AN OVERVIEW OF PLANT BIOTECHNOLOGY TOOLS FOR FOOD SECURITY IN CLIMATE CHANGE

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ABSTRACT

Over the years, climate change has been a major obstacle to virtually all human endeavors. Ongoing climate change could have a negative impact on global food security. The rate of agricultural productivity must be doubled to feed the world's growing population. Through genetic modification, biotechnology can play an incredibly positive role in reducing the vulnerability of natural and human systems to the effects of climate change, including reducing greenhouse gases and increasing agricultural production on less land to help meet future food needs. However, the responsible use of contemporary agricultural biotechnologies significantly improves agricultural productivity and food security to ensure the availability of or access to food for all people and the efficient use of food resources globally. The applications of plant biotechnology are responding to the increasing demands for food security, socio-economic growth, conservation, diversification, and sustainable use of plant genetic resources as fundamental components of the future agricultural sector. Moreover, it has a significant positive impact on current and future climate change adaptation and mitigation efforts. Thus, this review aims to assess biotechnology's current challenges and potential future applications through genetic modification for food security.

Keywords: *Agricultural biotechnology, Biotechnology tool, Climate change, Genetic engineering, Food security.*

Abbreviations: *APRR2: pseudo-response regulator 2, GM: genetically modified, GMOs: Genetically modified organisms, KNOX: knotted-like homeobox, miR398:microRNA398, NBTs: new breeding techniques, NO: nitric oxide.*

INTRODUCTION

The ever-increasing human population is one of the modern era's societal, economic and scientific concerns. Consequently, existing levels of food production cannot meet the needs of such a large population. Global data show a strong correlation between high rates of undernourishment and low agricultural productivity (Zaidi et *al*, 2019). Achieving global food security by 2050 will not be easy. The main challenge facing the globe today is ensuring food security for an ever-increasing world population, which will require increased food production beyond previous decades. In addition, the agricultural sector will be affected by climate change and soil erosion, which will significantly reduce the productivity of the world's agricultural resources unless we take urgent action to halt the severe collateral consequences (Fedoroff et al, 2010).

The major global environmental issues facing our planet, our society, and our businesses at the beginning of the 21st century are dominated by the potential and imminent risk posed by the greenhouse effect and the resulting impact of climate change. According to the United Nations Framework Convention on Climate Change (UNFCCC 1992), climate change refers to a statistically significant change in the mean state of the climate or in its variability that persists over long periods (typically decades or more). These changes are attributed directly or indirectly to human activity and look at other important global and local environmental changes, including freshwater supplies, the carbon and nitrogen cycle, biodiversity, land cover and soils. Extensive research on the effects of climate change states that the increase in greenhouse gases leads to higher atmospheric temperatures, creating extreme weather events and threatening food production at various stages, especially in arid and semi-arid regions (Pickson and Boateng, 2022). Thus, the relative effect of climate change on food security will be much higher in developing countries.

The FAO (1983) defines food security as the act of ensuring that every person has constant access to the essential nutrition they need physically and economically. From this definition, four main dimensions of food security can be identified: physical availability of food; economic and physical access to food; food utilization; stability of the other three dimensions over time. According to FAO (2008), all four dimensions must be fulfilled simultaneously to realize food security objectives. In addition, the removal of organic matter and nutrients, soil impoverishment and the reduction of the soil's capacity to retain water are all consequences of the higher erosion rate in agricultural areas than in soil formation (Verheijen et *al*, 2009). Farmers need to fertilize their plots heavily to return nutrients to the soil and produce the best possible yields. Chemical supplementation is also used to control diseases.

Furthermore, losses caused by biotic and abiotic stresses justify such high pesticide use, with direct yield losses caused by pathogens, animals and weeds accounting for 20-40% of global agricultural productivity (Culliney 2014; Pandey et *al*,2017). The issue of food production has become critical in light of rapid global population growth, especially in the context of climate change. In addition to overcoming the challenges of providing enough food, it is essential to learn how to manage resources sustainably and reduce their adverse effects on the environment.

Therefore, modern agriculture has increasingly benefited from the use of plant biotechnology. Increasingly used in crop development, genetic engineering, and biotechnology have made it possible to produce higher yields of food and fiber while preserving the environment. These techniques have intensively illuminated the gene networks that lead to the generation of many bio-products that can benefit human health and the environment. Biotechnology is the application of science and technology to living creatures and their components, products, and models to modify living or non-living materials for developing knowledge, goods and services (Sawicka et al, 2020). The complexity of microbes and plants makes it more challenging to improve applied genetics. Practical genetic engineering of bacteria has prompted agronomists to use plant breeding techniques. This paper provides an overview of the key role of modern biotechnology through genetic engineering as a promising strategy to improve food production and ensure food security threatened by climate change.

BIOTECHNOLOGY BACKGROUND

Various cultivated varieties have been the basis of daily human and animal diets for thousands of years due to agriculture, domestication, and the slow, long-term introduction of alterations through natural and human-directed selection. Less than 200 of the 400,000-plant species have been domesticated and exploited as food sources and feed, providing up to 75% of the food consumed worldwide (Moshelion and Altman,2015). It is estimated that the amount of food produced globally needs to double to meet the demand of the expanding world population (2.4% more per year over the next 30 years) (Ray et al, 2013).

Biotechnology-related processes have been present for a very long time. Although they were unaware, our distant ancestors interacted with biotechnology through activities such as growing plants, baking bread and making wine.

Hungarian engineer Karl Ereky coined the term “biotechnology” in 1919 to refer to the science and methods that permit products to be produced from raw materials with the aid of living organisms. Biotechnology is a diverse field involving either working with living cells or using molecules derived from them for applications oriented toward human welfare using various tools and technologies. It is an amalgamation of biological science and engineering whereby living organisms, cells, or parts are used to produce products and services (Gupta V and al,2016).

There exist a wide variety of definitions of biotechnology. The definition of the OECD (Organization for Economic Co-operation and Development) specifies as follows: *“Biotechnology is interdisciplinary branch of science and technology dealing with transformation of living and inanimate matter by the use of living organisms, their parts or products derived from them, as well as creation of models of biological processes in order to produce knowledge, goods and services.”*

Thus, modern biotechnology is one tool that can help meet the challenge this growth poses and also contribute to (a) an eco-friendly environment, (b) safety and health, (c) reduce water demand in manufacturing processes, (e) reduce industrial waste and (f) aid in pollution remediation (Vigneswaran C el al,2014).In general, biotechnology uses either living material or biological products to create new products for their use in various pharmaceutical, medical, agricultural, and environmental applications, with the ultimate goal of benefiting humanity, for example, the production of recombinant proteins, resistant crops, vegetables, higher milk-producing animals, and the list is endless.(Verma A et *al*, 2011**).**

Biotechnology can be classified into 5 divisions: Red biotechnology, which includes gene therapy, the creation of new biopharmaceuticals, genetic diagnostics and xenotransplantology, which is concerned with health protection; White biotechnology, also known as biocatalysis and bioprocessing, is the use of biological systems in industrial production and environmental protection; Green biotechnology aims to increase the productivity of crops and livestock; Blue biotechnology refers to contemporary biology used in the creation of marine-derived food and obtaining new drugs; and Purple biotechnology which addresses social and legal concerns (Sawicka et al, 2020).

Green biotechnology is commonly considered the next phase of the green revolution and brings hope to defend against hunger on Earth. It uses technologies that enable it to produce more fertile and resistant to biotic and abiotic stress and plants and ensures the application of environmentally friendly fertilizers and bio-pesticides. Major technologies applied here are:

- plant cells and tissue cultivation and micro-propagation.
- application of molecular engineering for selection of plants (and to lower extent animals) with designed properties (GMO).
- marker-assisted selection - the use of tools such as molecular markers or DNA fingerprinting can map thousands of genes.

Thus, it allows plant breeders to screen large populations of plants for those that possess the trait of interest • reverse breeding and doubled haploids - a method for efficiently producing homozygous plants from a heterozygous starting plant, which has all desirable traits (Kafarski P ,2012).Applications of plant biotechnology are responding to growing concerns about food security, socio-economic progress and the sustainable use of plant genetic resources as fundamental components of future agriculture.

AGRO-BIOTECHNOLOGY FOR FOOD SECURITY

Agricultural biotechnology is a set of tools that use living organisms or parts of them to make or modify a product, improve plants, trees or develop microorganisms for specific uses related to food production as a whole to ensure food security for the population (Oluwambe and Oludaunsi ,2017). It is based on technical skills and competencies that describe its fundamental use in plants as medicines and foods. Using simple biotechnology based on Mendelian genetics, two types of plants of the same species are crossed to create a better type of plant. It is considered one of the products and processes of agricultural biotechnology.

The most crucial element of agro-biotechnology is agricultural supply, which is a significant part of the world economy and goes far beyond food supply. As genetically modified crops can help solve some of these problems, conventional genetic engineering approaches and recently developed new breeding techniques (NBTs) based on genome editing are promising technologies for the future of agriculture. Food production safety should come before incorporating new traits and properties, not the other way around. The analysis of 1783 research studies on the safety of GM crops (Nicolia et al, 2014) found no substantial risks that could be directly linked to Genetically Modified food (GM foods).

Furthermore, none of the 128,000 cases of food-borne infections resulting in hospital admissions and 3,000 deaths could be attributed to GM foods, demonstrating that food contaminated with pathogens poses a significantly higher threat to human health than Genetically Modified Organisms (GMOs) (De Francesco 2013). A possible explanation for these results is that GM maize grains had lower concentrations of mycotoxins (29%), fumonisin (31%) and thricotecens (37%) than their non-GM counterparts (Pellegrino et al. 2018). A reported 59.6% decrease in damage in GM maize lines led to a decrease in fungal contamination (Pellegrino et *al*,2018). Insect attacks (through physical damage to plant tissue) enable and promote fungal contamination.

PLANT BIOTECHNOLOGY TOOLS FOR ABIOTIC STRESS

Reverse breeding methods are also used to accelerate breeding and create new cultivars to meet changing climate demands. Many studies have been done on the genetic advancement of plants, in particular, on their increased tolerance to stress. The review paper by Gerszberg and Hnatuszko-Konka (2017) on the genetic engineering of abiotic stress in tomatoes is an excellent review of the topic. As several abiotic stimuli have a negative impact on it, tomato is an excellent research model to study stress tolerance in fleshy fruits. Genetic engineering has allowed studying the expression of stress-related genes in tomatoes. Several studies have described the physiological basis of the ability of plants to tolerate abiotic stress before describing the different genetic engineering techniques and the progress made in this field. The roles of crosstalk between microRNA and nitric oxide (NO) in signaling related to stress responses are briefly discussed by Singh et al (2016).

In contrast to NO signaling, which has been discovered as a new player in these processes, microRNAs are emerging as a crucial component in plant stress responses. In the review, the authors present three models that illustrate the signaling pathways involved in drought/cold-induced, NO-miRNA-mediated gene expression and the dual but opposite regulation of miR398 under oxidative stress or copper deprivation to help readers better understand the content. In addition, Savadi et *al* (2016) provided an overview of genetic techniques applied to increase the oil content of plants. Plant oils play an essential role in human food as a raw ingredient in industry and, more recently, as a component of biofuels. The enzymatic and regulatory mechanisms controlling lipid metabolism are regulated by hundreds of genes, making it difficult to genetically modify the oil content.

To identify genes involved in a specific biological activity, such as protein-coding genes or non-coding RNAs that respond to a specific stress, RNA profiling using microarray or high-throughput sequencing is frequently used. Reverse genetics encompasses this technique. This method was used by Xie et *al* (2016) to profile microRNA expression in Masson pine (*Pinus massoniana*) that was exposed to the pine wilt pathogen Bursaphelenchusxylophilus. They found ten microRNAs differentially expressed due to pathogen attack and are promising candidates for further functional investigation. Identifying microRNAs is the first step towards their use, which is strongly involved in plant growth, development, and stress responses.

In addition, Jiao et *al* (2017) used this method to genetically map the green skin trait in an F2 cucumber population. Cucumber skin color is a crucial organoleptic characteristic that influences consumer preference. Jiao et *al* (2017) functionally analyzed the strong candidate gene, APRR2, using various biochemical and molecular methods. Their results collectively imply that APRR2 and two Class-I KNOTTED1-like homeobox (KNOX) genes (TKN4 and TKN2) participate in mechanisms related to chloroplast formation in cucumber skin. Finally, developing a successful regeneration system for a target species is another requirement for crop improvement through genetic transformation and identifying functional genes in genomes. Bao *et al* (2017) created a rapid and efficient in vitro shoot regeneration process using explants called cotyledons for the London plane tree. They developed a viable strategy for shoot regeneration of this resistant species after a significant study on optimizing plant growth regulator recombination and seedling age.

The applications of plant biotechnology are responding to the increasing demands for food security, socio-economic growth, conservation, diversification and sustainable use of plant genetic resources as fundamental components of the future agricultural sector. Advanced biotechnologies can be successfully used to combat genetic erosion, strengthen ex-situ collections and in-situ conservation, improve the supply of improved and healthy seeds and planting material to farmers, integrate a new approach into food product development programs, and address other issues (Avila and Izquierdo,2006).

GENETIC ENGINEERING: AN OPPORTUNITY FOR CROP IMPROVEMENT

The growing role of genetic engineering and biotechnology in plant improvement and the new uses of these technologies in the industry, medicine and environmental protection will be enabled by the variety of molecular breeding procedures and technologies covered in this journal. Metabolic engineering and plant-based bioreactors will contribute to the delivery of valuable medical goods. The development of bio-products such as biofuels and bioplastics with lower production costs and inputs will be made possible by genetic engineering and biotechnology, which will also positively affect the environment.

The focus should be on increasing crop yields through new genetic sequencing, advanced "genomic breeding" technologies and proteomics to maintain food security for a growing world population. These technologies allow for an increase in the volume of plant production by establishing crop species in particular environmental circumstances. In addition, through these technologies, plant breeders can successfully and simultaneously focus on new crop species and functionalities, such as resistance, quality and crops essential for global food security. Molecular breeding is essential for improving crops (El-Esawi,2018).

CONCLUSION

Biotechnology produces effective products using microorganisms and organic materials derived from living organisms. Intellectual property rights protection for biotechnology procedures and modifications is likely to apply if the biotechnology tool is used for commercial purposes, which could limit its usefulness to impoverished farmers. The importance of industrial biotechnology is increasing due to rising oil prices and the depletion of non-renewable energy sources. However, manufacturing bioproducts presents several challenges that biotechnologists hope to overcome. Investing in agricultural biotechnology methods such as genetic modification, tissue culture and biofortification, the full potential of advancing food security and economic self-sufficiency in climate change can be realized.

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