has enabled scientists to develop crops with enhanced traits such as drought tolerance, disease resistance, and improved nutritional quality. Over the years, biotechnology has found its way to several fields, including medicine, agriculture, genetic engineering etc. In this article, the application of biotechnology in agriculture and its role will be discussed briefly.

2. Advancements in Biotechnology for Crop Improvement

Agricultural biotechnology as a set of scientific techniques, can improve plants, micro-organisms, and animals based on DNA and its concepts. The use of biotechnology in agriculture is to be more effective than that of agrochemicals. The latter is believed to be responsible for causing environmental distress and is also somewhat unfeasible for farmers. The following highlights the few ways in which biotechnology has found its way in agriculture:

1.1 **Genomics and Genetic Engineering:** The advent of genomics has allowed scientists to identify and manipulate genes responsible for desirable traits. For instance, the development of transgenic crops, such as *Bt. Cotton* and herbicide-resistant soybeans have significantly reduced crop losses due to pests and weeds. The importance of integrating genomics with conventional breeding to accelerate the development of stress-resilient crops has been emphasized by several researchers.

1.2 **Proteomics and Molecular Markers:** Proteomics has emerged as a powerful tool to understand the functional roles of proteins in plant growth and stress responses. While studying protein quantity loci (PQLs), Birhanu Babiye et al. (2020) have linked protein expression patterns to specific traits, enabling marker-assisted selection (MAS) in breeding programs. This approach has been particularly useful in developing crops with improved tolerance to abiotic stresses such as drought and salinity.

1.3 **Nanotechnology in Agriculture:** Nanotechnology has opened new frontiers in crop improvement by enabling precise delivery of nutrients and pesticides. For example, Nano fertilizers have been shown to enhance nutrient uptake and reduce environmental impact. Majumdar and Keller (2021) and Kumar et al. (2021) have highlighted the potential of nanoparticles in improving crop resilience to climate change and biotic stresses.

1.4 **Chloroplast Biotechnology:** Chloroplast engineering offers a unique approach to crop improvement by enabling high-level expression of transgenes and reducing the risk of gene flow through pollen. Studies conducted by Maliga and Bock (2011) have demonstrated the potential of chloroplast biotechnology in enhancing photosynthetic efficiency and producing high-value compounds such as vaccines and bioplastics.

1.5 **Tissue culture:** Tissue culture involves nurturing fragments of plant or animal tissue in a controlled environment where they survive and continue to grow. For this tissue has to be isolated first.

1.6 **Embryo rescue:** It is a form of *in vitro* culture technique for plants. Here, an immature embryo is nurtured in a controlled environment to ensure its survival. This can help in the preservation of species of seeds that are nearing extinction. This can include heritage seeds, local grains of cultural significance, etc.

1.7 **Somatic hybridization:** It is a process through which the cellular genome is manipulated through the process of protoplast fusion.

1.8 **Molecular diagnostics:** Molecular diagnostics is a set of techniques used to analyze biological markers in the genome and proteome. It helps in determining how their cells express their genes as proteins

1.9 **Vaccine:** It is a formulation that is injected into a host body to stimulate a desired immune response. It helps in preventing various diseases such as polio. Its production is carried out widely currently to fight against COVID-19.

1.10 **Micropropagation:** It is a clonal propagation of plants in a closed vessel under aseptic and controlled conditions.

3. Role of Agricultural Biotechnology in Crop Improvement

The role of biotechnology in agriculture is multifaceted. Some of the most prevalent benefits of biotechnology in agriculture include –

3.1 **Increased Crop Yield:** Biotechnology, particularly genetic engineering, can help develop crops with enhanced growth and reproductive capabilities, leading to higher yields per unit area. For example, crops can be engineered to improve nutrient uptake, photosynthetic efficiency, or seed germination, all contributing to increased productivity (Pingali et al., 2012).

3.2 **Disease and Pest Resistance:** Biotechnology has enabled the development of crops with enhanced resistance to diseases and pests. For example, transgenic rice varieties with the Sub1 gene have shown remarkable tolerance to submergence, benefiting farmers in flood-prone regions

3.3 **Abiotic Stress Tolerance:** Advances in biotechnology have led to the development of crops that can withstand adverse environmental conditions. For instance, drought-tolerant maize and salinity-tolerant wheat have been successfully cultivated in arid regions.

3.4 **Nutritional Enhancement:** Biofortification has been used to improve the nutritional quality of crops. For example, Golden Rice enriched with vitamin A and fortified potatoes with increased protein levels are a notable example of how biotechnology can address malnutrition.

3.5 **Development of Climate-Resilient Crops:** Biotechnology plays a vital role in developing crops that can withstand adverse environmental conditions such as drought, flooding, heat, and salinity. This includes engineering crops with improved water-use efficiency, tolerance to extreme temperatures, and resistance to drought stress.

3.6 **Sustainable Agricultural Practices:** Biotechnology can contribute to more sustainable agricultural practices by reducing the need for chemical inputs, optimizing resource use, and minimizing environmental impact. Examples include biofertilizers, which enhance nitrogen fixation and reduce the need for synthetic fertilizers, and precision agriculture techniques, which utilize biotechnology to optimize resource allocation.

3.7 **Other Applications:** Biotechnology also plays a role in improving the quality and shelf-life of produce. For example, transgenic tomatoes with delayed softening can be vine-ripened and shipped without bruising. Furthermore, biotechnology can assist in the development of disease-free planting material through techniques like tissue culture.

In essence, agricultural biotechnology provides a powerful toolbox for addressing some of the most pressing challenges facing the agricultural sector, from food security to environmental sustainability.

4. Achievements:

Agricultural biotechnology is breaking new ground with advanced research in genomics, proteomics, transgenics, and gene editing. The Agriculture Biotechnology programme supports innovative biotechnological research for achieving sustainable agriculture by leveraging the latest advances in technologies. The main achievements include:

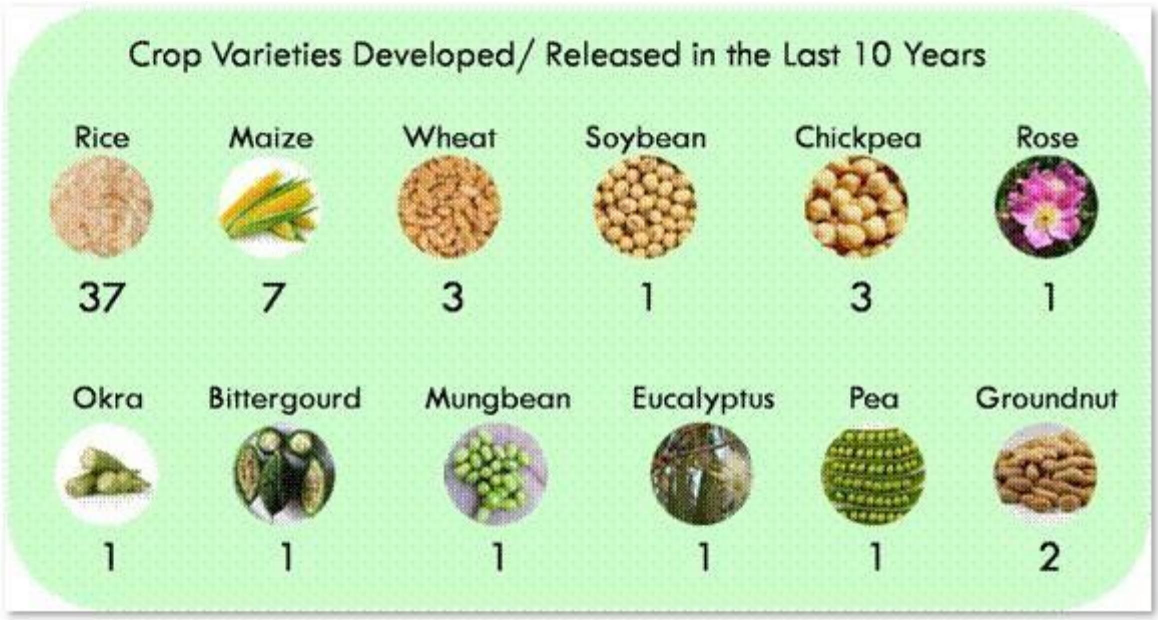
4.1 **Genotyping Arrays:** The first-ever 90K Pan-genome SNP genotyping array, IndRA, developed for rice has been commercialized for public use. Similarly, the first-ever 90K Pan-genome SNP genotyping array, IndCA for chickpea, has been developed. The arrays will help DNA fingerprinting, variety identification, and testing the genetic purity of rice and chickpea varieties.

4.2 Genome-Edited Crops: Genome editing was employed to generate loss-of-function mutations in several rice genes that negatively regulate crop productivity. These lines have been developed in the genetic background of the popular Indian rice variety, MTU-1010, and exhibit higher yield (in greenhouse conditions) over the parent line. In particular, similarly, the DEP1 (DENSE ERECT PANICLE; a G protein subunit) genome-edited rice lines produced larger spikes with increased grain numbers and yield.

4.3 **Amaranth Genetic Resources:** The Department of Biotechnology has developed an Amaranth Genomic Resource Database, Near Infrared Spectroscopy (NIRS) techniques for screening nutritional qualities of amaranth grain, and a 64K SNP chip. Amaranth accessions screened using the above resources have been shown to counteract high-fat diet-induced obesity. This is a significant enabler for rapid screening of amaranth accessions for cultivation as well as varietal development.

4.4 **Fungal Biocontrol:** A stable fungal enzyme nano-formulation from Myrothecium verrusiae has been developed for eco-friendly biocontrol of powdery mildew in tomato and grape.

4.5 **Kisan-Kavach:** An anti-pesticide suit designed to combat the pervasive threat of pesticide-induced toxicity in agricultural settings. Developed with a deep understanding of the challenges faced by farmers, Kisan Kavach stands as a beacon of safety and innovation in the field.



5. Challenges and Future Directions

Despite its potential, the adoption of biotechnology in agriculture faces several challenges, including regulatory hurdles, public acceptance, and ethical concerns. Future research should focus on developing cost-effective and scalable solutions, as well as addressing the socioeconomic implications of biotechnological interventions.

6. Conclusion:

Biotechnology has transformed crop improvement by providing innovative tools to enhance yield, resilience, and nutritional quality. From genomics to nanotechnology, these advancements hold the key to achieving global food security and sustainable agriculture. However, continued collaboration between scientists, policymakers, and stakeholders is essential to overcome existing challenges and fully realize the potential of biotechnology in agriculture.

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