European Journal of Social Sciences Studies
ISSN: 2501-8590
ISSN-L: 2501-8590
Available on-line at: www.oapub.org/soc

doi: 10.5281/zenodo.1403250 Volume 3 | Issue 2 | 2018

FROM THE GREEN REVOLUTION TO THE GENE REVOLUTION: A PANACEA TO THE FOOD SECURITY CRISIS IN THE TWENTY-FIRST CENTURY AND BEYOND?

Tanyaradzwa Chigonda[1i],
Tendekai Rusena[2]
[1]Department of Physics, Geography and Environmental Science,
Faculty of Agriculture and Natural Sciences,
Great Zimbabwe University, Masvingo, Zimbabwe
[2]Department of Curriculum Studies,
University of Zimbabwe, Harare, Zimbabwe

Abstract:
This paper assesses the positive and negative impacts of agricultural genetic engineering on food security, and is informed by an extensive review of relevant documents analysed through content and thematic analysis. While the Green Revolution technologies of the 1970s up to the 1990s markedly enhanced food production in developing countries, such approaches, due to various reasons, are proving to be inadequate in solving the food security challenges of the twenty-first century and beyond. Today, the world is home to 842 million people experiencing chronic food shortages. Agricultural genetic engineering, which seeks to enhance agricultural production through novel approaches, has been hailed as a panacea to food insecurity by proponents. On the other hand, opponents of agricultural biotechnology highlight its various dangers to food security. While, to date, no adverse safety issues of transgenic foods have been reported, this does not mean that foods derived from genetically modified organisms are risk free, but is probably just a reflection of the inadequacies in current regulatory, testing and evaluation procedures. Under such circumstances of lack of scientific certainty on the adverse human health impacts of foods produced through genetic engineering, the application of the precautionary principle would be the best route to take. As such there is need for the scientific community to do more research into agricultural biotechnology so as to enable the development of food products that meet wider societal concerns. This should be followed up by cautious case-by-case evaluation procedures to objectively determine the benefits and risks of each individual transgenic organism or food products derived from it. To further enhance the protection of consumers, all foods derived from genetically modified organisms should be adequately labelled. In addition, consumers

[i] Correspondence: email tanyachigonda@gmail.com

should be informed of the lack of scientific certainty on the long-term health impacts of consuming transgenic foods, so that they may make informed, and independent, choices. Another important issue of concern is the need to protect traditional farmers, who play a pivotal role in conserving agricultural genetic diversity, from powerful transnational seed companies aiming to have total control over seed.

Keywords: recombinant DNA, transgenic foods, genetically modified organisms, green revolution, gene revolution, food security, food safety, agricultural genetic engineering, biotechnology

1. Introduction

The Green Revolution of the 1970s brought high-yielding semi-dwarf wheat and rice varieties, developed with conventional breeding methods, to millions of small-scale farmers, initially in Asia and Latin America, and later in Africa (FAO, 2004; FAO, 2009). Indeed, the later part of the 1970s saw cereal production more than doubling in the developing countries. The gains achieved during the early decades of the Green Revolution were extended in the 1980s and 1990s to other crops and to less favoured regions (Evenson and Gollin, 2003; FAO, 2004). Rapid adoption of modern varieties, a threefold increase in chemical fertilizer and pesticide consumption and a doubling in irrigated area were key factors driving the Green Revolution (Alarcón and Bodouroglou, 2011; FAO, 2004; FAO, 2009). The countries that were able to make the most of the opportunities presented by the Green Revolution were those that had, or quickly developed, strong national capacity in agricultural research, and were able to make the necessary local adaptations to ensure that the improved varieties suited the needs of their farmers and consumers (FAO, 2004).

In spite of the continued application of Green Revolution technologies, agriculture and food production in the twenty-first century is facing unprecedented challenges. Achieving universal food security is a staggering challenge, especially in a world with an expanding population, accelerating consumption, and many signs of a deteriorating biophysical environment (Bourne, 2015; Ehrlich and Harte, 2015). Massive population growth, rising incomes and growing consumption are driving the demand for food (FAO, 2004). An additional 2.7 billion people will have to be fed over the next 30 years from an increasingly fragile natural resource base, while food production could be as much as 25 percent less than demand by 2050 (FAO, 2004; FAO, 2015). FAO estimates the number of undernourished people at 842 million: 798 million in the developing countries, 34 million in the countries in transition, and 10 million in the developed countries. More than half of the total number of the undernourished (60%) are found in Asia and the Pacific, followed by sub-Saharan Africa which accounts for 24% of the total. However, in terms of the proportion of the population undernourished by region, by far, the highest incidence of undernourishment is found in sub-Saharan Africa where 33% of the population is undernourished, compared to 16% for Asia and

10% for both Latin America and the Caribbean and the Near East and North Africa (FAO, 2004; FAO, 2010). It is true that some progress has been made over the past four to five decades in reducing undernourishment in the developing countries through the Green Revolution. For instance, the incidence of undernourishment has declined from 28% of the population in the 1970s to 17% according to data from 1999-2001 (Alarcón and Bodouroglou, 2011; FAO, 2004; FAO, 2011). However, as a result of population growth, the decline in terms of absolute numbers has been slower, and was more pronounced in the 1980s, but appeared to have slowed down in the 1990s and also in these first two decades of the 21st century.

Due to several shortcomings and criticisms, it is clear that Green Revolution approaches are no longer suitable as a strategy for effectively addressing the food supply challenges of the 21st century and beyond (Ehrlich and Harte, 2015). Firstly, because these high-yielding varieties require inputs such as fertilizer and irrigation water, social scientists criticized the Green Revolution technologies for not being resource neutral. For this reason, many farmers across the globe, and especially in developing countries, remain trapped in subsistence agriculture (Alarcón and Bodouroglou, 2011; FAO, 2004; IFAD, 2013), as they cannot afford the high input costs. Second, environmentalists attacked the Green Revolution because of potential damage to long-term productivity as a result of excessive use of pesticides, herbicides, fertilizers and mono-cropping. Thirdly, under conditions of diminishing per capita arable land due to growing populations, coupled with declining irrigation water availability, the prospect of expanding agriculture into new areas is fast disappearing. Arable land per person is shrinking, from 0.38 hectares in 1970 to 0.23 in 2000, with a projected decline to 0.15 hectares per person by 2050 (Alarcón and Bodouroglou, 2011; Ehrlich and Harte, 2015).With the exception of acid-soil areas in Africa and South America, the potential for expanding global crop area is limited (FAO, 2004). Additionally, while irrigation has played a pivotal role in the success of the Green Revolution towards boosting agricultural production in the developing countries, it has by no means come without costs, partly due to injudicious application. It is important to note that less than half of the world's land is suitable for irrigation and the amount of irrigated land area is falling because of soil erosion, salination, acidification, and nutrient depletion. About 20 percent of irrigated land in the developing world has been damaged to some extent by waterlogging or salinity, especially in arid to semi-arid areas. By 2020, 30 percent of arable land may be salinated and as much as 50 percent by 2050 (FAO, 2004). So, notwithstanding the aforementioned successes of the Green Revolution in raising millions of people out of misery in the last four to five decades, the incidence of poverty, endemic hunger, infant and maternal mortality rates, low birth-weight children and stunting remain high in the developing countries of the world.

There is growing rhetoric that biotechnology, particularly genetic engineering, can overcome the food production constraints of the 21st century that have proven to be more difficult or intractable with the conventional breeding practices of the Green Revolution. Biotechnology, also referred to as the Gene Revolution, can foster continued genetic improvement of food crops and livestock, which is needed to shift the yield frontier higher and to increase stability of yield. However, biotechnology in food and agriculture, particularly genetic engineering, has also become the focus of a 'global war of rhetoric' (Alarcón and Bodouroglou, 2011; FAO, 2004; Stone, 2002). While proponents of genetic engineering view it as essential to addressing food insecurity and malnutrition in developing countries, opponents, on the other hand, claim that genetic engineering will worsen poverty and hunger, and lead to a corporate takeover of traditional agriculture and the global food supply chain (FAO, 2004; Five Year Freeze, 2002).

The objective of this review paper is to explore the debate regarding the hazards and opportunities posed by biotechnology towards meeting the food security needs of the world, with a special focus on developing countries. In light of the polarised rhetoric on biotechnology and food production, and the attendant health and safety concerns, the paper attempts to come up with a more balanced view point on the contribution of biotechnology to food security.

The review process was guided by the following research questions:

- What are the various techniques used in agricultural biotechnology?
- What are the actual or potential positive impacts of agricultural biotechnology on food security?
- What are the actual or potential negative impacts of agricultural biotechnology on food security?
- What are the actual or potential health and safety concerns posed by transgenic foods?
- What measures can be taken so as to enhance the contribution of biotechnology to food security?

2. Key terms

2.1 Food security

The Food and Agriculture Organization (FAO) defines food security as 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, 2002). From the above definition, it emerges that food security consists of having, on an individual level, the food one needs and wants.

Food security comprises three key dimensions of food supplies, namely: availability, access, and utilisation. The first dimension relates to the availability of sufficient food, that is, the overall ability of the agricultural system to meet food demand. The subdimensions of food availability include the agro-climatic fundamentals of crop and pasture production, and the entire range of socio-economic and cultural factors that determine where and how farmers perform in response to markets (Schmidhuber and Tubiello, 2007).

The second dimension, access, covers access by individuals to adequate resources or entitlements to acquire appropriate foods for a nutritious diet. Entitlements have been defined by Schmidhuber and Tubiello (2007: 19703) as "*the set of all those commodity bundles over which a person can establish command given the legal, political, economic, and social arrangements of the community of which he or she is a member*". Thus, a key element is the purchasing power of consumers. However, these resources need not be exclusively monetary, but may also include traditional rights, for example, sharing of common resources (Schmidhuber and Tubiello, 2007). Finally, utilisation encompasses all food safety and quality aspects of nutrition. The subdimensions of food utilisation are thus related to health, including the sanitary conditions across the entire food chain. It is not enough that someone is getting what appears to be an adequate quantity of food if that food is not nutritious, or if the person is unable to make use of the food because he or she has been sickened by the consumed food (Schmidhuber and Tubiello, 2007).

Food insecurity can be categorised into three conditions which are acute, occasional and chronic. Acute food insecurity involves sever hunger and malnutrition to the point that lives are threatened immediately, for example in the event of a famine. When food insecurity occurs due to a specific temporary circumstance, it is categorised as occasional. Chronic food insecurity occurs when the ability to meet food needs is consistently under threat. As noted earlier, a total of 842 million people across the globe face chronic food insecurity.

2.2 Biotechnology

The Convention on Biological Diversity (CBD) defines biotechnology as: "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products for specific use" (Secretariat of the Convention on Biological Diversity, 1992).

The Cartagena Protocol on Biosafety defines modern biotechnology more narrowly as the application of *in vitro* nucleic acid techniques, including recombinant deoxyribonucleic acid (rDNA) and direct injection of nucleic acid into cells or organelles; or the fusion of cells beyond the taxonomic family, that overcome natural physiological reproductive or recombination barriers and that are not techniques used in traditional breeding and selection. (Secretariat of the Convention on Biological Diversity, 2000). Recombinant DNA techniques, also known as genetic engineering or genetic modification, refer to the modification of an organism's genetic make-up using transgenesis, in which DNA from one organism or cell (the transgene) is transferred to another without sexual reproduction (FAO, 2004).

Modern agricultural biotechnology includes a range of tools that scientists employ to understand and manipulate the genetic make-up of organisms for use in the production or processing of agricultural products. Table 1 shows the timeline for agricultural technology.

Table 1: An agricultural technology timeline

Technology	Era	Genetic interventions
Traditional	About 10 000 years BC	Civilizations harvested from natural biological diversity, domesticated crops and animals, began to select plant materials for propagation and animals for breeding
	About 3 000 years BC	Beer brewing, cheese making and wine fermentation
Conventional	Late nineteenth century	Identification of principles of inheritance by Gregor Mendel in 1865, laying the foundation for classical breeding methods
	1930s	Development of commercial hybrid crops
	1940s to 1960s	Use of mutagenesis, tissue culture, plant regeneration. Discovery of transformation and transduction. Discovery by Watson and Crick of the structure of DNA in 1953. Identification of genes that detach and move (transposons)
Modern	1970s	Advent of gene transfer through recombinant DNA techniques. Use of embryo rescue and protoplast fusion in plant breeding and artificial insemination in animal reproduction
	1980s	Insulin as first commercial product from gene transfer. Tissue culture for mass propagation in plants and embryo transfer in animal production
	1990s	Extensive genetic finger printing of a wide range of organisms. First field trials of genetically engineered plant varieties in 1990 followed by the first commercial release in 1992. Genetically engineered vaccines and hormones and cloning of animals
	2000s	Bioinformatics, genomics, proteomics, metabolomics

Source: FAO, 2004

From Table 1, it is apparent that human intervention for the improvement of crops and livestock is nothing new. For millennia, humans have bred, crossed and selected those varieties, ecotypes and breeds that were more productive, better adapted or particularly useful. While this is true, modern biotechnology involves an array of advanced tools and techniques for introducing or deleting a particular gene or genes to produce plants, animals and micro-organisms with novel traits, which was not the case under traditional or conventional approaches (FAO, 2003a).

Agricultural biotechnology is being used to address problems in all areas of agricultural production and processing including: speeding up conventional breeding programmes and providing farmers with disease-free planting materials; creating crops that resist pests and diseases, thereby replacing toxic chemicals that harm the environment and human health; providing diagnostic tools and vaccines that help control devastating animal diseases; and improving the nutritional quality of staple foods such as rice and cassava (FAO, 2004). The application of biotechnology to agriculture has, however, also brought some real and imagined negative impacts to the attainment of food security. The review paper will thus assess the positive and negative impacts of biotechnology on food security, especially on the availability and utilisation dimensions of food security.

3. Methodology

This paper is informed by an extensive documentary review of literature on the impacts of biotechnology on food security. The secondary data sources for the review included textbooks, journal articles, academic theses, relevant websites and policy documents carefully selected based on their relevance in addressing the objective of the research and the research questions. Resources accessed on the internet were searched through academic search engines such as EBSCOHOST, Scopus, and Science Direct, among others, using various search phrases including, *inter alia*, 'genetic engineering and food security', 'biotechnology and food security', 'transgenic foods', 'genetically modified foods', 'genetic modification and agriculture', and 'positive and negative impacts of biotechnology on food security'. A total of 30 documents were finally selected for the review exercise. The documentary sources of information were analysed through content and thematic analyses.

4. Results: The impact of biotechnology on food security

4.1 Biotechnology and food availability

The food availability dimension of food security, compared to access and utilisation, is arguably the most important, as the other two dimensions directly derive from it. In other words, we cannot talk about food access or utilisation when the food itself is not available. The impact of biotechnology on food security also tends to be more pronounced within the availability dimension.

4.1.1 Positive impacts

A. Crop production

a. Biotic stress tolerance: Crops, through biotechnology, can be made more tolerant to the various biotic stresses that affect them, thereby reducing the danger of crop failure and enhancing food security. Various advances to this end have successfully been made as illustrated below:

- *Increased tolerance to pests and diseases* - genetically engineered resistance to pests and diseases could greatly reduce the chemicals needed for crop protection. Farmers are now growing maize, cotton and potatoes that no longer have to be sprayed with the bacterial insecticide *Bacillus thuringiensis* - because they produce its insecticidal agent themselves (FAO, 2003b). For example, genes from the common soil bacterium Bacillus thuringiensis (Bt) have been inserted into cotton plants, causing them to produce a protein that is toxic to certain insects.

Bt cotton is highly effective in controlling caterpillar pests such as pink bollworm (*Pectinophora gossypiella*) and cotton bollworm (*Helicoverpa zea*), and is partially effective in controlling tobacco budworm (*Heliothis virescens*) and fall armyworm (*Spodoptera frugiperda*) (FAO, 2004). The new pest-resistant crops reduce the need for chemical sprays, and farmers may spend less money on chemicals and less time and effort applying them, resulting in higher effective yields (FAO, 2004). These cost savings and output gains can translate into higher net returns at the farm level, thereby enhancing food security.

- *Herbicide tolerance* - genetically engineered herbicide tolerance (HT) crops feature a gene from the soil bacterium *Agrobacterium tumefaciens*, which makes the recipient plant tolerant to the broad-spectrum herbicide glyphosate (FAO, 2004). Introduced to a crop plant, the technology can facilitate weed management. It can reduce production costs, through the substitution of glyphosate for an array of more expensive (and more toxic) herbicides. Herbicide tolerance for various crops was developed by Monsanto under the name RoundupReady® (RR), and RR soybeans were commercially released in Argentina and the United States in 1996. In Argentina, the total variable cost of production is about 8 percent ($21/ha) lower for RR soybeans than for a conventional crop while, in the United States, Moschini et al (2000) estimated a cost advantage of $20/ha for 2000. Qaim and Traxler (2004) estimated that RR soybeans created more than $1.2 billion in economic benefits in 2001, about 4 percent of the value of the world soybean crop, while soybean consumers worldwide gained $652 million (53 percent of total benefits) as a result of lower prices. Soybean producers in Argentina and the United States received benefits of more than $300 million and $145 million, respectively, whereas producers in countries where RR technology is not available faced losses of $291 million in 2001 as a result of the induced decline of about 2 percent ($4.06 per tonne) in world market prices (FAO, 2004).

b. Abiotic stress tolerance

Biotechnology can also be used in improving the tolerance of crops to various abiotic stresses such as severe weather (e.g. frost, extreme heat and drought), salt and toxic metals in acid soils among other plant stressors through *in vitro* selection (FAO, 2003b; FAO, 2004). *In vitro* selection refers to the selection of germplasm by applying specific selection pressure to tissue culture under laboratory conditions. Many recent publications have reported useful correlations between *in vitro* responses and the expression of desirable field traits for crop plants (FAO, 2004). One of the most successful abiotic stress tolerance applications have been done on aluminium resistance in crops. Aluminium in acid soils limits plant growth on more than 30 percent of all arable land, primarily in developing countries. There are two approaches to increasing crop production on acid soils. While lime can be added to the soil to increase the pH, this is a costly and temporary measure. Alternatively, genetically improved cultivars, tolerant to aluminium, can be developed. Existing wheat cultivars do not contain significant genetic variation for increasing aluminium tolerance, and improved tolerance will have to be introduced into wheat from the gene pools of related, more tolerant species (FAO, 2004). Fish have also been caught up in the gene revolution in a big way. In one novel application of genetic engineering, which has seen fish genes finding their way onto dry land, the anti-freeze protein gene from the Arctic flatfish is being transferred to food crops (FAO, 2003b). This will allow for crop production in areas experiencing severe winters, thereby enhancing food security in such areas.

c. More food from less land

Improved productivity from genetically modified organisms (GMOs) might mean that farmers in the next century won't have to bring so much marginal land into cultivation. With the fast dwindling per capita arable land size across the world due to rapidly growing populations, genetically modified high-yielding crops could be an effective guarantee for food security especially in developing countries. Indeed, much of the increase in agricultural output over the past 40 years has come from an increase in yield per hectare rather than an expansion of area under cultivation (FAO, 2004).

d. Rehabilitation of damaged or less-fertile land

Through genetic modification, crop and tree varieties might also be selected or bred for rehabilitation of degraded land (FAO, 2003b). As noted earlier, large areas of cropland in the developing world have become saline due to unsustainable irrigation practices. Rehabilitation of damaged land may also become possible through organisms bred to restore nutrients and soil structure, a process called bioremediation (FAO, 2003b). All these measures will put back into production land that had become agriculturally useless, thereby enhancing food security in affected areas.

e. Longer shelf lives

The genetic modification of fruits and vegetables can make them less likely to spoil in storage or on the way to markets, and this could expand trade opportunities as well as reduce massive wastage incurred in transport and supply (FAO, 2003b). The implications of longer shelf lives of agricultural produce on food security are apparently clear, as the produce, especially that which is highly perishable, could now be enjoyed for longer by consumers. This is particularly important among poor rural communities lacking other means to extend shelf lives of agricultural produce such as refrigeration. Additionally, extended shelf lives tend to have the impact of reducing prices of commodities, as supply is more likely to be increased, or maintained, on the market.

B. Animal production

a. Animal health

Genetic engineering has potential benefits for animal health. Besides the distress that illness causes to animals, disease results in economic damage, especially in poor communities that depend heavily on livestock, with enormous implications for food security. Over the last 15-20 years, US$ 100 million has been spent on unsuccessful attempts to control African swine fever, hence the need to try new methods such as those offered by biotechnology (FAO, 2003b).

The impact of modern biotechnology on animal health falls into three categories (FAO, 2003c; FAO, 2004):

- *Diagnostics*. It is now possible to analyse gene sequences of microbes and parasites, allowing rapid and accurate diagnosis of the exact type. Animal diseases are difficult to diagnose because the signs may be misleading or even entirely absent until serious damage has occurred. Advanced biotechnology-based diagnostic tests make it possible to identify disease-causing agents and to monitor the impact of disease control programmes to a degree of precision not previously possible.
- *Vaccines*. Recombinant vaccines, that is, those developed through gene manipulation, can be highly effective. Although vaccines developed using traditional approaches have had a major impact on the control of foot-and-mouth and tick-borne diseases, rinderpest and other diseases affecting livestock, recombinant vaccines can offer various advantages over conventional vaccines in terms of safety, specificity and stability. Genetic markers can also be inserted into vaccines, so that workers in the field can distinguish between animals that have a disease and those that have simply been vaccinated. This means that vaccinated animals won't have to be destroyed on suspicion of being disease carriers.
- *Epidemiology*. Epidemiology is the study of the spread of diseases. Organisms such as viruses evolve and mutate very quickly, and so do their behaviour and resistance. From the sequence of an organism's genes, it is possible to understand how and where it evolved, a process known as phylogenetics. This can show how the organism is evolving now and what it will do next, thereby helping to identify the right vaccines for combating fast-evolving viruses such as foot-and-mouth disease and rinderpest. For example, the molecular analysis of rinderpest viruses has been vital for determining the lineages circulating in the world, which has been instrumental in aiding the Global Rinderpest Eradication Programme (GREP), which has made the world almost free of rinderpest today.

c. Animal nutrition

Biotechnologies have already resulted in animal nutrition aids such as enzymes, probiotics, single-cell proteins and antibiotic feed additives that are already widely used in intensive production systems worldwide to improve the availability of nutrients from feeds and the productivity of livestock and aquaculture. Gene-based technologies are increasingly being employed to improve animal nutrition, either through modifying the feeds to make them more digestible or through modifying the digestive and metabolic systems of animals to enable them to make better use of the available feeds (FAO, 2004).

d. Improving animal productivity

Genetic engineering is also becoming very crucial in the productivity of various livestock. Its obvious uses include increased milk, meat and egg production (FAO, 2003b). Genetic engineering in animals can be used to introduce foreign genes into the animal genome through direct microinjection of DNA into the pronuclei of fertilized eggs, or new approaches such as nuclear transfer. For example, genes responsible for growth were introduced into pigs to increase growth. With regards to fish, genetic engineering can speed up growth, such that modified fish could be ready for the market much sooner. An example is that of a transgenic salmon with a gene from a cold-water species, which enables it to continue growing during cold periods, thereby reaching its commercial weight far faster (FAO, 2003d). It grows 4 to 11 times faster than its ordinary relatives.

4.1.2 Negative impacts

A. Crop production

a. Loss of farmers' access to plant material

Since biotechnology research is carried out predominantly by the private sector, there are genuine concerns about market dominance in the agricultural sector by a few powerful companies. This could have a serious negative impact on food security among small-scale farmers all over the world. Farmers fear that they might even have to pay for crop varieties bred from genetic material that originally came from their own fields when they buy seeds from companies holding patents on specific genetic 'modifications' (FAO, 2003e). One of the best examples of the total control of seeds by the private sector is from India where 95 per cent of India's cotton seed is now controlled by Monsanto (Shiva, 2016). Thus, through patents on seed, Monsanto has become the 'Life Lord' of our planet, collecting rents for life's renewal from farmers, the original breeders (Shiva,

b. Intellectual property rights could slow research

The proprietary nature of biotechnology products and processes may prevent their access for public-sector research (FAO, 2003e). This might have a stronger negative impact in developing countries where no private research initiatives are in place. In addition, most developing countries still do not provide patent protection to biotechnological products and technologies.

c. Impact of "terminator" technologies

Although these are still under development and have not yet been commercialized, they would, if applied, prevent a crop from being grown the following year from its own seed, through 'switching off' or terminating the genes controlling germination. This means that farmers could not save seeds for planting in the next season (FAO, 2003e).

d. Interaction with wild and native populations

GMOs could compete or breed with wild species. GM crops could pose a threat to crop biodiversity, especially if grown in areas that are centres of origin of that crop. In addition, GM crops could compete with and substitute traditional farmers' varieties and wild relatives that have been bred, or evolved, to cope with local stresses. For example, local varieties in Latin America permitted the recovery from the catastrophic potato blight in Ireland in the 1840s. Today such plants often help improve climate tolerance and disease resistance. If genetically modified crop varieties substitute them, they could be lost (FAO, 2003e).

e. Genes can end up in unexpected places.

Through "gene escape" genes introduced in GMOs can pass on to other members of the same species and perhaps other species. Problems could result if, for example, herbicide-resistance genes got into weeds, resulting in 'superweeds'. While research on this is inconclusive, there is, however, scientific consensus that once widely released, recalling transgenes or foreign DNA sequences, whose safety is still subject to scientific debate, will not be feasible (FAO, 2003e).

B. Animal production

Literature on the negative impacts of agricultural biotechnology on food security, with regard to the livestock sector, seems to be relatively limited compared to that on crop production. It appears fewer researches have been done on the negative impacts of genetic engineering on animal production. However, the little information available seems to indicate more or less the same negative impacts of genetic engineering on animal production as on crop production.

The main environmental concerns associated with genetically engineered animals involve the possibility that the transgenic animals could escape with resultant negative effects on wild relatives or ecosystems (FAO, 2004). For this reason, transgenic animals should be evaluated for their ability to escape and become established in different environments.

The environmental implications of genetically modified fish are more pressing than those of terrestrial animals. Since the life cycles of fish are so much shorter and they are so much more numerous, genetically modified fish would have a faster impact (FAO, 2003d). In addition, farmed fish do not always stay where they are meant to. About 30 percent of the salmon in Norway's rivers are escaped farm fish, while in the Canadian province of New Brunswick, around 33 percent of salmon are thought to be escapees. Farmed fish in the wild are already associated with the spread of pests and diseases such as sea lice (FAO, 2003d). Transgenic fish may also compete for food, reducing the wild populations, thereby disrupting the livelihoods of fish-dependent communities. In addition, transgenic fish are also being bred for resistance to disease and pests. In the wild, resistant fish could act as hosts for organisms that would normally kill them. Those organisms could then attack 'real' wild fish (FAO, 2003d).

4.2 Biotechnology and food utilisation

As a recap, the utilisation dimension of food security encompasses the food safety and nutrition aspects.

4.2.1 Positive impacts

A. Crop production

a. More nutritious staple foods: By inserting genes into crops such as rice and wheat, their food value can be increased:

- *Golden Rice* – Golden Rice has been genetically engineered to produce beta-carotene, the precursor to vitamin A, by inserting in rice plants genes responsible for producing beta-carotene (FAO, 2003b; FAO, 2004). As rice feeds more than 50 percent of the world's population, Golden Rice could help reduce vitamin A deficiency, which is a serious problem in the developing world, especially among people depending on rice for the bulk of their diets (FAO, 2003b). Vitamin A deficiency affects more than 200 million people worldwide and is responsible for an estimated 2.8 million cases of blindness in children under five years of age (FAO, 2004). Critics argue that Golden Rice is an expensive, high-tech solution to a problem that should be addressed through dietary diversification and dietary supplements. On the other hand, while supporters of Golden Rice agree that dietary diversification would be ideal, they argue that this goal is not attainable for the millions of people who cannot afford more than a subsistence diet (FAO, 2004).
- *Protato* - Researchers at Jawaharlal Nehru University in India have developed a genetically engineered potato, the 'protato', which produces about one-third to one-half more protein than usual, including substantial amounts of all the essential amino acids such as lysine and methionine. Protein deficiency is widespread in India and potato is the staple food of the poorest people. The protato includes a gene from the amaranth plant, a high-protein grain that is native to South America (FAO, 2004).

b. Food safety

Scientists generally agree that genetic engineering can offer direct and indirect health benefits to consumers including, according to FAO (2004):

- Reducing the presence of toxic compounds in foods, for example cassava with less cyanide.
- Removal of toxic compounds from soil to produce healthy food.
- Reducing allergens in certain foods, for example in groundnuts and wheat. Molecular biology could be used to characterize allergens and remove them from foods.

B. Animal production

The utilisation dimension of food security on animal-based foods has also been enhanced through biotechnology. For example, genetic engineering has been applied in increasing the casein content of milk in dairy cows (FAO, 2004). In another example, genetic engineering has been applied to improve carcass quality in pig, cattle, goat and chicken.

4.2.2 Negative impacts

A. Crop production

a. Transfer of allergenic genes

Notwithstanding the important role of genetic engineering of reducing or removing allergens from foods, the same allergens could be accidentally transferred to other species, causing dangerous reactions in people with allergies. For example, an allergenic Brazil-nut gene was transferred into a transgenic soybean variety (FAO, 2003e). However, its presence was discovered during the testing phase, and the soybean was, fortunately, not released.

b. Transfer of antibiotic resistance

Horizontal gene transfer and antibiotic resistance is a food safety concern because many first-generation GM crops were created using antibiotic-resistant marker genes (FAO, 2004). Genes that confer antibiotic resistance are inserted into GMOs as "markers" to indicate that the process of gene transfer has succeeded. Concerns have been expressed about the possibility that these "marker genes" could be transferred from a food product into the cells of the human body or to bacteria in the gastrointestinal tract, which could lead to the development of antibiotic-resistant strains of bacteria, with adverse health consequences (FAO, 2003e; FAO, 2004). This approach is now being replaced with the use of marker genes that avoid medical hazards.

c. Mixing of GM products in the food chain

Unauthorized GM products have appeared in the food chain. For example, the GM maize variety Starlink, intended only for animal feed, was accidentally used in products for human consumption (FAO, 2003e). Although there was no evidence that Starlink maize was dangerous to humans, strict processing controls may be required to avoid similar cases in the future.

B. Animal production

New research on transgenic varieties of fish species that are widely farmed in the developing world such as tilapia and carps has expanded greatly. For example, scientists are developing tilapia with human growth hormone (FAO, 2003d), which obviously raises major concerns about the safety of such fish for human consumption. In addition, and as noted earlier, transgenic fish in the wild are already associated with the spread of diseases and pests. Animal nutrition aids developed through biotechnology, such as enzymes, probiotics, single-cell proteins, antibiotic feed additives and growth hormones widely used in intensive production systems worldwide to improve the availability of nutrients from feeds and the productivity of livestock and aquaculture (FAO, 2004), could find their way into humans consuming foods derived from such animals. This might result in some negative consequences on human health.

5. Discussion, recommendations and conclusion

Beyond any doubt, substantial empirical evidence exists on the vast potential of agricultural biotechnology and genetic engineering in effectively addressing the food security challenges facing the world. On the other hand, scientific evidence concerning the impacts of genetically engineered foods on human health is still emerging.

Thus far, in those countries where foods derived from transgenic crops and animals have been grown, or consumed, there have been no verifiable reports of them causing any significant health or environmental harm. While millions of people have consumed foods derived from genetically modified plants and animals, no verifiable toxic or nutritionally deleterious effects resulting from the consumption of such foods have been discovered anywhere in the world (ICSU, 2003). Moreover, pests have not developed resistance to Bt, while HT superweeds have not invaded agricultural or natural ecosystems as feared by some (FAO, 2004). As reported by renowned international food safety watch dogs, currently available transgenic foods have been judged safe to eat, while the methods used to test their safety have been deemed appropriate (ICSU, 2003; WHO, 2002). In addition, several national regulatory authorities, using their own national food safety procedures, have also assessed genetically modified foods for increased human health risks, and have not reported any adverse impacts to date (ICSU, 2003).

However, lack of evidence, so far, of negative effects does not mean that they cannot (or do not already) occur, or that transgenic foods are without risk (ICSU, 2003; GM Science Review Panel, 2003). Scientists acknowledge that not enough is known about the long-term effects of transgenic foods. Much remains unknown, complete safety can never be assured, and regulatory systems and the people who manage them are not perfect (ICSU, 2003). It will be difficult to detect long-term effects because of many confounding factors such as the underlying genetic variability in foods and problems in assessing the impacts of whole foods (FAO, 2004). Furthermore, newer, more complex genetically transformed foods may be more difficult to assess and may increase the possibility of unintended effects (ICSU, 2003; GM Science Review Panel, 2003). New profiling, or tools, may thus be needful in testing whole foods for unintended changes in composition (ICSU, 2003). The main food safety concerns associated with transgenic products and foods derived from them relate to the possibility of increased allergens, toxins or other harmful compounds; horizontal gene transfer particularly of antibiotic-resistant genes; and other unintended effects (FAO/WHO, 2000).

Given the lack of scientific certainty on the actual or potential adverse impacts of transgenic foods on human health or on agricultural production, and in light of the immense potential of agricultural genetic engineering to eradicate hunger and starvation in the world, an important question to ask is, how then should we proceed? Declaring a moratorium on agricultural genetic engineering research is, arguably, not the way to go, though this is strongly supported by some who argue on moral grounds that, through genetic engineering, man is attempting to play God. The best possible recommendation could be that research into agricultural genetic engineering should be sustained, governed by a reasonable application of the precautionary principle, which maintains that "*lack of scientific certainty is no reason for inaction at the risk of potentially serious or irreversible harm to the environment*".

First, there is a clear need for the scientific community to do more research in a number of areas in agricultural biotechnology so as to make good choices in terms of, for example, transgene design, so as to enable the development of transgenic food products that meet wider societal concerns (GM Science Review Panel, 2003). Practices such as the transfer of genes across species, including the infusion of human or animal genes into plant hosts or, similarly, plant genes into animal hosts, should be discouraged outright, as it would be difficult to determine the long term impacts of consuming transgenic foods derived through such novel approaches. Second, a science-based evaluation system that would objectively determine the benefits and risks of each individual transgenic organism or food products derived from it, on a cautious case-by-case approach to address legitimate concerns for its biosafety, must be adopted (FAO, 2000). Such an evaluation process should also aim to strengthen national regulatory authorities, especially in developing countries, so that they are well equipped to competently perform the important task of clearing imported transgenic food products. More often than not, poor developing countries have acted as guinea pigs for novel products from developed countries. A third important area in the regulation of genetically modified foods revolves around the all-important issue of labelling. It must be made mandatory for all foods produced through genetic engineering to be labelled as such, so that consumers choosing to eat such foods are fully aware of what they are consuming. This should be augmented by an education drive to inform the public that the actual or potential adverse impacts of consuming such foods are not known. As the review has shown, agricultural genetic engineering also poses the risk of acting as a means to control seed by private companies at the expense of poor traditional farmers especially in developing countries (Sarich, 2015; Shiva, 2016). The contribution of traditional farmers across the world towards the conservation of plant genetic resources over time and for future generations cannot be overemphasised. To this end, organisations such as the World Trade Organization's agreement on Trade-Related Intellectual Property Rights (TRIPS) and the International Treaty on Plant Genetic Resources for Food and Agriculture must take more robust measures to protect traditional farmers across the world from totally depending on unscrupulous private seed companies.

From the foregoing, it is clear that science can hardly declare any technology, no matter how important it may be to society, to be completely risk free to humans. Indeed, genetically engineered crops and livestock have the potential to immensely reduce food insecurity across the world compared to foods produced through conventional agriculture. As noted in the review, such novel foods have the potential to introduce adverse actual or potential, short-term or long-term food safety issues that must be addressed. Society, therefore, and particularly the scientific community, has a noble duty to decide when and where agricultural genetic engineering is safe enough, and to err on the side of caution in such important matters is much wiser.

References

1. Alarcón, D. and Bodouroglou, C. 2011. *Agricultural innovation for food security and environmental sustainability in the context of the recent economic crisis: Why a gender perspective?* United Nations Department of Economic and Social Affairs (UN-DESA). World Economic and Social Survey.
2. Bourne, J. 2015. The end of plenty: The race to feed a crowded world. Norton, New York.
3. Ehrlich, P. R. and Harte, J. 2015. Opinion: To feed the world in 2050 will require a global revolution. *PNAS 112(48): 14743-14744.*
4. Evenson, R.E. and Gollin, D. 2003. Assessing the impact of the green revolution: 1960– 2000. *Science, 300: 758-762.*
5. FAO. 2000. *FAO statement on biotechnology* (available at http://www.fao.org/biotech/state.asp; accessed April 2017).
6. FAO. 2002. *The state of food insecurity in the world 2001.* Food and Agriculture Organization, Rome.
7. FAO, 2003a. *Agricultural biotechnology: will it help?* Food and Agriculture Organisation, Rome.
8. FAO, 2003b. *Weighing the GMO arguments: for.* Food and Agriculture Organisation, Rome.
9. FAO, 2003c. *Animals: unexpected products*. Food and Agriculture Organisation, Rome.
10. FAO, 2003d. *Fish: the stakes are high*. Food and Agriculture Organisation, Rome.
11. FAO, 2003e. *Weighing the GMO arguments: against.* Food and Agriculture Organisation, Rome.
12. FAO, 2004. *Agricultural biotechnology: Meeting the needs of the poor?* The State of Food and Agriculture 2003-2004. Food and Agriculture Organisation, Rome.
13. FAO. 2009. *Investing in food security.* Food and Agriculture Organization of the United Nations. Rome.
14. FAO. 2010. *The state of food insecurity in the world 2010: Addressing food insecurity in protracted crises.* Food and Agriculture Organization of the United Nations. Rome.
15. FAO. 2011. *The state of food and agriculture 2010/2011: Women in agriculture - closing the gender gap for development*. Food and Agriculture Organization of the United Nations. Rome.

16. FAO, 2015. *Social protection and agriculture: breaking the cycle of rural poverty.* The State of Food and Agriculture, Food and Agriculture Organization of the United Nations. Rome.
17. FAO/WHO, 2000. Safety aspects of genetically modified foods of plant origin. Report of a joint FAO/WHO expert consultation on foods derived from biotechnology, Geneva, Switzerland, 29 May–2 June 2000 (available at ftp://ftp.fao.org/es/esn/food/gmreport.pdf; accessed June 2017).
18. Five Year Freeze, 2002. *Feeding or fooling the world? Can GM really feed the world?* (available at http://www.fveyearfreeze.org/Feed_Fool_World.pdf; accessed July 2017)
19. GM Science Review Panel, 2003. *GM Science Review: First report-an open review of the science relevant to GM crops and food based on the interests and concerns of the public.* London, Department of Trade and Industry, London.
20. ICSU, 2003. *New genetics, food and agriculture: scientific discoveries – societal dilemmas*. International Council for Science, Paris.
21. IFAD, 2013. *Smallholders, food security, and the environment.* International Fund for Agricultural Development, Rome.
22. Moschini, G., Lapan, H. & Sobolevsky, A. 2000. Roundup Ready® soybeans and welfare effects in the soybean complex. *Agribusiness, 16: 33-35.*
23. Qaim, M. and Traxler, G. 2004. Roundup ready soybeans in Argentina: farm level, environmental, and welfare effect. *Agr. Econ…*
24. Schmidhuber, J. and Tubiello, F.N. 2007. Global food security under climate change. *PNAS 104(50): 19703-19708.*
25. Sarich, C. 2015. *Supreme court of Philippines confirms genetically modified (gm) eggplant ban based on the 'precautionary principle'.* Natural Society.
26. Secretariat of the Convention on Biological Diversity. 1992. *Convention on Biological Diversity* (available at http://www.biodiv.org/convention/articles.asp; accessed March 2018).
27. Secretariat of the Convention on Biological Diversity. 2000. *Cartagena Protocol on Biosafety to the Convention on Biological Diversity: text and annexes*. Montreal, Canada.
27. Shiva, V. 2016. *The seeds of suicide: how Monsanto destroys farming*. Global Research.
28. Stone, G.D. 2002. Both sides now: fallacies in the genetic modification wars, implications for developing countries, and anthropological perspectives. *Curr. Anthropol. 43(4): 611-630.*
29. 30. WHO, 2002. *20 questions on genetically modified (GM) foods. World Health Organization.* (available at http://www.who.int/foodsafetypublications/biotech/en/20questions_en.pdf; accessed March 2018).