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Application of Modern Biological Tools in Crop Improvement

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Agricultural science is undoubtedly critical for its contribution to food security around the world, productivity increase, and sustainability assurance in agriculture. Traditional advancement in plant breeding techniques has allowed the breeding of advanced and resistant crops to unfavorable climate conditions. However, modern challenges such as climate change, pest and disease outbreak as well as natural resources depletion and changes in eating habits necessitate the need for more precise breeding techniques. Advanced biological processes, including molecular markers, marker-assisted breeding, genomic selection, genetic engineering, gene editing, tissue culture, and omics, have been really groundbreaking in crop enhancement as they facilitate identifying the required genes, having complex traits, speeding the breeding process, and producing newly developed crops. The combination of modern and traditional techniques has created new chance for increasing sustainable agriculture production. This piece of writing describes the main biological innovations that have been introduced by applied biotechnology in crops and mentions their ways of application, advantages and disadvantages, and outlook.

Keywords: Crop Improvement, Molecular Markers, Marker-Assisted Selection, Genetic Engineering, CRISPR-Cas9, Genomics, Plant Tissue Culture, Plant Breeding.

Introduction

Agricultural activities lead to the breeding of the improved crops that have favorable characteristics such as high yield, quality, and resistance to pests and diseases. Conventional breeding methods such as selection, hybridization, and mutation are very significant in the enhancement of farming. Nevertheless, the traditional breeding method is long because gaining the desired traits requires several generations of plant individuals. Furthermore, many genes and surrounding conditions influence the complexity of traits that make a crop plant drought-, heat- and yield resistant.However, modern technologies in the field of science allow plant breeding specialists to make better use of genetic variation and pay attention to vital genes in order to create new varieties in a much faster way.

Selection based on molecular markers is the first method

Molecular markers are sequences of DNA corresponding with a particular gene trait. Among these types are SSRs, SNPs, RAPDs, and AFLPs. In marker-assisted selection, molecular markers linked to desirable QTLs or genes are selected for when selecting the better plants prior to maturity. This technology also has wide applications in transferring traits-for example, disease resistance, resistance to abiotic stresses, enhancement of grain quality, and

pest control. For example, some rice varieties developed through marker-assisted breeding have resistance to bacterial blight and provide a good level of resistance to various diseases.

Genetic Engineering and Transgenic Technology

Genetic engineering is the process of introducing, changing, or moving particular genes in order to give plants desired traits. Transgenic technology is a method where genes can be added to plants from the same or another organism. This technology is used to produce crops that are resistant to insects and herbicides, as well as crops that have better nutritional value. An example of this technology is Bt cotton, a plant that has genes that combat pests. Another example is Golden Rice, rice that has more provitamin A.

Genome Editing Technology

Genome editing is a cutting-edge biotechnological approach applied to targeted modifications of specific DNA sequences. Amidst several technologies available, CRISPR-Cas9 has become one of the important tools in plant genetic improvement. With this, a guide RNA is used to provide specific instructions to Cas9 to direct it to a particular site in the genome that needs modification, as opposed to leaving it in a kind of free state.

Its applications include:

- Development of disease-resistant crop varieties.
- Improvement of drought and salinity tolerance.
- Modification of plant architecture.
- Enhancement of nutritional quality.
- Improvement of yield-related characteristics.

Genome editing is able to provide a greater degree of accuracy and versatility than conventional methods of genetic modification. Yet, genome editing is only effective if genes are properly identified and modified, and if a correct evaluation of the regulation follows.

Plant Tissue Culture and Micropropagation

Plant tissue culture is a commonly used biotechnological process, during which growth of different plant cells, tissues or organs takes place in controlled sterile environment and appropriate nutrient media. The essence of the process is cellular totipotency, i.e. the fact that the plant cell can develop into a whole plant.

Major applications include:

- Rapid multiplication of elite planting materials.
- Production of disease-free plants through meristem culture.
- Development of haploid and doubled-haploid plants.
- Germplasm conservation.
- Embryo rescue and in vitro selection.

Micropropagation is particularly useful in crops such as banana, potato, sugarcane, and several horticultural plants.

Genomic Selection

Genomic selection is a modern breeding technique that uses molecular markers across the whole genome to forecast the genetic breeding values of individuals. Unlike conventional marker-assisted techniques that usually deal with specific genes or QTLs, genomic selection uses thousands of markers which are distributed over different genomes.

Omics Technologies

This method provides a unique chance to enhance complicated quantitative characteristics such as production, drought resistance, and biomass yield. Genomic selection significantly shortens breeding programs and improves efficiency when combined with excellent phenotypic information. Omics technologies involve a variety of approaches that give information about different biological processes in plant systems.

The most notable omics approaches are:

- Genomics – analysis of complete genome of the object under interests.

- Transcriptomics – studies of gene expression and RNA molecules.
- Proteomics – analysis of proteins and their functions.
- Metabolomics – studies of metabolic processes of plants.
- Epigenomics – the study of gene activity changes which occur without change of DNA sequence.

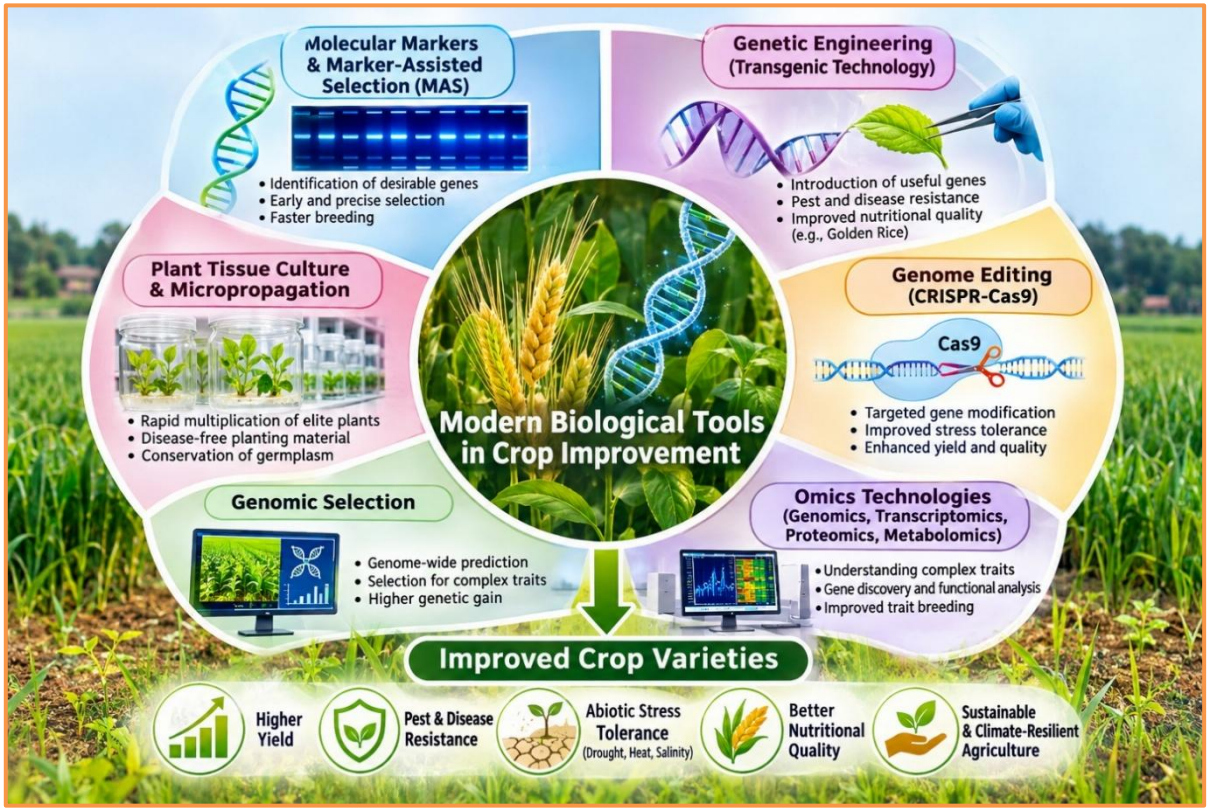
The combined use of these methods gives an opportunity to expand the knowledge of the process of molecular regulation of the growth and development of plants, their reactions to environmental conditions, as well as yield.

Crop Improvement Applications

Biological approaches are also used to improve germplasm of crops and develop new varieties with better agronomic and nutritional value.

Table 1. Major biological tools and their applications in crop improvement

Biological tool	Major application	Expected improvement
Molecular markers	Identification of desirable genes	Faster selection
Genetic engineering	Introduction of useful genes	Pest and disease resistance
CRISPR-Cas9	Targeted genome modification	Improved specific traits
Tissue culture	Rapid plant multiplication	Quality planting material
Genomic selection	Prediction of breeding values	Faster genetic gain
Omics technologies	Understanding gene and protein functions	Improved stress tolerance



Role of new biological methods in agriculture that can withstand climate changes

Climate changes have brought about climate changes that are characterized by frequent and longer duration of droughts, periods of heat stress and floods with occurrence of salinization. All these climatic factors have a negative impact on plants as in the process of the growth, development and productivity are disrupted. Modern biotechnology approaches allow us to detect genes and genomic regions responsible for stress resistance. Molecular markers and genomic selection can be applied in order to produce resistant lines. Genetic engineering may be used for changing certain genes that affect stress responses. Omics technology enables specialists to understand the way plants resist drought conditions, endure high temperature,

and survive in salinized soils. The application of this technology leads to the improvement of new climate-resistant plants by means of conventional breeding.

Challenges and Limitations

Modern biological technologies come with many advantages, yet they have their own downfalls. Indeed, molecular biology approaches require specific laboratory apparatus and highly skilled practitioners, which makes them even difficult to employ. In addition, the limited availability of such technology restricts its use in agricultural systems of developing nations. Some of the challenges facing this technology include complicated interactions between genes, efficacy of transformation depending on genotype, off-targeting in genome editing, various regulations, and acceptance of GMO products. In addition, molecular changes need to be tested in the field to verify their effectiveness in agriculture in different environmental conditions.

Conclusion

Recent advancements in biological technology have completely changed the way that crops are cultivated since these tools enhance the accuracy and efficiency of plant breeding tremendously. Number of technologies, including molecular marker-assisted selection, genetic engineering, genome editing, tissue culture, genomic selection, and omics, give excellent opportunities in the area of crop improvement, resulting in creation of crops with greater yields and resistance to diseases, better nutritional properties, and improved ability to adapt to climate change. At the same time, there are still some issues associated with the implementation of modern biological tools, including the lack of infrastructure and expertise along and high costs. However, the combination of innovative and traditional approaches can speed up the process of genetic improvement of crops in the near future.

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