Crimson Publishers
Wings to the Research

Review Article

GMOS: The Past & The Future

Claudine Chegini* and Andrew Schmitz

Department of Food and Resource Economics, University of Florida, USA

***Corresponding author:** Claudine Chegini, Department of Food and Resource Economics, University of Florida, USA

Submission: March 12, 2021

Published: March 26, 2021

Volume 2 - Issue5

How to cite this article: Claudine Chegini, Andrew Schmitz. GMOS: The Past & The Future. J Biotech Biores. 2(5). JBB. 000547. 2021.

Introduction Background and Development of GMOs

Since the development of GMO technology in the 1990s, the introduction of GM products into the market has resulted in scientific, economic, and societal debate. Despite potential benefits towards food security, crop production (first generation GMOs), food quality (second generation GMOs), and pharmaceutical applications (third generation GMOs), opponents argue that long-term environmental and health side effects of GMO use are still largely unknown. This article offers a survey over the broad scope of the economics surrounding GMO use and the implementation of agricultural biotechnology.

First generation GM crop traits are agronomic qualities such as pest resistance and herbicide tolerance. More than 50% of current field trials are second generation traits which enhance product quality and stress tolerance. Third generation GM crops, which are engineered to produce pharmaceutical products such as vaccines, antibodies, or proteins, are less widely used and many are still in developmental stages. Here we focus mainly on first and second generation GM crops that are intended for use as food and feed. GM crops that are used for fiber, such as Bt Cotton, have a different supply and demand structure and should be considered a separate class of GM agricultural products.

GM technology stands to provide increased benefits to producers through multiple channels. Furthermore, the advantages that GM technology offers to establishing increased food security are unparalleled by conventional breeding methods. However, global consumer and therefore policymaker response to GM technology has been prolific and widely varied. Many of the concerns regarding first and second generation GMOs center on environmental issues. Some of these arguments raise the potential for cross pollination of GM and non-GM crops, resulting in the transfer of GM genes into wild populations. Cross pollination of GM and non-GM crops can also result in the persistence of the gene after a GMO has been harvested, the susceptibility of non-target organisms to the gene product, the instability of new genes, the reduction of the spectrum of other plants, a significant loss of biodiversity, and an increase in the use of chemicals in agriculture [1]. Additionally, the mixing of GM crops with those derived from conventional seeds could have an indirect negative effect on food safety and food security. The main concerns for human health have been the possibility of a transfer of allergens into foods, or the gene transfer from GM foods to human cells or to bacteria in the gastrointestinal tract. The same debate also occurs at the societal level. Without a consensus of approval by society, GM food crops struggle in the marketplace as consumer attitudes with respect to genetically modified foods differ widely, particularly between North America and Europe.

Lakkakula P et al. [2] dispel a few common misconceptions surrounding the use of GM technology. They present the overall health and environmental safety of GM technology in the context of global food security. Their findings support those of others that the implementation of different types of GM crop technology are not only safe for human consumption and decrease pesticide and herbicide inputs but can increase farmer profit by up to 68% while simultaneously reducing food insecurity. Also, mandatory labeling would have a negative impact on certain consumers through increased food costs. Indeed, because GMO labeling necessitates separate supply chains for GM and non-GM food, any additional production costs are passed on to the consumer in the form of higher prices.

The Magnitude of GM and Biotech Production

While relatively few GM crops are planted in the United States, those crops make up a large percentage of crops planted. These crops include corn, soybeans, canola, sugar beets, and cotton. From a world perspective, while overall adoption of biotech crops slightly declined, the adoption rate of the top five biotech growing countries (United States, Brazil, Argentina, Canada, India) reached close to 100%. In 2018, 20 countries planted GM crops and an additional 42 countries imported those crops. Furthermore, economic gains from biotech crops cumulatively reached US$225 billion from 1996 to 2018 [3].

Table 1 gives a breakdown of hectares planted to biotech crops globally in 2019. Biotech cotton, corn, soybeans, and canola are still the top biotech crops planted in the United States and globally. The diversity of biotech crops has expanded over the past ten years to include summer squash, papaya, apples, alfalfa, sugar beets, eggplant, safflower, potatoes, and pineapple. The United States leads in both area planted to biotech crops and in biotech crop diversity. This is partly because other countries are slower to approve new biotech crops. However, major crops such as wheat and rice are not currently GM crops. On a global scale there is increasing public and private research in development of new varieties of biotech rice, bananas, chickpeas, wheat, pigeon peas, and mustard [3].

Table 1: Global area of biotech crops in 2019.

Country	Area (Hectares)	Biotech Crops
United States	71.5	Maize, soybeans, cotton, alfalfa, canola, sugar beets, potatoes, papaya, squash, apples
Brazil	52.8	Soybeans, maize, cotton, sugarcane
Argentina	24	Soybeans, maize, cotton, alfalfa
Canada	12.5	Canola, soybeans, maize, sugar beets, alfalfa, potatoes
India	11.9	Cotton
Paraguay	4.1	Soybeans, maize, cotton
China	3.2	Cotton, papaya
South Africa	2.7	Maize, soybeans, cotton
Pakistan	2.5	Cotton
Bolivia	1.4	Soybeans
Uruguay	1.2	Soybeans, maize
Philippines	0.9	Maize
Australia	0.6	Cotton, Canola, Safflower
Myanmar	0.3	Cotton
Sudan	0.2	Cotton
Mexico	0.2	Cotton
Spain	0.1	Maize
Colombia	0.1	Maize, cotton
Vietnam	0.1	Maize
Honduras	<0.1	Maize
Chile	<0.1	Maize, Canola
Malawi	<0.1	Cotton
Portugal	<0.1	Maize
Indonesia	<0.1	Sugarcane
Bangladesh	<0.1	Brinjal (eggplant)
Nigeria	<0.1	Cotton
Eswatini	<0.1	Cotton
Ethiopia	<0.1	Cotton
Costa Rica	<0.1	Cotton, pineapple

Data Source: ISAAA 2019.

We focus on oats, potatoes, and peanuts in the United States to exemplify a range of problems that arise with the creation, adoption, and proliferation of biotech crops. Creating new GE and GM varieties requires significant research and development expenditure that sometimes cannot be justified by the potential returns. Such is the case with oats, especially as large manufacturers, such as General Mills, move towards a "non-GMO" marketing technique. Mitchell D [4] quotes Ron Barnett, oat breeder and professor emeritus of agronomy at the University of Florida, in saying "there's no money and no desire" for research into creating a biotech oat variety as there is not enough demand for such a product. The non-existence of a GM or GE oat variety presents a contrast between certain brands of oats and their respective marketing and labeling techniques with regard to non-GMO labeling. For example, Quaker Oats is owned by parent company PepsiCo that has a global market presence. Quaker Oats, along with other PepsiCo owned brands such as Tropicana and Naked Juice, carries a voluntary Non-GMO Project Certified label in the United States. Conversely, the majority of generic or supermarket brands in the United States tend not to carry any such labels. Notable exceptions are the Whole Foods 365 and the Publix Greenwise brands that are either non-GMO Project certified or have a USDA Organic certification, which requires products to be non-GMO. Companies that choose not to label their generic brands, even if the product is inherently non-GMO, such as with oats or orange juice, likely choose not to do so because of added costs associated with labeling and product segregation. Furthermore, local and regionally based generic supermarket brands are not held to the same consumer standards as those brands produced by multinational companies with high market visibility such as PepsiCo or General Mills. As Bjorn Bernemann, vice president and manager for the Tropicana brand in North America, stated to the New York Times [5] "consumers today have a desire and transparency from brands, and that desire is only going to increase....Some consumers...are expressing a desire to get beyond what brands are actually telling them, and we felt having external verification would give our consumers assurance."

As Dr. Jordan D [6], an extension peanut specialist at NC State, explains, peanuts present a slightly different case in which investments have been made in creating varieties that are resistant to some fungi and viruses. However, these varieties are not currently in use due to their non-marketability and will "not be used as long as the industry perceives that the markets could be lost because people fear or have a philosophy against this approach." Jordan goes on to say that the "peanut industry as a whole is trying to capture more markets around the world, including Europe. For that reason and knowing the mixed feelings about GMOs by the general public and the possible loss of potential markets, the industry has decided not to go in the GMO direction."

Multiple GM cultivars of potatoes have been created, tested, and brought to market over the past two decades. The Monsanto New Leaf potato was introduced in 1995 and was rapidly adopted and planted acres increased to 50,000 by 1999. However, this initial popularity was short lived due to the concurrent increase in consumer concerns surrounding GM food products. At the time, techniques for testing and segregating GM and non-GM potatoes were not well developed and rather than seeing increased profits, potato processors were being forced to change market channels due to consumer preference. As such, in 2001 Monsanto stopped producing New Leaf potato seeds [7]. BASF's amflora potato that was created specifically for industrial production of potato starch went much the same way due to opposition to the GM product in the European Union [8]. Simplot's Innate line of potato varieties approved by the USDA in 2014 has faced a similar demise in the United States. Designed to resist bruising, browning, and to contain less of the amino acid asparagine that forms a carcinogen acrylamide at high temperature cooking, Innate potatoes present a possible health benefit when used instead of conventionally grown potatoes. However, although Simplot is a major supplier for McDonalds, the company has no intentions of purchasing a GM potato due to consumer concerns over GM and GE technology [9]. This is perhaps a reason why some fast food chains have shifted from the use of GMO to non-GMO potatoes.

The African Case/Developing Countries/Food Security

Until very recently, Africa's use of GM technology has been intertwined with the strict regulations put in place by the European Union. As a major export market for many African countries, EU consumer demand for non-GMO agricultural products has greatly deterred the implementation of GM crops in Africa since the late 1990s. Historically, African leaders and regulatory boards have been hesitant to approve first and second generation GM food products for human consumption. Part of this hesitancy is derived from the Precautionary Principle perspective of their European trading partners. However, some would argue that the situation is more complex. Rock J et al. [10] suggest that the ultimate adoption of GM crops on the African continent will depend upon a complex interaction between domestic, foreign, social, economic, political, and scientific factors. Especially relevant is the participation of multinationals, public private partnerships, and foreign aid.

"To wit, external donors must be relied upon to supply monies for projects that often take upwards of 8 to 10 years; biotechnology companies must agree to share their proprietary technologies and see their engagement in African biotechnology projects as being in their interests; legal frameworks that satisfy the owners of gene technologies have to be established; relationships among organizations with different motives, agendas, organizational cultures, and degrees of power have to be built and maintained over long periods; external partners (aid agencies, philanthropic foundations, and multinational firms) must remain satisfied that their resources are not being wasted; public support must be cultivated; activist and public opposition must be kept at bay; concerns about encroachments on sovereignty must be overcome; the GM crop varieties that are produced must be affordable and profitable for farmers; and farmers and sellers must see them as attractive. Seldom is this complex choreography successfully achieved" [10].

However, Asian trading partners such as India have recently begun to eclipse the European Union as a trading partner for the African continent [3]. Furthermore, with recent increases in intra-African trade and the approval of GM cowpea in Nigeria, many African countries are initiating field trials of other GM crops such as bananas and cassava. With trading partners more willing to accept GM products and a gradual shift of consumer and policymaker attitudes towards GMOs, the African continent as a whole may begin to implement the use of more GM technology. Small farmers in African countries provide a large share of domestically consumed food. A recent interview by Cornell scholars [11] spoke directly with Zambian farmers recently affected by climate related crop loss. Due to recent struggles to produce crops under current conditions, many of these small-scale farmers are also beginning to recognize the importance of GM crop technology in the future of food security for the African continent. Notably, Uganda has begun field trials for a GM banana. Indeed, as Lakkakula P et al. [2] state, with decreasing natural resources, methods for increasing agricultural productivity will help ensure food security.

Lakkakula P et al. [2] find that the introduction of a GM rice variety that increases global yield by 5% could result in a consumer gain of US$23.4 billion to US$74.8 billion but could also result in a producer loss of US$9.7 billion to US$63.7 billion. The estimated net gain to society could be US$11.1 billion to US$13.7 billion. Overall, they find a positive economic surplus for major exporters and importers of rice based on a 5% supply increase with a GM rice variety. Additionally, the adoption of transgenic or GM rice varieties would have a far greater impact on rice prices for poorer counties than for richer countries. Therefore, GM rice may help ensure that more people throughout the world would have food security. Furthermore, GM crops need not be directly for food or feed in order to have a positive impact on general food security. This is evidenced by Qaim M et al. [12] who show that increased crop yields from the adoption of Bt cotton increases farm household income and thereby indirectly reduces food insecurity by almost 20%. When considering public investment in parts of Africa, the focus appears to be away from basic food crops, such as cassava. Moss C et al. [13] calculate that the rate of return to R&D in cassava cultivation in Uganda in general (both GMO and non-GMO) is extremely high. They find that expanding the supply of cassava in Uganda with investments directed towards increasing production (such as expanding the use of GM cassava) results in gains to both consumers and producers. However, when cassava is used for ethanol, the supply becomes split and returns to R&D are greatly diminished due to reduced consumer surplus.

The Economics of Assessing GMOs

In assessing the economics of GMOs, we use a simplified version of the framework given in Schmitz A et al. [14]. Four cases are considered here to demonstrate the complexities of supply and demand for GM and non-GM food products. Much research on the returns to GM crop adoption focuses on potential gains to society. Often neglected are potential market risks, the complex dynamics of producer profitability, and the effect of consumer preference for GM or non-GM on the demand schedule for a certain product. For example, producer profitability depends on many factors, including the savings on overall inputs from GMO adoption and the impact of commodity prices that depend on consumer acceptability [14].

Additionally, for almost all GM varieties, there still exist varying numbers of non-GM producers. When consumers differentiate between a GM and non-GM product, which is often the case, this producer duality results in one group bearing the cost of market segmentation. In some instances, differentiating the GM and non-GM product results in additional gains for the producer group that receives the higher price. However, this is not always the case. Indeed, for some GM products, not only is there an excess supply of the non-GM counterpart to satisfy consumer demand, but often no significant price premium is paid. Ultimately, because there are few instances in which consumers view a GM food product as a perfect substitute for the same conventionally produced non-GM item, the continuing adoption of agricultural biotechnology will depend critically on consumer perception [14].

To measure the aggregate welfare, change from GM adoption, Schmitz A et al. [15] consider the segmented market for GM products. Because some consumers may differentiate between GM or non-GM products, and are willing to pay accordingly, aggregate welfare change must consider the change in producer and consumer surplus for GM and non-GM channels separately. Additional segregation costs and changes to government support payments due to GM implementation also affect the net gains to society.

Supply increases with no change to demand

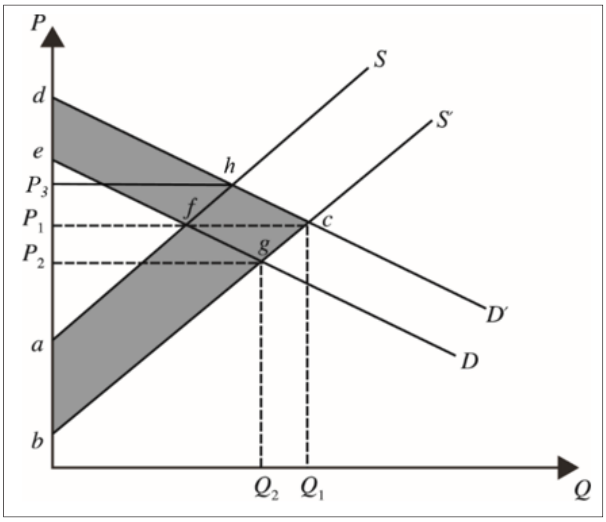

Figure 1: Gains from GMOs.

If consumers consider the GM product to be identical to its non-GM counterpart, then the two products will be perfect substitutes for each other. In Figure 1, suppose an increase in efficiency from the introduction of the GM crop shifts the supply schedule from S to S'. If there is no change in the demand schedule, then producers gain (P2bg-P1af) and consumers gain (eP2g-eP1f) for a net gain to societal welfare of (abgf).

Demand increases with no change to supply

Consider the case where consumers consider the GM product to be superior to its non-GM counterpart, but supply remains unchanged. Demand shifts from D to D' and S remains unchanged. This might be the case for a GM trait that provides nutritional or taste benefits to the consumer rather than increasing producer efficiency through improving yields or providing pesticide/herbicide resistance. In this scenario, consumer surplus increases by (dP3h-eP1f) and producer surplus increases by (P3P1fh). However, segregation costs will be incurred to GM producers in order to maintain separate market channels to receive higher prices from consumers who view the GM product to be more favorable. Therefore, overall net gains are slightly limited when compared to the first scenario.

Outward shift in supply is offset by decreased demand

Suppose that consumers consider the GM product to be in some way inferior to the conventionally produced product so that an outward shift in the supply schedule is offset by an inward shift of demand. In this case, non-GM products may sell at a higher price than the GM product or there may be zero demand for the GM product. Consumer preference for the non-GM product will incur segregation costs to non-GM producers who will maintain separate market channels in order to receive a higher price. If segregation costs equally offset increased prices, then non-GM producers lose. If there remains a market for the GM product, it is still possible to society to gain on net from the introduction of the GM product, but gains will be significantly smaller than in the first scenario.

Supply and demand both increase

Now suppose that the introduction of a GM product causes supply to shift from S to S' and demand to shift from D to D'. In this case, the adoption of the GM crop creates increased efficiency for producers and consumers who consider the GM product to be superior. This case results in large potential gains to society with a net gain of the area (abcf + defc).

While not discussed in the above model, the adoption of GMOs can affect international trade and the welfare of importers and exporters [14]. If an exporting country adopts a GM crop, countries importing that crop will benefit on net, but producers in the importing country will lose as prices fall. Many countries, especially those in the European Union, have implemented varying levels of regulation on the importation and domestic production of agricultural goods that are considered GM. Governmental regulatory bodies often cite health and environmental concerns over GM products; however, from a trade perspective, their policies could be interpreted as protectionist rent-seeking behavior stemming from lobbying of import-competing producers [14].

GMO Regulations

While the majority of policy makers agree that GE crop technology requires safety regulations, regulatory laws surrounding GE technology vary greatly among countries. For example, the United States implements regulations under the assumption that GM and non-GMO crops are similar based upon the concept of substantial equivalence. The European Union rejects this basis and instead uses a Precautionary Principle to design their regulatory framework, which greatly limits the implementation and adoption of GMO crops in the European Union. Furthermore, differences in domestic and international GE crop regulations have the potential to impede international trade, especially for countries trading with EU members. While most would agree that regulations are necessary, the required degree of stringency is controversial. Therefore, an approach to regulatory policy that considers reversible and irreversible costs and benefits may be useful when implementing regulations for new GE technology. The European Union also requires mandatory labeling of products containing GMO crops while the United States does not.

As Schmitz A et al. [14] state, "Producer and environmental groups in many countries, especially import-competing countries, oppose GM crops. This is especially true in the European Union. In some cases, certain producer groups may play on consumer fears over the health risks of GMOs in order to create or maintain non-tariff barriers to protect their domestic industry. Domestic producers competing against foreign imports can participate in rent-seeking behaviour-that is, the behaviour of individuals seeking profits through political action to ban imports so that producers can keep the domestic price for their product at high levels."

Recently, the European Court of Justice passed a judgment that organisms obtained by genome editing are regulated under the same restrictions as transgenic organisms [16]. Under this new judgment, genetically edited organisms that are indistinguishable from conventionally bred organisms created through methods such crossing or random mutagenesis, will be subject to the same regulations as transgenic organisms, such as those modified with CRISPR and Cas9 technology. This new judgment poses multiple regulatory and consumer confidence issues [16]. It has been suggested that "GE crops are diverse and the decision to treat them as one entity is justified on political and social attitudes more than a reflection of scientific reality" [17].

While there are many arguments as to why the European Union has adopted much more stringent policy on GMO regulation than the United States and other large agricultural exporters, the EU consumer resistance to GM food products has come to dominate both global and domestic perspectives. The global consumer attitude towards GM food products over the past decade has greatly affected the marketability of GM food products. Moreover, although there seems to be a global consensus on the use of GE technology in production of cotton fiber and for some animal feeds, a wide array of disagreements remains amongst both consumers and policymakers concerning the use of GE technology in food production.

When the lines become blurred around the definitions of agriculturally traded products or it becomes difficult to segregate and identify otherwise homogenous products, producers, importers, and exporters become vulnerable to lawsuits in relation to GM regulatory laws. In the StarLink corn case [18] the United States exported a non-licensed GMO corn to Japan. The Japanese embargoed US corn exports to Japan after this occurred. Later, in 2013 the Chinese embargoed imports of GMO corn from the United States because it was according to the Chinese a GMO variety they did not want to purchase. The result of the case involving the Chinese embargo of US corn is discussed with reference to Figure 2. A GMO can be licensed for production, but this does not guarantee that there will be any foreign buyers for the product. For example, in 2013, China embargoed the importation of corn from the United States, arguing that the GMO corn variety may not have met Chinese standards. This embargo resulted in market disruptions. As shown in Figure 2, US exports to China dropped dramatically from 2013 onwards. In terms of consumption, there are many regulations that dictate the giving of import and export licenses concerning food quality. These intricacies further complicate the matter with international trade and create inefficiencies throughout the supply chain.

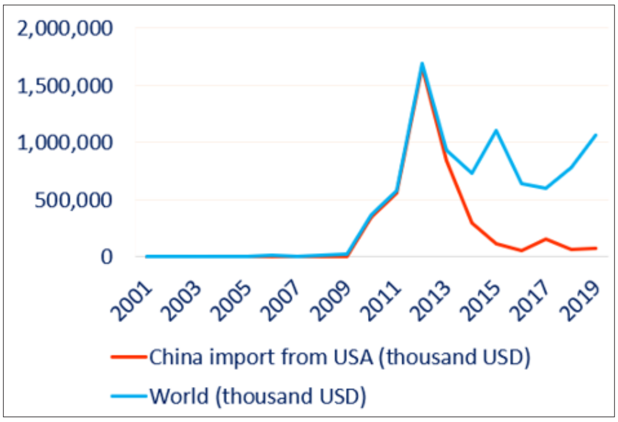

Figure 2: China and world corn imports (1000 USD).

Crop Yields

Since 1996 the use of GE technology has increased substantially in North and South America, specifically in the United States, Canada, Brazil and Argentina. The GE food crops planted in these countries are maize, soybeans, canola, and sugar beets, of which 90-100% of these crops planted are GE [3]. Recent literature has focused on the impact of pest-control traits and yields in these crops. "Although the adoption of GE varieties may tend to increase yields by reducing pest damage, it may also inadvertently decrease yield if the GE trait is inserted into a variety inferior to the one it is intended to replace.

As such, some may argue that first generation GE crops have a more significant impact in areas that are vulnerable to extreme infestations where traditional pest control methods have not been effective and in developing countries that have less access to alternative pest control mechanisms [19]. However, this perspective neglects the potential input savings and risk reduction from use of GE crops, such as decreased expenditure on pesticides and herbicides. Furthermore, multiple studies have found that implementation of GE cotton has resulted in a decrease of farmer exposure to pesticides and herbicides, especially in China and other Asian countries. This is also relevant to the case of Bt corn which has been shown to decrease the level of aflatoxin in Asian crops.

Zilberman D et al. [17] argue that there is a greenhouse gas reduction potential of implementing GE crops. Due to the yield effect of GE technology and the inelastic nature of demand for food, the adoption of agricultural biotechnology can increase input demands in terms of land, water, and energy use. However, adoption of herbicide tolerant GE crops has simultaneously reduced greenhouse gas emissions through allowing the expansion of double-cropping and no-tillage practices.

Proponents of conventional breeding and those who oppose GM technology in agriculture may pose the argument that conventional breeding methods can lead to equal and sometimes greater yield growth than the use of GM varieties. However, Chavas JP et al. [20] find that while both conventional and GM maize hybrids have been selected for yield and stress tolerance and over time have both given higher average yields, GM maize increases the yields associated with higher planting density and by reducing the adverse effects from maize-maize rotations can be a substitute for crop rotation all together.

In their overview, Ahmar S et al. [21] present that in most crop breeding programs, despite increased yields, the rate of increase is insufficient to match the food demand from the rapid growth in global population. Because of long crop durations and time intensive development processes, creating new cultivars through traditional methods can take anywhere from one to two decades. However, as Ahmar S et al. [21] suggest, the ability to develop new varieties more quickly would aid in alleviating food scarcity problems and increasing food security. While older transgenic breeding methods can also be time consuming, recent advances in genome editing technology using programmable nucleases, clustered regularly interspaced short palindromic repeats (CRISPR), and CRISPR-associated (Cas) proteins present new options such as speed breeding, genome editing and high-throughput phenotyping to more quickly increase crop efficiency. Indeed, they conclude that the targeted mutagenesis allowed by genome editing breeding technologies is superior to conventional methods and older GE methods in its ability to provide fast, efficient, and specifically targeted results.

Consumer Acceptability and the Spin on GMOs

The marketability and introduction of GM food products can be categorized as follows:

1. The GM variety is viewed by the consumer as equivalent to conventional crops.
2. The GM variety is viewed inferior to conventional varieties; or
3. The GM variety is viewed superior to traditional crops.

Consumers in general seem to prefer non-GM varieties when given a choice between those and their GM equivalents. Lewis KE et al. [22] examine consumer Willingness to Pay (WTP) for imported and GM labeled sugar and find that participant WTP for bags of sugar and sugar in soft drinks labeled as “GM” was significantly negative while participant WTP for bags of sugar and sugar in soft drinks labeled as “Not GM” was significantly positive. Their results can be extrapolated to suggest that mandatory GM labeling laws might be detrimental to US producers who grow GM sugar beets. Meanwhile, this could be beneficial to the US sugarcane industry because, although GM sugarcane is available, they do not currently use GM seeds. Furthermore, their results that participants have a positive WTP for sugar labeled as “Not GM” indicate that there may be incentive for farmers and food manufacturers to voluntarily label their food products as “Not GM.” This strategy is often seen on food products with sources that do not necessarily even have a GM counterpart, such as many fruit juices, baby foods, and snacks.

The issue of sugar from GM sugar beets verses sugar from non-GM sugarcane raises a secondary controversy. Both sugar beets and sugarcane are grown and processed to produce sucrose. While it is clear that GM sugar beets should be considered a GM product and any non-GM sugarcane is not a GM product, it is less clear how sugar that is derived from these two sources should be labeled. Cane sugar and beet sugar are both sucrose that is chemically indistinguishable from the other. Furthermore, refined sucrose contains no proteins which are what would help identify the product as GM or not GM. Very similar arguments surrounding definitions and labeling apply to the market for oils and starches that are derived from a GM product but contain no novel DNA or proteins due to the nature of processing.

On this issue, Kennedy PL et al. [23] show that the negative demand impacts for sugar from GM sugar beets can outweigh the supply-induced gains of GM sugar beet research and development. They conclude that while one may assume agricultural biotechnology would benefit producers through increased productivity and reduced input requirements, consumer demand response to the GM product can affect the market to the point that the producer benefits from GM adoption become eroded. The work by Lewis KE et al. [24] and McConnell M [25,26] suggests that this particular model presented by Kennedy PL et al. [23] is likely the case for the cane and beet sugar market, especially if mandatory labeling is required. They show that if given constant demand, sugar beet producers stand to benefit from biotechnology adoption while sugarcane producers may experience depressed prices. However, consumer aversion to the biotech product could alter this outcome. If demand for the GM beet sugar decreases while demand for non-GM cane sugar increases, then scenarios could exist in which sugar beet producers are worse off while sugarcane producers benefit from the sugar beet industry’s adoption of GM product.

Regarding consumer attitude towards GE and GM products, Schmitz TG et al. [27] develop a signaling game in order to derive the equilibrium conditions under which certain special interest groups have the incentive to truthfully release information versus manipulating consumer opinions by spinning facts about the health impact of GE food products. They find that consumer strategies depend upon their inspection costs, which is a function of the time required to learn about each piece of information. When the overall supply of information is increased, consumer inspection costs rise. Marketing strategies of both pro and anti GE special interest groups are dependent upon consumer actions and when it becomes too costly for consumers to inspect any messages, anti-GE groups will signal negative messages as long as their spin costs are relatively low. Pro-GE groups are put in a more difficult position because they take on relatively more risk when spreading positive messages about GE food products. If it were to turn out that the consumption of GE food does in fact pose a risk to human health, then knowingly claiming the opposite would at best hurt the credibility of the pro-GE group and at worst could lead to litigation. When compared to the message of anti-GE groups, pro-GE groups lose out because conventional and organic foods are already readily accepted by consumers.

Demand Attributes and Labeling: Confusion in the Marketplace

A continuing source of confusion for many consumers is the topic of product labeling. There are many different labeling options for producers, manufacturers, and retailers, most of which require a regulatory approval or verification process. However, some labels, especially those that do not require any certification, can be confusing at best and deliberately misleading at worst. For instance, the United States currently has no requirement to label produce or products that do or do not contain GE or GM components. However, due to general consumer mentality and brand presence in foreign markets, many companies and producers choose to label their goods as non-GE or non-GMO. Unfortunately, while the FDA recommends a third-party verification to substantiate the claim of voluntary non-GMO labeling, in the United States there is no legal enforceability against entities that inaccurately label their products. Rules for meat, poultry, and eggs that are labeled non-GMO are slightly more stringent and the USDA requires these manufacturers to comply with the standards of an accredited third-party verification organization such as the Non-GMO Project or those that are able to certify for the USDA Organic label. In the United States, the use of GMOs is prohibited in products with the USDA Organic label. Some individual states have passed legislation requiring mandatory labeling of some products that contain GMOs; however, enforcement remains difficult as long as the United States has no mandatory federal requirements in place. Furthermore, in the United States there is no agreed upon standard for non-GMO labeling nor is there a firm regulatory definition of GM or non-GM.

In stark contract with the United States, at least 64 countries, including all those in the European Union, the United Kingdom, Japan, South Korea, China, New Zealand, and Australia, require some form of labeling and traceability of all produce and products containing genetically modified material in a quantity of higher than a certain threshold percentage of each ingredient considered individually.

Lakkakula P et al. [2], argue that GMO labeling results in increased costs due to the creation of separate supply chains for GM and non-GM products. When this labeling is mandatory, costs are passed on to consumers in general. Loureiro ML et al. [28] find that consumers in the United States are generally unwilling to pay higher costs associated with mandatory labeling. However, when labeling is voluntary, the cost is passed on to those consumers who are willing to pay a premium for items labeled non-GMO, organic, or pesticide free, to name a few. In the case of voluntary labeling, while there are federal regulations and guidelines surrounding the use of these labels, it is up to producer or middleman discretion as to whether these labels are included. If enough consumers are willing to pay for these labels, then there may be producer incentive to include voluntary labels in order to receive a certain price premium over a non-labeled product. Grebitus C et al. [29] analyze the effect of voluntary food labeling in Medjool dates with a focus on GMO, pesticide usage, and region of origin. They find that while consumers are willing to pay a premium for both GMO-free and pesticide-free products, they are willing to pay more for a pesticide-free label. Furthermore, they find that the GMO-free and pesticide-free labels are sub-additive in that the willingness to pay for products labeled both pesticide-free and GMO-free is lower than the sum of the willingness to pay for both labels individually.

As with sugar beets and sucrose and other processed products derived from a raw GM or GE product, controversy arises in regard to GM labeling when livestock are fed GM or non-GM feed. While 70-90% of all GM crops and their biomass are used for animal feed, there are comparably very few risk assessment studies regarding the use of GM or GE crops primarily as animal feed [30]. Furthermore, while the USDA's FSIS has recently increased requirements for voluntary labeling of meat and poultry products that are produced without GM or GE feedstock [31] there are no federal requirements for labeling in the United States. As with produce, the European Union is stricter on labeling requirements. Additionally, the United States has approved

Third Generation GMOs

While not yet widely implemented, third generation GM crops are not intended to enhance crop productivity or for use as food or animal feed. One example of this is Plant-Made Pharmaceuticals (PMPs) which are intended for use as therapeutic drugs for humans or livestock, or as materials for research and industry. PMP plants are used as factories to produce the PMP product, the product is extracted from the plant, and the plant remains are discarded. Two reasons cited by proponents of pursing PMP production are lower cost of production and increasing demand. Production of high-quality pharmaceutical components (proteins and antibodies) is presently done using cell cultures inside bioreactors, which is very costly and limits the size of the consumer market. Proponents of PMP crops claim that PMP production will increase the range of available drug products, reduce the time required to bring new drugs to market, lower the cost of drug production, and provide additional markets for farmers. Opponents of PMP crops cite similar concerns to opponents of GM products in general, such as potential food safety risks from cross contamination of food crops, consumer skepticism of genetically engineered products, potential environmental hazards, and past regulatory mistakes as reasons for their opposition.

Despite the early promise of Plant Molecular Farming (PMF) for a variety of applications, it has failed to take an industry foothold except in very niche areas. More recently, new plant breeding techniques such as the CRISPR-cas 9 system offer even more potential for improvement when oriented towards designing plants for PMF use. Some believe that communication of the benefits and purpose of PMF may improve social acceptability of genetic modification for those purposes.

Conclusion

Since the introduction of agricultural biotechnology in 1996, global use has increased more than 100-fold, making it the fastest adopted crop technology introduced to date. Despite both advances and setbacks, the established economic benefits and yet unrealized potential of recent innovations in agricultural biotechnology with regards to resource use and food security are irrefutable. While it is important to recognize that this potential in no way undermines the enduring importance of conventional breeding, there still remains a somewhat unfounded pushback on the integration of agricultural biotech into general use. Much of this controversy arises from a combination of marketing spin from anti-GMO special interest groups, stringent EU regulatory policy, and consequent consumer reactions. Indeed, many major food commodities, such as rice and wheat, are still predominantly conventionally bred. As in the case of peanuts, many of these items will remain as such unless major producers and processing companies are willing to undertake the risk to convince consumers that genetically modified products are safe.

Theoretically, ideally the highest payoff to society from GMOs is a win-win situation where both producers and consumers benefit. However, defining empirical evidence of such cases is difficult. With the introduction of CRISPR and Cas9 technology, separation and segregation of genetically modified and conventionally products food products are becoming increasingly complicated. Without known genome data, there is no fast or practical method for determining if a product has been modified using CRISPR technology. However, based upon new EU regulations, CRISPR modified products must be labeled and treated in the same way as other biotech products. This decision will likely drive some of the choices made by global consumers and producers. It remains to be seen if increasing demand amidst diminishing resources and the pursuit of global food security will sway consumer choices.

In perspective, evidence shows that there have been significant increases in yield and productivity from GMO production. But this is also true for traditional plant breeding activities. In their three volumes on productivity and food security Schmitz A et al. [32-34] raise the point that in spite of widespread optimism about productivity increases brought about by GM and GE technology, there is no consensus on whether agricultural productivity growth can keep pace with the increase in world population [35,36].

References

1. Buiatti M, Christou P, Pastore G (2013) The application of GMOs in agriculture and in food production for a better nutrition: Two different scientific points of view. Genes and Nutrition 8(3): 255-270.
2. Lakkakula P, Haynes JD, Schmitz TG (2015) Genetic engineering and food security: A welfare economics perspective. In Schmitz A, Kennedy PL, Schmitz TG (Eds.), Food Security in an Uncertain World, Volume 15. Emerald Group Publishing, Bingley, UK.
3. ISAAA (2019) Global status of commercialized biotech/gm crops in 2019: Biotech crops drive socioeconomic development and sustainable environment in the new frontier, ISAAA Brief 55, ISAAA, New York, USA.
4. Mitchell D (2014) Why there are no GMO oats. Modern Farmer, USA.
5. Strom S (2015) Some Tropicana and other PepsiCo products to carry non-GMO project seal. The New York Times, USA.
6. Jordan D (2020) Question about GMO peanuts. North Carolina State University, Raleigh, North Carolina, USA.
7. Thornton M (2004) The rise and fall of newleaf potatoes. Biotechnology: Science and society at a crossroad. Cornell University, Ithaca, New York, USA.
8. Kantner J (2012) BASF to stop selling genetically modified potatoes in Europe. The New York Times, USA.
9. Purkowski M (2014) McDonalds has no plans for GMO potatoes. Capital Press, Salem, Oregon, USA.
10. Rock J, Schurman R (2020) The complex choreography of agricultural biotechnology in Africa. African Affairs 119(477): 499-525.
11. Sikapizye L (2020) African farmers yearn for biotechnology in the face of climate change. Cornell University, Ithaca, New York, USA
12. Qaim M, Kouser S (2013) Genetically modified crops and food security. PLoS ONE 8(6): e64879.
13. Moss C, Schmitz A (2019) Distribution of agricultural productivity gains in selected Feed the Future African Countries. Journal of Agribusiness in Developing and Emerging Economies 9(1): 78-90.
14. Schmitz A, Moss CB, Schmitz TG, Furtan HW, Schmitz HC (2010) Agricultural Policy, Agribusiness, and Rent Seeking Behavior, third edition. University of Toronto Press, Toronto, Canada.
15. Schmitz A, Moss C, Schmitz T (2003) Market segmentation and GMOs. Western Agricultural Economics Association Conference, Denver, Colorado, USA.
16. Wassmer M (2019) Roads forward for European GMO policy—uncertainties in wake of ECJ judgement have to be mitigated by regulatory reform. Frontiers of Bioengineering and Biotechnology 7: 132.
17. Zilberman D, Wesseler J, Schmitz A, Gordon B (2018) Economics of agricultural biotechnology. In: Cramer GL, Paudel KP, Schmitz A (Eds.), Routledge Handbook of Agricultural Economics, first edition. Routledge Publishing, London, UK.
18. Schmitz TG, Schmitz A, Moss CB (2005) The economic impact of StarLink corn. Agribusiness 21(3): 391-407.
19. Qaim M, Zilberman D (2003) Yield effects of genetically modified crops in developing countries. Science 299(5608): 900-902.
20. Chavas JP, Shi G, Lauer J (2014) The effects of GM technology on maize yield. Crop Science 54(4): 1331-1335.
21. Ahmar S, Rafaqat AG, Jung KH, Faheem A, Qasim MU, et al. (2020) Conventional and molecular techniques from simple breeding to

speed breeding in crop plants: Recent advances and future outlook. International Journal of Molecular Science 21(7): 2590.

22. Lewis KE, Grebitus C, Nayga RM (2016) US consumers' preference for imported and genetically modified sugar: Examining policy consequentiality in a choice experiment. Journal of Behavioral and Experimental Economics 65: 1-8.
23. Kennedy PL, Schmitz A, DeLong KL (2020) Biotechnology and demand concerns: The case of genetically modified US sugar beets. AgBioForum 2020(1): 1-13.
24. Lewis KE, Grebitus C, Nayga RM (2016) The Impact of brand and attention on consumers' willingness to pay: Evidence from an eye tracking experiment. Canadian Journal of Agricultural Economics 64(4): 753-777.
25. McConnell M (2016) Sugar outlook. USDA Agricultural Outlook Forum, United States Department of Agriculture, Economic Research Service, Washington, DC, USA.
26. McConnell M (2017) US sugar market and the divergence of beet sugar and cane sugar markets. United States Department of Agriculture, Economic Research Service, Washington, DC, USA.
27. Schmitz TG, Smith MZ (2020) Spinning the facts against genetically engineered foods? Theoretical Economics Letters 10(3): 458-480.
28. Loureiro ML, Hine S (2004) Preferences and willingness to pay for GM labeling policies. Food Policy 29(5): 467-483.
29. Grebitus C, Peschel AO, Hughner RS (2018) Voluntary food labeling: The additive effect of "free from" labels and region of origin. Agribusiness 34(4): 714-727.
30. Giraldo PA, Shinozuka H, Spangenberg GC, Cogan NOI, Smith KF (2019) Safety assessment of genetically modified feed: Is there any difference from food. Frontiers in Plant Science 10: 1592.
31. FSIS (2021) Food safety. United States Department of Agriculture, Food Safety and Inspective Service, Washington, DC, USA.
32. Schmitz A, Kennedy PL, Schmitz TG (2015) Food security in an uncertain world: An international perspective, Volume 15. Emerald Group Publishing, Bingley, UK.
33. Schmitz A, Kennedy PL, Schmitz TG (2016) Food security in a food abundant world: An individual perspective, Volume 16. Emerald Group Publishing, Bingley, UK.
34. Schmitz A, Kennedy PL, Schmitz TG (2017) World agricultural resources and food security: An international perspective, Volume 17. Emerald Group Publishing, Bingley, UK.
35. Cramer G, Paudel K, Schmitz A (2019) The Routledge handbook of agricultural economics, first edition. Routledge Publishing, London, UK.
36. Kerr W (2017) Genomics, international trade, and food security. Estey Journal of International Law and Trade Policy 18(2): 78-101.