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The Role of Genetically-Modified (GM) Crops in Food Security

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Abstract: The consistent increase in the global population, estimated to reach 9 billion people by 2050, poses a serious challenge for the achievement of global food security. Therefore, the need to feed an increasing world population and to respond adequately to the effects of climate change must be urgently considered. Adverse environmental conditions, such as drought, flooding, extreme heat and so on, affect crop yields more than pests and diseases. Thus, a major goal of plant scientists is to find ways to maintain high productivity under stress as well as developing crops with enhanced nutritional value. Genetically-modified (GM) crops can prove to be powerful complements to those produced by conventional methods for meeting the worldwide demand for quality foods. Genetically engineered (GE) crops that provide protection against insects and diseases, or tolerance to herbicides are important tools that complement a diversified integrated pest management (IPM) plan. The GM crops have the potential to increase agricultural productivity on existing arable land; address issues of loss related to pests, disease, and drought; increase access to food through income gains; raise nutrition levels; and promote sustainable agriculture.
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Introduction

The Food and Agricultural Organization (FAO) of the United Nations states that "Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Genetic engineering and biotechnology are becoming widely used in crop improvement and have provided a means by which increased yields of food and fiber can be produced in an environmentally sustainable manner. One of the biggest challenges that faces humanity in the 21st Century is food insecurity. More than 800 million people globally lack adequate food and at least 10% of global food production from crops is lost due to unfavorable weather conditions, pests and diseases (Meyers et al., 2015). Since the production of the first transgenic plants 30 years ago and following the first planting of GM crops in 1996, plant biotechnology has had an increasingly significant role in modern agriculture (FAO, 1996). Food security is a useful heuristic for understanding food-related health concerns at overlapping scales. However, biotechnology is viewed as one of the techniques to help in ensuring food security. It is also viewed as a solution to promoting sustainable agriculture and conservation of biodiversity especially in the developing countries which are still behind in a number of developments. Biotechnology technique alone cannot solve all the problems that are associated with agricultural production, however it has potential to address specific problems. These problems include increasing crop productivity, diversifying crops, enhancing nutritional value of food, reducing environmental impacts of agricultural production and promoting market competitiveness (Ghasemi, Navab, & Ghavidel, 2015). Addressing such problems is of great importance as poor soils, low rainfall, high temperatures and the prevalence of pests undermine food security in many parts developing states. Food security also depends on four interrelated factors: quantity of food, which translates into the need for increased agricultural productivity; access to food, which is determined both by income levels and quality of infrastructure; nutrition; and overall stability of the food system, such as resilience to shocks. The major types of GM crops commercially available are herbicide-tolerant (HT) crops that are resistant to broad-spectrum herbicides such as glyphosate and gluphosinates; insect-resistant (IR) crops that include a specific bacterium, *Bacillus thuringiensis* (*Bt*), which is poisonous to certain insects; and/or crops with a combination of both (stacked trait). HT and IR traits help make weed and pest control more efficient, as crops need fewer applications of herbicides and/or eliminate the need for pesticides. HT crops are the most common, comprising more than half of the 175 million hectares of GM crops grown globally in 2013, followed by stacked-trait crops at 27 %, and IR crops at around 16 % (James, 2014). In developing countries more generally, where smallholder farmers use sig- nificantly fewer inputs than in developed countries, IR crops could have the greatest impact on production. By adapting the technology to local conditions, developing countries could also address the issue of yield drag, which occurs because companies typically modify generic seeds that are unspecific to a particular region. Developing countries could increase the production potential of GM crops by applying the technology to high-quality, local germplasm.

Higher production is not the only positive impact of GM crops. They also help reduce loss due to pests, weeds, and diseases. The potential of this technology lies in how it is adapted to meet specific, local needs in developing countries, which can range from combating diseases to improving indigenous crops.

Researchers in Uganda, for example, are using biotechnology to reverse the trend of *Xanthomonas* wilt, a bacterial disease that causes discoloration and early ripening of bananas and costs the Great Lakes region approximately $500 million annually. There is currently no treatment for the disease, and given its status as a staple crop in this region, solving this problem would directly increase food security and income (Juma et al. 2014; Juma 2011b). The most efficient method of containing the disease is by growing transgenic bananas instead of more labor-intensive methods. By transferring two genes from green peppers, scientists were able to grow highly resistant bananas.

In Nigeria the insect *Maruca vitrata* destroys nearly US$300 million worth of blackeyed peas—a major staple crop—and forces farmers to import pesticides worth US$500 million annually. To solve the problem, scientists at the Institute for Agricultural Research at Nigeria's Ahmadu Bello University have developed a pest- resistant, transgenic blackeyed pea variety using insecticide genes from the *Bacillus thuringiensis* bacterium.

GM crops *versus* classically-bred crops

Classically-bred and GM crops are the outcomes of genetic modifications created through different means of gene transfer technology. Both conventional breeding and GM technology may involve changes in the genetic makeup of an organism with respect to DNA sequences and the order of genes. However, the amount of genetic changes brought about by the GM technology is small and well defined as compared to classical breeding where thousands of uncharacterised genes of an organism may be involved. Furthermore, GM crops are the outcome of very specific and targeted modification in the genome where the end products such as proteins, metabolites or the phenotype are well characterised. In traditional breeding the genomes of both the parents are mixed together and randomly re-assorted into the genome of the offspring. Thus, undesirable genes can be transferred along with the desirable genes and at the same time some genes may be lost in the offspring. To rectify these problems plant breeders carry out repeated back-crossing to the desirable parent. This is a time-consuming task and may not always be able to separate a tightly linked unsafe gene. For example, potato varieties developed using traditional breeding produce excessive amounts of naturally occurring glycoalkoloids (Hellenäs et al., 1995). These glycoalkoloids cause alkaloid poisoning leading to gastrointestinal, circulatory, neurological and dermatological problems. Hybrids of *S. tuberosum* and *S. brevidens* produce a toxin demissidine, which is not produced in either parent. Another instance was the conventionally-bred insect-resistant high psoralens variety of celery which was found to produce skin rashes in farm workers who were involved in harvesting this crop [13]. Thus, classical (non-GM) breeding methods can have unintended effects and generate potentially hazardous new products. On the other hand, GM technology employs a precise control on the timing and location of gene products resulting in tissue/organ/development/stress-specific expression - an outcome not easy to accomplish with classical breeding. Moreover, GM techniques allow introduction of new traits at one time without involving extensive cross-breeding as in the case of classical breeding. From the scientific point of view, foods developed either by conventional breeding or by GM technology can impart the same effects on human health and the environment.

Opportunities and Challenges for Using GM (Bt) Crops in IPM

Over the past 30 years, traits have progressed from single events with one mode of action against one insect order, to pyramided and stacked events containing multiple modes of action against the same or different pest orders, respectively. GE crops have also progressed from insect protection traits expressing proteins from Bt to new traits based on RNAi or expressing proteins from non-Bt sources (ISAAA, 2019). There are many widely accepted benefits of using GE crops for insect control, including the ability to reduce the use of less effective and/or less environmentally friendly insecticides, high specificity toward pests, and a more convenient insect pest management strategy for growers (Brookes and Barfoot,2016). An additional benefit seen in some systems, such as with Bt maize in the US (Dively et al., 2018) and Bt cotton in China (Zafar et al., 2020) and the US (Carrière et al., 2003), has been area-wide suppression of key target pests that has reduced pest pressure and input costs for both growers adopting Bt crops and non-adopters in the same area. Nevertheless, there remain several challenges for sustainable use of this technology and successful implementation in an IPM approach for many Bt crops and regions. A well-structured IPM approach should balance the use of one technology with other complementary approaches and avoid relying on only one solution for pest control. Genetic engineering is not a "silver bullet" for all problems and an agricultural production system will not automatically become a durable IPM strategy just by adding GE technology or, for that matter, host plant resistance developed through conventional means. Therefore, understanding the challenges for each crop, pest complex and region and acknowledging the limitations of GE crops is important for education, training and development of robust IPM strategies for future crops and traits.

GM Crops of Pakistan

Pakistan is dominated by agriculture. The sector provides a livelihood for more than 47 percent of the country's inhabitants, accounting for 24 percent of its gross domestic product and about 70 percent of its foreign exchange. Pakistan meets its own agricultural requirements and also exports crops to Afghanistan, the Middle East and several Central Asian nations. However, in recent years, Pakistan's agricultural sector has faced serious challenges. Drought, increasing soil salinity, plant stress and other impacts of climate change threaten the nation's stable agricultural growth rates, which are essential for keeping the economy on track. These threats have raised concerns about food security in Pakistan, where the current population of about 200 million is projected to reach 240 million by 2035. While other parts of the world have adopted genetically modified (GM) crops in order to tackle similar challenges, the use of GM crops remains both limited and controversial in Pakistan.

Cotton and maize are the two major GM crops in Pakistan that are developed with resistance properties against insects and weeds. In 2002, *Bt* cotton was developed for first the time as a genetically modified crop in Pakistan. In 2005, Pakistan atomic energy commission (PAEC) commercialized four varieties of *Bt*-cotton exhibiting insect-resistance (IR) i.e. IR-CIM-443, IR-CIM-448, IR-NIBGE-2, and IR-FH-901 across the Pakistan to sort out the issue of insect attack which was getting epidemic (Abdullah, 2010). These genotypes reduced pesticides use resulting in increased farm income. Between 2013 and 2016, 50 more *Bt*-cotton varieties were approved by the National Biosafety Committee (NBC), PSC, and the Pakistan Central Cotton Committee (PCCC) for commercialization (Ali and Ali 2019). At present, 96% of the total cotton production in Pakistan is *Bt* cotton which is planted on a total area of 3 million hectares. However, in 2015 resistance breakage against Pink bollworm (*Pectinophora gossypiella*) was reported.

EU and USA

Considering severe regulatory atmosphere in EU, only one type of GM plant (pests-resistant GM corn) is allowed to be cultivated in the EU. Spain is the only European country with many farms under cultivation of GM products. Farmers have had good experiences and high economic yield regarding efficiency of GM corn compared to ordinary corn in regions contaminated with pests since introduction of this technology in 1998 (Lefebvre et al., 2014). In 2018, 35 and 6% of total areas of Spain and Portugal (about 121.000 hectares of lands) were allocated to cultivation of GM corn, respectively. While, low amount of GM corn has been cultivated in four other European countries (Portugal, Czech Republic, Romania, and Slovakia). According to reports published by European countries, there is high amount of the imported and consumed GM foods because this ultimately helps in meeting their nutritional demands. On the other hand, when about 80% of the world's soybean crop is transgenic, European countries have to import it, whether they like it or not (Lucht, 2015). USA authorities had adopted and approved a permissible policy for GM foods without any need to label GM plants. Now, EU has set a certain regulatory framework for cultivating, consuming, and importing GM products for livestock feed and foodstuffs.

GM Crops in India

India has the world's fourth largest GM crop acreage on the strength of Bt cotton, the only genetically modified crop allowed in the country. Many varieties of GM crops are at various trial stages in India, including rice, mustard and vegetable crops. Recently, a technical subcommittee of GEAC has concluded that Dhara Mustard Hybrid 11 (DMH-11), a transgenic crop, is safe for human consumption, animal feed and environment. DMH-11 is developed by researchers at the Delhi University under a publicly funded project (Mishra, 2020). Cultivation and production of Bt cotton has grown exponentially since then and India has become second largest producer of cotton and leading exporter in the world (Choudhary and Gaur 2010). Farmers growing Bt cotton have been benefiting largely and their socio-economic conditions has changed positively. As per an estimate, approximately 7.2 million farmers cultivated Bt cotton on 10.8 m ha equivalent to 93 per cent of India's total 11.6 m ha cotton in the season of 2012 (James 2012). Approximate 40 million bales of cotton was produced in 2014 in India and becomes the world's leading producer of cotton in 2014 after 13 years of deregulation and commercial release of Bt cotton in India (Choudhary and Gaur 2015). A number of GM crops or transgenic crops carrying novel traits have been developed and released for commercial agriculture production with the rapid advances in biotechnology.

GM crops in China

China has more than 20% of the world's population but less than 7% of the arable land. Rapid urbanization and excessive application of pesticides and fertilizers have led to loss of arable land (Duan et al., 2010). China is dependent upon food imports and, in 2017, imported 130.6 million tons of various crops (http://www.agrogene.cn/info-4673.shtml). Against this background, China's central government made the strategic decision to develop and apply agricultural biotechnology to increase agricultural productivity and to promote national food security and green agricultural development (Liu et al., 2014). Since the 1980s, research and development of genetically engineered (GE) crops has received steadily increasing financial support. The Chinese government initiated the National GM Variety Development Special Program (NGSP) in 2008 with the intent of investing $3.5 billion to identify additional functional genes and to develop new GE varieties, improving the level of research and industrialization of agricultural GE organisms (Lu, 2016). Great progress has been made in the development of insect-resistant GE (IRGE) crops, especially cotton, rice, and corn. We examine the current status of research and application of IRGE crops in China, analyze the prospects and challenges, and discuss strategies to promote the development and application of GE crop technology in China. The Chinese experience with Bt cotton (i.e., cotton plants modified to produce one or more endotoxins derived from the bacterium Bacillus thuringiensis) should provide valuable lessons in sustainable use of a wide range of Bt crops for other countries, in particular developing countries with agricultural situations similar to China's. In China, cotton is an important cash crop, and rice and corn are important cereal crops (Liu et al., 2016). Cotton is mainly planted in Xinjiang Province, while rice and corn are grown in most provinces. All of these crops suffer severe damage from many insect pests, with lepidopteran species being the most damaging. Management of these pests once relied primarily on chemical insecticides, resulting in environmental and human health problems (Huang et al., 2003).

Conclusions

The genetically modified crops have the potential to increase agricultural productivity on existing arable land; address issues of loss related to pests, disease, and drought; increase access to food through income gains; raise nutrition levels; and promote sustainable agriculture.

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