



Genetically Modified Foods for Sustainable Food Security: Debunking the Myths

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ABSTRACT

The world food production may not support the population that is growing at an exponential rate. Genetically modified crops and foods may therefore provide solutions for such shortcomings. However, uncertainties and myths such as the socio-economic impact of genetically modified foods on humans, the environmental and health risks may impede the use of these foods and instil fear among the public. Contrarily, it was learned that genetically modified crops and foods were generally deliver a positive outlook as they improved the socio-economic qualities in the farmers of third world countries. Besides, it was also noted that the genetically modified crops and foods impose a minimal adverse effect on the environment and human health while more benefits were attested. As genetically modified crops and foods seem to be more advantageous to humanity in general, long-term studies and meta-analyses are still required to ascertain the safety of these genetically modified organisms as staple foods.

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1. INTRODUCTION

At present, the world population is growing at an exponential rate and documenting 7.9 billion inhabitants. However, 13% of the populations were undernourished, most linked to micronutrient deficiency [1]. With the ongoing trends, thus, by the year 2050, the world population would be expected to reach 9 billion, and there would be severe food scarcity. This may succumb to a more significant challenge to address world hunger problems and ensure food security for all the inhabitants of the Earth. Furthermore, conventional crops are often susceptible to diseases and have a lower production rate. Thus, scientists and world leaders have proposed using genetically modified (GM) crops that possess many advantages over conventional crops to eradicate such shortcomings. Some of the advantages of GM crops are with the boosted yields, minimising the need for pesticides and herbicides, and providing economic advantages to both big and small-scale farmers [2]. However, GM crops and foods' perceived danger

is still in continuous debate, especially concerning their safety and ethical issues. The consumers are mainly worried about transgenic crops' long-term implications on human health, including antibiotic resistance, allergenicity, and toxicity.

The anxiety towards GM crops and foods were mainly perceived due to the unpleasant ideas associated with such technologies and lacking evidence to disregard such baseless allegations towards GMOs. For instance, the widespread negative view on GM foods in Europe was mainly perceived due to the bovine spongiform encephalopathy (BSE) crisis (also known as mad cow disease) in the late 1980s and 1990s. The public was convinced that GMOs may be utilised to hide the impacts of inadequate animal housing [3]. In Asia, on the other hand, GM crops are least popular due to the concerns involving the usage of animal DNA that elicit solid emotions for religious and dietary reasons. Besides, due to the fact that many Asian producers and farmers operate on a small-scale, there is additional worry about who should benefit from such advantage

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[4]. Contrarily, in Africa, GMOs and GM crops are widely accepted by policymakers and scientists. It was generally accepted that GMOs have enormous potential to tackle both nations and agricultural challenges in Africa. However, the absence of an acceptable legal framework, insufficiently qualified workers, weak institutions, and inadequately equipped laboratories, among other factors, pose a considerable barrier to adopting GM technology in this region [5].

Therefore, this review article is intended to shed light and debunk the myths on the unending controversies revolving around GM crops and foods, especially in addressing the potential risks it may pose to human health and the environment. Besides, this article also reviews the impact of seed-producing industries on small-scale farmers' socio-economic which often not discussed widely in many reviews.

2. GENETICALLY MODIFIED ORGANISM (GMO)

Plants and animals whose genomes were genetically manipulated in the laboratory are known as genetically modified organisms (GMO). The definition provided by the World Health Organisation (WHO) is: "Organisms (e.g. plants, animals or microorganisms) in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and natural recombination" [6]. Hence, these organisms' trade value was usually improved via recombinant DNA technology. Therefore, they are exploited for desired biological derivatives at the downstream applications or catered to produce genetically modified (GM) foods.

Though the "modern biotechnology" and genetic engineering techniques were employed to create GMOs and GM foods, selective breeding has been the renowned method applied by the traditional farmers to create the farming animals and crops of desired quality conventionally in the past [7]. The first proof of concept in developing GMOs was shown by Cohen *et al.*, (1973), who developed the DNA recombinant technology with the construction of biologically functional bacterial plasmid [8]. This spurred the engineering of the first GMOs, the antibiotic-resistant tobacco and petunias in 1983 [9]–[11], while the first GM food authorized for commercialization was the tomato Flavr Savr™ in 1994 [12]. Flavr Savr™ tomato was engineered to suppress the polygalacturonase (*PG*) gene; the translated enzyme that makes the fruit squishy as it dissolves the fruits' cell wall pectin (Figure 1). Downregulation of *PG* has thus, delayed ripening in the Flavr Savr™ tomatoes (Figure 2) [13]. Today, as more sophistications were added to experimental techniques and the discovery of new technologies in gene cloning, many GM crops and foods were made available in the market [14]. Some of the GM crops approved by the Food and Drug Administration (FDA) for sale to the public include alfalfa (*Medicago sativa*), apple (*Malus x Domestica*), Argentine canola (*Brassica napus*), cotton (*Gossypium hirsutum L.*), maize (*Zea mays L.*), potato (*Solanum tuberosum L.*), rice (*Oryza sativa L.*), soybean (*Glycine max L.*), and Tomato (*Lycopersicon esculentum*) [15]. To-date, there are as many 42 countries have engaged in research and development of GM crops (Table 1) [15].

3. GMO AND THE FOOD SECURITY

As the world population is rapidly expanding with the turn of the 21st century, there is an utmost need to cater a sustainable food production and improve the supply chain to feed human-

kind. Therefore, food security implies that humans must have physical and financial access to nutritious and safe foods that can meet their dietary requirements and for social well-being [16]. Thus, the GM crops could significantly increase world food productions and improve the food supply globally. This is especially relevant with the generated robust GM crops to both biotic and abiotic stresses, hence, enabling less agricultural loss due to natural calamities such as climate change or land and water scarcity. For instance, climate change and drought had significantly impacted crop plant productivity across the world and in China. Hence, development of Green super rice (GSR) in China had enabled this variant to withstand prolonged drought, resistant to disease, and resistant to pest. Figure 3 shown the methods and genes used to develop the GSR [17]. Development of GSR improves the plant growth with high water-use efficiency (WUE); thus, permitting continuous food supply to peoples in China [18].

Even though GM plants and foods can safeguard sustainable food supply to the world, scepticisms are still perceived. In 2012, approximately 170 million ha (12% worldwide arable land) were planted with GM crops; however, these crops were not explicitly catered for food [19]. This is mainly due to a lack of public acceptance and fear towards GM crops and foods. With the shortage of world food supply and increasing agricultural commodity prices, farmers of the emerging nations are mostly affected. Therefore, government authorities and other relevant stakeholders must step forward to play prominent roles in ensuring the safety of GM foods and remove the fear in the public [19].

Secondly, GM crops and foods could have direct implications on food safety and quality. This is mainly due to the crops with new traits, or enhanced quality being often perceived as food safety risks. However, long-term research confirmed that GM crops were not fundamentally riskier when compared to conventionally bred plants. Conventional breeders often use insecticides, fungicides, herbicides, and rodenticides to protect their crops against pests. The use of such pesticides was proven to directly impact humans, the environment and other non-targeted organisms [20]. Though there was a possibility for the augmented intrinsic effects (antibiotic resistance, allergenicity, and toxicity) with the consumption of GM crops, the severity of developing cancer or tumour were not reported till-to-date; on the other hand, pesticides exposure may contribute to the cancer development [21]. On top of that, the GM technology could help to develop foods with improved micro-and macronutrients, such as rice with enhanced vitamin A. This may help to reduce the problem of vitamin A deficiency in the public which has seen as one of the major concerns with affected 250 million school children worldwide [22]. Deficiency in vitamin A may result in visual and ocular breakdowns such as xerophthalmia and night blindness [23], diminished immune system [24], and respiratory infections [25]. As such, the engineering of Golden Rice-1 and Golden Rice-2, which contain up to 1.6 - 35 μg β -carotene per gram of dry rice, may serve as a cost-effective staple food to remediate the population deficient in vitamin A [26].

Thirdly, the socio-economic status of the small-scale farmers from developing countries could be improved with the cultivation of more GM crops [19]. For instance, the *Bacillus thuringiensis* (*Bt*) cotton, grown widely in countries such as Pakistan, India, China, Malaysia, and other developing nations,

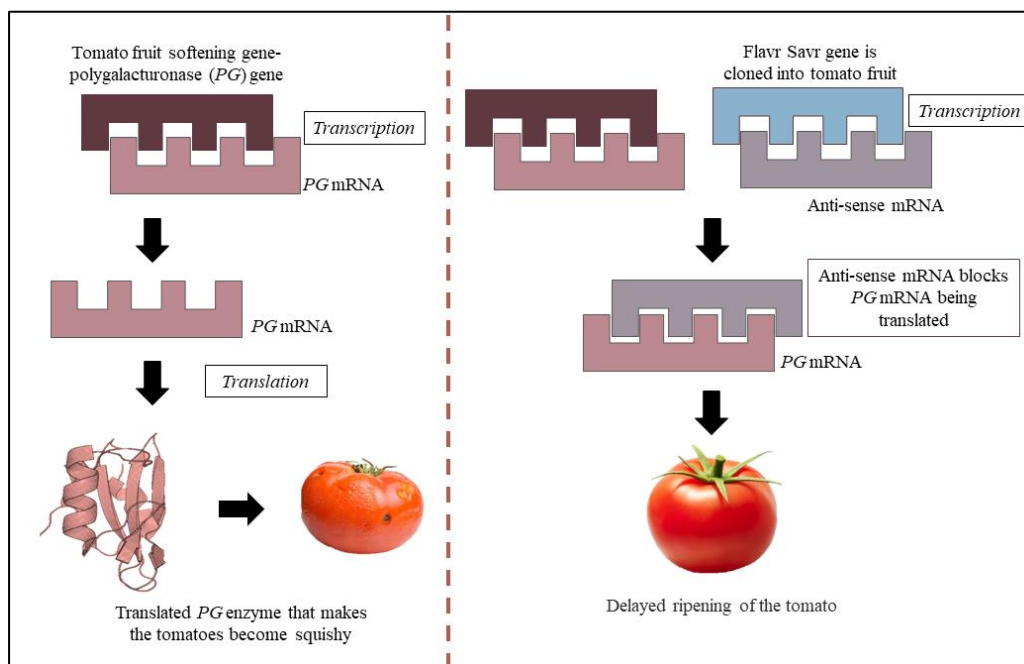


Fig. 1. Flavr SavrTM tomato genetically engineered to delay the ripening.

may partake in resistance against insects and pests. As such, the cultivation of *Bt* cotton have directly benefitted 15 million smallholders with the reduced use of chemical pesticides and increased yield of *Bt* cotton has directly improved the living standard of these farmers [27].

4. SOCIO-ECONOMIC IMPACT OF GM FOODS

While the potential threat of GM foods to the public could be intrinsic, the socio-economic impact on society cannot be neglected. Economically, the GMO technology may contribute to increased crop yield while reducing the cost for agriculture management, including the reduced cost of pesticide usage, reduced labour cost, and reduced medical cost due to the consumption of nutritious GM foods and living a healthy life. A study conducted by Klümper and Qaim (2014) stated that GM crops planted in 19 countries had generated a profit of 69% for the farmers with a 21.5% increased crop yield while decreasing the usage of insecticides cost by 39% [28]. Such events may benefit the small-scale farmers and farmers from the developing countries, especially as this can relieve them from financial burdens acquired from the agricultural activities. Besides, GMOs also may improve farmers socio-economic status as they are fed well, living a healthy life, and improved financially from increase sales of crops. This may fund their children to obtain good education.

The profit acquired through the yield and the sale of GM crops can succumb to colossal social implications. However, GM crops' challenges and risks were not thoroughly addressed previously, especially with the extrinsic factors. For instants, the involvement of multinational corporates (MNCs) and seed-producing industries had started to monopoly the technologies related to GM crops. As a result, the GM crops which were intended to overcome world hunger and malnutrition may instead worsen the situation due to the involvement of these MNCs that are running for profits. Monsanto company which was an American agrochemical and agricultural biotechnology corporation, for example, is a seed-producing MNC known for acquiring bad business ethics when it comes to GMO technolo-

gies and their related machinery. With the corporate power, Monsanto can move into any marketplace with new products, purchase technologies through corporate acquisitions, manoeuvring favours from government policymakers and be capable of bending laws for their benefit [29]–[31]. Monsanto had prosecuted many poor farmers for breaching contracts and sued individuals and other small corporations for patent infringement [29]. Such acts had restricted the conventional practice of seed selection, saving, and sharing among the farmers. Besides, it gave the seed-producing MNCs autocratic rights to criminalise the farmers for accidental violation of agreements. These MNCs usually patented the genetically modified crops and their seeds. With 78% of countries reported child malnutrition, these MNCs in the developing countries were exporting foods to other nations around the globe. This explains the "paradox of plenty", that is, the seed-producing MNCs exploiting the third world countries to gain profits but failed to feed the hunger or eradicate the malnutrition among the poor farmers [29], [32]. Such abuses must be curbed with policies and regulations to protects the small-scale cultivators and breeders.

Finally, there exist an ethical issue on the 'playing God' regarding GMOs and GM foods. The religious group from multiple faiths was against GM crops as they believe it is unethical to tamper with nature despite its benefit. Till-to-date, it is an enduring dispute. However, a clear definition and explanation for GMOs and GM foods should be made available by the authority concern and government bodies to safeguard trust in consumers, especially when it comes to ethical concerns.

5. ENVIRONMENTAL RISK OF GM FOODS

The environmental risks anticipated with GM foods were the indirect transmission of genes across organisms during the feeding of GM foods, thus creating a harmful effect on the environment and its ecosystems. The transmission of a gene may also occur through the distribution of pollen from the GM crops to the environment. Hence, the selective pressure could create organisms

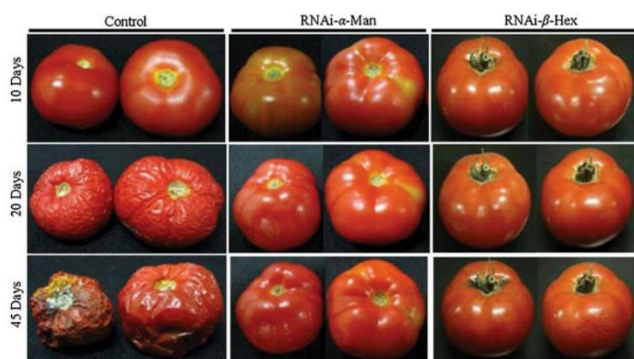


Fig. 2. The suppression of N-glycoprotein modifying enzymes, α -mannosidase (α -Man) and β -D-N-acetylhexosaminidase (β -Hex) were shown to enhance tomato's shelf life and reduce the rate of softening.

The figure was adopted from Meli *et al.*, (2010) [13]

that potentially possess resistance to the pesticide, making the pest hard to kill.

The notable biological pesticide designed using recombinant technology is the *Bt* genes to protect genetically modified plants against insects. Two of the significant genes used to create transgenic *Bt* plants are the crystal delta-endotoxins (*cry*) and the vegetative insecticidal proteins (*Vip*) [33]. While these two genes serve by killing the targeted insects that feed the *Bt* engineered plants, the endotoxicity activity was anticipated to affect the non-targeted pests indirectly. Thus, the non-targeted pests may be acquiring resistance against the biological insecticides (*Bt* genes) when subjected to selective pressures [34]. For instance, the gene flow from the *Bt* plants to the closely related species, weeds, or even the wild type plants were predicted to create new traits and gave rise to the superweeds [35]. These superweeds may tend to disrupt the ecosystem and spoil the nearby traditional crops.

However, research outcomes had shown that there was no direct toxicology effect of the *Bt* plant against other non-targeted organisms [36], [37]. Thus, the use of such biological control against pests was proven to be safer and possess the least harm compared to the use of chemical insecticides. Chilcutt and Tabashnik (2014) reported that the gene flow from the *Bt* maize pollen to kernels of non-*Bt* maize plants is evident with low to moderate *Bt* toxins [38]. Furthermore, the gene transfer study between the transgenic potato and non-target aphids affirmed that the gene transmission occurs only in the first generation of aphids but does not evident to the subsequent generations [39]. Hence, this dismisses the allegation that the GM plants contribute to the pest-resistant in the non-targeted organisms (pests).

6. HEALTH RISK OF GM FOOD

The most promising feature of GM foods is that they elevate the nutritional content of a food. In many developing nations worldwide, people rely solely on a single crop plant to obtain their nutritional requirements. With GM food technologies, crop plants that possess additional nutrients were made possible. For instants, the "Golden Rice Project" was an effort made to annihilate malnutrition in many developing countries. Through genetic modifications, certain metabolic activities were introduced into the endosperm of the rice grains.

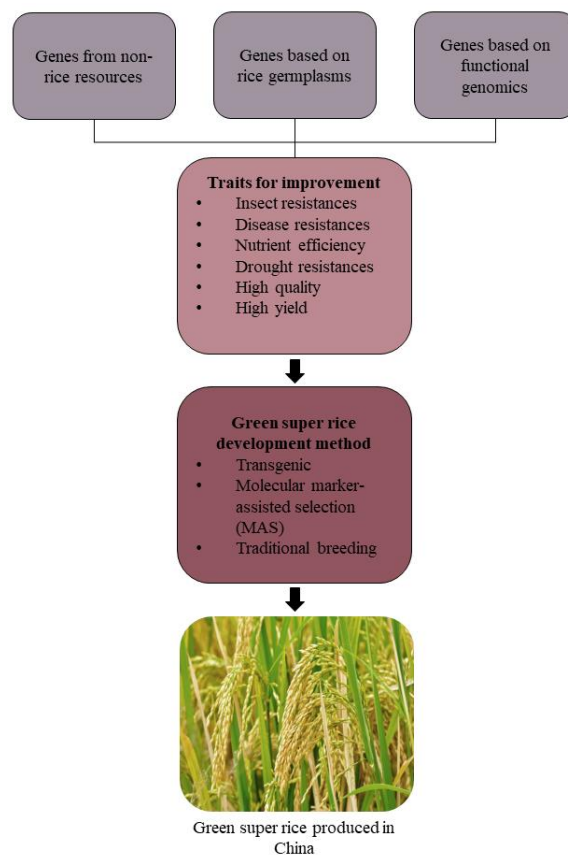


Fig. 3. Development of Green super rice (GSC) and the methods utilized to develop GSC.

This induced the synthesis of β -carotene that are usually not found in these grains. By consuming the "Golden Rice", humans would be able to synthesize vitamin A from their precursors, the β -carotene [14]. Another health benefit of GM food technology was in the production of plant-based vaccines. Plant-based vaccines lessen the possible side effects of injectable vaccines in humans. Plant-based vaccines were produced using potatoes and corns, where the crop plants were genetically modified to express the enterotoxigenic *Escherichia coli* (ETEC) toxin, known as the LT-B. This vaccine stimulates the immune response against the glycolipids of the plant cell membrane with the LT-B, without any possible side effects [40].

GM foods, however, may still have adverse effects on human health. These foods can cause pleiotropic effects. The transgenes in GM foods mainly encode for an enzyme that alters specific biochemical pathways. The presence of a new enzyme in the body may lead to depletion of its substrates, the accumulation of its products, and fluctuations in the levels of some biochemical compounds. These may not be tolerated and subsequently leads to the build-up of toxins in the body. Certain secondary metabolites from these plant sources can also be toxic to humans, like the steroidal glycoalkaloids in a green potato skin. This compound causes gastrointestinal discomfort in humans at high concentrations [7], [41].

7. CONCLUSION

GM crops and foods have many benefits to the environment and human health in general, while their impact on the socio-economic aspect cannot be denied. This is especially in impro-

Table 1. Countries approved GM crops for research and developed

No	Country	Bt crops	Total no. GM crop events
1	Argentina	Alfalfa, Maize, Potato, Soybean	78
2	Australia	Alfalfa, Argentine Canola, Carnation, Cotton, Maize, Potato, Rice, Rose, Safflower, Soybean, Sugar Beet, Wheat	140
3	Bangladesh	Eggplant	1
4	Bolivia	Soybean	1
5	Brazil	Bean, Cotton, Eucalyptus, Maize, Soybean, Sugarcane	111
6	Burkina Faso	Cotton	1
7	Canada	Alfalfa, Apple, Argentine Canola, Cotton, Flax, Maize, Papaya, Pineapple, Polish canola, Potato, Rice, Soybean, Squash, Sugar Beet, Sugarcane, Tomato	191
8	Chile	Argentine Canola, Maize, Soybean	3
9	China	Argentine Canola, Cotton, Maize, Papaya, Petunia, Poplar, Rice, Soybean, Sugar Beet, Sweet pepper, Tomato	77
10	Colombia	Carnation, Cotton, Flax, Maize, Rice, Rose, Soybean, Sugar Beet, Wheat	108
11	Costa Rica	Cotton, Maize, Soybean	20
12	Cuba	Maize	1
13	Egypt	Maize	1
14	eSwatini	Cotton	2
15	Ethiopia	Cotton	2
16	European Union	Argentine Canola, Carnation, Cotton, Maize, Potato, Soybean, Sugar Beet, Tobacco	109
17	Honduras	Maize, Rice	8
18	India	Cotton, Soybean	11
19	Indonesia	Maize, Potato, Soybean, Sugarcane	22
20	Iran	Maize, Rice, Soybean	18
21	Japan	Alfalfa, Argentine Canola, Carnation, Cotton, Maize, Papaya, Potato, Rose, Soybean, Sugar Beet	196
22	Malaysia	Argentine Canola, Carnation, Cotton, Maize, Potato, Soybean	44
23	Mexico	Alfalfa, Argentine Canola, Cotton, Maize, Potato, Rice, Soybean, Sugar Beet, Tomato	188
24	Myanmar	Cotton	1
25	New Zealand	Alfalfa, Argentine Canola, Cotton, Maize, Potato, Rice, Soybean, Sugar Beet, Wheat	113
26	Nigeria	Cotton, Cowpea, Maize, Soybean	28
27	Norway	Carnation,	11
28	Pakistan	Cotton, Maize	6
29	Panama	Maize	1
30	Paraguay	Cotton, Maize, Soybean	22
31	Philippines	Alfalfa, Argentine Canola, Cotton, Eggplant, Maize, Potato, Rice, Soybean, Sugar Beet	129
32	Russia	Maize, Potato, Rice, Soybean, Sugar Beet	28
33	Singapore	Alfalfa, Argentine Canola, Cotton, Maize, Soybean, Sugar Beet,	38
34	South Africa	Argentine Canola, Cotton, Maize, Rice, Soybean,	72
35	South Korea	Alfalfa, Argentine Canola, Cotton, Maize, Potato, Soybean, Sugar Beet	170
36	Sudan	Cotton	1
37	Switzerland	Maize, Soybean	4
38	Taiwan	Argentine Canola, Cotton, Maize, Soybean, Sugar Beet	150
39	Thailand	Maize, Soybean	15
40	Turkey	Maize, Soybean	30
41	United States	Alfalfa, Apple, Argentine Canola, Chicory, Cotton, Creeping Bentgrass, Flax, Maize, Molon, Papaya, Petunia, Pineapple, Plum Potato, Rice, Rose, Soybean, Squash, Sugar Beet, Sugarcane, Tobacco, Tomato, Wheat	211
41	Uruguay	Maize, Soybean	17
41	Vietnam	Maize, Soybean	22
42	Zambia	Maize	6

ving the livelihood of small-scale farmers of the developing nations. However, there are some concerns about GM foods' side effects to humans and nature. When GM crops are used to improve the sustainability and quality of foods, and contribute to a cleaner environment, they benefit humanity. They may result in an enhanced economy without causing more damage than good. Moreover, GM crops also maximise their potential to relieve hunger and illness globally if employed carefully. However, the full potential of GM crops cannot be exploited without exercising due diligence and paying close attention to the hazards connected with them. A meta-analysis on GM crops' potential risks needs to be continuously assessed. Additional research is required to determine the indirect effects of GM crops, which may include economic consequences, environmental and health consequences. Therefore, the outcomes from such assessments must be transparently communicated to all stakeholders. On the other hand, the monopoly of seed-producing MNCs on GM crops must be regulated with proper laws and policies. Small-scale farmers and breeders must be protected from being exploited by seed-producing MNCs.

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