REVIEW

Consumer Perception of Genetically Modified Organisms and Sources of Information[1–3]

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ABSTRACT

Genetically modified organisms (GMOs) have been available for commercial purchase since the 1990s, allowing producers to increase crop yields through bioengineering that creates herbicide-resistant and insect-resistant varieties. However, consumer knowledge about GMOs has not increased at the same rate as the adoption of GMO crops. Consumers worldwide are displaying limited understanding, misconceptions, and even unfamiliarity with GMO food products. Many consumers report that they receive information about GMO food products from the media, Internet, and other news sources. These sources may be less reliable than scientific experts whom consumers trust more to present the facts. Although many in the United States support mandatory GMO labeling (similar to current European standards), consumer awareness of current GMO labeling is low. A distinction must also be made between GMO familiarity and scientific understanding, because those who are more familiar with it tend to be more resistant to bioengineering, whereas those with higher scientific knowledge scores tend to have less negative attitudes toward GMOs. This brings to question the relation between scientific literacy, sources of information, and overall consumer knowledge and perception of GMO foods. *Adv Nutr* 2015;6:842–51.

Keywords: genetically modified organisms, GMOs, genetic engineering, knowledge, awareness, labeling

Introduction—History of Genetically Modified Organisms

Consumers are generally interested in knowing about the food they consume, including its source and, if processed, the ingredients that may have been added to it. As novel concepts emerge in food production systems, consumers may also be more concerned about and apprehensive of purchasing newly developed foods. Genetically engineered (GE)[4] or genetically modified (GM) foods, or those that contain some genetically modified organisms (GMOs), were introduced to the US market and appeared on supermarket shelves in 1994 with the Flavr Savr tomato (1). The FDA approved the method by Calgene of inserting a gene that prevents buildup of an enzyme that would otherwise cause softening in fruit, allowing the commercially sold Flavr Savr tomato to have a longer shelf life than conventional tomatoes (2). However, its production ceased in 1997. Two years after the introduction of Flavr Savr, in 1996, herbicide-resistant soybeans were introduced into the food system to allow farmers to use the widely applicable herbicide glyphosate (Roundup) in fields to kill a wide range of weeds without harming their glyphosate-resistant (Roundup Ready) crops (3).

These crops represent the beginning of an era of biotechnology adoption in which bioengineered crops are being developed continually to display advantageous traits. GMOs can be modified in a number of ways, classified by generation. First-generation traits offer tolerance to herbicides, resistance to pests, and hearty resistance to environmental conditions; second-generation traits add value such as improved nutritional quality; and third-generation traits provide qualities beyond those of traditional food items and are used for pharmaceuticals and similar products (4). The majority of GM crops in the United States are first-generation. The USDA's Animal and Plant Health Inspection Service (APHIS) already has approved second-generation crops such as high-lysine corn, high–oleic acid soybean oil, and improved FA profile soybeans (5). As of February 2015, the most approved phenotype traits in the United States were herbicide tolerance, agronomic properties, improved product quality, and insect resistance (6). For an overview of GMO history, refer to **Figure 1**.

[1] This article is a review from the poster session Consumers' Awareness of Biotechnological Food Production Systems presented at the Advances & Controversies in Clinical Nutrition Conference held 4–6 December 2014 in National Harbor, MD. The conference was jointly provided by *The American Society for Nutrition* and Tufts University School of Medicine.

[2] Scholarship provided by Montclair State University Faculty Scholarship Program.

[3] S Wunderlich and K Gatto, no conflicts of interest.

[4] Abbreviations used: APHIS, Animal and Plant Health Inspection Service; Bt, *Bacillus thuringiensis*; GE, genetically engineered; GM, genetically modified; GMO, genetically modified organism.

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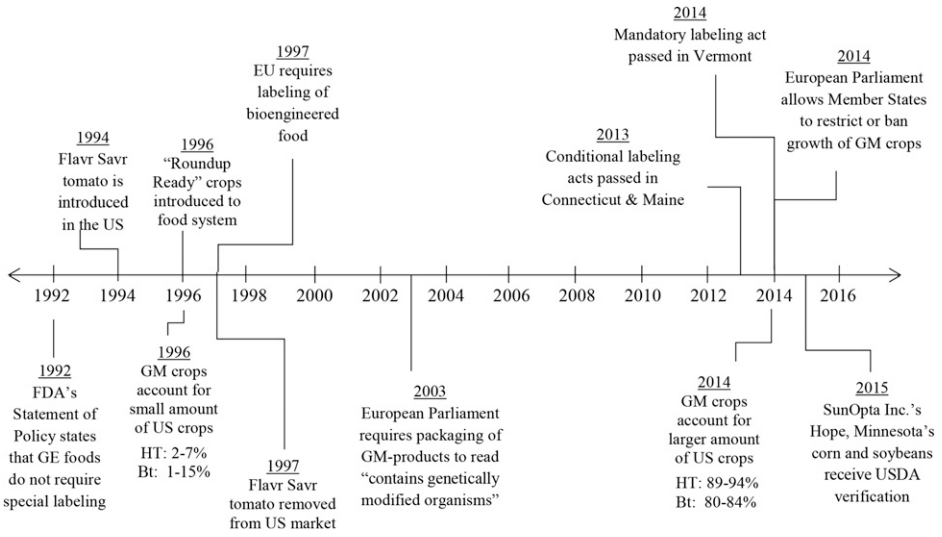

FIGURE 1 Timeline of genetically modified organism history. Bt, *Bacillus thuringiensis*; EU, European Union; GE, genetically engineered; GM, genetically modified; HT, herbicide tolerant.

The growing presence of GMOs in the food system has been closely tied to discussion of the scientific research on their safety and effects. A review of studies examining GMO safety found that results were fairly evenly split between those indicating that GM versions of many crops are entirely safe and those that felt that bioengineering was a concern and requires more thorough long-term testing (7). As a result, rather than confirming that a scientific consensus on the safety of all GMOs has been reached, large groups within the scientific community assert the need for thorough evaluation of each individual GMO, as well as rigorous epidemiologic studies on the effects of GMO consumption (8).

The 3 most widely grown US GMO crops—cotton, soybeans, and corn—initially accounted for very small percentages of farmland in 1996, but have expanded rapidly as farmers continually adopt them, citing their ability to increase yields as the primary reason (5). Herbicide tolerance, which relies on a gene that allows crops to survive the potent herbicides needed to kill competitive weeds, saw massive adoption in the US food industry between 1996 and 2014, with herbicide-tolerant soybeans expanding from 7% to 94% of US soybean acreage, herbicide-tolerant cotton expanding from 2% to 91% of cotton acreage, and herbicide-tolerant corn expanding from 3% to 89% (9). Insect resistance is known as *Bacillus thuringiensis* (Bt), the bacterial source of a protein that is toxic to insects and protects crops from pest damage; as technology has grown to include resistance to additional pests such as corn rootworm and corn earworm, so has adoption of Bt crops (5). From 1996 to 2014, Bt corn usage grew from just 1% to 80% of US corn acreage, and Bt cotton grew from 15% to 84% (9). A common method of modification now includes the insertion of multiple genes, resulting in stacked traits, which accounts for the majority of both GE cotton and corn grown in the United States; GE cotton accounts for 96% acreage, 79% of which is stacked-trait, and, similarly, 93% of corn acreage is GE, with 76% of the crops containing stacked traits (9). In addition to corn, soybeans, and cotton, the United States currently grows GM canola, sugar beets, alfalfa, papaya, and squash (10).

Currently, the United States is the lead producer of genetically bioengineered produce, contributing 73.1 million hectares of land and accounting for 40% of global GMO crops, followed by Brazil (42.2 million hectares), Argentina (24.3 million hectares), India (11.6 million hectares), and Canada (11.6 million hectares). Twenty-eight countries grew GM crops in 2014; 8 of these are industrial countries, whereas 20 are developing and rely on the ability of biotechnologically engineered crops to increase yields. Overall, GMO crops are now grown on 181.5 million hectares of land, which is 100 times the area cultivated with GMOs in 1996 (10). It must be noted, however, that the European Union has a low adoption rate for modified foods, with the main GM crop—an insect-resistant corn—currently grown on 150,000 hectares spread over 5 member states; Spain alone grows 92% of the European Union's modified corn crop (10, 11).

Current Status of Consumer Knowledge about Genetic Modification of Food

Generally, consumer knowledge of GMOs is low, according to studies based on direct consumer surveys (an overview of which can be found in **Table 1**). A survey conducted by the Food Policy Institute at Rutgers University found that US consumers as a whole were fairly unknowledgeable about GMOs, with just 48% knowing that GMOs were available in supermarkets and only 31% believing that they have most likely consumed a GM product. The majority of participants also self-rated their knowledge to be poor; 48% said that they knew very little about GMOs, whereas 16% felt they knew nothing at all, compared with 30% knowing a fair amount and just 5% knowing a great deal about GMOs (12). The results of a more recent survey by Rutgers University found even lower knowledge, with just 43% knowing that GM products are sold in supermarkets, 26% believing that they have probably eaten a GM food, 54% reporting that they knew very little or nothing at all, and 25% admitting that

TABLE 1 Consumer knowledge of GMOs[1]

Reference	Population	Sample size[2]	Main findings
Hallman et al., 2004 (12)	US consumers	*N* = 1201	• 48% know that GMOs were available in supermarkets • 31% believe that they have most likely consumed a GM product
		n = 600	• Limited self-rated knowledge about GMOs • 48% know very little • 16% know nothing at all • 30% know a fair amount • 5% know a great deal
Hallman et al., 2013 (13)	US consumers	*N* = 1148	• 43% know GM products are sold in supermarkets • 26% believe they have probably eaten a GM food • 54% know very little or nothing at all about GMOs • 25% have never heard of GMOs
		n = 491	• 59% know that GM soybeans are sold in US supermarkets • 56% mistakenly believe that GM tomatoes are sold • 55% mistakenly believe that GM wheat is sold • 50% mistakenly believe that GM chicken is sold
Aleksejeva, 2014 (14)	Latvian consumers	(not reported)	• 50.0% believe that an ordinary tomato does not contain genes, but a GM tomato does. • 68.2% believe that GM food genes can get into human generative cells and can be passed to future generations • 40.9% believe that by eating a GM tomato, a person's genes could also be changed • 90.0% know that insertion of a fish gene would not make a tomato taste fishy • 95.5% know that both non-GM and GM foods could cause toxic or allergic reactions • 22.7% self-rate their knowledge as 6 out of 10 • 77.3% self-rate their knowledge as 5 out of 10 or lower
Turker et al., 2013 (15)	Turkish nursing students	*N* = 346	• 32.4% correctly identified soy, corn, and cotton as the most cultivated GMOs • 58.4% incorrectly identified tomatoes, peppers, and zucchini as the most cultivated GMOs • 5.5% incorrectly identified potatoes, wheat, and eggplant as the most cultivated GMOs • 77.7% believe that production of GM food is risky for all living things • 72.8% believe that it could be dangerous to consume GMOs • 82.9% felt that society was not adequately informed about GMOs • 16.8% felt that they themselves had sufficient knowledge about GMOs

Jurkiewicz et al., 2014 (16)	Polish students	*N* = 500	• 57.4% of participants doubted that studies of GMO health effects are reliable
			• 64.1% stated that media reports on GMOs are untrustworthy
			• 59.9% had negative opinions of GM plants in the food production system
			• Self-reported knowledge regarding genetic modification is as follows:
			  • 81.4% report either, "I know very little about it" or "unlikely I know"
			  • 16.8% report knowing rather a lot
			  • 1.8% report knowing a lot

McGarry et al., 2012 (17)	US, Italian, and Japanese food shoppers	*N* = 550 US consumers, 200 Italian consumers, and 128 Japanese consumers	• 40.9% of US consumers were somewhat or very familiar with GMOs
			• 28.0% of Italian consumers were somewhat or very familiar with GMOs
			• 33.3% of Japanese consumers were somewhat or very familiar with GMOs
			• Cultures varied in their ranking the most desirable characteristics of foods:
			  • US consumers rated "GMO-free" as the 17th most important characteristic on their list
			  • Italian consumers listed "GMO-free" as the 5th most important characteristic
			  • Japanese consumers listed "GMO-free" as the 7th most important characteristic

[1] GM, genetically modified; GMO, genetically modified organism.
[2] *N* = total sample; *n* = question-specific sample.

they had never heard of them, all of which indicates that awareness of GMOs may not be increasing along with their actual usage (13). Even those who did know that GM foods were currently available were often misinformed about which varieties are sold in the United States, with only 59% knowing that GM soybeans are sold but over 50% mistakenly believing that bioengineered tomatoes, wheat, and chicken are sold in the United States (13).

A recent polling of Latvian consumers demonstrated limited understanding of genetics and food, with one-half of the respondents believing that "an ordinary tomato does not contain genes, but a GM tomato does." Accordingly, because knowledge of genetics was limited, understanding of the impacts of eating GE food was muddled, with almost one-half of participants believing that a person's genes could be altered as a result of eating GMOs and more than two-thirds believing that modified genes from GMOs could enter human reproductive cells and be passed to offspring. Certain misconceptions about flavor and allergenicity were uncommon, although with over 90% knowing that insertion of a fish gene would not make a tomato taste fishy, and over 95% knowing that both nonmodified and modified foods could cause toxic or allergic reactions. Still, based on self-reported measures of GMO-related knowledge, the participants felt that they had low to moderate knowledge at best, with 22.7% ranking their knowledge as 6 out of 10 and the rest of the participants reporting knowledge of 5 or lower (14).

A similar study conducted in Turkey examined the knowledge of a population with somewhat higher scientific knowledge implied: nursing students. Specific knowledge about GMO use was still moderately low; when asked which GMO was the most cultivated, just 32.4% correctly identified the soy, corn, and cotton option, whereas others believed incorrectly that other crops were the most cultivated GMOs (tomatoes, peppers, zucchini, potatoes, wheat, eggplant). The low knowledge was accompanied by heightened feelings of precaution, with over 70% believing that GM food production is risky for all living things and that it could be dangerous to consume GMOs. In addition to the objective measures of GMO knowledge, the students also self-rated their GMO knowledge, and although the majority seemed aware that GMOs were widely used and that they may be purchasing GM products, they felt overall uninformed; 82.9% felt that society was not adequately informed about GMOs, and only 16.8% felt that they themselves had sufficient knowledge about GMOs (15).

A study of Polish students highlighted similar dissatisfaction with the body of available information. A total of 57.4% of participants doubted that studies of GMO health effects were reliable and 64.1% stated that media reports on GMOs are untrustworthy. The participants self-reported low knowledge regarding genetic modification, with 81.4% reporting either "I know very little about it" or "unlikely I know," and just 18.6% feeling that they were knowledgeable on the subject, although their distrust in the current sources of information may be related. Again, the majority of participants had negative opinions of GMOs in the food production system and cited that they seemed dangerous and unhealthy, although they also showed understanding that GMOs could be associated with both positive and negative outcomes for food production (16).

Familiarity with genetic modification varies by country. A crosscultural survey comparing the knowledge of consumers in the United States, Japan, and Italy showed that US consumers were more likely to be at least somewhat familiar with GMOs (40.9% reported being somewhat or very familiar) compared with Italian (just 28.0%) and Japanese (33.3%) consumers. When ranking the most desirable characteristics of food, US consumers rated "GMO-free" to be the 17th most important characteristic on their list, whereas Italian consumers listed it as 5th and Japanese consumers listed it as 7th, indicating that the non-GMO sentiment in the United States may not be as strong as elsewhere in the world (17).

Reviews have supported the finding that US consumers tend to accept GMOs more readily than European counterparts, with Europeans having higher willingness to pay for non-GMO foods than Americans, but meta-analyses of consumer behavior still show that consumers as a whole are willing to pay more for non-GM products than GMO products, with a willingness to pay an extra 29–45% more to avoid GM goods (18–20). Interestingly, whereas European aversion to GM goods is increasing dramatically over time and at a slower but still growing rate in the United States, other parts of the world are becoming less resistant to GM foods based on changes in the percentage premium that consumers would pay for non-GM alternatives (20).

Source of Knowledge about GMOs

The flow of knowledge from its source, scientific studies, to its destination, the public, is a crucial aspect of consumer education. An overview of consumer sources of GMO knowledge can be found in **Table 2**. Media sources are often used as a main method of communication to transfer this information. Media sources can be incredibly effective at reaching massive amounts of people who may not otherwise seek out scientific information, but the accuracy of the final message may be less than desired (21). The same surveys that show low GMO knowledge also report a disproportionately strong reliance on the media as a source of GMO information. Of the Latvian consumers surveyed by Aleksejeva (14), 77.3% received GMO information from the Internet, 63.6% from television, 54.5% from people they know (relatives and friends), 36.4% from the radio, 22.7% from newspapers and magazines, and just 13.6% from scientific papers. Turkish nursing students, despite their medical schooling, reported similar reliance on nonscientific sources of information, with 74.3% of the participants reporting that they had heard of GMOs from the television or radio, 27.7% from newspapers, 22.3% from a friend, 21.7% from the Internet, and 9.2% from the questionnaire alone (15).

A study on media discussion of GMOs noted that the topics of popularity in the press did not always mirror the actual significance of the information. During the 1990s, there were often more scientific articles than news articles

TABLE 2 Sources of GMO knowledge[1]

Reference	Population	Sample size	Main findings
Aleksejeva, 2014 (14)	Latvian consumers	Not reported	• 77.3% received GMO information from the Internet • 63.6% received GMO information from television • 54.5% received GMO information from people they know (relatives and friends) • 36.4% received GMO information from the radio • 22.7% received GMO information from newspapers and magazine • 13.6% received GMO information from scientific papers
Turker et al., 2013 (15)	Turkish nursing students	$n = 346$	• 74.3% received GMO information from television or radio • 27.7% received GMO information from newspapers • 22.3% received GMO information from a friend • 21.7% received GMO information from the Internet • 9.2% received GMO information from the questionnaire alone

[1] GMO, genetically modified organism.

published about GMOs, but in 1999, yearly GMO news articles more than tripled (from <500 to 1500) and far exceeded academic articles, which increased by 50% (from <500 to ~750). The authors' analysis traced this disproportionate growth of media attention to 2 events: a press release about a small preliminary study on the negative effects of Bt corn on monarch butterflies in 1999, and the recall of foods containing a bioengineered corn that had not been approved for human consumption in 2000. Although the recall of GMO-tainted food is obviously important to the public, the small preliminary article on GMO ramifications for butterflies was a surprising catalyst that sparked greater conversation about GMO labeling, protests, industry discussion, politics, and public opinion. This media attention can be problematic, however, because popular media can propel incomplete and simplified knowledge to the masses, leading to partial or inaccurate knowledge and concern (21).

Although GMO-related information may not always come directly from scientific sources, consumers tend to trust these sources over alternative sources. A study of US consumers found that scientists were some of the most trusted sources of GMO information, acting as impartial evaluators alongside university research groups and medical professionals. They were ranked as more trustworthy than advocacy groups, environmental groups, farmers, the government, the media, grocery stores, and industry organizations (22).

A study of risk perception also found that the public trusts experts (including university scientists, environmental groups, and consumer organizations) above government, supermarket, and industry scientists as sources of GMO information. When these expert sources agreed with government agencies about GMOs, government messages appeared more impartial and were viewed more positively, implying that consumers trust messages with expert backing more than those without knowledgeable input (23). More recent surveys revealed similar results, with consumers trusting university scientists the most, followed by farmers, environmental organizations, government agencies, grocery stores, and food manufacturers (in that descending order). It should be noted that, on a trust scale of 1–7, scientists still received only 4.73 ± 1.68, indicating that no group was trusted completely. Overall, the perceived degree of honesty in any group was a predicting value of trust, whereas degree of knowledge was also a factor for consumers regarding scientists and environmental organizations (24).

US consumer opinion varies based on degree of trust as well. In a survey, consumers who trusted scientific organizations were 24% more likely to find GMOs useful; those who trusted the government were 21% more likely; and those concerned about government regulations were 10% more likely, which the authors hypothesized may be due to the fact that these individuals believed that the government would not permit unsafe foods to enter the food system (25) With the role of scientific researchers consistently being tied to trusted GMO information, those at the heart of GMO research should play a key role in the education of consumers about biotechnology.

Relation between GMO-Related Knowledge, Awareness, and Attitude

Knowledge of GMOs is an area of interest because it may affect consumer opinions, attitudes, and behaviors. In a 2001 survey of US citizens, only 44% felt that they had at least some information about GMOs, with just 9% receiving a great deal of information. However, 54% had heard not much or even nothing about biotechnology and food. A large amount of indecision accompanied this lack of information, with 46% of consumers not knowing what to think about GM foods and their degree of safety, 29% finding them safe, and 25% feeling that they were unsafe. However, attitude toward GMO safety may be a result of limited awareness, because it was not stable for some consumers; after reading that over 50% of foods available in grocery stores contained GM ingredients, 20% of participants who originally found GMOs unsafe changed their answers (26). Negative emotions, including fear and disgust, have been correlated to GMO rejection in previous studies, indicating that any cause of fear can play a role in negative attitudes toward biotechnology (27).

Awareness of GMOs may be related to preference for non-GMO alternatives, with knowledge affecting attitudes toward purchasing and consuming the newly introduced foods. Vecchione et al. (28) conducted a survey of adult supermarket consumers in New Jersey and found a slight correlation between knowledge and attitude ($r = 0.41$, $P < 0.001$) in which consumers with higher GMO knowledge, measured by

self-reported familiarity with the term and ability to define it, had slightly more positive attitudes toward non-GMO products. These consumers were also slightly more likely to purchase non-GMO goods, as evidenced by a moderate correlation between knowledge and behavior ($r = 0.59$, $P < 0.001$). There was, however, a weak positive correlation between knowledge and education level ($r = 0.15$, $P < 0.01$). It is important to note that there was a relatively strong relation between attitude and behavior ($r = 0.70$, $P < 0.001$), indicating that those who preferred non-GMO goods were more likely to purchase them, so consumers' anti-GMO attitudes were reasonable predictors of their purchasing behaviors (28).

Consumers with high self-reported GMO knowledge have also shown lower willingness to pay for GM products compared with those with low self-reported knowledge, according to a study involving an auction of both GM and non-GM consumer goods. Researchers first asked participants to self-rate how informed they were about GM food before participating. A total of 42% reported being informed to some degree (only 3.5% of whom felt extremely well informed), whereas the remaining 58.1% felt uninformed. To gauge the impact of new information on consumer choice, researchers provided the participants with some combination of pro-GMO industry perspective, anti-GMO environmental perspective, or impartial third-party perspectives before asking them to bid on food products with and without GMO labels. Overall, participants were willing to pay an average of 14% less for food items labeled as GM, with those with prior knowledge of GMOs (the informed group) bidding 18% less for the GM product and the uninformed groups bidding just 11% less. Because the informed group bid less on GM products than the uninformed group, those in that group appeared to hold negative opinions of GMOs. They were also less likely to change their valuation of GM versions based on new information throughout the study than the uninformed group, the members of which altered their bids based on the content and perspective of new information. This implies that a lack of prior information and opinion may increase consumer susceptibility to the sway of novel information (29).

Interestingly, consumer attitude may be affected by the potential for improved nutritional qualities in bioengineered foods. Only 8.7% of Turkish students approve genetic modification for improved nutritional content, compared with 68.2% who oppose modification for nutritional purposes and 22% who remain undecided (15). However, a meta-analysis of food valuation studies found that consumers are willing to pay smaller premiums for non-GM foods when they are informed of GMO benefits such as improved nutrition, indicating that nutrition may increase the acceptability of GMOs (19).

Whereas Vecchione et al. (28) and Huffman et al. (29) examined self-reported participant awareness of GMOs, other studies have looked at how scientific knowledge and educational background may affect understanding of the genetic modification process and, in turn, affect attitude differently. A study by McComas et al. (30) showed that those who are more knowledgeable about bioengineering seem to view GMO products less negatively than those who are less informed. The participants in this study read statements about how GMOs could be used to protect crops from the spread of plant diseases; overall, knowledge was positively related to the perceived benefits and perceived legitimacy of the genetic modification process, indicating that those who know more about GMOs are more confident of the strength of their benefits and can justify their use.

High scientific knowledge was also tied to more positive attitudes toward GMOs in a study of Danish consumers by Mielby et al. (31). Participants with college preparatory education scored higher on a test of objective biology knowledge than those without the same schooling background (with an average of 6 out of 8 questions correct compared with just 4.5 questions), and higher scientific knowledge was greatly associated with acceptance across varied applications of genetic modification, including as human food, medical use, or animal feed.

The study by Mielby et al. (31) also explored how depth of scientific understanding relates to broader acceptance of genetic modification by examining variance in acceptance based on 2 methods of genetic modification: transgenic (involving insertion of a gene from a foreign species, such as bacteria) and cisgenic (involving genes from a closely related plant). Higher knowledge scores were significantly correlated to acceptance of both cisgenic and transgenic products. The participants who accepted transgenic crops (which may strike consumers as unnatural) had significantly higher knowledge than others, meaning that deeper understanding of the actual science behind genetic modification may play a large role in mitigating fear. Those with college preparatory education as well as high knowledge scores were less likely to differentiate between cis- and transgenic modification at all, which the authors interpreted to mean that they drew upon their educational background to inform their opinions rather than judging the safety of a product based on how natural it is.

A survey of US consumers found a slight relation between education and attitude, with participants whose highest level of education was a high school diploma being 12% less likely to believe in the usefulness of GMOs than those with higher education (25). This relation is intriguing in relation to the findings by Mielby et al. (31), in which those without a college preparatory background had lower science scores and were more likely to have differing opinions about transgenic and cisgenic GMOs, meaning that those with less rigorous scientific education may have more negative perceptions of GMOs.

GMO Regulation and Labeling

The regulation of GM foods in the United States is the responsibility of 3 federal agencies: the FDA, which handles food destined for human or animal consumption); the Environmental Protection Agency, which regulates the use of pesticides; and the APHIS, which evaluates and regulates GMOs through their Biotechnology Regulatory Services Program. Before a bioengineered crop can be allowed into the food system without regulation, the creator must provide solid evidence to the APHIS that the crop does not present any risk beyond that of

the nonmodified version. The Biotechnology Regulatory Services Program performs an environmental assessment of the GMO in question and then decides either to issue a permit, should the crop possibly pose a threat to any other organism, or to grant nonregulated status if there is no evidence of threat (32).

Labeling of GM foods is not currently mandatory in the United States. In 1992, the FDA published a Statement of Policy announcing that GE foods did not require labeling because they were not materially different from nonmodified versions, and under the Federal Food, Drug, and Cosmetic Act, only material information (that which would lead to health issues, environmental risks, or misinterpretation of nutritional content, usage, or information if omitted from a label) needed to be included on a label (33).

In response to public desire for labeling communicated during information requests and meetings, however, the FDA released a "Guidance for Industry" document advising interested companies on how they could label modified or nonmodified foods in a way that is informative and nonmisleading (34). The term "genetically modified" itself is brought into question because it technically refers to any genetic modification of a food item, which would include mutations or genetic breeding, in addition to the bioengineering that is meant by "GMO." In addition, the term "GMO-free" is prohibited because, as a result of an inability to test for the low-level presence of GM ingredients, there is currently no maximum threshold for GM ingredients below which a food can be legally deemed free. Companies can therefore state that a product was not made through genetic engineering but not that it is GMO-free. Non-GMO labels cannot be used to imply that a food is of higher quality than GM versions, because that is misleading and not supported by research, nor can the term be applied to crops for which there is no bioengineered version, because that would also mislead customers by making them think the product is different from other versions (34). Currently, the only US organization that offers verified testing for the presence of GMOs in products is the Non-GMO Project, which places a "Non-GMO Project Verified" seal on products to indicate not that they are GMO-free but, rather, that they contain no more than 0.9% GMO ingredients, which is the threshold used in the European Union for labeling (35).

The process for approval of GM foods in the EU is strictly regulated, with all new GM crops having to be presented to the European Food Safety Agency for a thorough risk assessment, after which the European Commission presents the results to the public, brings the resulting comments back to the Food Safety Agency, and then makes a final decision whether or not to grant authorization for the next 10 y. Unlike the United States, the European Union has enforced mandatory labeling and strict traceability of all bioengineered food, including any product, food, or animal feed produced from GMOs, since 1997 (11). In a 2003 ruling of the European Parliament, it was established that any packaged product that contains GMOs must clearly state, "This product contains genetically modified organisms" or "This product contains genetically modified [name of organism(s)]" directly on the label; all nonpackaged products that contain GMOs must include the statement within the product display (36). However, as of 12 June 2014, the European Parliament approved a political agreement allowing individual member states to restrict or even ban the growth of GM crops within their territory, with hopes of finalizing the text and enacting the proposal in 2015. Six countries have already embraced what is being called the "safeguard clause" to prohibit the growth or sale of bioengineered foods in their territory: Austria, France, Greece, Hungary, Germany, and Luxembourg (37). Because research has not currently indicated any heightened risks from GM foods, the restriction of GMOs in the commercial European market reflects the strong anti-GM public opinion among European consumers (38).

A recent survey of over 1700 US adults found that only 52% of consumers knew what GMOs were, and only 28% knew which products may have GMO ingredients. Overall, 40% of consumers report avoiding GMOs in their diet, 71% of whom were worried about health repercussions and 48% wanting to know "exactly what goes into the food [they] eat." However, the researchers noted that a small proportion could actually specify any particular disease or risk that they were avoiding with respect to GMOs, leading the researchers to conclude that consumers are mostly concerned about transparency in the food system. Accordingly, 66% of consumers responded that they want mandatory labeling for GMO products (39). This desire for labeling is echoed in other national surveys, including a 2012 survey of US votes in which 91% favored mandatory labeling of GE foods. Even when presented with arguments for and against GMO labeling, 89% of participants still supported the mandatory labels, indicating that the desire for transparency in the food system is deep-rooted (40).

Currently, labeling of GM foods is not mandatory in the United States despite the emergence of prolabeling movements. The Non-GMO Project, currently the only third-party verification organization in the United States, leads the most prominent US labeling effort by offering voluntary food testing and placing the "Non-GMO Project Verified" seal on foods containing $\leq$0.9% GM ingredients (based on the 0.9% threshold used in the European Union) (41). Additional global efforts to label or restrict GMOs in food include Dr. Vandana Shiva's antigenetic engineering campaigns throughout Africa, Asia, Ireland, Latin America, Switzerland, and Austria; the "Just Label It" movement, which unites partner organizations to motion for mandatory labeling in the United States; and the Center for Food Safety, an environmental organization that promotes consumer education and sustainable organic agriculture (42–44).

Although stricter regulation has been proposed, major legislation has not always succeeded; California's Proposition 37, which would have enforced mandatory labeling of GMO-containing foods, was defeated in November 2012, and similar proposals also failed in Washington, DC, Colorado, and Oregon since 2013 (38, 45). On 8 May 2014, however, Vermont passed its Genetically Engineered Food Labeling

Act, which will require all foods that contain >0.9% GM ingredients to be labeled as "may be partially produced with genetic engineering" beginning in July 2016 (46). Conditional provisions have been enacted in several other legal situations, such as Connecticut's 2013 decision to label all GMO-containing infant formulas, which will not go into effect until ≥4 other states pass similar bills, as well as Maine's 2013 law for labeling of products with >0.9% GMO ingredients if ≥5 other states pass a similar law (45).

Aside from mandatory labeling efforts, there have been recent advances in the legitimacy of voluntary labeling. In February 2015, The USDA's Process Verified Program applied its verification process to the world of GMOs by verifying SunOpta's Hope, Minnesota, facility as having the first completely audited and verified non-GE/GMO soybeans and corn (47). This advancement allows the USDA to ensure quality management and will result in non-GMO labeling of SunOpta's corn and soybeans based upon the 0.9% threshold until renewal in August 2015 (48). The application of USDA verification to GMO regulation will add a legitimacy to non-GMO claims that has been unprecedented in US GMO labeling policy.

The desire for labeling in the United States may not be as strong as elsewhere in the world, according to a crosscultural survey in which US consumers were slightly less likely to find labeling of GMOs to be somewhat or very important (80.8%) compared with Italian consumers (93.5%). Overall, 82.0% of consumers surveyed felt that labeling was somewhat or very important (17). However, a lack of awareness about labeling itself may be a barrier to knowledge as well. In a 2013 Rutgers University survey, 73% of participants felt that products containing GMOs should be labeled, yet only 26% knew that labeling was not currently mandatory in the United States (13). In the Hartman Group's survey (39), among anti-GMO participants, 57% were not familiar with the Non-GMO seal, 12% had noticed it but did not know what it represented, and 16% knew its purpose yet did not use it to make food choices. Only 15% reported actively seeking out the seal in order to choose non-GMO foods. Similarly, only 49% of anti-GMO consumers would use the Organic seal to find a non-GMO product, indicating a knowledge deficit, because products must not contain GMOs in order to be certified organic (39).

Conclusion and Discussion

GM products have been in the food system for decades and are becoming even more present, yet consumer knowledge and awareness are not improving accordingly. Surveys show that large percentages of consumers are unaware of GMOs or do not fully understand GM products, their traits, and their effects, and they themselves are dissatisfied with their self-rated knowledge, indicating a desire and a need for widespread consumer education. Thorough assessment of deficits in consumer knowledge of GMOs can lead to the development of guidance and policies to improve consumer understanding and improve knowledge. There is a demonstrated need for accurate and well-organized educational materials that provide scientifically supported information, as well as both the pros and cons of biotechnology. Future studies should examine methods of disseminating scientific information to consumers by using popular channels of information to help increase the volume and quality of GMO-related information available to the average consumer.

Sources of GMO knowledge need to be critically examined, because they have a major impact on what information consumers are exposed to, as well whether or not they trust what they are hearing. The majority of consumers are relying on the internet and media sources (including television and magazines) for GMO-related information, yet this information can be inaccurate, incomplete, or misleading, depending on the news outlet. The education of those responsible for disseminating scientific knowledge through such public media sources is of crucial importance, because their explanations of biotechnology directly inform the public.

Interestingly, consumers themselves tend to view "expert" sources as more trustworthy than the media, government, supermarket, or industry groups. Because media sources act as the primary source of GMO knowledge for many consumers, experts such as scientific researchers should consider stepping into the media spotlight in order to disseminate factual information. Similarly, more rigorous training of media representatives such as writers for news shows or magazines should be made a priority to ensure the accuracy of the information being spread to the public. Other sources of information are more difficult regulate, including information published on the Internet, informal blog posts written by nonscientific individuals, and conversations shared among friends. The presence of this type of informal information sharing may require consumers themselves to be more educated about which sources are reliable in terms of scientific information.

In light of the current research, a distinction must be made between self-reported familiarity with GMOs (which is sometimes referred to as "GMO knowledge," but could more accurately be referred to as "GMO familiarity") and "scientific understanding," which involves a deeper knowledge of scientific principles. Whereas GMO familiarity is tied to a preference for non-GMOs and higher willingness to pay for these alternatives, as was the case in Vecchione et al. (28) and Huffman et al. (29), higher scientific understanding is tied to less negative opinions of GM products, higher acceptance ratings, and less distinction between types of genetic modification, as seen in McComas et al. (30) and Mielby et al. (31). Although studies seemed to show some connection between level of education and a corresponding level of scientific understanding, level of education has not been shown to reliably predict understanding of or attitude toward GMOs.

Although consumers across the globe support mandatory GMO labeling, the limited extend of consumer knowledge regarding GMO characteristics, processing, and effects may present an issue for actual interpretation of the labels. Experts in the field should consider methods of educating the public more thoroughly so that they can use the information about GM contents responsibly and make fully informed judgments about their food choices.

Acknowledgments

Both authors read and approved the final manuscript.

References

1. Biotech Chronicles [Internet]. Access Excellence at The National Health Museum Resource Center; c1994–2009 [updated 1999; cited 2015 Feb 3]. Available from: http://www.accessexcellence.org/RC/AB/BC/1977-Present.php.
2. Bruening G, Lyons JM. The case of the flavr savr tomato. California Agriculture [Internet]. 2000 July-Aug [cited 2015 Feb 5];54(4):6–7. Available from: http://californiaagriculture.ucanr.org/landingpage.cfm?article=ca.v054n04p6.
3. Benbrook CM. Impacts of genetically engineered crops on pesticide use in the U.S.—the first sixteen years. Environ Sci Eur [Internet]. 2012 Sept 28 [cited 2015 Feb 4]; 24(24). Available from: http://www.enveurope.com/content/pdf/2190–4715–24–24.pdf.
4. Fernandez-Cornejo J. Agriculture Information Bulletin 786: The seed industry in U.S. agriculture: an exploration of data and information on crop seed markets, regulation, industry structure, and research development. Economic Research Service, United States Department of Agriculture; 2004 Feb.
5. Fernandez-Cornejo J, Wechsler S, Livingston M, Mitchell L. Economic Research Report Number 162: Genetically engineered crops in the United States. Economic Research Service, United States Department of Agriculture. 2014 Feb. [cited 2015 May 15]. Available from: http://www.ers.usda.gov/media/1282246/err162.pdf.
6. Information Biosystems for Biotechnology [Internet]. Virginia: Information Systems for Biotechnology; c2014 [updated 2015 Feb 4; cited 2015 Feb 4]. Available from: http://www.isb.vt.edu/.
7. Domingo JL, Giné Bordonaba J. Review: a literature review on the safety assessment of genetically modified plants. Environ Int 2011;37:734–42.
8. Hilbeck A, Binimelis R, Defarge N, Steinbrecher R, Székács A, Wickson F, Antoniou M, Bereano PL, Clark EA, Hanson M, et al. No scientific consensus on GMO safety. Environmental Sciences Europe. 2015;27:1–6.
9. Economic Research Service [Internet]. Recent Trends in GE Adoption. Washington (DC): United States Department of Agriculture; [updated 2014 July 14; cited 2015 Feb 4]. Available from: http://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us/recent-trends-in-ge-adoption.aspx.
10. International Service for the Acquisition of Agri-biotech Applications [Internet]. ISAAA brief 49–2014: Top Ten Facts. c2015 [updated 2014; cited 2015 Feb 4]. Available from: http://www.isaaa.org/resources/publications/briefs/49/toptenfacts/.
11. European Commission [Internet]. Food and feed safety: biotechnology. European Union; c1995–2015 [cited 2015 Feb 4]. Available from: http://ec.europa.eu/food/food/biotechnology/index_en.htm.
12. Hallman W, Hebden W, Cuite C, Aquino H, Lang J. Americans and GM food: knowledge, opinion & interest in 2004. New Brunswick (NJ): Rutgers, the State University of New Jersey, Food Policy Institute; 2004 Nov Report No. RR-1104–007.
13. Hallman WK, Cuite CL, Morin XK. Working Paper 2013–1: Public perceptions of labeling genetically modified foods. New Brunswick (NJ): Rutgers, the State University of New Jersey, School of Environmental and Biological Sciences; 2013 Nov 1. Available from: http://humeco.rutgers.edu/documents_PDF/news/GMlabelingperceptions.pdf.
14. Aleksejeva I. Latvian consumers' knowledge about genetically modified organisms. Management of Organizations: Systematic Research. 2014;71:7–16.
15. Turker T, Kocak N, Aydin I, Istanbullouglu H, Yildiran N, Turk YZ, Kilic S. Determination of knowledge, attitude, behavior about genetically modified organisms in nursing school students. Gulhane Tip Derg 2013;55:297–304.
16. Jurkiewicz A, Zagórski J, Bujak F, Lachowski S, Florek-Luszczki M. Emotional attitudes of young people completing secondary schools towards genetic modification of organisms (GMO) and genetically modified foods (GMF). Ann Agric Environ Med 2014;21:205–11.
17. McGarry Wolf M, Bertolini P, Shikama I, Berger A. A comparison of attitudes toward food and biotechnology in the U.S., Japan, and Italy. Journal of Food Distribution Research. 2012;43:103–10.
18. Colson G, Rousu MC. What do consumer surveys and experiments reveal and conceal about genetically modified foods? GM Crops Food 2013;4:158–65.
19. Lusk JL, Jamal M, Kurlander L, Roucan M, Taulman L. A meta-analysis of genetically modified food valuation studies. J Agr Resource Econ 2005;30:28–44.
20. Dannenberg A. The dispersion and development of consumer preferences for genetically modified food—a meta-analysis. Ecol Econ 2009;68:2182–92.
21. McInerney C, Bird N, Nucci M. The flow of scientific knowledge from lab to the lay public. Sci Commun 2004;26:44–74.
22. Lang JT, Hallman WK. Who does the public trust? The case of genetically modified foods in the United States. Risk Anal 2005;25:1241–52.
23. Dean M, Shepherd R. Effects of information from sources in conflict and in consensus on perceptions of genetically modified food. Food Qual Prefer 2007;18:460–9.
24. Lang JT. Elements of public trust in the American food system: Experts, organizations, and genetically modified food. Food Policy 2013;41:145–54.
25. Puduri VS, Govindasamy R, Nettimi N. Consumers' perceptions towards usefulness of genetically modified foods: a study of select consumers in USA. IUP Journal of Agricultural Economics. 2010;7:7–17.
26. Pew Initiative on Food and Biotechnology. Pew initiative on food and biotechnology finds public opinion about genetically modified foods "up for grabs." 2001 March 26.
27. Sorgo A, Jausovec N, Jausovec K, Pukeh M. The influence of intelligence and emotions on the acceptability of genetically modified organisms. Electron J Biotechnol [Internet]. 2012 Jan 15[cited 2015 Feb 5];(1):1–11. Available from: http://www.ejbiotechnology.info/index.php/ejbiotechnology/article/view/v15n1–1.
28. Vecchione M, Feldman C, Wunderlich SM. Consumer knowledge and attitude about genetically modified food products and labelling policy. Int J Food Sci Nutr [Internet]. 2014 Dec 18 [cited 2015 Feb 22];1–7. Available from: http://informahealthcare.com/doi/abs/10.3109/09637486.2014.986072.
29. Huffman WE, Rousu M, Shogren JF, Tegene A. The effects of prior beliefs and learning on consumers' acceptance of genetically modified foods. J Econ Behav Organ 2007;63:193–206.
30. McComas KA, Besley JC, Steinhardt J. Factors influencing U.S. consumer support for genetic modification to prevent crop disease. Appetite 2014;78:8–14.
31. Mielby H, Sandoe P, Lassen J. The role of scientific knowledge in shaping public attitudes to GM technologies. Public Underst Sci 2013;22:155–68.
32. Animal and Plant Health Inspection Service [Internet]. Washington (DC): United States Department of Agriculture; Biotechnology Regulatory Services. [updated 20 Jan 2015; cited 2015 Feb 4]. Available from: http://www.aphis.usda.gov/wps/portal/aphis/ourfocus/biotechnology.
33. Federal Food, Drug, and Cosmetic Act. United States Code, 2006 Edition, Supplement 3. Subchapter IV: Food. [Internet]. United States Food and Drug Administration; [cited 2014 Dec 4]. Available from: http://www.fda.gov/RegulatoryInformation/Legislation/FederalFoodDrugandCosmeticActFDCAct/default.htm.
34. U.S. Food and Drug Administration[Internet]. Guidance for industry: voluntary labeling indicating whether foods have or have not been developed using bioengineering; draft guidance. Silver Spring (MD): United States Food and Drug Administration; [updated 2014 Dec 16; cited 2015 Feb 4]. Available from: http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm059098.htm.
35. Non-GMO Project [Internet]. Bellingham (WA): Non-GMO Project; c2015 [cited 2015 Feb 4]. Available from: http://www.nongmoproject.org/.
36. Regulation (EC) No 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and feed. Official Journal European Union. L 268. P 0001–0023 (2003).

37. European Commission [Internet]. European Union; New EU approach. c1995–2015 [updated 6 Apr 2014, cited 2015 Feb 4]. Available from: http://ec.europa.eu/food/plant/gmo/legislation/future_rules_en.htm.
38. Twardowski T, Malyska A. Uninformed and disinformed society and the GMO market. Trends Biotechnol 2015;33:1–3.
39. Hartman Group. Organic & Natural 2014. Released 28 Aug 2014.
40. The Mellman Group, Inc. Voters overwhelmingly support a labeling requirement for GE foods. [Internet] 2012 March 22. [cited 2015 Feb 1]. Available at: http://justlabelit.org/wp-content/uploads/2012/01/Mellman-Survey-Results.pdf.
41. Non-GMO Project Verified: Understanding Our Seal [Internet]. [cited 2015 Jun 30]. Available from: http://www.nongmoproject.org/learn-more/understanding-our-seal/.
42. Vandana Shiva [Internet]. [cited 2015 Jun 30]. Available from: http://vandanashiva.com/.
43. Just label it [Internet]. [cited 2015 Jun 30]. Available from: http://www.justlabelit.org/about-just-label-it/.
44. Center for Food Safety [Internet]. [cited 2015 Jun 30]. Available from: http://www.centerforfoodsafety.org/about-us.
45. Hemphill TA, Benerjee S. Mandatory food labeling for GMOs. Regulation 2014/2015;37:7–10.
46. McPherson MJ. What's in a name: the Vermont genetically engineered food labeling act. J Law Biosci 2014;1:359–68.
47. SunOpta [Internet]. SunOpta's Hope, Minnesota facility becomes first to receive non-GMO/GE USDA process verified program certification. Globe Newswife. [cited 15 May 2015]. Available at: http://investor.sunopta.com/releasedetail.cfm?ReleaseID=913622.
48. USDA Agricultural Marketing Service [Internet]. Grading, Certification and Verification. Washington (DC): United States Department of Agriculture; [updated 11 June 2015; cited 4 Jul 2015]. Available from: http://www.ams.usda.gov/AMSv1.0/processverified.