Chapter 1
Biotechnology Approaches to Food Security: Risks and Solutions

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Introduction

Food security, agricultural sustainability, and hunger issues in developing countries continue to be a worldwide concern (Challa et al., 2019; Mustafa, 2020). Food security is a subject of great concern due to the growing population, urbanization, and the consequences of increasing demands on food supplies (Beddington, 2010). The general definition of food security is the ability to secure a healthy food supply to feed the whole population, maintain a healthy life, and be available at any time (Challa et al., 2019). Based on the Food and Agriculture Organization of the United Nations (FAO), food is secure when it is available, able to be accessed, and suitable for consumption. Due to global climate changes and a fast-growing population, the concept of food security has changed over the last 55 years (Challa et al., 2019) (Fig. 1.1).

Today, 800 million people worldwide are suffering from hunger, and the population continues to increase every day. The global population is estimated to increase to 8.3 billion by 2030 (Baulcombe, 2010). It is estimated that global food production must increase by 50–100% in order to meet food availability (United Nations, 2017). Thus, food production must dramatically increase in order to address and overcome starvation challenges (Godfray & Garnett, 2014).

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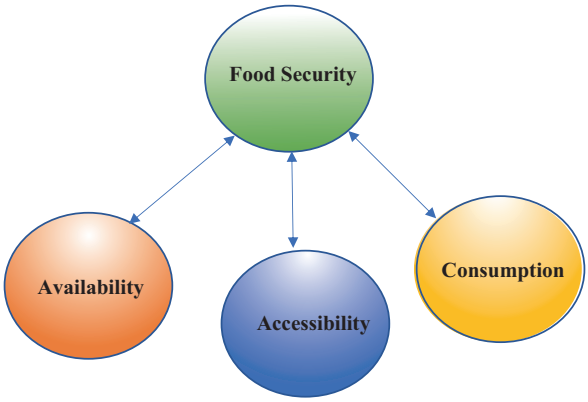

Fig. 1.1 The success of food security

Climate change has affected the earth's water sources, land, and soil, and we are losing clean, safe drinking water on a regular basis. The critical solutions are agriculture, increasing productivity improvement of plants, and introducing novel approaches to food processing (Ghoshal, 2018). Therefore, innovative technologies that ensure sustainable agriculture and improve plant productivity are paramount. Biotechnology approaches must be given more attention and take advantage of their innovative applications to ensure food security and an adequate food supply both now and in the future. For example, expanding the application of biotechniques in the agriculture system to include more genetically engineered crops, more focus on bioengineered approaches to improve soil functionality, hybridization, agricultural plant breeding, and other selection activities for agriculture, and increasing the biotechnology applications in the food industry.

Biotechnology is the approach that manipulates living organisms or their materials to convert certain products, enhance plant and animal production, and generate microorganisms for specific purposes (Abah et al., 2010). The innovative biotechnology technique has been used to develop and domesticate plants into tastier, safer, more nutritious, and healthier crops (Pal et al., 2017). Biotechnology is not a new approach, this approach has been in place since ancient times (Copeland, 2017). For example, humans began the process of involving the use of microorganisms in food to produce bread, wine, cheese, and dairy products preservation (Copeland, 2017).

GMOs are examples of a modern biotechnology approach used to modify a plant's DNA in order to enhance the plant's yield, taste, and resistance to diseases (De Souza & Bonciu, 2022). Manipulating DNA and genetic material helps to reduce diseases and adverse environmental effects (De Souza & Bonciu, 2022). As a result, biotechnology can contribute to food security through plant preservation, sustainable agriculture, and food safety. This chapter covers the role of biotechnology in food security, the challenges of using biotechnology to enhance food security, and the risks of using modern biotechnology approaches.

Role of Biotechnology in food security

Biotechnology plays a significant role in food security because of its innovative technology that can be manipulated in agriculture and food processing systems. This provides opportunities to increase food production and, at the same time, control the current challenges, including diseases, climate changes, and so on (Ghoshal, 2018).

Biotechnology is a promising approach for agriculture production and food supplies because it depends on plant genes to control food production (Mustafa, 2020; Scarpato & Ardeleanu, 2014). In this regard, food processing operations took advantage of biotechnology applications and were among the first investors that intensively utilized biotechnology applications earlier and recently (Johnson, 2018; Mustafa, 2020; Scarpato & Ardeleanu, 2014). The applications of biotechnology are currently expanding to involve more in the food chain system (Mustafa, 2020). These allow modern biotechnology to play a significant role in food processing, agricultural sustainability, and future food security by manipulating the agricultural production and food system (Sengar et al., 2016).

Modern biotechnology emerged in the last three decades and brought the very first evolution of gene recombinant. Hence, it changes the way humans live by impacting all aspects of life, including food, health, drink, and other daily needs (Johnson, 2018). The application of modern biotechnology has expanded and positively affected the agriculture and food industries. Biotechnology has great potential to resolve the issue of hunger now and meet the food requirements to prevent starvation in the future. (Ghoshal**,** 2018**).**

Biotechnology contributes to improving various areas, including plant preservation, sustainable agriculture, and food safety (Ghoshal, 2018; Sengar et al., 2016). These three areas can be expanded into sub-aspects, including the production of disease-resistant plants, fortification of crops, increase in aquaculture, pest-resistant crops, drought-tolerance crops, biofuel, enzymes, progress in fermentation, improve plant yield, increase shelf life, improve animal feed (Ranjha et al., 2022) (Fig. 1.2).

Plant Preservation

Since plants are essential sources of life for humans and animals, improving and enhancing the plants must be the primary goal. Thus, securing the required foods for the future growing population and feed for animals (Francis et al., 2017). Biotechnology can do a lot to improve plants and has the ultimate capacity to secure this vital source of humans' lives.

Fermentation is an example of the application of biotechnology in plant preservation that has been dramatically improved (Johnson, 2018). Fermentation is utilized to provide favorable changes to food using microorganisms, such as bacteria or yeast. This process can occur naturally in some foods, but most of the time, the

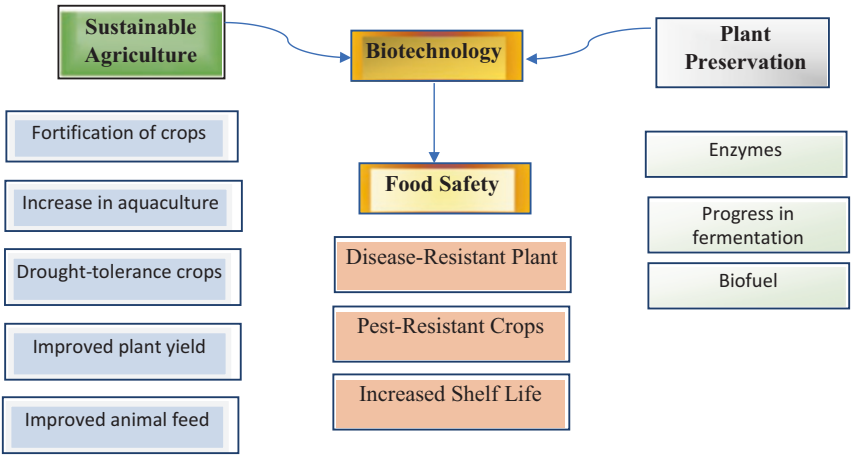

Fig. 1.2 The types of biotechnology

process is achieved by intentionally adding certain bacteria, yeast, or a combination of both under an anaerobic environment (Johnson, 2018). This process is essential in producing beer, wine, lactic acid, vinegar, and bread leavening. Fermentation improves food processes in several areas, including enriching foods with proteins, essential amino acids, and vitamins, preserving foods through acid production, eliminating antinutritional factors, changing diets by modifying flavors, aromas, and texture, and reducing the processing time. The production of these vitamins, amino acids, and other acids has been produced using genetically modified microorganisms (Johnson, 2018). For example, biotechnology can be used to increase the vitamin content in specific crops by transgenic plants.

Recently, with the emergence of modern biotechnology, a new recombinant genetic engineering technique has significantly impacted food fermentation by altering the purified microbial strain related to food fermentations. Recombinant basically means building or generating new microorganisms, animals, plants, or even cells with more valuable features by recombinant DNA methods (Abah et al., 2010).

Another area that biotechnology plays a significant role in is generating various types of enzymes. Enzymes are used by the food industry for food production and food processing (Lokko et al., 2018). These enzymes are generated by using genetically modified microorganisms (Ranjha et al., 2022). Generally, genetically modified applications can be utilized in two different methods, either by biolistic methods, which is performed using particle gun, or by agrobacterium tumefactions mediated r transformation method. Recombinant DNA methods have facilitated the construction of specific enzymes that align with certain food processing conditions (Ghoshal, 2018). For example, the enzyme Alpha amylases has been generated with high heat stability to be used for manufacturing high-fructose corn syrups that require this type of enzyme. These enzymes were engineered by modifying DNA sequence in the α-amylase amino acid sequences genes (Katsimpouras et al., 2014; Ranjha

et al., 2022). Many other similar enzymes have been engineered and used in food processing and food preservation manufacturing, and these enzymes historically have been proven to be non-toxic.

The application of biofuel also significantly impacts the agriculture and food system by protecting the environment, providing alternative resources to current fuel, and providing many other advantages (Ranjha et al., 2022). Biofuels are generated from plant and plant-based resources, and they are either bioethanol or biodiesel (Hood, 2016). Both types of biofuels are mainly used for transportation. Bioethanol is primarily made from sugar fermentation of cellulose, usually from maize and sugar cane. Bioethanol is used as an alternative to petrol for transport cars. While biodiesel is made from crops oil of palm, soybean, or rapeseed (Sivakumar et al., 2010). However, providing a substitute for the current fuel is not the only goal for biofuel production; biofuels offer many other advantages, including reducing greenhouse emissions, protecting the environment, improving plant yields, and increasing plant protection against abiotic and biotic stress.

Global warming or climate change is a subject of great worldwide concern, and there is quite evidence that emissions from greenhouse gasses contribute to global warming. The primary sources of greenhouse gasses are fossil fuel and electricity usage. Therefore, providing an alternative plant-based fuel will help to reduce greenhouse emissions. Which ultimately prevents a human from the risk of global warming. Biofuels are also carbo-neural, meaning that carbon dioxide is dragged from the environment during biofuel production. Which results in the consumption of greenhouse gas emissions (zero emissions).

Additionally, biofuels reduce the amount of volatile organic materials because of the oxygenation of ethanol and gasoline, and also no need to add lead. Finally, biofuels are non-toxic and have no risk to human health compared to current fossil fuels. The production of biofuels can also be used to increase plant yields by enhancing the efficiency of light during plant photosynthesis. This can be achieved by incorporating photosynthetic bacteria genes into plants, resulting in more light capture and increased productivity than the light from the sun. To this end, biofuels can be used to improve plant protection against abiotic stress by generating plants that are more resistant to stress and producing plants with genes that make the plant more resistant to pathogens and various types of pests (Sawicka et al., 2020). Thus, the production of biofuels has the potential to contribute to future energy security. However, more research and efforts are needed to be carefully evaluated to ensure the safety and adverse effects of food production or other process activities.

Sustainable Agriculture

Agriculture is the backbone of the food system because it provides a renewable raw material for the food industry and serves as the basis of the integrated economy. Building a strong economy through agriculture contributes to substantial development, which will tend to increase in the future by producing higher quality

renewable raw materials sustainably (Lokko et al., 2018). Then, food security and environmental protection will remain guaranteed (Lokko et al., 2018). Having a strong economy in all sectors will ensure global food security and enhance food nutrition value and public health, which will reduce the impact of climate change. Sustainable agriculture using innovative techniques provides the generation of a concrete economy, a healthy environment, and high-quality foods because sustainable agriculture aims to preserve environmental quality, decrease environmental impact, and maintain economic viability (Anderson et al., 2016). Recently, biotechnology has played a significant role in improving the food industry and agricultural activities regarding the quantity and quality of food and agricultural products (Singh & Mondal, 2017).

The application of biotechnology in agriculture provides a great variety of scientific tools to improve every area related to agriculture, including plants, animals, and microorganisms and offers a promising solution to the development of plant productivity and sustainability (Montagu, 2019; Singh & Mondal, 2017). Examples of some of these approaches include genetic engineering, tissue culture, molecular breeding, and molecular evaluation (Singh & Mondal, 2017). These approaches provide farmers with tools to generate high-quality new varieties of agricultural crops, identify diseases, or help the industry produce high-added value molecules for food and health (Lokko et al., 2018).

To have sustainable agriculture, it is crucial to manage and maintain natural resources wisely; sustainability must be in all areas of the supply chain to guarantee food security (Montagu, 2019). For example, sustainability in raw materials and energy, reducing emissions, eliminating waste, and promoting the economy. Biotechnology offers magnificent opportunities and provides tools for the sustainability of the whole supply chain and agriculture development (Abah et al., 2010), for example, treating wastewater, solid waste, climatic smart food production.,

For this purpose, biotechnology facilitates the enhancement of agricultural practices, specifically selection and breeding, through genetic engineering. Genetic engineering is commonly used to improve crops that are rich in important sources of diet, such as vitamins, proteins, lipids, and carbohydrates (Fiaz et al., 2021; Francis et al., 2017; Ghoshal**,** 2018). Besides, biotechnology applications can be utilized to improve animal productivity, including transgenic dairy cattle to improve the milk quality and muscle growth in cattle, Transgenic swine to reduce fat in swine, and transgenic eggs as bioreactors to enhance poultry productivity, fish bioengineered to increase production and improve antifreeze property of fish (Abah et al., 2010; Fiaz et al., 2021). Regarding microorganisms' transformation of microorganisms, biotechnology using genetic engineering can perform many improvements to microorganisms, including the removal of carcinogenic compounds, the Inhabitation of pathogenic bacteria, and the generation of carotenoids in microorganisms (Abah et al., 2010).

Finally, numerous biotechnology approaches are used in detecting and identifying disease-causing microorganisms, including pathogens, through molecular techniques (Johnson, 2018). Thus, preventing and reducing diseases utilizing the application of modern biotechnology. Genetically engineering (modified) plants

have different applications, including vitamins-rich plants, essential Minerals, essential amino acids, essential phytochemicals, Iso-flavonoids, flavors, amino acids, sweeteners, and DNA vaccines (Johnson, 2018). Rice modification with enhanced vitamin A content is an example of a vitamin-rich plant using genetic engineering. To this end, it is crucial to mention that genetic engineering (GMO) is not the only technique of biotechnology but includes all other engineering techniques that use living organisms or bio-based methods. Those techniques are non-GMO and do not include genetic modification, for example, improving plant yields by increasing their resistance to disease and pests, droughts, and harsh environments or improving the economy (Jauhar & Khush, 2003). Therefore, novel and existing biotechnology must be manipulated to ensure the production of enough food supply, maintain our resources, and meet food security in the future. Biotechnology has great potential to fight the global challenges of food insecurity (Pal et al., 2017).

Food Safety

Food safety is a field in food science that focuses on the safety of food products and ensures that food is safe for human consumption. Food processing involves many steps and unit operations, which convert raw food items or perishable into edible food products with improved quality and shelf life (Johnson, 2018). The production of safe food with high quality requires all processing steps and techniques must be food-grade and free from any risks to human health, including biological, chemical, and physical contaminants (Maryam et al., 2017). Biotechnology provides tools to aid in successful food safety. For example, it is also a diagnostics tool for monitoring food safety, preventing and detecting food-borne illnesses, and verifying the food safety application. Some other approaches are applied for the purpose of pathogen detection and food safety practices (Ghoshal, 2018). For example, developing emerging methods to protect plants against pathogenic bacteria, viruses, and fungi (Anderson et al., 2016; Maryam et al., 2017). In this context, several plant defensins are being used to produce disease-resistant plants; defensins plants are used against fungal infections due to their robust antifungal properties (Anderson et al., 2016).

On the other side, biotechnology is widely used in food industries to produce different products, such as genetically modified food, to enhance taste and yield, increase shelf life, and improve nutritive value. Food Safety is one of the major worldwide concerns. Ensuring the production and provision of safe food. The application of biotechnology in the food industry is used to improve the quality of food products, enhance the nutritional value, and increase the shelf life of food products (Maryam et al., 2017). Genome sequencing of plants is one of the biotechniques that address problems of food safety, human health, and food security (Agrawal et al., 2013). Therefore, biotechnology could help to ensure the production of a sustainable food supply with high-quality and safe products.

Challenges of Using Biotechnology to Enhance Food Security

The worldwide challenges for the coming decades are the growing population, demographic changes, climate changes, lack of resources, and increased gas emissions from the greenhouse (Charles et al., 2014).

Currently, the growing population in the coming decades and how to secure enough food is one of the most global challenges (Charles et al., 2014). The increased population will affect not only the food supply chain but also other resources such as health and education sectors, lands, and jobs. Another consequence of the upcoming growing population is raising the average income and people becoming richer due to the high demand for foods, willingness to pay more to obtain food products, and the tendency of people to change their diets towards healthier foods (Drewnowski & Popkin, 1997). This diet transition will cause a rise in the price of foods with nutritional value. As the average rich people are more, the demand for other resources, such as land, energy, water, goods, and other resources, will cause the scarcity of resources, leading to adverse effects on the environment (waste, water, and soil pollution) (Charles et al., 2014). Another challenge is global climate or environmental changes, which already have negatively affected our food resources by reducing agricultural productivity due to global warming. This global warming will trigger temperature rise and severe weather occurrences (Charles et al., 2014).

Consequently, global warming may cause worse events, such as floods or droughts. In this case, food production, especially plant productivity and livestock, will be severely affected if the problem is left without proper solutions, leading to food insecurity. Since the primary source of global warming is gas emissions from the greenhouse, immediate action is needed to reduce the amount of gas emissions from the greenhouse. This is not an easy task, but immediate action is required to stop the adverse consequences of the gradual temperate rises. This challenge, but the solution is still possible, and agriculture here must play a role in controlling this problem by using biotechnology to overcome greenhouse gas emissions. Finally, the food industry and the amount of waste. The global concern is the ability to increase food production to meet the growing population. However, the challenge here is not about the capacity to increase food production but rather how much we waste, how to reduce the amount of waste, and how much feed goes to livestock. If we reduce or eliminate the waste, then we can solve the risk of future starvation, feed the growing population, decrease the agricultural inputs, and save the environment at the same time. Changing the human daily habit of diet towards more plants instead of meat will also positively affect human health.

Risks of Using Modern Biotechnology Approaches

Meeting the increasing global demands for food, bioenergy, and specialized products while addressing environmental threats presents significant hurdles for agricultural production. Agricultural biotechnology holds promise in facing these

challenges, but it must first handle the ethical and sociocultural concerns to gain widespread public trust and acceptance. Effectiveness necessitates the development of ethically responsible solutions that are socially inclusive, culturally relevant, and communicated to the public transparently (Harfouche et al., 2021).

Health and Ecological Concerns

Genetically improved (GI) foods are neither inherently good nor bad for human health; their impact depends on their specific composition. GI foods enriched with higher iron content can provide health benefits to individuals with iron deficiencies. However, the transfer of genes between species may inadvertently introduce allergenic properties. Therefore, it is crucial to subject GI foods to allergy testing before their commercialization. Additionally, GI foods with potential allergy risks should be clearly labeled. Labelling serves various purposes, including disclosing ingredients for cultural, religious, or consumer information reasons. Ensuring the safety of GI foods and appropriate labeling is a shared responsibility between the public and private sectors. While public authorities must establish and enforce safety standards and mandatory labeling to safeguard public health, the private sector can address other requirements driven by consumer preferences. It is imperative to remove antibiotic-resistant marker genes used in research before commercializing GI foods to mitigate potential health risks, even if they are unproven. The regulation of GI foods, including assessing environmental risks, should be integrated into a country's general food safety regulations. Developing nations may require support from international agencies and donors to establish regulatory frameworks that are tailored to their specific risk factors. These regulatory systems must encompass food safety, environmental impact assessment, compliance monitoring, and enforcement mechanisms, all of which should be adapted to each country's unique circumstances. Given the pace of economic globalization, efforts to achieve a global consensus on biosafety standards are urgently needed. Policymakers and regulators must consider ecological risks associated with GI foods, such as the potential spread of traits like herbicide resistance to non-modified plants, increased resistance in insect populations, and threats to biodiversity resulting from extensive cultivation of genetically improved crops.

Seeds that allow farmers to deactivate specific genetic traits offer a promising solution to prevent unintended cross-pollination (Pinstrup-Andersen & Cohen, 2000). Due to extensive crossbreeding with wild relatives and ancestral species, the unregulated exchange of genetic traits, particularly those responsible for various forms of resistance to pesticides, pests, and plant diseases. Consequently, this process leads to diminished biodiversity among wild ancestral variations of cultivated crops and the emergence of problematic "superweeds" (Nezhmetdinova et al., 2020). Both food safety and biosafety regulations should align with international agreements and reflect society's acceptable risk thresholds, considering the potential benefits of biotechnology. Inclusivity is vital, and it is essential to involve

impoverished communities directly in discussions and decisions concerning technological advancements, associated risks, and the consequences of alternative approaches (Pinstrup-Andersen & Cohen, 2000).

Socioeconomic Risk

Without implementing policies that ensure equitable access to agricultural biotechnology resources, services, and markets for small farmers in developing countries, there is a significant risk of exacerbating income and wealth inequality. In such scenarios, larger farmers are more likely to reap the benefits of early technology adoption, increased production, and reduced production costs (Leisinger, 1999). Consolidating agricultural biotechnology research among a few companies can decrease competition, leading to monopolistic or oligopolistic profit structures, potential exploitation of small-scale farmers and consumers, and the possibility of obtaining preferential treatment from governments. Effective antitrust legislation and enforcement mechanisms are essential to address these challenges, particularly in small developing nations where only a limited number of seed companies operate. International standards regarding industrial concentration must also be developed, as global policies have not kept pace with economic globalization. Additionally, robust legislation is required to enforce Intellectual Property Rights (IPRs), including those related to farmers' rights to germplasm. These rights should align with the agreements established within the World Trade Organization (WTO) and the Convention on Biological Diversity (Pinstrup-Andersen & Cohen, 2000).

Ethical Consideration

A significant ethical issue arises from genetic engineering and the concept of "life patents" as they can be seen as contributing to transforming plants, animals, and microorganisms into mere commercial commodities, stripped of their inherent sacred qualities. This concern carries substantial weight and is far from being an insignificant matter. The utilization of biotechnological seeds also has the potential to reduce the genetic diversity of crop varieties (Nezhmetdinova et al., 2020). However, it is essential to acknowledge that all agricultural practices involve humans intervening in natural systems and processes, and any attempts to enhance crops and livestock inherently entail some level of genetic manipulation. The continued survival of humanity hinges on precisely these interventions (Pinstrup-Andersen & Cohen, 2000).

The responsible utilization of agricultural biotechnology mandates ethical scrutiny involving experts, beneficiaries, stakeholders, and the broader public. The potential benefits of modern biotechnology in food and agriculture and associated

risks and opportunities are primarily explored in initial applications within industrialized country agriculture (Harfouche et al., 2021). This debate is intricately connected with concerns like food safety, animal welfare, industrialized farming practices, and the role of private-sector corporations (Pinstrup-Andersen & Cohen, 2000).

Conclusion

Biotechnology holds great promise for agriculture and the food industry because it can help us to manipulate the production of food for a variety of improvements in the food and agriculture sectors. Biotechnology thus has the potential to increase the availability of food products and provide sustainable agriculture by increasing crop productivity and yields. It, therefore, plays a significant role in food security.

Biotechnology could also help to support the environment by reducing the use of traditional pesticides in agriculture and reducing the continual need for more agricultural land on which to grow crops. In the food industry, the application of biotechnology improves the production and food supply chain by utilizing genetically modified approaches to enzymes, fermentation, and vitamins, increasing crop variety, and increasing plant resistance to diseases (Jauhar & Khush, 2003). Moreover, the application of modern biotechnology in breeding selection ensures increased crop production and variety as well as the production of crops that are resistant to diseases and pests and more tolerant to different environmental conditions. Additionally, biotechnology significantly enhances the nutritional value of various foods. This novel technology can be expanded to even small-scale farmers if provided with biosafety regulations and proper policies to ensure that there are no risks to human health and no adverse environmental effects. Biotechnology has become a leading technology for supporting the future of global food security by providing sustainable agriculture and safe and healthy foods.

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