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An Overview of Attitudes Toward Genetically Engineered Food

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Abstract

Genetically engineered food has had its DNA, RNA, or proteins manipulated by intentional human intervention. We provide an overview of the importance and regulation of genetically engineered food and lay attitudes toward it. We first discuss the pronaturalness context in the United States and Europe that preceded the appearance of genetically engineered food. We then review the definition, prevalence, and regulation of this type of food. Genetically engineered food is widespread in some countries, but there is great controversy worldwide among individuals, governments, and other institutions about the advisability of growing and consuming it. In general, life scientists have a much more positive view of genetically engineered food than laypeople. We examine the bases of lay opposition to genetically engineered food and the evidence for how attitudes change. Laypeople tend to see genetically engineered food as dangerous and offering few benefits. We suggest that much of the lay opposition is morally based. One possibility is that, in some contexts, people view nature and naturalness as sacred and

genetically engineered food as a violation of naturalness. We also suggest that for many people these perceptions of naturalness and attitudes toward genetically engineered food follow the sympathetic magical law of contagion, in which even minimal contact between a natural food and an unnatural entity, either a scientist or a piece of foreign DNA, pollutes or contaminates the natural entity and renders it unacceptable or even immoral to consume.

Contents

1. INTRODUCTION

The appearance and growing importance of genetically engineered (GE) food and the extensive resistance to it raise many issues specific to this technology as well as more general issues, including lay views about what is natural. For the purpose of this article, we use the definition of GE food from the National Academies of Sciences, Engineering, and Medicine (NASEM), which is "the introduction of or change to DNA, RNA, or proteins manipulated by humans to effect a change in an organism's genome or epigenome" (76, p. 36). The topic is of interest to nutritional scientists and the public at large for the reasons outlined below.

1. Genetic engineering and related technologies are becoming increasingly important and prevalent in the food world (see Sections 3 and 6).
2. GE food has a major economic impact, as does what consumers consider to be the opposite of GE food, organic food (see Sections 3 and 6).

3. There is both strong support for and strong opposition to GE food from individuals, governments, and other institutions (see Sections 3 and 4).
4. There is a large gap between the attitudes of the lay public toward GE food and the attitudes of life scientists (see Section 4).
5. GE food touches on a more general issue in our time that extends well beyond food: the perceived nature and meaning of natural, and its desirability (see Section 2).
6. GE food arouses moral as well as consequential concerns (see Sections 2 and 4).

2. LAY MEANINGS OF NATURAL AND THE PREFERENCE FOR NATURAL

2.1. Belief in the Benevolence of Nature Versus Technological Change

Some of the public's concerns about GE food are a relatively late manifestation of the general concern among many in the developed world about the tension between technology and what is natural. The first section of this review establishes the pronatural context that preceded the appearance of GE food.

Interest in and affection for nature begin with the appeal of the natural world, that is, natural landscapes and the animals and plants that inhabit them. This has a long history, although the dominant view in the West, derived in large part from Judeo–Christian tradition, divides the world into humans and everything else. It emphasizes dominance over nature, a utilitarian view of nature, a stewardship over nature, and mastery over nature (58, 59, 123, 135). In traditional cultures and in much of Asia, Latin America, and Africa (i.e., most of the world), humans are seen as part of nature rather than apart from nature (58, 71, 134). This difference may have major effects on preferences for naturalness and on attitudes toward GE food, but this has not been explored.

Given the Western tradition of transforming and overcoming nature, it is quite remarkable that natural and organic food became of major interest and an important part of food sales (87, 126). The rise in interest in natural food and disinterest in or opposition to GE food is associated with a general belief among many Westerners in what we will call the benevolence of nature (98, 137). In the contemporary developed Western world (principally the United States, Canada, Australia, New Zealand, and Western Europe), nature is viewed as a positive, benevolent force. To some extent, this may result from an innate human predisposition to prefer engaging with the environments that surrounded us through most of our evolution. This has been called biophilia by E.O. Wilson (137), an idea that has been developed by Stephen Kellert (58, 59). Biophilia refers to an innate predisposition to have an aesthetic appreciation of and attraction to natural environments, including the flora and fauna in these environments. It does not claim that these environments are actually safer or better for humans. Nature is responsible for decay, disease, and death itself, whereas human intervention has provided us means such as refrigeration, freezing, canning, nutritional supplements, and preservatives to sharply reduce the incidence of nutrient deficiencies and acute food poisoning.

2.2. The Meaning and Attributes of Naturalness for Laypeople

There is no single definition of naturalness agreed to by either laypeople or experts (88). Unlike organic, naturalness is not legally defined by the US Food and Drug Administration. There are, however, some features of naturalness that are relevant to understanding reactions to GE food.

2.2.1. Additivity dominance. Adding things to a natural entity tends to reduce naturalness, more so when the additive is itself unnatural. However, taking things out (e.g., the fat from whole milk) has a surprisingly small effect on naturalness (93). In many cases, adding something (e.g., pulp to orange juice, for extra-pulp orange juice) lowers naturalness more than removing the same thing (e.g., pulp from orange juice, for pulp-free orange juice) (104).

2.2.2. Contagion. Unnatural entities have a contagious property when they interact with desirable, natural food. The sense of contagion here is not the same as the most common use—spread by infection—but rather that unnatural food can act as a contaminant. The naturalness of products is fragile in that even tiny amounts of artificial additives can have a major effect on naturalness. This is consistent with the sympathetic magical law of contagion: Tiny amounts of a negative entity can permanently render a desirable entity unacceptable, as when a cockroach touches a desirable food (91, 96, 97). Contagion will be revisited below in the discussion of attitudes toward GE food (see Section 4.3).

2.2.3. Process. When it comes to determining the naturalness of an entity, in many situations the processing an entity has undergone is more important than its content. At first glance, it would seem that naturalness is determined almost entirely by the content of an entity. However, human intervention—a process—is a major part of the lay definition of naturalness. The most common definition of naturalness given by Western Europeans and Americans in open-ended responses is the "absence of human processing," followed closely by the "absence of additives" (94). Under many conditions, the history of the processing of an entity may be more important than its actual content (91, 92). The preference for naturalness is only slightly reduced when the natural and processed alternatives are stipulated to be chemically identical in their content (98). Furthermore, when natural spring water A is described as being supplemented with a natural mineral additive, the resultant water B is rated as less natural. This could be because it was subjected to a process or because its content was changed, or both. Yet when the natural additive is removed, the resultant water C is chemically identical to the original natural water, but has been subjected to two stages of processing. This reconstituted water is rated less natural than water B, arguing strongly for processing as the major force in reducing naturalness (92). However, it is clear that the presence of pesticides or antibiotics in food (content) renders it less natural in the absence of any information about how these contaminants entered the food (process). We do not know what determines the relative potencies of content and process in degrading naturalness.

2.2.4. Domestication (human-caused genetic selection). Domestication has a minimal effect on naturalness: Domesticated products, such as corn or tomatoes, and domesticated animals, such as dogs, are rated as very natural (91).

2.3. The Growing Importance of Natural and Organic Food

The preference for natural and organic food is very strong in developed countries (88, 94, 98). There are a number of scales that measure the determinants of food choice, and all scales, to our knowledge, include a natural factor or subscale (e.g., 3, 86, 116). Results from studies using these scales [principally the nine-factor Food Choice Questionnaire (116)] in many developed countries (and in some others) generally show that the natural subscale is one of the most highly endorsed dimensions of choice (54, 85). In the Nielsen Global Health & Wellness Survey (79), which includes results from 30,000 respondents in 60 countries, the food attributes that were considered most desirable were freshness, naturalness, and minimal processing.

Because natural is not a regulated term—and hence can be placed on almost any product and is not tracked systematically—the only meaningful sales data come from the organic food sector. Worldwide, the sale of organic food has risen steadily from 1999 ($15.2 billion) to 2016 ($90 billion) (115). According to the US Department of Agriculture, "Consumer demand for organically produced goods continues to show double-digit growth, providing market incentives for U.S. farmers across a broad range of products. Organic products are now available in nearly 20,000 natural food stores and nearly 3 out of 4 conventional grocery stores. Organic sales account for over 4 percent of total U.S. food sales, according to recent industry statistics" (126). Fruits and vegetables account for 43% of all organic food sales. Interestingly, the growing demand by American consumers for products not containing genetically modified organisms (GMOs) has led to the development of the non-GMO label, which currently competes with the organic label in the marketplace since it is cheaper (13, 69).

2.4. Summary

What emerges from this research is that the lay conception of naturalness (particularly the strong emphasis on processing, additivity dominance, and the treatment of additives as contagious) relies on heuristics and intuitions. These lay intuitions likely play a strong part in attitudes toward GE food, which is discussed in Section 4. First, however, we provide an overview of the technical and regulatory landscape of GE food products.

3. GENETICALLY ENGINEERED FOOD PRODUCTS

3.1. Definition of Genetically Engineered Food (and Nonfood)

Selective breeding has been a standard practice in agriculture since long before modern genetic engineering techniques were developed. Humans transformed teosinte (corn's wild relative) into maize (corn) by strategically selecting seeds from plants with highly desirable traits. Because of these human interventions, maize evolved from a plant with many branches and small cobs to a plant with fewer, larger stalks and larger kernels (19). Similarly, the tomatoes sold in stores today are the product of careful genetic selection used to alter their size, shape, seeds, and taste (4). However, the process of creating new traits is slow because it requires waiting for rare genetic mutations.

As genetic technology advanced, so did the area of research now known as genetic engineering. The term genetic engineering is synonymous with genetic modification, and the products of these processes are often referred to as GMOs, GE or genetically modified crops, and GE or genetically modified foods. The process is defined as "the introduction of or change to DNA, RNA, or proteins manipulated by humans to effect a change in an organism's genome or epigenome" (76, p. 36). While genetic engineering has been used with plants and animals, the technology is applied more often to plants.

In the 1970s, researchers explored ways to insert genetic material from one organism into the genetic material of another organism (16). This research, and other related developments, provided the foundation for making changes to plants' traits more efficiently and effectively. As technology advanced, experts transferred specific genes between organisms through transgenesis to alter the expression of specific traits. Most commercial GE crops had a single transgene added to their genome using either gene gun– or *Agrobacterium*-mediated methods (76). However, the use of transgenic engineering in food has prompted concerns about the effects the genetic material might have on consumers (117). To address these concerns, research has focused on approaches that use genes only from the same or related species (89, 102). These approaches have demonstrated higher consumer acceptance than transgenic approaches (66).

Recent advances in genetic technologies have fueled a rapid evolution in genetic engineering capabilities (76). Traditional genetic engineering techniques, such as the use of gene guns and *Agrobacterium*, were much simpler and produced products that were easier to classify as GE. While generally effective, these methods are not always precise (76). However, modern genome editing techniques, such as CRISPR/Cas9 (105), enable precise, untraceable genetic changes and produce products that may prove difficult to classify and regulate as either GE or non-GE. Beyond technological engineering, conventional breeding also changes the genetics of plants and animals, but it does so through selective breeding or by causing genetic mutations in a plant or animal.

3.2. Prevalence of Genetically Engineered Food

GE products first arrived in the US commercial market in 1996. The first product was the Flavr Savr tomato, engineered to have a longer shelf life. However, after initial success and sales, stores stopped carrying the product because of mounting customer concerns (10).

Just over two decades later, GE plants are now prevalent. In the United States alone, GE crops are planted on half of the country's cropland (26). Worldwide, GE crops are planted on 12% of total cropland (179.7 million hectares) (53), mainly in North America, South America, and Asia. The acreage planted with GE crops remains extremely small in Western Europe and Africa. Of the 12 most common GE crops, 9 are grown for human consumption (maize, soybeans, canola, sugar beet, papaya, squash, eggplant, potato, and apples) and 3 are not (cotton, poplar trees, and alfalfa). In addition to the GE crops that are directly consumed by humans, several are used to feed livestock (e.g., alfalfa) or processed into other food ingredients (e.g., sugar from sugar beets) (128). Since soybeans and corn (the most widely planted GE crops) are common ingredients in many food products (corn starch, corn syrup, corn oil, and soybean oil) (128), it is likely that foods in the United States listing soybeans and corn as ingredients contain some GE ingredients unless it is specifically stated that they do not (99). Even by the more-stringent European Union regulations, if these GE ingredients are present in small amounts (less than 0.9% of overall food ingredients), they are exempt from traceability and labeling requirements (24), as is discussed in more detail in Section 3. The complexities surrounding GE ingredients and products make it difficult to quantify exactly how much of the food sold for human consumption contains some level of genetic engineering.

The majority of commercialized GE crops today—that is the first-generation GE crops—has genetic alterations that increase resistance to herbicides and insects (76). The most common of these are maize, soybeans, and cotton. However, genetic engineering can be used to engineer plants for many potentially beneficial purposes, such as having a longer shelf life, nonbrowning quality (for apples), higher vitamin content, and resistance to various diseases (105). Other GE crops are in the research pipeline, particularly with the development of new technologies such as the above-mentioned CRISPR/Cas9, which has already been used to produce and commercialize nonbrowning apples in the United States (105, 132).

The applications of genetic engineering have also moved beyond plants to include animal products, such as salmon. In 2015, GE salmon were approved for human consumption in the United States, long after researchers were able to engineer the fish to grow faster in the 1990s (84). From the outset, the approval process for GE salmon has met strong resistance from consumers, grocery stores, and restaurants. Areas of concern for these groups are the regulatory aspects, such as labeling (36, 78), and the federal approval processes for GE animals for human consumption (60, 113). Additional concerns involve the potential effects that GE fish might have on ecosystems if they escape or are released into the wild (60, 75, 113). Despite these and other concerns, the first order for GE salmon was sold by an American company to Canadian consumers in 2017, marking the first sale of GE animals as a food product for human consumption (133).

3.3. Legal Status

GE food is regulated differently around the world (82, 131). There are some international standards, such as the Codex Alimentarius Commission's guidelines, that address assessments of GE crops and foods that contain them (14). However, no single international authority oversees the food production process (12). This leaves the regulation of GE crops and foods up to individual countries, with many having extremely different approaches. As a 2016 NASEM report on GE crops emphasized (76), it is not surprising to find a diversity of regulatory processes for products of genetic engineering because the processes mirror the broader social, political, legal, and cultural differences between countries.

In Europe, countries largely adhere to the precautionary principle, a conservative attitude toward regulation. All GE foods (just like all new foods) are considered case by case, and they undergo extensive evaluation by the European Food Safety Authority. Only two GE crops (potato and maize) have been licensed to be grown commercially in the European Union during the past two decades (67). However, none of these crops are in production for human consumption due to consumer resistance. Conversely, other countries, such as the United States, approach regulation with an attitude referred to as substantial equivalence, focusing more on assessing GE products by comparing them with similar ones (37). In the United States, GE products are "generally recognized as safe" unless the product "differs significantly in structure, function, or composition from substances found currently in food" (127). Regulations developed using the substantial equivalence approach tend to be more accepting of GE crops.

Four distinct types of regulatory approaches have been categorized: promotional, permissive, precautionary, and preventive (83). Promotional policies attempt to increase the use of genetic engineering technologies. Permissive policies are relatively neutral. Precautionary policies attempt to slow the use of genetic engineering without directly blocking it. Lastly, preventive policies seek to limit or eliminate the use of genetic engineering. On one end of the spectrum, countries such as Peru, Turkey, and Ukraine have regulations that are not restrictive and lean toward more promotional policy approaches, while countries such as Denmark, France, and Italy are much more restrictive and have more preventive policies (130). Countries that are more restrictive have more stringent requirements for labeling GE ingredients, and for conducting risk assessments and approval processes. Some countries have more lenient policies or may not regulate certain aspects, such as labeling. Countries such as India, Mexico, and the United States are among the least-restrictive countries (130), but each country takes a slightly different approach toward regulating GE crops and food.

Moving forward, it will be increasingly important that regulators become more active in engaging and communicating with the public about how both GE and non-GE foods are regulated and evaluated (76). This is especially important because, in many respects, GE crops and foods are just as much social and political issues as they are scientific issues. The social and political dimensions of the technology are an integral part of understanding the attitudes surrounding GE foods. Consumers may be responding to a variety of factors beyond those rooted only in science, as we discuss in the remainder of the review.

3.4. Labeling Genetically Engineered Foods

Two of the most contentious debates have been whether foods containing GE ingredients should be allowed to be commercialized for human consumption and, if this is allowed, how they should be labeled. Americans largely agree that these products should be labeled (43, 99). Those in favor of labeling argue that consumers have a right to know and right to choose whether their foods contain GE ingredients (50). Opponents of labeling claim that labels imply a warning and add unnecessary costs for consumers (50), that the use of GMO labels could stigmatize the technology (23), and that such labeling may actually lead to fewer choices for consumers because producers will likely remove products containing GE ingredients to avoid the negative implications of the labels (38). The issue of labeling is a social and political issue rather than a strictly scientific one (50, 76), and as a result it is generally addressed by political regulation.

Approaches to labeling products containing GE ingredients vary worldwide, with some countries not requiring labeling and others enforcing strict, mandatory labeling laws. Many countries—including the United States in 2016—have passed legislation that requires GE foods to be labeled. In the United States, this highly debated law overrides state-level regulations (like the more stringent law passed in Vermont) and requires agencies to set national standards for GE labeling by 2018 (42). The law gives wide latitude to the federal government in setting US policy for regulating labels. Conversely, the European Commission requires labeling of foods made with GE ingredients (24). However, because of the restrictive regulatory approaches toward genetic engineering outlined above, very few GE crops are approved for cultivation in the European Union, and many GE products are imported or used for animal feed, or both (25). These varied approaches to labeling reflect the differences in regulatory approaches toward GE products.

3.5. Known Benefits and Risks

In 2016, NASEM released a consensus report that summarized the research into the health, environmental, agronomic, and societal impacts associated with GE crops (76). A team of experts serving pro bono analyzed more than 1,000 research articles and other publications. The committee also held a series of meetings to gather information and reviewed more than 700 comments submitted by the public (76). After reviewing this vast amount of information, the authors reported key findings about the effects of GE crops.

The report listed both the benefits and the potential risks associated with GE crops. With respect to agronomic and environmental effects, there was no conclusive evidence to connect GE crops with environmental problems, but there was also no evidence that using GE technology had helped increase US crop yields. Although there was some evidence that gene flow (the movement of genetic material from one organism to another) had occurred, there were no examples of it causing adverse effects on a related wild species (76).

Among the general public, the effects on human health (such as the risks of cancers and allergies) of consuming GE food raise the most concerns. Therefore, the NASEM report reexamined most of the original studies in that area and concluded they had failed to find "persuasive evidence of adverse health effects directly attributable to consumption of GE foods" (76, p. 157). Importantly, the authors added the caveat that, as with any technology, there may be subtle health impacts that are not detected or that may develop over time and that new food products using genetic engineering technologies should continue to be carefully assessed.

3.6. The Future of Genetically Engineered Products

The perceptions and regulation of GE crops and genetically modified food are going to become more complex with technological advancements such as CRISPR/Cas9 (105). Tools such as CRISPR allow more precise and advanced genetic engineering. Advances are not limited to genetic engineering. New methods in conventional breeding are making the already thin line between genetic engineering and conventional breeding harder to define. As a result, the NASEM consensus report on GE crops recommended that the concern surrounding these crops should be directed more broadly at modern agriculture instead of focusing exclusively on GE crops (76).

4. THE BASES OF LAY ATTITUDES TOWARD GENETICALLY ENGINEERED FOOD

4.1. Risks, Benefits, Knowledge, and Trust

Research about the bases of lay attitudes toward GE food has focused heavily on rational predictors of opposition to GE food, including the perceived risks and benefits, (lack of) knowledge, (lack of) trust in science, and (lack of) trust in institutions (17, 34, 74, 107). A large amount of research has focused on perceived risks because these seem a priori to be likely causes of anti–genetic engineering attitudes. A follower of the precautionary principle, for example—which holds that an action that might cause harm should not be undertaken without near certainty about its safety—might well oppose GE food based on its possible risks (119) (for a review of critiques of the precautionary principle, see 118). The public perceives GE food as very risky (35, 43), which is inconsistent with the scientific consensus (76, 111). Perceived risk has repeatedly been documented to be a predictor of lay opposition (72, 74, 108, 111). Some models find that risk perceptions explain more variance than benefit perceptions (72, 74). Indeed, other factors, such as trust or sociodemographic variables, might exert effects indirectly by changing risk perceptions (74).

Perceptions of benefits—more specifically, the absence of benefits—are also related to opposition to GE food. First-generation GE crops provide benefits that accrue more directly to producers than consumers, such as resistance to pests, disease, and herbicides (65). Consumers are likely to reject GE crops that do not provide any direct, tangible benefits to them. Consistent with this possibility, benefit perceptions predict attitudes toward GE food (108, 111, 124). Moreover, according to a meta-analysis of consumers' willingness-to-pay valuations, the premium consumers are willing to pay for non-GE food is halved when GE food offers them a direct, tangible benefit (65). Some models even suggest that a segment of consumers rejects GE food based on its absence of benefits, without much consideration of risks at all (34).

Another important predictor of attitudes is trust in the institutions handling genetic engineering technology and providing information, such as industry, government regulatory bodies, and scientific institutions. In this case, the effect of trust on attitudes is likely to be indirect, via risk and benefit judgments. That is, if laypeople feel that they know little about gene technology, they may rely on other institutions to manage risks. If those institutions are trusted, the technology is not considered risky. Some empirical support for this indirect role of trust comes from models suggesting that trust alters risk and benefit perceptions, which in turn affect overall attitudes toward GE food (107, 108).

A final potential predictor of attitudes might be consumers' knowledge about the science of genetic engineering. The public knows little about genetic engineering. In one nationally representative survey in the United States in 2013, 54% of people said they knew "very little" or "nothing at all" about GE food, and 25% were not aware of the existence of GE food prior to the survey (43). Therefore, policy-makers have attempted to increase the public's knowledge of science broadly and the science of genetic engineering specifically in the hopes that that this will increase the acceptance and favorability of genetic engineering (11). These practices are grounded in a deficit model of science communication, which holds that people oppose novel technologies, such as genetic engineering, primarily because they do not understand them (6, 11).

According to this view, if people understood the science of genetic engineering, they would be more accepting of it. Consistent with the deficit model, some researchers have found positive associations between specific knowledge and acceptance of genetic engineering (44, 52, 62). However, these associations (if significant) are usually small. Some researchers distinguish subjective knowledge (how much one believes one knows) from objective knowledge (how much one actually knows, usually captured by true-or-false quizzes). However, even when both subjective and objective knowledge are measured, some studies find effects only for subjective knowledge (52) and others find effects only for objective knowledge (138). Finally, a meta-analysis across countries found a potentially negative relationship between biology-specific knowledge and attitudes about GE food, indicating that the knowledge–attitudes relationship is complex and context specific (2).

4.2. Moral Values

Focusing on rational influences on attitudes, particularly beliefs about risks and benefits, is clearly useful, but it also has drawbacks. First, differences in risk–benefit beliefs are unsatisfying as an explanation for the divergent attitudes between life scientists and laypeople. These differences are real, but they need to be explained: Why would the public's risk–benefit assessments differ from the scientific consensus? Second, the causal model—which assumes that attitudes toward genetic engineering result from preexisting risk–benefit beliefs—may be incorrect. Instead, beliefs about the risks of genetic engineering and its benefits may follow from preexisting general attitudes toward genetic engineering or toward scientific innovations in general, rather than independently determining them (18, 27, 110). Third, there is some evidence that information about risks and benefits does little to persuade individuals about the acceptability of GE food (see Section 5) (32, 101). If attitudes are based on risk–benefit analyses, information on risks and benefits should have an impact, especially if individuals are aware that they have negligible preexisting knowledge about the risks and benefits.

There is evidence that for some people, GE food is a moralized issue for which individuals base their opposition on moral convictions about the process of genetic engineering. There is an extensive literature in social psychology and judgment and decision-making about the cognitive and affective consequences of treating one's commitment to certain values as moral. Researchers have described these moralized values as "sacred values" (122), "protected values" (5), or "moral convictions" (112). The authors of these studies agree on two basic features: First, moral values are treated as absolute and, thus, as exempt from consequence-based trade-offs. Many people believe, for example, that buying and selling human organs are intrinsically morally wrong and should be prohibited regardless of whether organ markets might make people better off on average (90). Second, violating these values evokes strong negative emotions, including anger, contempt, and disgust (95).

Attitudes toward GE food exhibit both of these features of moralized values. First, in prior work, we have found that most Americans (64%) were opposed to GE plants and animals (103) and that a majority of these opponents (71% of those opposed, i.e., 46% of the entire sample) were moral absolutists. Moral absolutists thought genetic engineering should be prohibited "no matter how great the benefits and minor the risks from allowing it"—that is, they treated their opposition as absolute, a hallmark of moral values (5, 122). These moral opponents were absolutists in other ways, too; 95% of them agreed that "It is equally wrong to allow some of this to happen as to allow twice as much to happen. The amount doesn't matter," and 93% of them agreed that "This would be wrong even in a country where everyone thought it was not wrong." For these opponents, the process of genetic modification itself appears to violate some basic moral principles such that it is unacceptable regardless of the consequences, quantity, or context. Therefore, this opposition is, quite reasonably, refractory to cost–benefit evidence, and it is resolute despite little knowledge about risks and benefits. Second, broadly speaking, GE evokes moral outrage among many opponents. GE food evokes negative imagery (109) and negative emotions, especially disgust (103).

Furthermore, there is some evidence that including measures of moral values and moral opposition increases model fit when predicting opposition. Moral judgments about genetic engineering (e.g., it is an immoral risk, the degree of moral acceptability) help account for overall risk perceptions and attitudes even when accounting for demographics and other risk-perception variables (111, 120). However, evidence concerning the predictive power of moral values is mixed: Some investigators have found that moral concerns are not predictive after controlling for other factors (114) or that moral concerns and risk are so highly correlated they should be treated as one factor (73).

We do not know precisely which moral intuitions underlie opposition to genetic engineering. Numerous values have been proposed and examined, including socio–moral attitudes, such as individualism (versus communitarianism) (22); hierarchicalism (versus egalitarianism) (22); valuing power and dominance (21); alienation from the marketplace (39); deference to scientific authority (9); and attitudes toward the role of technology in society (7, 107). Levels of religiosity are sometimes predictive of opposition to genetic engineering, which suggests that one intuition underlying moral opposition might be that genetic engineering is a way of playing God or goes against God's creation (51).

In addition to the above values, we believe that naturalness is a particularly promising candidate value underlying moral opposition to genetic engineering. As reviewed above, opposition to genetic engineering emerged against a backdrop of a deep-seated affinity for nature and a belief in the benevolence of nature. Genetic engineering is viewed as very unnatural, and positive attitudes toward the natural world repeatedly predict negative attitudes toward genetic engineering (either directly or indirectly by influencing perceptions of risks and benefits) (7, 103, 106). This suggests that for many people, intuitions about the unnaturalness of GE food may underlie moral opposition—that is, it may be that the perceived unnaturalness of GE food makes it not only unappealing or undesirable but actually morally repugnant. This would imply that naturalness is a sacred or protected value (5, 122) in the food domain. A fair amount is known about the psychology of naturalness (see Section 2), but there is not much research applying this specifically to GE food. We believe that the psychology of contagion—which is known to be important in judgments of (un)naturalness more generally—is especially important in regards to GE food. Contagion is not a moral value itself, but principles of contagion operate in lay perceptions of naturalness. If what is natural is moral, then contagion explains when something is unnatural and, therefore, how people perceive that moral value to be violated. We outline this account in the next section.

4.3. Contagion Intuitions

Originally described as one of the laws of sympathetic magic by Tylor (125), Frazer (29), and Mauss (68), the law of contagion holds that "once in contact, always in contact"—in other words, invisible essences can be communicated between objects by physical contact. In anthropological work conducted around the beginning of the twentieth century, the laws of sympathetic magic were thought to describe beliefs in preindustrial cultures. However, they have also been found to underlie the intuitions of educated adults in developed countries, although these individuals may experience conflict between their intuitive reactions and their explicit beliefs (96, 97). Contagion is closely related to judgments of naturalness, which follow the laws of contagion (91, 104). In fact, one reason why entities might be judged as unnatural is that they are contaminated by human processing (i.e., contact with either a foreign entity or the individual doing the processing).

In the context of contagion, the end product (GE food) is called the target, and the negative contagion (the source) is either the foreign essence (DNA) or the actual contact with the scientist or other stranger who accomplishes the transfer. Note that unlike many other examples of contagion (e.g., an insect leg in a bowl of soup), here the source is not intrinsically negative, but becomes negative by virtue of being where it should not be (20).

The law of contagion has four features that are relevant to beliefs about GE food (97).

1. Physical contact is critical: In order for contagion to occur, the source must come into contact with the target, either directly or via an intermediary.
2. Once in contact, always in contact: Physical contact is essential, but it need not be ongoing. Once the source and target have come into contact, essence has been transferred—that is, ongoing contact is not necessary.
3. Any part represents the whole (metonymy): Any part of the source can transfer the essence of the whole. A single fingernail clipping, for example, contains the essence of the person it came from.
4. Amount does not matter (dose insensitivity): Even a tiny amount of a contaminating substance (e.g., a single insect leg) is sufficient to contaminate a large amount of a previously desirable substance (e.g., a kettle of soup).

There is some anecdotal evidence that the contagion heuristic is important in beliefs about GE food. GE food is often described by opponents as contaminating people by ingestion and as contaminating the natural environment by contact (70). Furthermore, laypeople often seem to think of genetic engineering as transferring essences from the donor organism to the host. For example, GE tomatoes incorporating a frost-resistance gene from the Arctic char fish were developed but never brought to market. The mere existence of this product stoked popular revulsion about "fish tomatoes"; in a subsequent poll, 27% of respondents agreed that tomatoes with fish genes would taste "fishy" (45). It seems that laypeople intuitively regard a transfer of genes as a transfer of essence. Scientifically, this is mistaken, as the vast majority of a species' genes are not unique. For example, by some estimates about 60% of the fruit fly's genome also appears in humans (77), and chimps and humans share more than 95% of their genomes (129). However, these intuitions follow straightforwardly from the contagion heuristic. Single genes carry the essence of the organism from which they came (metonymy), and when they are inserted into a different organism (physical contact), they contaminate it, even though the amount of inserted DNA is very small relative to the organism's entire genome (dose insensitivity). This contamination is passed on to the organism's offspring (once in contact, always in contact).

Based on this anecdotal evidence and our prior work on the association between disgust and reactions to GE food (see the final paragraph of this section), we expected that the contagion heuristic would provide a useful framework for understanding GE food. We surveyed the evidence about reactions to GE food with an eye toward findings that speak to the appropriateness of a contagion framework and found a number of relevant results.

A few studies have examined which types of genetic modification are more or less acceptable. These studies paint a picture consistent with the predictions of the law of contagion. First, if the contagion hypothesis is correct, organisms produced via gene insertion should be evaluated more negatively than those produced via gene deletion because insertion introduces foreign, contaminating DNA into the host organism, whereas gene deletion does not. Consistent with this hypothesis, Scott & Rozin (104) found that organisms with a gene inserted are perceived as less natural than those with a gene deleted.

Second, the contagion hypothesis predicts that the source of the gene should matter. According to the metonymy principle, people will treat DNA from a source as transferring properties of the entire organism (e.g., inserting fish DNA makes a food "taste fishy"). Therefore, the more distant the source organism is from the target organism, the more contaminating or foreign the gene transfer is. Indeed, the more foreign the source of DNA, the less accepting people are of genetic engineering. Transferring DNA from a different species is seen as less acceptable than transferring DNA from an organism in the same species (35, 66), and transferring DNA from an animal to a plant is less acceptable than transferring DNA from one plant to another (66).

A third prediction of the contagion hypothesis is that the number of genes transferred should not matter much if they are all from the same source. This prediction follows directly from the dose insensitivity property of contagion. One study provides data consistent with it. In this study, 38% of US consumers were unwilling to eat a vegetable with one gene inserted from a different vegetable. Changing the dose (the number of genes inserted) had a minor impact: Unwillingness increased by only nine percentage points if the vegetable had several extra genes inserted instead of one. This increase in opposition was reliable, but—consistent with dose insensitivity—the change in opposition was small compared with other manipulations. For example, manipulating how foreign the gene source was (e.g., a gene from a different vegetable versus an animal versus a bacterium) changed opposition by up to 45 percentage points. Patterns of results in France were similar, although opposition was higher overall (66).

Finally, there is also some indirect empirical evidence from investigations of individual differences for the role of contagion in attitudes toward GE food. Scott et al. (103) found higher disgust sensitivity—as assessed by the Disgust Scale-Revised (41) and modified by Reference 81—among opponents of GE food. The Disgust Scale-Revised partly assesses contagion beliefs (e.g., "I never let any part of my body touch the toilet seat in public restrooms"; "It would bother me to sleep in a nice hotel room if I knew that a man had died of a heart attack in that room the night before"), although it was not designed specifically for this purpose.

4.4. Political Aspects of Genetically Engineered Food

Other scientific topics with large public–expert gaps are polarized politically; for example, in the United States, self-identified political conservatives are much less likely than liberals to think that the Earth is warming because of human activity or that people have evolved over time (33). Once a scientific issue becomes aligned with a broader social or ideological orientation, people tend to ignore the views of experts in favor of the views of their ideological in-group (56). This linkage of an attitude to issues outside of its domain can be self-reinforcing as people will seek out and preferentially attend to information that supports their prior preferred beliefs (56, 64).

However, in contrast to climate change and evolution, beliefs about GE food are not linked to political (e.g., liberal-to-conservative) commitments. Representative surveys consistently show that in the United States, attitudes toward GE food have nonsignificant, minimal correlations with political ideology (33, 55, 61, 103).

There is no single compelling explanation for why this should be. One possible reason works from the top down: It may be that political elites, for whatever reason, have not aligned on opposing sides of this issue in the way that they have on, for example, climate change. Partisans commonly look to party elites for guidance when evaluating policy questions, especially novel or complex ones (15), and in the absence of partisan cues, attitudes toward GE food may vary based on a variety of other determinants. Intuitions about naturalness and contamination may be relatively nonpartisan; if these are major drivers of opposition to genetic engineering, there should not be a relationship overall between attitudes toward it and toward politics.

The second possible reason is that opposition to genetic engineering is equally appealing or unappealing to people on the political left and right for different reasons. Attitudes toward

GE food may be based on a variety of intuitions, some of which are more prevalent on the left and some of which are more prevalent on the right. The political right in the United States is more religious than the left, and in particular has a higher incidence of religious fundamentalists, and religiosity may be associated with opposition to GE food in the United States (51). The link to religiosity may occur because genetic engineering is seen as playing God—that is, as the intrusion of humans into domains reserved for the divine. In contrast, opposition from the left may be motivated in part by a lack of trust in the major corporations that profit from GE food (49).

4.5. Media and Other Sources

Because most consumers hear about GE food through media sources, these communication channels may attenuate or amplify risk perceptions (57) through different processes, such as framing (80); the spiral of silence, in which the minority is less willing to express opinions for fear of isolation, which over time establishes the majority opinion as the social norm (100); and other information processing mechanisms (see 8 for a review). Recent coverage of agricultural biotechnology has centered around specific issues or events, such as proposed legislation for labeling, and includes expressive and emotive headlines (28) that likely trigger heuristic processing.

As discussed in Section 4.4, attitudes toward GE food are not politically polarized, and therefore political elites do not have a prominent role in the public discourse around genetic engineering. There are, however, activists, nongovernmental organizations (NGOs), and businesses that do attempt to shape this discourse. Generally, activists and NGOs take an anti–genetic engineering stance and often work in concert. For example, both local activists and the NGO Greenpeace have led opposition to GE golden rice in the Philippines (46). Likewise, activists, organic farmers, and environmental organizations worked in concert to advocate for a ban on GE crops in Hawaii (47).

For some firms, stoking consumer suspicions about GE food is a prominent marketing strategy. The fast-food Mexican chain Chipotle, for example, promotes its food as being GMO-free; according to founder Steve Ells, "They say these ingredients are safe, but I think we all know we'd rather have food that doesn't contain them" (1). The grocery chain Whole Foods similarly promotes "your right to know" and offers information about how to shop to avoid GMOs (136). Whole Foods customers interested in avoiding GE food can choose from "more than 30,000 organic and 13,500 Non-GMO Project Verified products" (136). The relationship between consumer anxiety around GE food and firms promoting non-GE offerings is likely reciprocal. Given some amount of preexisting consumer skepticism toward GE food, offering non-GE alternatives is, for some firms, a rational response to customer demand. Having established themselves as offering non-GE alternatives, these firms then are incentivized to further heighten consumer anxiety, both to increase demand for their products and to impair competitors who offer fewer non-GE alternatives.

On the pro–genetic engineering side, agricultural and biotech firms are less likely to attempt to communicate to consumers directly, probably because consumers dislike and distrust them (48). Agricultural biotechnology firms (most prominently, Monsanto) do fund the research and outreach (e.g., op-eds, speaking tours, and expert testimony) of scientists that support genetic engineering, a strategy that has also been adopted (in reverse) by organic trade groups (63).

5. CHANGING ATTITUDES

Research examining changes in attitudes toward genetic engineering has focused on the effect of providing more information about genetic engineering and its risks and benefits. This approach follows from research showing that perceived risks and benefits are correlated with the acceptance of genetic engineering and from research showing that more knowledge about it is sometimes associated with a greater acceptance of GE food (see Section 4.1). However, experiments in which people are provided with information about GE food have generally not found that information increases acceptance. Rather, providing information either does not change attitudes (31, 32) or on average makes people more negative toward GE food (30, 101, 139). It appears that consequentialist arguments about GE food are in many cases ineffectual, be they focused on consumer benefits or (the lack of) health and environmental risks. If attitudes toward GE food are based on moral or other intuitions, this makes sense. When people hold a moral belief, appeals to consequentialist reasoning are typically ineffectual because reasons are the product of moral intuitions, not the cause of them (40). What may be effectual, however, are appeals to the underlying moral intuitions or reframing the issue such that different intuitions are triggered. Some work by the authors of this review has begun to investigate this possibility.

As described in Sections 2.1 and 2.3, the preference for natural is strong in Western cultures, especially in the food domain. GE food is seen as highly unnatural (especially as opposed to organic food, which is perceived to occupy the contrasting pole of the naturalness continuum), and this is associated with more negative views of GE food overall and lower willingness to consume it (121). This suggests that undermining the intuition that genetic engineering is unnatural may shift attitudes toward it, although no published research has directly tested this proposition.

Another way to shift a moral intuition may be to pit it against another moral concern (40). This is what we attempted in presenting information to participants about the many benefits created through genetic engineering, including the benefit of golden rice, which is high in vitamin A and could be used to prevent blindness. (Vitamin A is often in short supply in the diet in Southeast Asia.) Here, the moral opposition to GE food is countered by the moral outcome of improving the health of other individuals. We found that, somewhat surprisingly, reading about golden rice convinced few opponents of GE food of its benefits (103). In theory, this might be because of respondents' concerns about how effective golden rice is at providing sufficient levels of vitamin A or because golden rice is seen as a Trojan horse for other GE crops (46). We think it more likely, however, that the limited effectiveness of this intervention reflects the difficulty of shifting established moral intuitions. After all, questionnaire or laboratory studies by their nature involve rather tepid manipulations. They do not compare, for example, to the effect of reading a book that is pro– or anti–GE food, let alone personally benefiting from drought- or pest-resistant crops as a farmer in a developing country may. It may be, therefore, that the types of interventions that have typically been done are not strong enough to counter strongly moralized attitudes toward genetic engineering in many respondents.

6. CONCLUSIONS

The inclusion of GE food and, for that matter, some other present or future technologies in the human food supply is a matter of deep concern for many people and institutions, and for the well-being of the human race. In developed countries, there is a general disagreement between the life sciences community and the majority of laypeople on two fundamental matters. One has to do with the balance of the risks and benefits of GE food, with the majority of life scientists on the pro–GE food side. A second, more problematic, difference has to do with how central the risk–benefit balance should be as a determinant of attitudes. For many laypeople, GE food represents a moral violation. Scientists have no particular standing on the morality of naturalness or of modifying nature. We can, as scientists, argue against the belief that nature is benevolent, but not against the belief that nature is sacred.

What we are seeing with GE food has been happening throughout human history: Food is frequently intertwined with moral systems. It plays a major part in many religious systems and has very strong moral connotations in daily eating in Hinduism, for example. What is new to some in the modern West is a deep connection to nature and a concern about the fate not only of humans around the globe but also of the planet. The sustainability movement is growing and interacts in many ways with the modern food world. Ironically, in some respects GE food may serve sustainability by reducing the amount of land that has to be devoted to agriculture.

We end with a reminder that almost all of the research we have cited comes from the Western developed world. It is sobering to realize that 60% of people alive today live in Asia, and that Africa is the second most populous continent. In the future, food consumption, and attitudes toward food and nature of the approximately 80% of the world outside the developed world will have to receive much more attention.

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LITERATURE CITED

1. Alesci C, Gillespie P. 2015. Chipotle is now GMO-free. *CNN Money*, Apr 27. **http://money.cnn.com/2015/04/26/investing/chipotle-gmo-free/index.html**
2. Allum N, Sturgis P, Tabourazi D, Brunton-Smith I. 2008. Science knowledge and attitudes across cultures: a meta-analysis. *Public Underst. Sci.* 17:35–54
3. Bäckström A, Pirttilä-Backman A-M, Tuorila H. 2004. Willingness to try new foods as predicted by social representations and attitude and trait scales. *Appetite* 43:75–83
4. Bai Y, Lindhout P. 2007. Domestication and breeding of tomatoes: What have we gained and what can we gain in the future? *Ann. Bot.* 100:1085–94
5. Baron J, Spranca M. 1997. Protected values. *Organ. Behav. Hum. Decis. Process.* 70:1–16
6. Bauer MW, Allum N, Miller S. 2007. What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. *Public Underst. Sci*. 16:79–95
7. Bredahl L. 2001. Determinants of consumer attitudes and purchase intentions with regard to genetically modified food—results of a cross-national survey. *J. Consum. Policy* 24:23–61
8. Brossard D. 2012. Social challenges: public opinion and agricultural biotechnology. In *The Role of Biotechnology in a Sustainable Food Supply*, ed. J Popp, W Jahn, M Matlock, N Kemper, pp. 1–15. New York: Cambridge Univ. Press
9. Brossard D, Nisbet MC. 2007. Deference to scientific authority among a low information public: understanding U.S. opinion on agricultural biotechnology. *Int. J. Public Opin. Res.* 19:24–52
10. Bruening G, Lyons J. 2000. The case of the FLAVR SAVR tomato. *Calif. Agric.* 54:6–7
11. Bubela T, Nisbet MC, Borchelt R, Brunger F, Critchley C, et al. 2009. Science communication reconsidered. *Nat. Biotechnol.* 27:514–18
12. Busch L. 2011. Food standards: the cacophony of governance. *J. Exp. Bot.* 62:3247–50
13. Charles D. 2014. *Why the 'non-GMO' label is organic's frenemy*. Natl. Public Radio, Feb. 28. **https://www.npr.org/sections/thesalt/2014/02/28/283460420/why-the-non-gmo-label-is-organic-s-frenemy**

14. Codex Aliment. Comm. 2003. *Guideline for the conduct of food safety assessment of foods using recombinant DNA plants*. Guideline CAC/GL 45-2003. Codex Aliment. Comm., Rome
15. Cohen GL. 2003. Party over policy: the dominating impact of group influence on political beliefs. *J. Personal. Soc. Psychol.* 85:808–22
16. Cohen SN, Chang AC, Boyer HW, Helling RB. 1973. Construction of biologically functional bacterial plasmids in vitro. *PNAS* 70:3240–44
17. Costa-Font J, Gil JM, Traill WB. 2008. Consumer acceptance, valuation of and attitudes towards genetically modified food: review and implications for food policy. *Food Policy* 33:99–111
18. Costa-Font J, Mossialos E. 2007. Are perceptions of 'risks' and 'benefits' of genetically modified food (in)dependent? *Food Qual. Preference* 18:173–82
19. Doebley J. 2004. The genetics of maize evolution. *Annu. Rev. Genet.* 38:37–59
20. Douglas M. 1966. *Purity and Danger*. London: Routledge
21. Dreezens E, Martijn C, Tenbült P, Kok G, De Vries NK. 2005. Food and values: an examination of values underlying attitudes toward genetically modified- and organically grown food products. *Appetite* 44:115–22
22. Druckman JN, Bolsen T. 2011. Framing, motivated reasoning, and opinions about emergent technologies. *J. Commun.* 61:659–88
23. Ellen PS, Bone PF. 2008. Stained by the label? Stigma and the case of genetically modified foods. *J. Public Policy Mark.* 27:69–82
24. Eur. Comm. 2018. *Traceability and labelling*. Eur. Comm., Brussels. **https://ec.europa.eu/food/plant/gmo/traceability_labelling_en**
25. Eur. Parliam. 2015. *Eight things you should know about GMOs*. Eur. Parliam., Brussels. **http://www.europarl.europa.eu/news/en/headlines/society/20151013STO97392/eight-things-you-should-know-about-gmos**
26. Fernandez-Cornejo J, Wechsler S, Livingston M, Mitchell L. 2014. *Genetically Engineered Crops in the United States*. Washington, DC: US Dep. Agric.
27. Finucane ML, Alhakami A, Slovic P, Johnson SM. 2000. The affect heuristic in judgments of risks and benefits. *J. Behav. Decis. Mak.* 13:1–17
28. Flipse SM, Osseweijer P. 2013. Media attention to GM food cases: an innovation perspective. *Public Underst. Sci.* 22:185–202
29. Frazer JG. 1981. *The Golden Bough: The Roots of Religion and Folklore*. New York: Avenel
30. Frewer LJ, Howard C, Hedderley D, Shepherd R. 1999. Reactions to information about genetic engineering: impact of source characteristics, perceived personal relevance, and persuasiveness. *Public Underst. Sci.* 8:35–50
31. Frewer LJ, Howard C, Shepherd R. 1998. The influence of initial attitudes on responses to communication about genetic engineering in food production. *Agric. Hum. Values* 15:15–30
32. Frewer LJ, Scholderer J, Bredahl L. 2003. Communicating about the risks and benefits of genetically modified foods: the mediating role of trust. *Risk Anal.* 23:1117–33
33. Funk C, Rainie L. 2015. *Americans, politics and science issues*. Pew Res. Cent., Washington, DC. **http://www.pewinternet.org/2015/07/01/americans-politics-and-science-issues/**
34. Gaskell G, Allum N, Wagner W, Kronberger N, Torgersen H, et al. 2004. GM foods and the misperception of risk perception. *Risk Anal.* 24:185–94
35. Gaskell G, Stares S, Allansdottir A, Allum N, Castro P, et al. 2010. *Europeans and Biotechnology in 2010. Winds of Change?* Brussels: Eur. Comm.
36. Grossman MR. 2016. Genetically engineered animals in the United States: the AquAdvantage Salmon. *Eur. Food Feed Law Rev.* 11:190–200
37. Gruère GP. 2006. *An analysis of trade related international regulations of genetically modified food and their effects on developing countries*. EPT Discuss. Pap. 147, Int. Food Policy Res. Inst., Washington, DC
38. Gruère GP, Carter CA, Farzin YH. 2008. What labelling policy for consumer choice? The case of genetically modified food in Canada and Europe. *Can. J. Econ.* 41:1472–97
39. Grunert KG, Bredahl L, Scholderer J. 2003. Four questions on European consumers' attitudes toward the use of genetic modification in food production. *Innov. Food Sci. Emerg. Technol.* 4:435–45

40. Haidt J. 2001. The emotional dog and its rational tail: a social intuitionist approach to moral judgment. *Psychol. Rev.* 108:814–34
41. Haidt J, McCauley C, Rozin P. 1994. Individual differences in sensitivity to disgust: a scale sampling seven domains of disgust elicitors. *Personal. Individ. Differ.* 16:701–13
42. Hall PK. 2016. Congress finalizes mandatory GMO labeling law. *Ag. Food Law Blog*, July 15. **http://nationalaglawcenter.org/congress-finalizes-mandatory-gmo-labeling-law-2/**
43. Hallman WK, Cuite CL, Morin XK. 2013. *Public perceptions of labeling genetically modified foods*. Work. Pap., Rutgers School Environ. Biol. Sci.
44. Hallman WK, Hebden WC, Aquino HL, Cuite CL, Lang JT. 2003. *Public Perceptions of Genetically Modified Foods: A National Study of American Knowledge and Opinion*. New Brunswick, NJ: Food Policy Inst. Rutgers
45. Hallman WK, Hebden WC, Cuite CL, Aquino HL, Lang JT. 2004. *Americans and GM Food: Knowledge, Opinion and Interest in 2004*. New Brunswick, NJ: Food Policy Inst. Rutgers
46. Harmon A. 2013. Golden rice: lifesaver? *New York Times*, Aug. 24. **http://www.nytimes.com/2013/08/25/sunday-review/golden-rice-lifesaver.html**
47. Harmon A. 2014. A lonely quest for facts on genetically modified crops. *New York Times*, Jan. 4. **https://www.nytimes.com/2014/01/05/us/on-hawaii-a-lonely-quest-for-facts-about-gmos.html**
48. Harris Poll. 2016. *The Harris Poll releases annual reputation rankings for the 100 most visible companies*. Harris Poll, Washington, DC. **https://theharrispoll.com/the-harris-pollr-today-released-its-17th-annual-reputation-quotientr-rqr-summary-report-revealing-corporate-reputation-ratings-for-the-100-most-visible-companies-in-the-u-s-as-perceived-by/**
49. Helliwell R, Hartley S, Pearce W, O'Neill L. 2017. Why are NGOs sceptical of genome editing? NGOs' opposition to agricultural biotechnologies is rooted in scepticism about the framing of problems and solutions, rather than just emotion and dogma. *EMBO Rep*. 18:2090–93
50. Hemphill TA, Banerjee S. 2015. Genetically modified organisms and the U.S. retail food labeling controversy: consumer perceptions, regulations, and public policy. *Bus. Soc. Rev.* 120:435–64
51. Hossain F, Onyango B. 2004. Product attributes and consumer acceptance of nutritionally enhanced genetically modified foods. *Int. J. Consum. Stud.* 18:225–67
52. House L, Lusk J, Jaeger S, Traill WB, Moore M, et al. 2005. Objective and subjective knowledge: impacts on consumer demand for genetically modified foods in the United States and the European Union. *AgBioForum* 7:113–23
53. James C. 2015. *Global status of commercialized biotech/GM crops: 2015*. Brief 51-2015. Int. Serv. Acquis. Agri-Biotech Appl., New York
54. Januszewska R, Pieniak Z, Verbeke W. 2011. Food choice questionnaire revisited in four countries. Does it still measure the same? *Appetite* 57:94–98
55. Kahan DM. 2015. Climate-science communication and the measurement problem. *Political Psychol*. 36:1–43
56. Kahan DM, Jenkins-Smith H, Braman D. 2011. Cultural cognition of scientific consensus. *J. Risk Res.* 14:147–74
57. Kasperson RE, Renn O, Slovic P, Brown HS, Emel J, et al. 1988. The social amplification of risk: a conceptual framework. *Risk Anal*. 8:177–87
58. Kellert SR. 1997. *The Value of Life: Biological Diversity and Human Society*. Washington, DC: Island Press
59. Kellert SR. 2003. *Kinship to Mastery: Biophilia in Human Evolution and Development*. Washington, DC: Island Press
60. Kelso DDT. 2004. Genetically engineered salmon, ecological risk, and environmental policy. *Bull. Mar. Sci.* 74:509–28
61. Khan R. 2013. Do liberals oppose genetically modified organisms more than conservatives? *Discover Blog*, June 11. **http://blogs.discovermagazine.com/gnxp/2013/06/do-liberals-oppose-genetically-modified-organisms-more-than-conservatives/#.WqhYvejwa70**
62. Klerck D, Sweeney JC. 2007. The effect of knowledge types on consumer-perceived risk and adoption of genetically modified foods. *Psychol. Mark.* 24:171–93

63. Lipton E. 2015. Food industry enlisted academics in G.M.O. lobbying war, emails show. *New York Times*, Sept. 5. **https://www.nytimes.com/2015/09/06/us/food-industry-enlisted-academics-in-gmo-lobbying-war-emails-show.html**
64. Lord CG, Ross L, Lepper MR. 1979. Biased assimilation and attitude polarization: the effects of prior theories on subsequently considered evidence. *J. Personal. Soc. Psychol.* 37:2098–109
65. Lusk JL, Jamal M, Kurlander L, Roucan M, Taulman L. 2005. A meta-analysis of genetically modified food valuation studies. *J. Agric. Resour. Econ.* 30:28–44
66. Lusk JL, Rozan A. 2006. Consumer acceptance of ingenic foods. *Biotechnol. J.* 1:1433–34
67. Manuel J. 2015. Europe compromises on GM crops. *Nat. Plants* 1:14022
68. Mauss M. 1972. *A General Theory of Magic*. London: Routledge
69. Mayer A. 2015. *How your food gets the 'non-GMO' label*. Natl. Public Radio, Jan. 20. **https://www.npr.org/sections/thesalt/2015/01/20/378361539/how-your-food-gets-the-non-gmo-label**
70. McWilliams J. 2015. 'Ban GMOs: That shit ain't food.' *Pac. Stand.*, Apr. 14. **https://psmag.com/environment/ban-gmos-that-shit-aint-food**
71. Medin DL, Bang M. 2014. The cultural side of science communication. *PNAS* 111:13621–26
72. Moon W, Balasubramanian SK. 2001. Public perceptions and willingness-to-pay a premium for non-GM foods in the US and UK. *AgBioForum* 4:221–31
73. Moon W, Balasubramanian SK. 2003. Willingness to pay for non-biotech foods in the US and UK. *J. Consum. Aff.* 37:317–39
74. Moon W, Balasubramanian SK. 2004. Public attitudes toward agrobiotechnology: the mediating role of risk perceptions on the impact of trust, awareness, and outrage. *Rev. Agric. Econ.* 26:186–208
75. Muir WM. 2004. The threats and benefits of GM fish. *EMBO Rep.* 5:654–59
76. Natl. Acad. Sci. Eng. Med. 2016. *Genetically Engineered Crops: Experiences and Prospects*. Washington, DC: Natl. Acad. Sci. Eng. Med.
77. Natl. Hum. Genome Res. Inst. 2015. *Comparative Genomics*. Natl. Hum. Genome Res. Inst., Bethesda, MD. **https://www.genome.gov/11509542/**
78. Nep S, O'Doherty K. 2013. Understanding public calls for labeling of genetically modified foods: analysis of a public deliberation on genetically modified salmon. *Soc. Nat. Resour.* 26:506–21
79. Nielsen Co. 2015. *We Are What We Eat: Healthy Eating Trends Around the World*. New York: Nielsen Co.
80. Nisbet MC, Huge M. 2006. Attention cycles and frames in the plant biotechnology debate: managing power and participation through the press/policy connection. *Int. J. Press/Politics* 11:3–40
81. Olatunji BO, Williams NL, Tolin DF, Abramowitz JS, Sawchuk CN, et al. 2007. The Disgust Scale: item analysis, factor structure, and suggestions for refinement. *Psychol. Assess.* 19:281–97
82. Paarlberg RL. 2000. The global food fight. *Foreign Aff.* 79:24–38
83. Paarlberg RL. 2001. *The Politics of Precaution: Genetically Modified Crops in Developing Countries*. Baltimore, MD: Johns Hopkins Univ. Press
84. Pollack A. 2015. Genetically engineered salmon approved for consumption. *New York Times*, Nov. 19. **https://www.nytimes.com/2015/11/20/business/genetically-engineered-salmon-approved-for-consumption.html**
85. Prescott J, Young O, O'Neill L, Yau N, Stevens R. 2002. Motives for food choice: a comparison of consumers from Japan, Taiwan, Malaysia and New Zealand. *Food Qual. Preference* 13:489–95
86. Renner B, Sproesser G, Strohbach S, Schupp HT. 2012. Why we eat what we eat: The Eating Motivation Survey (TEMS). *Appetite* 59:117–28
87. Rock A. 2016. Peeling back the 'natural' food label. *Consum. Rep.*, Jan. 29. **https://www.consumerreports.org/food-safety/peeling-back-the-natural-food-label/**
88. Román S, Sánchez-Siles LM, Siegrist M. 2017. The importance of food naturalness for consumers: results of a systematic review. *Trends Food Sci. Technol.* 67:44–57
89. Rommens CM. 2004. All-native DNA transformation: a new approach to plant genetic engineering. *Trends Plant Sci.* 9:457–64
90. Roth AE. 2007. Repugnance as a constraint on markets. *J. Econ. Perspect.* 21(3):37–58
91. Rozin P. 2005. The meaning of "natural": process more important than content. *Psychol. Sci.* 16:652–58

92. Rozin P. 2006. Naturalness judgments by lay Americans: Process dominates content in judgments of food or water acceptability and naturalness. *Judgm. Decis. Mak.* 1:91–97
93. Rozin P, Fischler C, Shields-Argelès C. 2009. Additivity dominance: Additives are more potent and more often lexicalized across languages than are "subtractives." *Judgm. Decis. Mak.* 4:475–78
94. Rozin P, Fischler C, Shields-Argelès C. 2012. European and American perspectives on the meaning of natural. *Appetite* 59:448–55
95. Rozin P, Lowery L, Imada S, Haidt J. 1999. The CAD triad hypothesis: a mapping between three moral emotions (contempt, anger, disgust) and three moral codes (community, autonomy, divinity). *J. Personal. Soc. Psychol.* 76:574–86
96. Rozin P, Millman L, Nemeroff C. 1986. Operation of the laws of sympathetic magic in disgust and other domains. *J. Personal. Soc. Psychol.* 50:703–12
97. Rozin P, Nemeroff C. 2002. Sympathetic magical thinking: the contagion and similarity "heuristics." In *Heuristics and Biases: The Psychology of Intuitive Judgement*, ed. T Gilovich, D Griffin, D Kahneman, pp. 201–16. Cambridge, UK: Cambridge Univ. Press
98. Rozin P, Spranca M, Krieger Z, Neuhaus R, Surillo D, et al. 2004. Preference for natural: instrumental and ideational/moral motivations, and the contrast between foods and medicines. *Appetite* 43:147–54
99. Runge KK, Brossard D, Scheufele DA, Rose KM, Larson BJ. 2017. Attitudes about food and food-related biotechnology. *Public Opin. Q.* 81:577–96
100. Scheufele DA. 2007. Opinion climates, spirals of silence and biotechnology: public opinion as a heuristic for scientific decision-making. In *The Public, the Media, and Agricultural Biotechnology*, ed. D Brossard, J Shanahan, TC Nesbitt, pp. 231–44. Cambridge, MA: CABI
101. Scholderer J, Frewer LJ. 2003. The biotechnology communication paradox: experimental evidence and the need for a new strategy. *J. Consum. Policy* 26:125–57
102. Schouten HJ, Krens FA, Jacobsen E. 2006. Cisgenic plants are similar to traditionally bred plants. *EMBO Rep.* 7:750–53
103. Scott SE, Inbar Y, Rozin P. 2016. Evidence for absolute moral opposition to genetically modified food in the United States. *Perspect. Psychol. Sci.* 11:315–24
104. Scott SE, Rozin P. 2017. Are additives unnatural? Generality and mechanisms of additivity dominance. *Judgm. Decis. Mak.* 12:572–83
105. Sharma S, Kaur R, Singh A. 2017. Recent advances in CRISPR/Cas mediated genome editing for crop improvement. *Plant Biotechnol. Rep.* 11:193–207
106. Siegrist M. 1998. Belief in gene technology: the influence of environmental attitudes and gender. *Personal. Individ. Differ.* 24:861–66
107. Siegrist M. 1999. A causal model explaining the perception and acceptance of gene technology. *J. Appl. Soc. Psychol.* 29:2093–106
108. Siegrist M. 2000. The influence of trust and perceptions of risks and benefits on the acceptance of gene technology. *Risk Anal.* 20:195–204
109. Siegrist M. 2003. Perception of gene technology and food risks: results of a survey in Switzerland. *J. Risk Res.* 6:45–60
110. Siegrist M, Sütterlin B. 2016. People's reliance on the affect heuristic may result in a biased perception of gene technology. *Food Qual. Preference* 54:137–40
111. Sjöberg L. 2008. Genetically modified food in the eyes of the public and experts. *Risk Manag.* 10:168–93
112. Skitka LJ, Bauman CW, Sargis EG. 2005. Moral conviction: another contributor to attitude strength or something more? *J. Personal. Soc. Psychol.* 88:895–917
113. Smith MD, Asche F, Guttormsen AG, Wiener JB. 2010. Genetically modified salmon and full impact assessment. *Science* 330:1052–53
114. Spence A, Townsend E. 2006. Examining consumer behavior toward genetically modified (GM) food in Britain. *Risk Anal.* 26:657–70
115. Statista. 2017. Worldwide sales of organic food from 1999 to 2016 (in billion U.S. dollars). *Statista*. **https://www.statista.com/statistics/273090/worldwide-sales-of-organic-foods-since-1999/**
116. Steptoe A, Pollard TM, Wardle J. 1995. Development of a measure of the motives underlying the selection of food: the Food Choice Questionnaire. *Appetite* 25:267–84

117. Stewart CN, Richards HA, Halfhill MD. 2000. Transgenic plants and biosafety: science, misconceptions and public perceptions. *BioTechniques* 29:832–43
118. Sunstein CR. 2005. *Laws of Fear: Beyond the Precautionary Principle*. Cambridge, UK: Cambridge Univ. Press
119. Taleb N, Read R, Douady R, Norman J, Bar-Yam Y. 2014. *The precautionary principle (with application to genetic modification of organisms)*. Work. Pap., Extreme Risk Initiat. NYU Sch. Eng.
120. Tanaka Y. 2004. Major psychological factors affecting acceptance of gene-recombination technology. *Risk Anal*. 24:1575–83
121. Tenbült P, de Vries NK, Dreezens E, Martijn C. 2005. Perceived naturalness and acceptance of genetically modified food. *Appetite* 45:47–50
122. Tetlock PE, Kristel OV, Elson SB, Green MC, Lerner JS. 2000. The psychology of the unthinkable: taboo trade-offs, forbidden base rates, and heretical counterfactuals. *J. Personal. Soc. Psychol.* 78:853–70
123. Thomas K. 1991. *Man and the Natural World: Changing Attitudes in England 1500–1800*. London: Penguin
124. Traill BW, Yee WM, Lusk JL, Jaeger SR, House LO, et al. 2006. Perceptions of the risks and benefits of genetically-modified foods and their influence on willingness to consume. *Acta Agric. Scand C* 3:12–19
125. Tylor EB. 1871. *Primitive Culture: Researches into the Development of Mythology, Philosophy, Religion, Art, and Custom*. London: John Murray
126. US Dep. Agric. 2017. *Organic market overview*. US Dep. Agric., Washington, DC. **https://www.ers.usda.gov/topics/natural-resources-environment/organic-agriculture/organic-market-overview.aspx**
127. US Food Drug Admin. 1992. *Statement of policy—Foods derived from new plant varieties*. Biotechnol. Guid. Doc., US Food Drug Admin., Silver Spring, MD. **https://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/Biotechnology/ucm096095.htm**
128. US Food Drug Admin. 2018. *Consumer info about food from genetically engineered plants*. US Food Drug Admin., Silver Spring, MD. **https://www.fda.gov/Food/IngredientsPackagingLabeling/GEPlants/ucm461805.htm**
129. Varki A, Altheide TK. 2005. Comparing the human and chimpanzee genomes: searching for needles in a haystack. *Genome Res*. 15:1746–58
130. Vigani M, Olper A. 2013. GMO standards, endogenous policy and the market for information. *Food Policy* 43:32–43
131. Vigani M, Olper A. 2015. Patterns and determinants of GMO regulations: an overview of recent evidence. *AgBioForum* 18:44–54
132. Waltz E. 2015. Nonbrowning GM apple cleared for market. *Nat. Biotechnol.* 33:326–27
133. Waltz E. 2017. First genetically engineered salmon sold in Canada. *Nature* 548:148
134. Watanabe M. 1974. The conception of nature in Japanese culture. *Science* 183:279–82
135. White L Jr. 1967. The historical roots of our ecologic crisis. *Science* 155:1203–7
136. Whole Foods Mark. 2018. *What are GMOs?* Whole Foods Mark., Austin, TX. **http://www.wholefoodsmarket.com/gmo-your-right-know**
137. Wilson EO. 1984. *Biophilia*. Cambridge, MA: Harvard Univ. Press
138. Zhang M, Liu GL. 2015. The effects of consumer's subjective and objective knowledge on perceptions and attitude towards genetically modified foods: objective knowledge as a determinant. *Int. J. Food Sci. Technol.* 50:1198–205
139. Zhu X, Xie X. 2015. Effects of knowledge on attitude formation and change toward genetically modified foods. *Risk Anal*. 35:790–810

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Contents

Indexes

Errata

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