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BIOTECHNOLOGY IN AGRICULTURE: A COMPREHENSIVE REVIEW OF CROP DEVELOPMENT STRATEGIES

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Abstract *This review article discusses the potential of biotechnology in agriculture, specifically in crop development. It highlights the benefits of genetic engineering, molecular markers, and genome editing techniques in enhancing crop productivity, nutritional value, and resistance to environmental stresses and pests. However, the article also acknowledges the challenges that must be addressed, such as regulatory frameworks, public acceptance, and ethical considerations. The article also discusses the importance of tissue culture in plant reproduction and the various techniques used in tissue culture, including protoplast fusion, cryopreservation, and micropropagation. It emphasizes the advantages of in vitro cell and tissue culture in plant and mutation breeding. Furthermore, the article mentions using transgenic crops, which have been genetically modified through genetic engineering techniques. It discusses the benefits of transgenic crop cultivation, such as increased revenue and agricultural output. However, it also acknowledges the public's concerns about potential environmental hazards and human consequences of transgenic crops. The article concludes by emphasizing the importance of biotechnology in addressing the challenges faced by the agricultural industry, such as pest and disease outbreaks, climate change, and soil fertility depletion. It highlights the need for sustainable agricultural practices and the development of crop varieties that can withstand extreme weather conditions and climate change to ensure global food security.*

Keywords: *Biotechnology; crop development; tissue culture; transgenic crops; molecular plant breeding*

Introduction

The exponential expansion of the global population is increasing the stress on the agricultural sector to optimize food production while mitigating adverse environmental effects. Biotechnology has proven to be a successful crop development strategy because of its inventive methods for enhancing agricultural output, nutritional composition, and resistance to both biotic and abiotic factors (Huang et al., 2005). This article explores the potential and constraints associated with the application of biotechnology to enhance crops. Biotechnology comprises a vast array of techniques for manipulating agricultural organisms' genetic makeup to achieve specific characteristics. As an illustration, genetic engineering enables the insertion of particular genes into plants to impart characteristics such as enhanced nutritional value, resistance to herbicides, and protection against pests (Das et al., 2023). Breeders can make informed selections regarding desirable qualities with the aid of molecular markers, which detect the presence or absence of particular DNA sequences. Genome editing techniques, including CRISPR-Cas9, have introduced novel prospects for crop development by providing accurate and efficient means of modifying particular genes within the plant genome. Biotechnology exhibits considerable potential in tackling critical agricultural issues (Parmar et al., 2017). Genetic modification of crops can increase their resistance to environmental stresses, parasites, and diseases, thereby decreasing output losses and the requirement for chemical inputs. To counteract malnutrition, biotechnology has the potential to increase the nutritional value of crops by supplementing them with vital vitamins, minerals, and other advantageous components. In addition, biotechnology can facilitate the development of crops with enhanced flavour, texture, and shelf life, thereby decreasing postharvest losses and boosting consumer acceptability. While biotechnology exhibits considerable potential, several obstacles must be surmounted before its effective integration into the agricultural sector. The regulatory regimes governing genetically modified organisms (GMOs) vary across countries, thereby introducing complications into the timely and effective distribution of such crops. It is essential to have scientifically grounded, transparent, and dependable regulatory frameworks to promote the responsible application of biotechnology. Moreover, the general public's acceptance and perception of genetically modified crops significantly influence their pervasive implementation (Zalila-Kolsi et al., 2023). To foster confidence and acceptance, it is imperative to disseminate information to the general public regarding the advantages and security of biotechnology while also confronting apprehensions regarding its ecological and human repercussions. Additionally, the ethical implications of biotechnology must be considered. Intellectual property rights, equitable benefit distribution, and potential impacts on biodiversity and traditional farming practices must be addressed to establish a sustainable and just agricultural system. The potential of crop enhancement in biotechnology to enhance agricultural resilience, sustainability, and production holds considerable promise. Molecular markers, genetic engineering, and genome editing techniques can produce crops with advantageous qualities, including increased yield, nutritional value, and resistance to duress (Saeed et al., 2021). To achieve the complete potential of biotechnology in the agricultural sector, it is imperative to confront challenges such as public opinion, ethical considerations, and legal structures. By surmounting these obstacles, we can utilize biotechnology to attain sustainable agriculture and global food security in the face of climate change.

Different approaches to crop improvement by various biotechnological tools

Tissue culture technique

The aseptic cultivation of cells, tissues, organs, or whole plants under controlled environmental and nutrient environments is called tissue culture. This field of study has been devoted to the "totipotency of plant cells" since the early 1900s. Numerous techniques are used in plant tissue culture, including protoplast fusion, cryopreservation, meristem culture, somatic embryogenesis, somaclonal variation, micropropagation, and secondary metabolite production. These techniques are predicated on plant tissues' totipotency and cellular plasticity (Shelke et al., 2023). Since in vitro cell and tissue culture makes it possible to cultivate single or partially-grown tissues, it's a great method for achieving somaclonal variation. This enables effective plant reproduction, prolonged exposure to mutagenic agents, identification of certain tissues with a higher susceptibility for mutation, and precise dosing of mutagenic agents. It is necessary to preserve the genetic integrity of in vitro proliferating material to ascertain whether tissue culture variation compromises genetic accuracy or can be used to obtain novel genotypes. After tissue culture, cytogenetic, biochemical, and molecular methods can be used to ascertain the creation of somaclonal variation (Duku et al., 2011).

A tissue culture technique called "embryo rescue" is utilized in breeding plans and genetic selection for individuals who conceive accidentally after fertilization. It also works well for conserving species whose seed division is inhibited by biotic or abiotic factors, rendering them sterile. Every year, more than 500 million plants of different species are grown by a process called micropropagation, which entails mass producing clonal offspring from minuscule plant parts in a lab environment. There is a lot of potential for micropropagated plants to improve the environment's cleanliness and greenness. They provide super-elite seed production material that is free from disease and true to type (Hafeez et al., 2023).

Transgenics

Transgenic, or genetically modified, crops have had their genomes altered through genetic engineering techniques. Genetic engineering and transgene-based research enables the transfer of genes from diverse origins into plants, in contrast to the labor-intensive nature of breeding, which transmits genetic information exclusively to closely related species (Bashir et al., 2023). A rigorous selection procedure and a well-established protocol for integrating the gene into the host species are necessary to enhance the probability of success. Utilizing Agrobacterium tumefaciens-mediated genetic transformation to generate stable transgenic lines is a time-tested method. To introduce foreign DNA temporarily, various biological techniques are employed, including particle bombardment, electroporation, and sonication. A comprehensive assessment of the advantages and disadvantages of genetic modification in cereals facilitated by A. Tumefaciens was performed. In addition to being labor-intensive and time-consuming, the process of procedure optimization is time-consuming. It severely limits the effectiveness of this approach concerning several crucial species (Bibi et al., 2023). Optimizing experimental parameters is also essential for enhancing transformation efficiency. To enhance phenotypic and performance attributes, it will be imperative to introduce numerous genes into the target genome once the process has been solidified. Currently, 32 cultivars have been introduced to the market, consisting of 525 transgenics; among these, *Zea mays* is the most widely recognized. Kumar et al. (2020) reported that implementing transgenic crop cultivation resulted in a 68% increase in revenue and an approximate 22% rise in agricultural output. There have been numerous applications of genetic engineering to enhance crops; a concise overview of these can be found in the following sections. Bt brinjal ensured the survival of farmers in low-income countries like Bangladesh, whereas Bt cotton provided a transitory economic lift to India. Despite these advantages, the public has been hesitant to adopt transgenic crops, citing concerns about potential environmental hazards and human consequences. Nevertheless, the safety of human health regarding transgenic crops remains unsubstantiated in scientific research (Tsatsakis et al. 2017; de Vos and Swanenburg 2018). Despite this, biotechnology continues to be indispensable to the future of agriculture in light of the escalating difficulties confronting the agricultural industry. Intensive agriculture presently facilitates the prosperity of cultivators while augmenting the global provision of cereals and vegetables. However, soon, agriculture's sustainability could be severely jeopardized by problems such as the spread of pests and insects, unanticipated diseases, inadequate precipitation resulting from the misuse of synthetic fertilizers, depleted soil fertility due to repeated cropping, and so forth. Plants in their natural environment must tolerate multiple stresses. Biotechnology manipulation of genes that regulate a broad spectrum of stress responses may contribute to developing more productive plant varieties in such circumstances(Khalid and Amjad, 2023). Biotechnology has been employed to modify a wide variety of crops, some of which have been introduced or will be introduced in the future. In conjunction with sustainable agricultural practices and climate change mitigation initiatives, cultivars that can withstand extreme weather conditions and climate change must be introduced to assure global food security (Amjad et al., 2022).

Molecular Breeding Approaches

Crop species and agricultural development institutes have used molecular plant breeding techniques in response to societal, economic, and technical factors. The resistance of some cereal crop species to Agrobacterium-mediated transformations and the ignorance of trait genetic regulation were the first challenges. Prominent horticultural and agricultural species have changed significantly thanks to technological advancements. Improved knowledge of gene structure and function, as well as DNA markers for plant genetics, results from genomic research (Iqbal et al., 2016). The genetic distinctiveness of strong QTLs would remain unknown, though, unless breeding plans and information management were changed to consider pedigrees, morphologies, and marker genotypes (Zafar et al., 2022). In molecular breeding, the mutation of regulatory function continues to be a scientific conundrum since it is challenging to identify the sequence basis for such modifications and anticipate their phenotypic consequences (Khalid and Amjad, 2018). While molecular breeding is acknowledged as a crucial element in large firms' efforts to improve their crops, some public sector plant breeders disagree with the extensive use of contemporary molecular techniques, especially for minor crops (Bhutta et al., 2023). Three other factors, in addition to concrete scientific and financial ones, support this perspective: the molecular biology and plant breeding fields' experience and practical knowledge, the difficulties in getting governments and consumer groups to accept transgenic crops, and the possibility that molecular plant breeding will influence changes in public institution funding, improving molecular generation's intellectual services and capabilities (BABAR et al., 2022).

Applications

Crop species and agricultural improvement organizations have embraced molecular plant breeding methods for technological, financial, and social reasons. The first difficulties were the resistance of cereal crop species to Agrobacterium-mediated transformation and a poor understanding of the genetic control of characteristics. Technological advancements have greatly aided in the transition of important agricultural and horticultural species. Genomic research has produced DNA markers for plant genetics and insights into the structure and function of genes. However, unless breeding plans and information management are updated to account for knowledge of pedigree, morphology, and marker genotype, robust quantitative trait loci (QTLs) remain genetically non-specific (BABAR et al., 2022). Because it's hard to forecast the phenotypic effects of regulatory modifications and to lay the sequencing groundwork for them, changing regulatory function in molecular breeding remains a scientific problem. While molecular breeding is acknowledged as an essential component of large corporations' crop development efforts, some public sector plant breeders remain adamant about the widespread application of current molecular techniques, particularly for small-scale commodities (Razzaq et al., 2021).

This viewpoint is supported by three additional factors in addition to the practical scientific and economic ones: knowledge and experience in the fields of molecular biology and plant breeding; difficulties associated with governments' and consumer groups' acceptance of transgenic crops; and enthusiasm for the potential of molecular plant breeding that drives changes in funding at public institutions to improve intellectual services and capacity for molecular genetics and genomics research.

Conclusion

In conclusion, biotechnology offers promising solutions to address the challenges faced by the agricultural industry, including increasing food production, enhancing nutritional value, and improving crop resilience to environmental stresses. However, obstacles such as regulatory frameworks, public perception, and ethical considerations need to be addressed for the effective integration of biotechnology in agriculture. Tissue culture and molecular breeding techniques are important for crop development and genetic selection. Biotechnology can contribute to global food security and agricultural sustainability by combining sustainable agricultural practices and climate change mitigation efforts.

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Declaration

Conflict of interest

There is no conflict of interest among the authors.

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All authenticated data have been included in the manuscript.

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These aspects are not applicable in this paper.

Consent for publication

Not applicable

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