Food Security and the Role of Biotechnology

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Summary

Biotechnological approaches are given a greater significance as they continue to show promising potential to facilitate food security. These biotechnologies may consist of manipulation and interference in plant breeding (Marker-assisted plant breeding, mutational breeding) genetically manipulating the crop themselves (GM foods), or even just influencing the environmental factors to bring about the desired changes in the crop production (use of bio-fertilizers and bio-pesticides). Some of the greater benefits such as, increased crop yield, enhanced nutritional quality, upgraded ability to adapt and survive, and lengthened shelf-life brought about by these techniques are making developing countries including Bangladesh lean heavily towards the increased commercialization of biotech crops. Even amidst strong oppositions and a few limitations, the popularity of Bt brinjal and the continual development of many biotech rice varieties in Bangladesh alone, further substantiate the favourability of biotech crops and their potential to better the situation favouring both the environment and the economy.

Keywords: Biotechnology, Biotech crops, Food security

Introduction

The 2030 Agenda for Sustainable Development and the UN Decade of Action on Nutrition 2016–2025 has raised the agenda that involves the active collaboration of all countries and relevant stakeholders with the aim to substantially reduce hunger and malnutrition by 2030. One in every nine individuals is affected by the phenomenon of "global hunger". The phenomenon of food security, as defined by the Food and Agriculture Organization (FAO) refers to a situation where the population in question is enabled with sufficient access to food sources that are not only safe for consumption but are also enriched in adequate nutritional values needed to meet dietary requirements for the sustenance of active and healthy life (CFS., 2012). Food security ensures the availability of food at the right place at the right time in the required amount. It encompasses three independent integral components of food namely: availability, access, and utilization. Availability of adequate food supply refers to the capacity of the agricultural system to cater to the persisting food demand and involves the agroclimatic attributes affecting crop yield (Schmidhuber and Tubiello, 2007). Another aspect of food security relates to the accessibility of the population to adequate resources for the acquisition of a stable nutritious diet (Schmidhuber and Tubiello, 2007), whereas utilization entails the innumerable list of components relating to food safety & nutrition quality (Schmidhuber & Tubiello, 2007).

Biotechnology and increased turnover of food crops

In recent times, the field of biotechnology has been projected to alleviate the threat of global food insecurity through the improvement of both the quantity and quality of the food crops that are cultivated and produced (Lokko et al., 2018). Cultivation of biotech food crops for commercial purposes is currently being employed across all the six continents of the world at an increasing rate (Nishimoto, 2019).

a. Agricultural biology aimed to maintain and enhance food security status primarily includes several aspects, namely: Micro reproduction of plants and animals by the use of techniques such as somatic hybridization, selection, and in vitro cultures of plant and animal cell lines to generate intensive replication of the desired cell lines (Babiye et al., 2020; Mwangangi et al., 2019).

b. Mutation breeding, an important part of plant breeding, is considered an important strategy for the enhancement of greater genetic diversity to enable the subsequent processes of selection and hybridization (Jankowicz-Cieslak et al., 2017).

c. Propagation of enhanced varieties of plants and animals that are highly productive and resistant to biotic and abiotic stresses (Parmar et al., 2017)

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through the use of genetic engineering techniques. This phenomenon involves the production of plants with specific traits (viz. nutrition enhancement), resistance to biotic (pathogens, pests), or abiotic stressors (low or high temperatures, drought, soil salinity, submergence, etc.) (Parmar et al., 2017). Moreover, such techniques are also applied to generate animal lines with increased production of meat and/or dairy products (Van Eenennaam, 2019).

A study in 2014 led by UK-based agriculture consultants on the global economic benefits of genetically modified crops found the market value of the same to be $150 billion (Brookes & Barfoot, 2014) and socioeconomic studies revealed beneficial impact on food security as a result of the cultivation of genetically modified (GM) crops (Carpenter, 2013). Consequently, recent advancements in the field of computational biology and molecular genetics have enabled the use of high-quality selective breeding in addition to the emergence of cultivars with improved agronomic traits that are important not only to the farmers but are also beneficial to the consumer and the environment.

Another key aspect of biotechnology in agriculture involves the production of biological products for plant growth (Singh and Yadav, 2020; Lokko et al., 2018). This includes biopesticides to curb the threat of biotic stress conferred by pests and parasites (Lengai and Muthomi, 2018), bio-fertilizers which involve the use of living microorganisms for colonization of the soil rhizosphere to enhance plant growth by augmenting the availability of vital nutrients (Soumare et al., 2020; Kaur & Purewal, 2019). On the other hand, the production of bio-stimulants includes agents for nitrogen fixation, phosphorus solubilisation, and inducers of plant growth-promoting rhizobacteria (Orts et al., 2019; Bulgari et al., 2019). The global revenue for biopesticides has been estimated to be around 1.8 billion USD with both the demand and availability for improved biotechnological tools such as microbial cultures and inoculants having increased in the past several years (Lokko et al., 2018).

Newer horizons in the use of biotechnology in agriculture

Green revolution refers to the phenomenon of specifically cultivating high-yielding food crops, especially: wheat and rice together with the implementation of modern strategies of irrigation and farming to ensure an overall increase in the turnover of food crops (Conway & Barbier, 2013). Although the implementation of the green revolution has overseen a drastic and unprecedented improvement in the overall global status of sustainable food production (Conway & Barbier, 2013), a rapid rate of urbanization has resulted in a decrease in the cultivable area (Conway & Barbier, 2013). This phenomenon together with the rise in global population, unforeseen natural calamities, and emergence of global pandemics has resulted in the persistence of the constant threat of food insecurity (Pathak et al., 2017; Henry, 2020).

By the year 2050, the world population will be 9.7 billion. It goes without saying that meeting the future demand for food is going to be a big challenge. Urbanization associated with depletion of agricultural land, climate change adversities, and land degradation are added burdens on the food supply. This calls for an essential change in the system for food production. In the past, breeding has been the vital means for improving crops, lifting people out of poverty, and increasing the world's supply of food. However, now with the looming food security challenges, it is necessary to use advanced techniques to develop cultivars which will be able to withstand the expected dangers of climate change. Currently, many scientific developments in a range of areas applicable to crop research, viz. Molecular breeding, functional genomics, genetic modification, and gene editing have the potential to increase crop yields, lower the use of non-organic fertilizers and pesticides, equip crops to thwart climate stress, and make foods healthier (Bailey-Serres et al. 2019; Eshed & Lippman 2019).

Molecular markers in plant breeding

Food biotechnology methods involving molecular markers curtail the time needed to develop and release plant products. These DNA markers allow users and producers to select for a plant with favourable genes at the seedling stage for the presence of DNA regions that can lead to resistance against different stressors, both biotic and abiotic such as phytopathogen infection or climate adversities.

Compared to the conventional white rice, which the Bangladeshis consume the most, red rice nutrition benefits are much higher. The functionality and the food value of red rice have increased its popularity. This variety can be grown with very low inputs under environmental conditions in which the modern rice varieties do not perform well. However, because of its low yield farmers are unwilling to cultivate red rice. Recently, Islam et al,

(2018) have developed molecular markers amenable for use in breeding techniques to improve the yield of red rice. Marker-assisted backcrossing has also been used for developing submergence tolerant variety rice, BRRIdhan52 (Rabbani et al., 2015). Farmers' fields have shown satisfactory performance with respect to grain yield and some yield contributing parameters. Ferdous et al, (2018) have established the method for the distinction between glutinous and non-glutinous cultivars of rice through the use of molecular markers. This breakthrough in turn will facilitate the selective breeding of crop varieties with better grain quality. However, the breeding techniques used traditionally can only be carried out between closely related species. In addition, it is not possible to select traits, which are not present in the gene pool of the plants used in traditional breeding.

Mutation breeding

Plant mutation breeding has been used over the years to develop plants with desirable traits (Griffiths et al., 2000). Globally over 3000 plant varieties have so far been bred using this technology. In this procedure, plant seeds, cuttings, or shredded plant leaves are first exposed to radiation, such as gamma rays. Next, the seeds are planted or the irradiated materials cultivated in a sterile rooting medium. The individual plants so raised are allowed to multiply and their traits examined. Subsequent use of molecular breeding techniques is used to expedite the process of selection of variants with the specific genes of interest. Varieties so developed are contributing significantly to meeting global food demand under diverse environmental conditions.

Through the use of radiation-mediated induction, scientists at the Bangladesh Institute of Nuclear Agriculture have successfully developed cultivars that are tolerant to a wide array of stress conferred climatic disasters. This has led to a three-fold increase in rice production, ensuring food security and allowing Bangladesh to stay a step ahead of the rising population (Jawerth, 2017). Rice, lentils, chickpeas, peanuts, mustard, sesame, soybean, jute, tomato, and wheat have been improved using this approach. These particular cultivars constitute approximately 10% of the total cultivation and are gradually contributing towards the attainment of a steady production and supply of these crops (BINA Annual report, 2019-2020).

Genetically modified (gm) crops

World Health Organization classifies genetically modified (GM) foods as edible items that originate from living organisms that have an artificially altered genetic material. This genetic modification is one of the strategic approaches to ensure food security, as it increases crop yield, provides sustenance and unlike many other agricultural techniques, theorizes to bring together many desired characteristics to be manifested in one crop. The biotechnologies used in this approach may be set to achieve a few definite objectives, for example, shelf-life extension, pest and herbicide tolerance, abiotic stress tolerance, quality enhancement by including additional beneficial characteristics, etc. The general procedure to produce a GM crop includes (Jhansi Rani & Usha, 2013):

1. Identifying and locating the desirable gene: A simple selection of a gene is in itself a monumental task. There are difficulties in identifying all the important parts of the gene, including sequences necessary to control expression of the same.

2. Modifying for insertion: After isolation and amplification, the gene needs to be modified in some ways so that it is fit for introduction in a plant.

3. Transformation: This step facilitates the establishment of the modified DNA inside the target organism, the desirable outcome being the heritability of the modified trait. The most preferred medium for transformation is mediated by Agrobacterium, a soil bacterium with a natural ability to transform plants. The biolistic transformation that uses a gene gun method is another transformation process specially used in monocot species. Apart from these, electroporation and microinjection of DNA directly into the host are some other methods used in transformation (Abbas, 2018; Maghari and Ardekani, 2011).

4. Selecting the successfully transformed tissue: A specific selection media is chosen that ensures the survival of only the transgenic tissue.

5. Regeneration of the whole plant containing the desirable trait and exhibiting the outcomes.

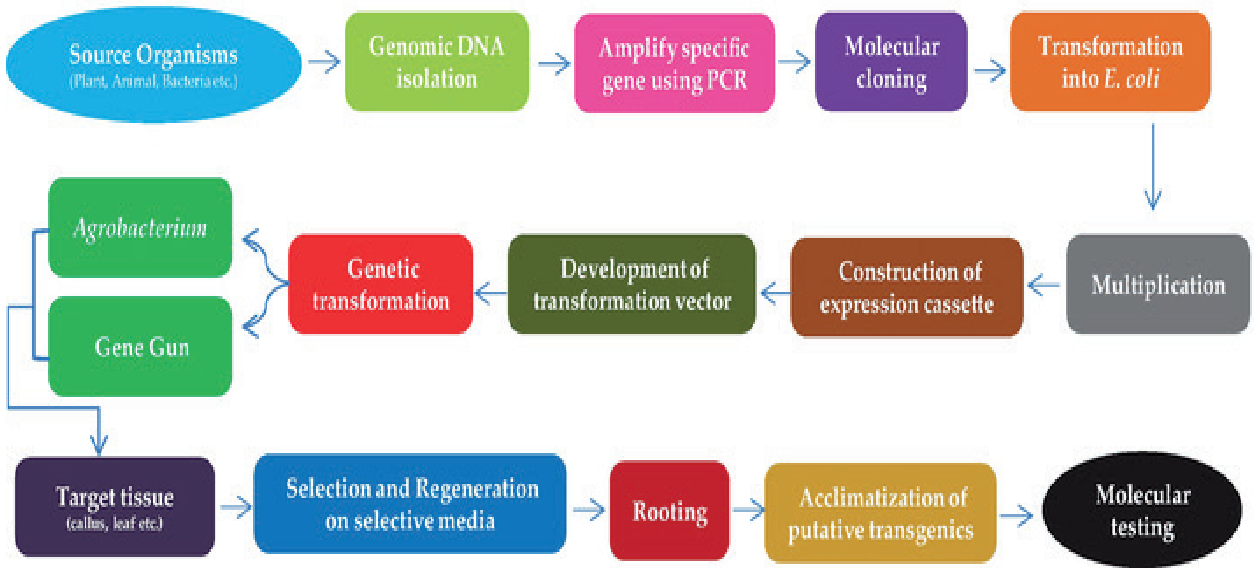

Figure 1. Flow diagram for GM crop production (Nazir & Iqbal, 2019)

The genetic manipulation used in the first ever GM crop licensed to be released commercially, Flavr Savr tomato, was designed to slow the ripening process and prevent the softening of tomato. In this case, the tomato was genetically modified through the insertion of an antisense gene that interfered with the pectin degrading enzyme β-polygalacturonase responsible for softening of the wall of the ripened fruit (Bruening & Lyons, 2000). Even though this objective to prevent the softening was not achieved, the genetic modification did extend the shelf life of Flavr Savr tomatoes.

Among the Bt crops, Bt potatoes were the first to be officially introduced as they were approved for culture in 1995. Some strains of *Bacillus thuringiensis* (Bt), a Gram-positive bacterium mostly living in soil, produce crystal protein insecticides during sporulation. This endospore toxin crystal protein (Cry toxin) producing gene is the target gene for Bt crops, slightly modified and inserted into the plant genome, enabling the plants to develop insecticidal ability after the genetic modification is established. The Bt crops are preferred because the Cry toxins are not detrimental to humans if consumed as the Cry proteins only become toxic when exposed to alkaline conditions, precisely the pH condition of the midgut of many pest insects and thus narrowing their targets, which prevents them from causing unnecessary harm to the environment. There are many Bt crops available including Bt maize, soybean, potato, brinjal, and the most common being Bt corn and cotton. Glyphosate is a broad-spectrum herbicide frequently used to get rid of weeds. It affects plants' ability to produce aromatic amino acids and eventually kills the plant. The development of transgenic Glyphosate-tolerant soybean lets the herbicide perform its work on weeds without damaging the main crop, increasing crop safety and maximizing yield.

An improved variety of *Brassica juncea* known as Dhara Mustard Hybrid-11 has been developed at the University of Delhi, India. This cultivar was generated through extensive genetic modification involving transgenic lines and involved the Bar, Barnase, and Barstar gene system (Boger et al., 2002). The Barnase gene facilitates infertility among the male gametes, while the Barster gene confers the GMmustard to generate viable seeds. Consequently, the introduction of the Bar gene confers the production of the enzyme, phosphinothricin-N-acetyl-transferase (PAT), which is responsible for the glufosinate resistance. PAT acetylates phosphinothricin, inactivating the herbicide and is then subsequently degraded. If this genetically modified mustard is allowed cultivation it is expected to significantly increase the yields of mustard oil. India is expected to allow cultivation of the GM mustard, only when an extensive environmental biosafety assessment is completed.

Many virus resistant fruits, vegetables, and crops have been developed by engineering the plant genome to deliberately overproduce a copy of important viral proteins, consequently stimulating the plant sensors and inhibiting both the engineered copy and viral copy of the proteins, thus imparting virus resistance to plants. Rainbow papaya is an example of the genetic modification of a commercially important fruit crop of Hawaii. It was developed to be resistant against the ringspot virus at a time when the virus has endangered the Hawaii papaya industry and the incomes of Hawaiian papaya farmers (Gonsalves, 2006).

Another important aspect of genetic modification is the ability to include additional nutritional value to a crop. One such example is the production of Golden Rice (GR) originally developed in the International Rice Research Institute, a rice variant genetically modified to biosynthesize β-carotene and other provitamins A carotenoids. The rice is named so because of its golden hue. IRRI used *Agrobacterium* to transfer the three genes required to biosynthesize carotene in the endosperm of rice, two genes, phytoene synthase, and lycopene β-cyclase were obtained from daffodil *Narcissus pseudonarcissus* and another gene phytoene desaturase from the bacteria *Bacillus thuringiensis*. Later the production of Golden Rice 2 constructed using phytoene gene from maize replaced the one which was taken from *N. pseudonarcissus*. Golden Rice-2 variant is reported to produce β-carotene by 23 folds in comparison to the wild type cultivar (Ye et al., 2000; Paine et al., 2005). A regular intake of Golden Rice is expected to deliver health benefits by decreasing cases of partial or complete blindness and reducing avertable deaths, especially of young children and mothers. In countries such as India, where there is an increased consumption of mustard oil, there has been genetic modification for the development of improved cultivars of mustard that accumulate up to 600 µg/g β-carotene (Berman et al., 2013).

In addition, genetic modification allows multiple desired heritable modified characteristics to be present in one crop, for example, SmartStax GM maize (Head et al., 2017). Insertion of 8 different genes in this maize genome imparts both herbicide tolerance (against two different types of herbicides) and insect resistance (against 6 species of insects).

The few examples stated above clearly depict the various advantages of the GM crops, including increased longevity, enhanced resistance to a number of biotic and abiotic stresses such as viruses, pests, herbicides, salinity, drought, or cold, consequently leading to yield improvement and even added beneficial nutrient value. Many crops have been modified to have improved photosynthesis and to produce various bioactive metabolites (Kromdijk et al., 2016). So, it can be said that GM crops strategically impart food security through crop safety, maximum yield potential, and various added benefits in one crop. A meta-data analysis has shown that GM crops increased crop yield by 22%, farmer profits by 68%, and reduced the use of pesticides by 37% (Klümper & Qaim, 2014). The benefits of GM crops are reportedly higher in percentage in developing countries than in developed countries, although in 2015, the USA produced genetically modified strains in the percentage of 92% corn, 94% soybeans, and 94% cotton. Even so, there are some limitations in the case of mass production of GM crops that must be considered in theory. Transgenic incidents may occur between related and non-target plant species, the toxins produced may affect non-target organisms and in case of mass production, the probable exposure of these toxins in the soil may lead to soil damage, disrupting the ecology and environment (Fontes et al., 2002).

Several national and global regulatory agencies validate the safety of GM crops through analyses and appraisals. The food and Drug Administration (FDA) warrants the overall security of GM crops as food on a global scale (Turnbull et al., 2021). The regulatory agencies concerning the production of GM crops either for experimental or commercial use involve DEFRA in the UK and for the members of the European Union, it involves European Food Safety Authority (EFSA) as well as independent member states' and EU central regulatory authorities (Authority et al. 2019). The USA involves three of its federal agencies, the FDA, Environmental Protection Agency (EPA), and the U.S Department of Agriculture (USDA) to ensure that the GMOs are safe for human, plant, and animal health (Nutrition, 2020). In Bangladesh, the Biosafety regulatory process for genetically engineered plants is monitored and enforced by the Department of Environment, Government of Bangladesh.

Bangladesh, with her agriculture dependent economy and rapidly increasing population, may benefit tremendously by using GM crops. In 2013, as the 29th nation to grow genetically modified crops Bangladesh released BARI Bt brinjal 1. Recent studies in Bangladesh reported a significant increase in crop yield by 51% with 37.5% less pesticide cost in GM Bt brinjal compared to the control group, along with 76% less pesticide toxicity (Ahmed et al., 2020). *Phytophthora infestans*, a fungal phytopathogen, is responsible for the late blight in potatoes, the most economically devastating disease globally. The Biotechnology Division of the Bangladesh Agriculture Research Institute (BARI) in collaboration with Michigan State University has developed genetically modified potato lines resistant to the disease (USDA, 2020). The modification involved the insertion of blight-resistant genes derived from three wild potato varieties of three different origins, Mexican (*Solanum bulbocastanu*), Argentinian (*Solanum venturi*), and Peruvian (*Solanum mochiquense*). These GM lines are expected to go for a contained trial later in the year 2021, a single location field trial in 2022, and multi-location trials in two subsequent years before getting the Biosafety approval and will be the second commercially available genetically modified crop in Bangladesh.

A

B

Figure 2. (A) A happy farmer with a harvest of Bt eggplant (B) Golden hue of Golden Rice on the right as compared to non-transgenic rice. Courtesy: Daily Sun and the International Rice Research Institute, respectively

Rice is the staple food of Bangladesh and with many of its population suffering from night blindness; a disease caused by a lack of Vitamin A, our country may derive great benefits from Golden Rice. As a staple food rice is a priority for genetic modification, especially to achieve its maximum yield potential. The GR-2 E BRRI Dhan-29, the Golden Rice variety engineered in BRRI, is reportedly going through field trials and is waiting to be released. The southern coastal region of Bangladesh is not compatible for rice production as the salinity there hinders the growth of rice. Prof. Zeba Islam Seraj, Department of Biochemistry and Molecular Biology, University of Dhaka and her team have successfully developed salt-tolerant rice varieties to overcome this challenge (Amin et al, 2016). These lines are awaiting government approval for commercial release. As rice provides for almost 20% of the world's total dietary energy, the production of rice in the coastal region will rise remarkably with this development.

Some significant GM crops are listed below:

Table 1. List of significant GM crops around the world

GM crops	Uses	Modified varieties
Rice	A major staple food used in bakery, brewery and other industry	Herbicide-tolerant Insect-resistant Vitamin A providing Golden rice Recombinant protein producing transgenic rice (Yang et al., 2018)
Maize	A major staple food globally used in the industrial production of corn syrup rich in fructose Corn starch production and in the production of animal feed	Herbicide-tolerant Insect-resistant Increased level of lysine Drought tolerant
Brinjal	Vegetable	Insect-resistant (Bt brinjal)
Canola	Major oil crop with the lowest level of saturated fat	Herbicide-tolerant High laurate content Phytase production
Cotton	All parts of the plant can be used, most importantly fibre and cottonseed oil	Herbicide-tolerant Insect-resistant
Soybean	Major oil crop and an important source of both protein and oil	Herbicide-tolerant Increased oleic acid-producing Stearidonic acid-producing
Papaya	Food	Virus resistant
Squash	Food	Virus resistant

Cellular agriculture

In order to meet the challenges of feeding an increasing population together with reducing the adverse implications on the environment exerted by food production, it is necessary to bring about fundamental changes in the methods used for food production. This has resulted in the emergence of a phenomenon called "cellular agriculture". The concept of cellular agriculture originates from the application of cell cultures specific to a range of host organisms for the yield of agricultural materials, instead of using conventional farming techniques (Mattick, 2018). Cellular agriculture was motivated by an apprehension of the impacts of animal agriculture in the present form and the issues involved with the predicted trend of the rising global population. This agricultural system is directed at addressing UN Sustainable Development Goal 2 (Zero Hunger) and Goal 12 (Responsible Consumption and Production). Cellular agriculture is thus predicted to be involved in the sustained production of food products of animal origin, with reduced involvement of animals in the process.

Additionally, the consumption of artificial meat in recent years has also integrated with the present spirit to ensure sustainability in the food supply. Artificial meat refers to substitutes for the conventionally consumed animal meat derived from either plant/fungi, meat from genetically modified animals and meat from animal cell lines (Lovvoron, 2017). Despite being genetically identical to conventional animal meat, the difficulty in developing artificial meat stems from the structural complexity along with the high expenses of the appropriate growth medium required to ensure the scalability of the procedure (Vickers, 2017).

In this context plant cells are being considered to serve the purpose. Even though plant cell culture is in use for a significant length of time for the production of secondary metabolites and also for drugs like paclitaxel (Head et al., 2017), the same has never been considered for the production of foods of significant nutritional value for human health. Such cell cultures do not suffer from abiotic stress involved with the variation of geographical and/or environmental conditions. A plant cell culture medium is fully defined consisting of common carbon sources and some vitamins and phytohormones. In this context, it is much less complex compared to animal cell culture and could soon become an important platform for cellular agriculture.

Biotechnology in bio-pesticide andbio-fertilizer: microbial products, the next wave of agricultural revolution

Pest control and use of fertilizers are important parts of agriculture, helping in crop safety, yield enhancement and ultimately contributing to food security. Chemical pesticides and fertilizers have been used for a long time and have achieved the desired result temporarily but the repercussions of using them have turned out to be fatal as lands turned infertile, environment polluted and ecology threatened with damage to both animals and plants. So, the focus is shifting towards bio-pesticides and bio-fertilizers that can achieve a similar effect as their synthetic chemical counterparts without the added harm to the environment. In many countries, biotechnology is applied in agriculture, where microorganisms are used to boost crop production, increase shelf-life and nutritional quality of food. Certain symbiotic soil microorganisms, including bacteria and fungi, enable plants to extract minerals and necessary nutrients from the soil by extending the root system and enhancing the uptake of soil water.

Specific characteristics enable microbes to act as bio-pesticides or bio-fertilizers as can be seen through the production of various metabolites that promote growth, enhance crop yield or inhibit other pathogens. Naturally occurring bio-pesticides or bio-fertilizers are only specific in number and may have many limitations, so to meet the surging demand, bio-engineered microbes are being developed that can have the characteristic that would manifest the desired result in a similar basic mechanism as the GM crops. For example, some fungal biopesticides that are sensitive to abiotic stress, which may lower their efficacy as bio-pesticide, could be engineered genetically to be stress-tolerant with even better activity against pathogens (Lovett and St Leger, 2018). Many naturally occurring bio-fertilizers are genetically engineered to be thermo-stable, drought-resistant, and have better fertilizing activity than wild strains (Ali et al., 2020).

Another group of microorganisms, the endophytes, a community of beneficial microorganisms that plants harbour, have important roles by providing plants with nutrients necessary for growth and by conferring plants with the ability to adapt to a plethora of biotic and abiotic stress. Currently, these microbes are being used to overlay seeds with the aim to enhance stress tolerance and eventual turnover and in turn lead to the development of cultivars that are tolerant to a myriad of stress conditions including climate change, scarcity of nutrients, and disease. Such changes are hypothesized to be triggered either via direct interaction with such microbes or via induction of the plethora of stress response signalling pathways of the plant.

The consortium of plant endophytes differs significantly between healthy and stressed cultivars of identical genotype and seed sources grown under similar conditions. Recent efforts involve the use of a characteristic microbiome of healthy plants is being used to designate the particular microbes which when added to seeds can generate the desired phenotypic traits. Strains of Streptomyces sp have been reported to distinctively improve growth responses and eventual vigour and turnover under a plethora of stress conditions (de Jesus Sousa & Olivares, 2016).

Acknowledgement of the role of the plant microbiome has led to the inception of newer dimensions in agriculture. Currently being on the verge of a third agricultural revolution, an immaculate perception regarding the critical interactions between the host plants and the microbiome will thus be integral for unveiling their prospects in a possible augmentation in crop turnover and in the persistence of agricultural sustainability (Kuźniar et al., 2019). Henceforth, with the continual rise in global demand to elevate food production while reducing the usage of other agrochemical utilities, a firm understanding of the means for a potential magnification of the beneficial roles of the plant microbiome, such as nitrogen fixation or phosphate solubilisation has become increasingly important.

Use of advanced genomic technologies in the maintenance of food safety

The advent of advanced genomics and bioinformatics systems has proved their worth in ensuring food safety through a sharp decrease in the time taken to respond to the threat of an outbreak caused by a foodborne or waterborne emerging or re-emerging infectious agent (Scharff et al., 2016). The Food and Agriculture Organization in 2016 had organized an event titled "application of genome sequencing for sustainable agriculture and food security" in which the experts emphasized the relevance of genome sequencing for developed and developing countries (Session, 2020). The use of next generation sequencing (NGS) strategies in the maintenance of food safety predominantly involves either the elucidation of the whole genome sequence of a single cultured isolate, commonly referred to as "whole genome sequencing (WGS)" or by the use of a metagenomics approach, which involves the application of next generation sequencing (NGS) to an environmental or biological specimen with the purpose of elucidating the presence of microorganisms in that specimen (Allard et al., 2013, Ashton et al., 2016). Regular use of WGS for the purpose of surveillance of foodborne infectious agents has gained prominence due to its enhanced discriminatory power over conventional molecular genotyping methods (Ashton et al., 2016; Jackson et al., 2016). A number of pilot-scale programs involving the use of NGS and modern computational analyses have been implemented to on-going surveillance for foodborne pathogens with the aim of establishing the concept of real-time molecular surveillance for the maintenance of food safety and food security status (Taboada et al., 2017). Such advanced genomic platforms facilitate the critical tracking of the epidemiological inclination of transmission, thus expediting a swift response for the purpose of curbing the transmission of foodborne infectious agents.

Although the application of WGS for the characterization of foodborne pathogens is a relatively recent phenomenon, the prospect of delineating the entire evolutionary history of such pathogens are proving to be integral in the aversion of food spoilage through the elucidation of the root cause of such contamination (Allard et al., 2018). The use of such advanced genomic platforms initiated through retrospective studies of past outbreaks demonstrates the feasibility of the same in ensuring food safety. This is supported by the use of phylogenetic pipelines aimed at providing critical data that may augment the outcome of the investigations of outbreaks caused by foodborne pathogens (Hoffmann et al., 2014; Ashton et al., 2015). For instance, in a retrospective study of the large shell-egg outbreak of 2012, the use of such advanced genomic technologies was able to clearly differentiate illnesses and attribute them to several farms, thus preventing spoilage of poultry products in nearby areas (Leekitcharoenphon et al., 2014). In several concurrent studies, the use of WGS and subsequent metadata phylogenetic analyses have enabled accurate identification of the source of contamination (Bell et al., 2015; Angelo et al., 2015).

Next generation sequencing platforms have undergone a rapid transition from being an exclusive research tool to currently being used in routine applications for the maintenance of food safety through the investigation of outbreaks and detection of emergence of antimicrobial resistance genes in food products (Goodwin et al., 2016; Quainoo et al., 2017). The Genomic Epidemiology Ontology (GenEpiO) consortium is the current lead global platform that is working to devise specific guidelines to enable the use of the current and expanded ontology to genomic epidemiology investigation in the maintenance of food safety and food security (Dooley et al., 2017).

Detection of non-halal components in food products is of immense significance to practicing Muslims and involves the identification of porcine derivatives in such products. Owing to the high sensitivity and specificity of such technologies, recent developments in DNA-based technology have greatly enhanced the differentiation of halal products from non-halal ones. Some methodologies based on DNA technology involve the use of conventional PCR using universal primers, through restriction fragment length polymorphism (RFLP) or by the use of species-specific primers in PCRs for the detection of porcine components in food products (Erwanto et al., 2018). As a basic molecular technique, PCR has been in use to identify porcine DNA in the food market to certify Halal food and in order to facilitate this ensuring process, many specific markers have also been developed over time including a swine specific hybrid probe for biosensor based validation (Ali et al., 2012).

Conclusion

Biotechnology is complementing conventional agriculture in many research areas and the world has started to witness its benefits in ensuring food security. Its range of tools has improved our understanding and management of genetic resources, be it a plant or the community of microorganisms that have a profound influence on plant growth and health. These tools have contributed to breeding and allowed the introduction of novel traits needed by a plant to cope with climate change adversities. It is also allowing for the production of agricultural products from cell cultures e.g. developing animal products without the use of animals thus contributing profoundly to environment friendly and sustainable agriculture to achieve the SDGs and other targets of nutrition.

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