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(Review Article)

The role of genetic breeding in food security: A review

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Abstract

Genetic engineering or breeding entails deliberate modifications of the characteristics of an organism by manipulating its genetic makeup. This technique has been used to develop crops which are high yielding, resistance to pest and disease, high nutritional value, high oil content etc. Genetic engineering technique offers mankind the ability to develop crops with desirable characteristics within a very short period compared to conventional breeding methods. The use of this breeding method has resulted in producing some varieties of crops which requires farmers to invest low during production for higher income after harvest.

The aim of this article is to summarise the known role genetically modified crops has played to reduce hunger and the provision of food with the required nutritional value in helping the world to become a food secured one.

Keywords: Genetic engineering; Breeding; Genetic makeup; Food security

1. Introduction

Human population keeps increasing at an exponential rate with an estimated figure of 6.7 billion to 9 billion in 2050 and to accommodate the increased request for food, world agricultural production desires to rise by 50% by 2030 (Royal Society 2009).The climatic conditions of known areas keeps changing from time to time and also there is rapid shrinking with regards to environmental resources due to increase in human population with the land size remaining the same due to urbanization and other factors.

Food security was defined by FAO (2012), as all people having physical and financial access to adequate, nourishing, and safe food. Unfortunately, food security does not exist for a significant proportion of the world population. Around 900 million people are undernourished, meaning they are undersupplied with calories (FAO (2012). It was reported by United Nations in the year 2012 that, many more people even suffer from specific nutritional deficiencies, often related to inadequate intake of micronutrients. Eradicating hunger is a central part of the United Nations' Millennium Development Goals (United Nations 2012). Due to the limited amount of arable lands and even what is in existence is been lost to urbanization, salinization, desertification, and degradation of the ecology, it no longer possible to simply open up more new land for farming to meet production needs. Watersystems are also under serious problems in many parts of the sphere. The fresh water accessible per person has declined four folds in the past 60 years (United Nations Environmental Programme 2002). 70% of already available water is already used for agriculture (Vorosmarty et al. 2000). Countless rivers no longer flow to the sea; 50% of the world's wetlands have disappeared, and major groundwater aquifers are being mined unsustainably, with water tables in parts of Mexico, India, China, and North Africa

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decreasing by as much as 1 m/year (Somerville and Briscoe 2001). The above reason shows that, increased food production will largely take place on the same acreage size while using less water. Compounding the challenges facing agricultural production are the anticipated effects of climate change (Lobellet al. 2008). Yields of our most significant food, feed, and fibre crops highly reduces at temperatures higher than 30 °C, so heat and drought will more and more limit crop production (Schlenker and Roberts 2009). In addition to these ecological stresses, losses to pests and diseases are also estimated to increase. Much of the losses caused by these abiotic and biotic stresses, which already result in 30–60% yield reduction worldwide every year, occur after the plants are fully grown: a point at which most or all of the production inputs has been invested (Dhlamini *et al*., 2005).

Genetic engineering or breeding entails deliberate modifications of the characteristics of an organism by manipulating its genetic material. This perceived method of breeding aims at maximizing the full potential of a desirable character exhibited by a gene of interest.

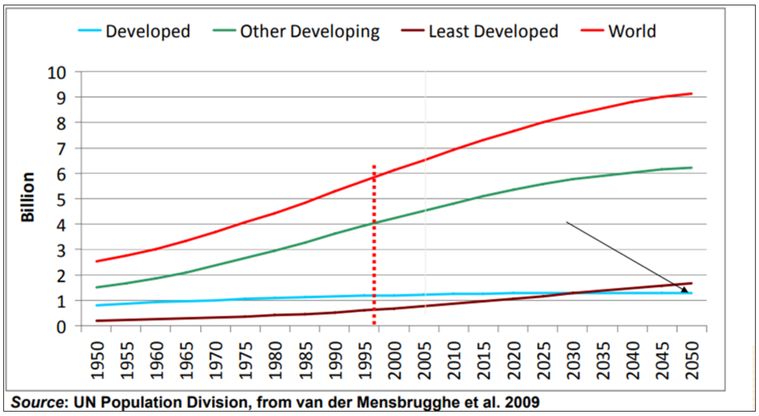

Figure 1 Anticipated World population growth from 1950 to 2050 (Source: UN Population Division, from van der Mensbrugghe et al. 2009)

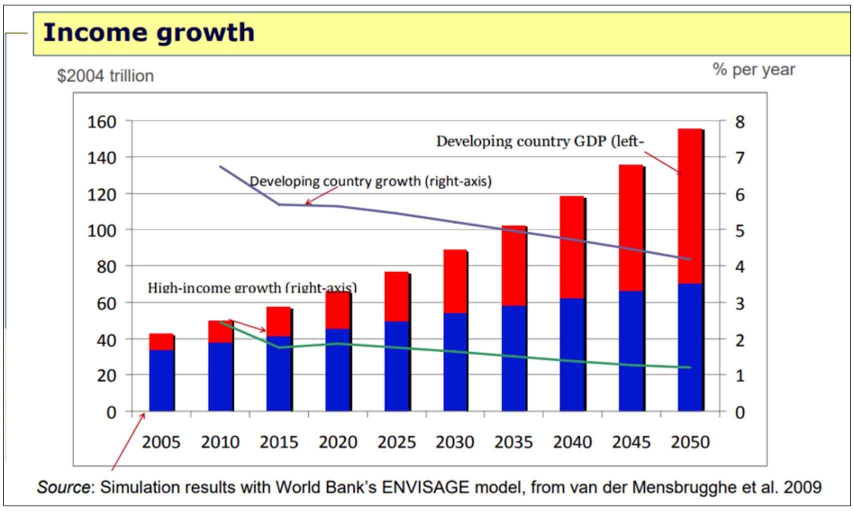

Figure 2 Income growth of developing and high income countries in the world (Source: Simulation results with World Bank's ENVISAGE model, from van der Mensbrugghe et al. 2009)

This method of breeding has been used to improve yields of crops, resistance to pest and disease, high nutritional value and high oil content of crops as well. For the above reasons mentioned, a reduction in losses to pests, pathogens, and environmental stresses is equivalent to creating more land and more water. Thus, an important goal for genetic improvement of agricultural crops is to adapt our existing food crops to increasing temperatures, decreased water availability in some places and flooding in others, rising salinity, and changing pathogen and insect threats and last but not the least improving the nutritional value of crops (Gregory et al. 2009).

This review paper is aimed at increasing knowledge on the role genetically modified crops is playing to make the world a food secured one by analyzing the peer-reviewed literature on yield, grain quality, drought tolerance, nutritional value improvement and resistance to pest and diseases with regards to Genetically modified crops. It is also hoped this review contributes to greater understanding of the impact of this technology and facilitates more informed decision making, especially in countries where crop biotechnology is currently not permitted.

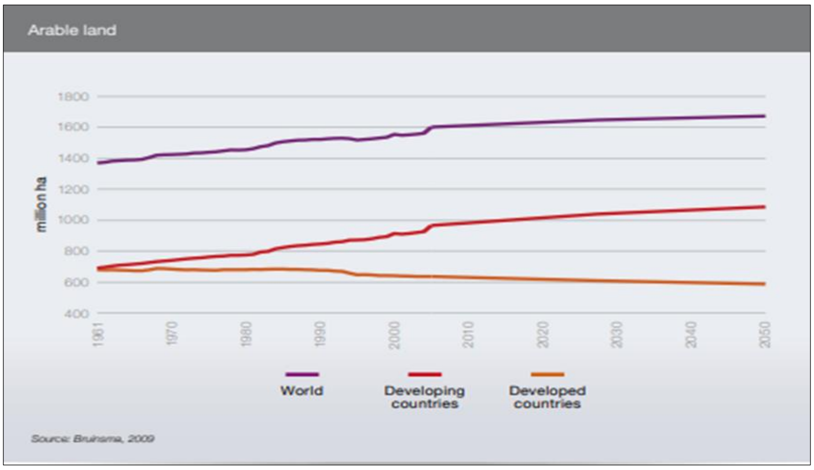

Figure 3 Land size considered arable in the world (Source: Bruinsma, 2009)

2. Genetically modified crops

Genetically modified crops are plants which DNA are been modified using genetic engineering methods. In some circumstances, the purpose is to introduce a new trait to the crop which does not occur naturally in the species. Examples in food crops involves resistance to some diseases, pests, or environmental conditions, reduction of spoilage, or resistance to chemical treatments (e.g. resistance to an herbicide), or upgrading the nutritional value of the crop. Pharmaceutical agents, biofuels, and other industrially useful goods, as well as for bioremediation are the examples associated with non-food products.

Genetic Modification method of breeding has been widely adopted by Farmers. It is known to be the fastest embraced crop technology in the world. The area under cultivation of genetically modified crops increased from 1.7 million hectares in 1996 to 185.1 million hectares in 2016, representing 12% of global cropland. As at the year 2016, major crop (soybean, maize, canola and cotton) traits consist of herbicide tolerance (95.9 million hectares) insect resistance (25.2 million hectares), or both (58.5 million hectares). In 2015, 53.6 million ha of Genetically Modified maize were under cultivation (almost 1/3 of the maize crop). Genetically Modified maize performed better than its predecessors: yield was 5.6 to 24.5% greater with lower levels of my cotoxins (−28.8%), fumonisin (−30.6%) and thricotecens (−36.5%). Organisms that were not targeted (Non-target organisms) were unaffected, excluding Braconidae, represented by a parasitoid of European corn borer, the target of Lepidoptera active Bt maize. Other biogeochemical parameters such as lignin content did not differ, while biomass breakdown was higher (Pallegrino et al., 2018).

In the year 2014, it was reported by Klumper and Qaim through a meta-analysis conducted that, Genetic Modification technology adoption had reduced chemical pesticide usage by 37%, improved yields ofcropsby 22%, and increased farmer profits by 68%. This reduction in pesticide use has been environmentallyhelpful, but benefits can be reduced by overuse.Perry et al. (2016)also reported that, with the benefits derived from modifying crops through genetic engineering, yield gains and pesticide reductions are larger for insect-resistant crops than for herbicide-tolerant crops. Yield and profit gains are higher in developing countries than in developed countries (Klumper and Qaim 2014).

Nicolia et al (2013), Ronald and Pamela (2011) and Domingo et al (2011), reported that, scientist believethat presently available food resulting from Genetically modified crops poses no superior risk to human health than conventional food. National Academics of science, Engineering and Medicine also reported in 2016 that each GM food needs to be tested on a case-by-case basis before it introduction. Nonetheless, members of the general public are much less likely than scientists to recognize genetically modified foods as safe (Scott et al., 2016, Marris and Claire 2001).

3. History of genetically modified crops

The first plant produced in using biotechnological means or method was an antibiotic-resistant tobacco plant in 1982 (Farley et al. 1983). France and USA were the countries in which the first field trials of genetically modified crops occurred, using tobacco plants engineered for herbicide resistance in 1986(James and Clive 1996). Plant Genetic Systems (Ghent, Belgium) was the first firm to genetically engineer insect-resistant (tobacco) plants by way of incorporating genes that produced insecticidal proteins from *Bacillus thuringiensis* (Bt) in 1987 (Vack et al., 1987).

The People's Republic of China was the first nation to allow the commercialization of transgenic plants by the introducing of virus-resistant tobacco in 1992 (James 1997), which was then withdrawn in 1997(Conner et al 2003). Approval of the sale of genetically modified crops happened in the U.S., in 1994, and FlavrSavr tomato was the crop. It had a longer shelf life, because it took longer period for it to become soft after ripening (Bruening and Lyons 2000). Debora Mackenzie reported (1994) reported that, tobacco engineered to tolerate the herbicide bromoxynil was the first genetically engineered crop to be marketed in the entire Europe due to its approval by the European Union In 1994.

Bt Potato then followed by gaining approval by the US Environmental Protection Agency in 1995, becoming the country's first-pesticide producing crop (Lawrence 1995). In 1995 canola with modified oil composition (Calgene), Bt maize (Ciba-Geigy), bromoxynil-tolerant cotton (Calgene), Bt cotton (Monsanto), glyphosate-tolerant soybeans (Monsanto), virus-tolerant squash (Asgrow), and additional delayed ripening tomatoes (DNAP, Zeneca/Peto and Monsanto) were approved (James and Clive 1996). As of mid-1996, 35 approvals had been granted to commercially grow 8 transgenic crops and one flower crop (carnation), with 8 different traits in 6 countries plus the EU (James and Clive 1996). In 2000, Vitamin A-enriched golden rice was developed, though as of 2016 it was not yet in commercial production.

In 2013 the leaders of the three research teams that first applied genetic engineering to crops, Robert Fraley, Marc Van Montagu and Mary-Dell Chilton, were awarded the World Food Prize for improving the "quality, quantity or availability" of food in the world(Andrew Pollack 2013).

In 2014 in the US, 94% of the planted area of soybeans, 93% of corn and 96% of cotton were genetically modified varieties (USDA-ERS). In the year 2013, about 18 million farmers planted 54% of Genetically Modified crops in developing countries worldwide by (ISAAA 2013).

4. Crops modified genetically for salt and drought resistance

By 2050, the world population is expected to reach 9.6 billion people (UNFPA, 2014). To sustainably provide sufficient food for the increasing population crop productivity needs to increase by 44 million metric tons annually. This is a challenge because there is very little potential for future expansion of arable lands whilst climate predictions suggest that a larger portion of the globe will be subjected to erratic environmental conditions and abiotic stress (Eckardt, 2009; FAO, 2009, 2012; Cominelli et al., 2013). Two abiotic stress factors that significantly hinder world crop production are soil water deficit and salinization (Munns, 2011). Due to the above reason, there has been a lot of plant engineering or modification works to produce plants that can endure other non-biological stressors. Paarlburg (2011) reported on drought resistant crops. Banjara et al 2012 also reported on a gene responsible for peanuts ability to tolerate soil which contains high levels of soluble salt. Monsanto's Drought Gard maize in 2011 became the first drought-resistant genetically modified crop to be accepted in US for marketing (Eisenstein 2013).

Drought resistance varieties, is developed by modifying the plant's genes in control for the mechanism known as the crassulacean acid metabolism (CAM), which permits the plants to survive despite low water levels. This holds potential for water-heavy crops such as rice, soybean, wheat, and poplar to hasten their adaptation to water-limited environs like regions which experiences high temperatures in the world (Michael Eisenstein, 2013). Several salinity tolerance mechanisms have also been identified in salt-tolerant crops. For example, rice, canola and tomato crops have been genetically engineered to intensify their tolerance to salt stress. Hoang et al 2015developed salt tolerance rice by constitutive-overexpression of genes involved in the regulation of programmed cell death.

5. Crops Modified Genetically For Nutritional Value

Genetically modification has also lead to the improvement of the nutritional values of some crops. Several crops have been genetically engineered for biofortification of phytonutrients. Some of them are ß-carotene-enriched 'Golden rice'(Ye et al., 2000; Paine et al., 2005), anthocyanin-enriched 'Purple Tomatoes' (Butelli et al 2008), and folate-enriched rice (Blancquaert et al., 2015). In rice, anthocyanin levels in endosperm is very low compared to pericarp but is the endosperm which is been consumed leading to low level of anthocyanin consumption. Due to the health benefits of anthocyanin, Zhu et al (2017) were able to use genetic engineering upon the complexity of the anthocyanin biosynthesis pathway to produce Purple endosperm rice (called 'Zijingmi' in Chinese) which has high anthocyanin content and antioxidant activity in the endosperm.

In recent years, there has been a growing demand for soybean oil due to it numerous utilizations such as renewable and sustainable raw material for biodiesel production, human consumption and others (Thelen and Ohlrogge, 2002; Clemente and Cahoon, 2009; Day, 2013; Wu et al., 2013). Due to the above reasons there was the need to produce soybean varieties with high oil content. Several genetic engineering approaches to develop soybean varieties with high oil content (Kinney, 1997: Buhr et al 2002: Cahoon, 2001: Cahoon et al., 2000). *Camelina sativa* has been modified to produce plants that accumulate high levels of oils similar to fish oils (Ruiz and Noemi 2013).

Ayer et al., (2011) reported on a genetically modified cassava under development which offered lower cyanogenglucoside sand enhanced protein and other nutrients (called BioCassava). Čermák and others in 2015 used high-frequency and precise modification approach to produce purple tomato plants with high anthocyanin content which has numerous health benefits when consumed. Although high scented rice is not a guarantee for higher nutritional value but majority consumers prefer high scented rice. Due to this reason, Shan et al (2015) used gene editing approach to knockdown a gene of interest to produce rice with high fragrance.

6. Herbicide, Pest and diseases desistance

Crops like tobacco, corn, rice and others have been engineered to express genes encoding for insecticidal proteins from *Bacillus thuringiensis* (Bt) (Bruening and Lyons 2000). It was reported by Naranjo and Steven in 2008 that Bt crops introduction in the USA between the period of 1996 and 2005 has been estimated to have reduced the total amount of insecticide active ingredient use in the United States by over hundred thousand tons, leading to a reduction of 9.4% in the usage of insecticide. With the wide range host of the cucumber mosaic virus and other viruses leading to devastation of both fruits and vegetables, Papaya, potatoes, and squash were engineered to resist these viral pathogens (National Academy of science 2001). Virus resistant papaya was developed in response to control and later prevent the papaya ringspot virus (PRV) outbreak in Hawaii in the late 1990s by incorporating PRV DNA (National Academy of Sciences 2001). By 2010, 80% of Hawaiian papaya plants were genetically engineered ones (Wenslaff et al 2012). **C**hungand others in 2013 engineered potatoes for resistance to potato leaf roll virus, Potato virus A and Potato virus Y to help increase the production of potatoes due to severe yield reduction caused by these pathogens attacks. CRISPR/Cas9 gene editing technology was used to develop non-transgenic cucumber with broad virus resistance (Chandrasekaran et al 2016). Li et al (2019), used gene editing approach to develop rice with resistance to bacterial blight.

Fuchs and Gonsalves (1995), used genetic engineering approach to develop Transgenic Hybrid Squash resistance to Zucchini Yellow Mosaic Virus and Watermelon Mosaic Virus 2 to help increase the production of this plant.

Infestation of maize by Maize dwarf mosaic virus, which causes stunted growth, carried in Johnson grass and spread by aphid insect vectors resulted in the modification of many corn strains to combat the spread of this virus. These strands are commercially available although the resistance is not standard among genetically modified corn variants Wang 2009). Shukla et al (2009), used zinc-finger nucleases gene editing technique to perform a precise genome modification in maize to produce an herbicide tolerant crop. Shi et al (2017) used CRISPR-Cas9 to produce variants maize which had improve grain yield under field drought stress conditions. The primary impact of genetically modified herbicide trait (largely tolerant to the broad spectrum herbicide glyphosate) technology has been to provide more cost effective (less expensive) and easier weed control for farmers. Nevertheless, some users of this technology have also derived higher yields from better weed control (relative to weed control obtained from conventional technology). The magnitude of these impacts varies by country and year, and is mainly due to prevailing costs of different herbicides used in genetically modified herbicide trait systems vs. conventional alternatives, the mix and amount of herbicides applied, the cost farmers pay for accessing the genetically modified herbicide trait technology, and levels of weed problems (Brookes and Peter, 2014).

7. Longer lifespan/shelf life

Bruening and Lyons (2000) reported that, the first genetically engineered crop accepted for sale in the U.S. was the FlavrSavr tomato, which had an extended shelf life. It is no longer on the market.

In November 2014, potatoes that are modified genetically to prevent bruising were approved by USDA (Federal Register 2013). Arctic Apples were approved in February 2015 by the USDA, becoming the first genetically modified apple accepted for US sale (Tennille 2016).Silencing of gene as a genetic engineering technique was used to limit the expression of polyphenol oxidase (PPO), thus preventing enzymatic browning of the fruit after it has been sliced open leading to extending shelf life of the crop even during usage (Chi, et al 2014:).

A potato variety that prevents bruising and yields less acrylamide when fried was also developed and in November 2014 got approval by the USDA (Federal Register 2103). This achievement makes it easy to transport such potato whiles reduction in its value is also reduced through the prevention of bruising thus increasing the lifespan of such materials due to the fact that bruising exposes plant materials to pathogens for faster detoliration and reducing the market value as well. Watz (2016) also used gene editing approach to produce a mushroom phenotype which is anti-browning.

8. Crops modified genetically for yield improvement

All the gene modification of crops against all sorts of stresses is to improve the yield of such crops or varieties. A plant which is engineered to be drought resistance, salt resistance among others is to help them to be able to produce enough or reasonable yields under such conditions. For example the overexpression of SNAC1 in rice resulted in significantly enhanced drought tolerance under severe drought conditions in the field at the reproductive stage making which lead to 22-34% higher seed setting than the control (Hu et al 2006).

9. Economic impact of genetically modified foods

In 2014, the largest assessment yet concluded that Genetically Modified crops impacts on farming remained positive. The meta-analysis considered all published English-language inspections of the agronomic and economic impacts between 1995 and March 2014 for three major GM crops: soybean, maize, and cotton. The study found that herbicide-tolerant crops have lower production costs, while for insect-resistant crops the reduced pesticide use was offset by higher seed prices, leaving overall production costs about the same (Klumper and Qaim 2014).

Areal et al (2012) and Finger et al (2011) reported that, one of the most important benefits of genetically modified foods is its economic value to farmers especially in the developing nations. A 2010 study found that Bt corn only gave economic benefits of $6.9 billion over the preceding 14 years in five Midwestern states (Hutchison et al 2010).

Brookes and Peter, 2014 reported that, there has been a very significant net economic benefits at the farm level amounting to $18.8 billion in 2012 and $116.6 billion for the 17-year period (in nominal terms). These economic gains have been divided roughly 50% each to farmers in developed and developing countries. GM technology have also made important contributions to increasing global production levels of the four main crops, having added 122 million tons and 230 million tons respectively, to the global production of soybeans and maize since the introduction of the technology in the mid-1990s.

It was also reported by Naranjo and Ellsworth in the year 2009 that, In Arizona, where an integrated pest management program for Bt cotton continues to be effective, growers reduced insecticide use by 70% and saved .$200 million from 1996 to 2008 in Arizona. This reduction in insecticide usage does not lead to only improving the income of the fame but making the environment also friendly for work as well.

10. Conclusion

From the above information gathered, it can be concluded that, genetically modified foods has played and still playing a significant role in elevating hunger and improving nutritional values of some already existing crop varieties through the production of crops with high yielding abilities, resistance to pest and diseases, adaptation to drought and other environmental stresses leading to making the world a food secured one when the full potential of this technique is utilised.

Prior to market approval, GM plant varieties requires in most countries an extensive food and Environmental safety assessments, contrary to similar conventionally bred crops, and this aspect is a facing challenge for the contribution of GM crops to food security which demands a better way of handling.

Sensitization needs to be done to help the general public understand issues better regarding the use and benefit of genetically modified food. Finally, a wider acceptance of genetically modified crops in the entire world will help in the provision of food for the populace.

Compliance with ethical standards

Disclosure of conflict of interest

All authors declare that they have no conflict of interest.

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