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Who Trusts in Gene-Edited Foods? Analysis of a Representative Survey Study Predicting Willingness to Eat- and Purposeful Avoidance of Gene Edited Foods in the United States

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CRISPR-Cas, ZFN, and TALEN provide gene editing opportunities which may lead to new food and agricultural products with identifiable benefits for end-use consumers. Given the public perceptions and backlash faced by previous generations of genetically modified food products, there is a lot of speculation regarding how gene edited food products will come to be understood, and if they will be accepted or avoided by society. This study provides timely and reliable data which reports representative coordinated study of the United States public as to what factors influence their willingness to eat- or purposeful avoidance of gene-edited foods. This study fills this gap to identify influential factors which, in concert, help to explain not only if members of the public trust GEF and are willing to eat GEF foods or choose to avoid them, but why they hold the trust attitudes they do. From our analysis, we find that social values, institutional trust, and awareness are the most important factors in why Americans would choose to either eat or avoid gene edited foods. Surprisingly, the public's attitudes about the tangible characteristics of food (such as safety, cost, taste, and appearance) had no bearing on GE food perceptions. This helps explains why the American public makes little distinction between willingness to eat processed or raw foods made with GE crops.

Keywords: gene edited food, trust, representative survey, food, public opinion

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INTRODUCTION

Biotechnology developments in food and agricultural sectors are developing swiftly. Tools and techniques including CRISPR-Cas, ZFN, and TALEN provide gene editing opportunities which may lead to new food and agricultural products with identifiable benefits for end-use consumers. Currently however, there are few publicly identifiable products using gene editing in the commercial marketplace (CAST, 2018; Shukla-Jones et al., 2018, Dahlstrom et al., under review). This emerging field is predicated on cisgenic editing, that is, editing the genome of a specific species or those sexually compatible with one another. This is distinct from the transgenic generations of genetically modified organisms (GMO) for human and animal consumption (GM food) as they do

not require the insertion or translation of foreign DNA to produce desired traits within a novel product.

This current generation of gene-edited foods (GEF) may be desirable from a research and development perspective as they can be produced quickly, with greater granular control, and more cheaply than traditional selective breeding or transgenic modification (NASEM, 2017; Pirscher et al., 2018; Shukla-Jones et al., 2018; Bain et al., 2020). The tools of gene editing proffer opportunity for biotechnologists to create new products that could provide a variety of agronomic and sustainability benefits, and may also enhance food security (Abdallah et al., 2015; Georges and Ray, 2017; Haque et al., 2018; Panda and Sahu, 2018; Chen et al., 2019). This desire to foster potential benefits of gene editing in agriculture and food is also reflected in the current regulatory scheme overseen by the USDA as its SECURE Rule (Sustainable, Ecological, Consistent, Uniform, Responsible, and Efficient) specifically establishes exemptions for gene edited plants that are created through methods "where the modification could otherwise have been made through conventional breeding" (USDA, 2021). To this point, the first GEF product entered the marketplace in March 2019 as a non-regulated article—a gene-edited soybean variety which provides cooking oil that is more shelf-stable than the conventional alternative and which is free of trans fats.

Historically, some GMO products have provided benefits to certain groups and consumers, but they also evoked a great deal of controversy regarding concerns of product safety, equitable distribution of benefits, and concerns about developmental practices and maintaining high ethical standards (Cummings et al., under review; Yue et al., 2015). Given the public perceptions and backlash faced by GMO products, there is a lot of speculation regarding how GEF products will come to be understood, and if they will be accepted or avoided by society.

Given the pernicious public perceptions of risks and benefits of GMOs, proponents and trade advocacy groups are seeking inroads to ensure that the public view GEF as less controversial than its predecessors. These groups seek means to avoid 'burdensome' regulations and restrictions which accompanied GMO development to introduce GEF into the commercial marketplace in a more favorable light (Bain et al., 2020; Bain and Dandachi, 2014; Schurman and Munro, 2010). Actualizing this potential for GEF depends readily on whether the public trusts the end-products (Cummings et al., under review; Cummings, 2017; Friedrichs et al., 2019), that being, are they willing to eat gene edited foods or will they choose to purposefully avoid them? While the study of potential GEF risks are ongoing, including off-target effects, unintended on-target effects, and unintended consequences from genome editing (Kawall et al., 2020) many scholars have postulated that trust regarding GEF will be influenced by factors that extend beyond technical risks and benefits (Cummings et al., under review; Dietz, 2013; NASEM, 2017; Kuzma and Kokotovich, 2011). However, there is little reliable data which reports representative coordinated study of the United States public as to what factors influence their willingness to eat- or purposeful avoidance of GEF. This study fills this gap to identify influential factors which, in concert, help to explain not only if members of the public trust GEF and are willing to eat GEF foods or choose to avoid them, but why they hold the trust attitudes they do. This paper thus seeks descriptive and theoretical ends to quantitatively report the degree to which the United States public trusts in GEF. Our analysis using ordinary least squares regression modeling is among the first to report individual-level antecedent characteristics which demonstrate why members of the public hold the attitudes they do and helps to evaluate 'which factors matter' when people make decisions about their willingness to eat gene edited food products. Thus, this evaluation clarifies which demographic, sociographic, and value-based characteristics most influence end-consumer trust in GEF which improves the theoretical understanding of food technology decision making. This data may also be of high value to practitioners who can better understand the motives and characteristics of audiences within the public who hold distinct views about GEF and are influenced similarly by distinct personal factors. Our approach is motivated by the following research questions which guides our inquiry, "Is the United States public willing to eat gene edited foods? Would they rather purposefully avoid them? Which individual-level characteristics most influence these trust outcomes?"

First, we review the related and contentious history of public perceptions and willingness to eat/avoid GMOs. We then turn to the methods and results of our representative survey study which extends previous descriptive and theoretical work to evaluate why members of the public are willing to eat or prefer to avoid GEF. Our results which demonstrate distinct "trusting" and "distrusting" publics is further explicated in our discussion which provides timely and valuable insights into how this data can be leveraged for public engagement and may inform subsequent evaluation as this set of food technologies becomes more familiar with United States audiences in coming years.

PUBLIC PERCEPTIONS AND WILLINGNESS TO BUY GEF

The future of GEF is invariably related to the history of GMOs. Critics, including many NGO and consumer advocacy groups regard GEF as an extension of GMOs and seek to influence the broader populous to believe these food technologies as similar or equal in how they should be trusted. Proponents too are concerned whether the public will accept gene editing in food and agriculture given the relationship to GMOs and public's skepticism toward it (Bain and Dandachi, 2014; NASEM, 2017) and are seeking new avenues to assuage public concerns toward GEF. These concerns are prompted by the extreme differences in risk perceptions of GMOs between scientific experts and members of the public, where, in 2015, for example, 88% of scientists believed that GMO foods were safe for human consumption as compared to only 37% of the public (Pew Research Center, 2015). Over the last decade, the anti-GMO movement has garnered significant attention and traction in the U.S. culminating in the 2018 USDA approval of the National Bioengineered Food Disclosure Standard that requires foods containing GMO ingredients to be labeled (Bain and

Dandachi, 2014; Federal Register, 2018). Now a similar campaign is being initiated by proponents and critics alike to 'garner social license,' among the public, that is, to win broad public acceptance or rejection of GEF technology (Cummings et al., under review).

Furthermore, studies of public trust in GMOs identified that coordinated efforts to educate the public about the science of food technologies did not instill favor or diminish mistrust or skepticism (Hagendijk and Irwin, 2006; Irwin et al., 2013; Macnaghten, 2008). Rather than repeat the risk and safety narratives of the GMO-era, many proponents now see to curry favor from the public for GEF through alternate means of establishing trust and acceptance including avoiding science-talk, seeking to instill shared values between consumers and developers, and increasing transparency of GEF development operations (Cummings et al., under review). However, NGOs and consumer groups critical of GEF note that it faces significant challenges to instill public trust given its relation to GMOs, scientific complexity, and social, environmental, and ethical concerns (Helliwell et al., 2019). As Cummings et al. (under review) noted, critics and proponents were conflicted with one another about how GEF should be defined, how the risks and benefits of GEF ought to be framed in public discourse, and what, if any, mandatory or voluntary product labeling initiatives should be undertaken. Critics were also more likely to call out the need for more stringent risk and safety testing prior to commercialization and increased governance and tracking of GEF products (Cummings et al., under review).

Other recent studies have also begun to explore this area to assess factors and personal motives for why general members of the public may be willing to eat GEF or will choose to avoid it. Pruitt et al. (2021) sought to identify if individuals' physical activity level influenced their acceptance of gene edited foods. Their study of approximately 300 people indicated that there is no link between individual physical activity level and one's willingness to pay for genetically engineered foods. However, their study did find that participants were more accepting of GEF than GMO products. Furthermore, the authors suggest that consumers found the availability of benefits of gene edited foods to be laudable but that in general they would prefer not to purchase gene edited food products.

Delwaide et al. (2015) conducted an international comparison study to compare consumer acceptance and willingness to pay for rice labeled as "GM" or "cisgenic" in an online survey study of approximately 3,000 participants across Belgium, France, the Netherlands, Spain, and the United Kingdom. They found that consumers across the countries we're willing to pay a premium to avoid purchasing GM rice, and that in all countries except for Spain, consumers we're willing to pay more to avoid GM rice as compared to cisgenic rice. This suggests that cigenically-produced rice may be viewed as more acceptable than GM alternatives. Similar findings have been observed more recently as well. For instance, in a choice experiment of 600 residents of in Denmark; Edenbrandt et al. (2018) found that consumers cisgenic over transgenic rye bread production methods, but that most of the sample favored historically traditional breeding methods over any method. Marette et al. (2021) compared consumer attitudes and willingness to pay for gene edited apples which do not turn brown after being cut in France (N = 162) and the U.S. (N = 166). They found that the French sample would purposefully avoid the product while the U.S. consumers found the innovation of value "as long as it is not generated by biotechnology" (n.p.). Another recent study by Shew et al. (2018) suggests that publics in many countries remain skeptical of agricultural biotechnology but that their panel of international respondents from USA, Canada, Belgium, France, and Australia were more likely to be willing to consumer foods derived from CRISPR than GM labeled foods.

The future of GEF is dependent upon consumer acceptance. While previous studies have found that consumers are split in their acceptance and willingness to pay for GEF products, no representative studies have yet identified antecedent factors that influence consumers' willingness to eat gene edited foods as well as what factors are associated with an individual's purposeful avoidance applying gene edited foods. Such information can inform policy makers, stakeholders, and risk communicators about the current public perceptions of GEF applications and guide future consumer engagements and governance initiatives. From this premise our representative survey study seeks to fill this gap and we are guided by the following two research questions:

RQ1: What factors influence individuals' willingness to eat gene edited foods?

RQ2: What factors influence individuals' purposeful avoidance of buying gene edited foods?

DATA AND METHODS

We conducted a cross-sectional survey on public attitudes and perceptions about plant-based gene edited (GE) foods (Cummings, 2018). Data are from a nationally representative sample of n = 2,000 U.S. residents over 18 years of age, drawn from YouGov's National Omnibus Panel during the last 2 weeks of September 2020. The results have an observed margin of error of ±2.2 percentage points. The National Omnibus is a compensated opt-in survey panel comprised of 1.8 million U.S. residents who have agreed to participate. Panel members are recruited by a number of methods to help ensure representativeness of the panel population. Recruiting methods include web advertising, permission based email contacts, partner sponsored solicitations, telephone contacts using random digit dialing, and mail contacts using random address selection (YouGov, 2020). Data are weighted to match the demographic characteristics of the adult population, based on the U.S. Census Bureau's 2018 American Community Survey.

Variables

Three *dependent variables* operationalize our main outcomes of willingness to eat and purposeful avoidance of GE foods. The first is willingness to eat plant-based processed foods containing GE crops (such as breads, pastas, snack chips, etc.); and the second is willingness to eat plant-based raw foods that are gene edited (such as fruits, vegetables, cereals, legumes, etc.). The third asks whether respondents would avoid buying foods with GE crops, if given the

choice. All dependent variables are on a five-point Likert scale ranging from definitely no to definitely yes. A list of variable scales is provided in the.

Based on extant literature on food technology adoption, particularly the large body of work on genetically modified foods, we selected the following covariates of willingness to eat and purposeful avoidance (Lang et al., 2003; Lang and Hallman, 2005; Peters et al., 2007; Lang, 2013). The *demographic and sociographic blocks* includes the respondent's age, gender, minority status defined as a non-white race or Hispanic ethnicity, self-reported health status on a five-point Likert scale between poor and excellent, educational attainment along a six-point ordinal scale, and family income along a 16-point scale ranging from under $10,000 to $500,000 or more. Where people get their *information about food risks and benefits* is also important. To measure this, we include the importance of friends and family, government agencies, food processors and manufacturers, the popular press, and social media as information sources about food (five-point Likert scale). *Awareness* of new technology facilitates its adoption. We constructed a GE food understanding scale that sums two items on a five-point Likert scale: how much respondents have heard or read about GE foods; and their self-reported understanding of GE food technology. The scale has a range between 1–10 and exhibits high reliability, as measured by Guttman lower bounds (both λ_4 and λ_3/α = 0.790). In addition, we included how much respondents personally care about the issue of GE foods as a single item control variable.

We control for different value orientations related to food technology. *General values* include self-identified political affiliation along a five-point scale between very liberal to very conservative; and a four-point Likert scale on the importance of religion in the respondent's everyday life. For specific values, we include three food choice measures and one technology orientation measure. The *food beliefs scale* sums the importance of personal beliefs and ethics, where the food comes from, and organic certification on how respondents make food decisions for themselves and their family. The *food product scale* sums the importance of food safety, cost, taste, and appearance on food decisions. The importance of *nutritional content* on food choices is included as a single variable. All items are on a four-point Likert scale ranging between 0 (not important) and 3 (extremely important). The food beliefs scale has a range of 0–9 and a Guttman lower bound reliability between λ_4 = 0.608 and λ_3/α = 0.679 (the latter equivalent to Cronbach's alpha). The food product scale range is 0–12, with reliabilities between λ_4 = 0.641 and λ_3/α = 0.653. Similarly, the *pro science and technology scale* is created by summing six items that rate disagreement on the following items (four-point scale): the world would be better off without technology, leaders should stop funding science research, science creates more problems than solutions, scientists hide the truth, scientists do not value my concerns, and scientists exaggerate the truth. The summed scale ranges from 0 to 18 with higher scores indicating more pro-technology attitudes. The scale has a Guttman reliability range of λ_4 = 0.818 and λ_3/α = 0.885.

Lastly, adoption of new technologies is often predicated upon public trust in the institutions overseeing the innovation (Hamm et al., 2019; Kato-Nitta et al., 2019). In the case of GE foods, the major institutional actors include government regulators tasked with overseeing GE foods, agriculture biotechnology companies who develop and commercialize GE foods, and environmental organizations who evaluate the potential impacts on the natural environment and human health. Respondents rated the trustworthiness of each actor along nine components of trust identified in the literature (Levi and Stoker, 2000). The components of trust include: scientific and technical competence to understand the risks and benefits of GE foods, understanding the social and ethical implications, willingness to act in the public interest with regards to GE foods, honesty about the risks and benefits of the technology, ability to act in an open and transparent manner when discussing GE foods, whether the institution shares the respondents' values about the technology, ability to follow through on promises to oversee GE foods, willingness to address respondents' concerns, and the ability to act without bias in decisions about GE foods. Each item was rated along a five-point Likert scale from 0 (low rating) to 5 (very high rating). Items for each scale were summed and has a range between 0–36. All scales exhibit high Guttman reliabilities: the *government food regulators trust scale* at λ_4 = 0.894 and λ_3/α = 0.931; the *agriculture biotechnology industry trust scale* at λ_4 = 0.862 and λ_3/α = 0.915; and the *environmental organizations trust scale* at λ_4 = 0.910 and λ_3/α = 0.948.

Analytic Approach

An ordinary least squares (OLS) regression model was used to predict the three dependent variables, with independent variables entered as hierarchical blocks (Johnson and Wichern, 2007). We also included state fixed effects to control for any regional variations and/or omitted variables across states and the District of Columbia, such as differences in state policy or culture, as is common in social science research (Verbeek, 2012). Fixed effects are entered as 49 state dummy variables, with excluded states being Alaska and Hawaii because of unique food delivery and cost issues. Although the outcome variables are ordinal in scale, we chose not to use an ordinal maximum likelihood regression for several reasons. First, the ordinal scale was designed to adequately capture the range of continuous responses on willingness to eat and purposeful avoidance. Second, the dependent variables all exhibit normal distributions. Third, estimation of an ordinal regression resulted in similar results, but parameters are reported in difficult to understand logits or odds ratios. For these reasons, we decided to use OLS to facilitate interpretation among non-technical audiences, while still maintaining statistical rigor. Most assumptions of the OLS model are met, with normal dependent variables (kurtosis and skewness within ±0.75), linearity between outcomes and predictors, low multicollinearity (no VIF exceeded 2.5), no spatial or time autocorrelation among residuals, and normally distributed and uncorrelated residuals (Greene, 2011). However, all models exhibited generalized heteroscedasticity (see White's χ^2 in **Table 1**), but the distributions of residuals by predicted values did not seem to be overly heteroscedastic.

TABLE 1 | Descriptive statistics for n = 2,000 adults in the U.S. in 2020.

Variable	Full sample		Willing to eat processed GEFs		Avoid buying GEFs	
	Mean	*SD*	*Mean (No)*	*Mean (Yes)*	*Mean (No)*	*Mean (Yes)*
Cases (n)	2,000	2,000	657	576	612	681
Willing to eat processed GE foods (1–5)	2.94	1.14	1.62	4.36	3.82	2.13
Willing to eat raw GE foods (1–5)	2.91	1.15	1.82	4.14	3.78	2.11
	3.13	1.17	4.05	2.23	1.75	4.50
Age (years)	47.89	18.01	51.72	43.60	46.33	51.10
Women (%)	51.82	49.98	59.51	40.39	42.97	57.05
Minority (%)	36.30	48.10	36.97	32.40	31.64	35.38
Health status, poor–excellent (1–5)	2.97	1.02	3.03	3.05	3.02	3.03
Educational attainment (1–6)	3.36	1.54	3.25	3.73	3.61	3.36
Family income (1–16)	5.99	3.36	5.64	6.79	6.60	5.86
Politics, liberal–conservative (1–5)	3.01	1.13	3.23	2.74	2.80	3.23
Importance of religion (1–4)	2.73	1.20	2.99	2.40	2.40	2.96
Food beliefs importance scale (0–9)	3.68	2.55	4.31	3.12	3.04	4.37
Your ethics and beliefs (0–3)	*1.25*	*1.14*	*1.42*	*1.14*	*1.12*	*1.44*
Where the food comes from (0–3)	*1.58*	*1.09*	*1.88*	*1.30*	*1.31*	*1.87*
Organic certification (0–3)	*0.85*	*1.04*	*1.00*	*0.69*	*0.60*	*1.06*
Food product importance scale (0–12)	8.86	2.49	9.17	8.67	8.80	9.15
Food safety (0–3)	*2.46*	*0.87*	*2.56*	*2.39*	*2.39*	*2.58*
Cost (0–3)	*2.08*	*0.95*	*2.11*	*2.07*	*2.14*	*2.07*
Taste (0–3)	*2.56*	*0.75*	*2.62*	*2.59*	*2.64*	*2.60*
Appearance (0–3)	*1.77*	*1.00*	*1.87*	*1.62*	*1.63*	*1.90*
Food nutrition importance (0–3)	2.01	0.97	2.10	2.05	2.03	2.08
Pro science and technology scale (0–18)	9.34	5.45	7.61	11.82	11.90	7.94
World better without today's technology (0–3)	*1.79*	*1.13*	*1.52*	*2.18*	*2.23*	*1.57*
Leaders need to stop funding science research (0–3)	*2.03*	*1.11*	*1.78*	*2.37*	*2.44*	*1.87*
Science creates more problems than solutions (0–3)	*1.68*	*1.14*	*1.33*	*2.14*	*2.20*	*1.39*
Scientists purposefully hide truth from public (0–3)	*1.37*	*1.18*	*1.07*	*1.86*	*1.81*	*1.10*
Scientists don't value my concerns (0–3)	*1.16*	*1.12*	*0.90*	*1.51*	*1.50*	*0.95*
Scientists exaggerate truth for personal gain (0–3)	*1.32*	*1.16*	*1.02*	*1.77*	*1.72*	*1.06*
Food info sources: friends and family important (1–5)	3.41	1.19	3.55	3.20	3.19	3.54
government agencies important (1–5)	3.23	1.24	3.14	3.37	3.27	3.19
food companies important (1–5)	3.33	1.24	3.36	3.29	3.21	3.37
popular press important (1–5)	2.61	1.25	2.48	2.69	2.62	2.53
social media important (1–5)	2.21	1.24	2.13	2.14	2.10	2.16
Government food regulators GE trust scale (0–36)	7.85	8.56	5.35	11.47	10.49	6.20
Govt—scientific and technical competence (0–4)	*0.96*	*1.19*	*0.69*	*1.40*	*1.31*	*0.76*
Govt—understand social and ethical implications (0–4)	*0.91*	*1.20*	*0.72*	*1.23*	*1.09*	*0.79*
Govt—willing to act in the public interest (0–4)	*1.00*	*1.25*	*0.68*	*1.41*	*1.34*	*0.81*
Govt—honest about risks and benefits (0–4)	*0.94*	*1.21*	*0.61*	*1.42*	*1.30*	*0.73*
Govt—act in open and transparent manner (0–4)	*0.86*	*1.18*	*0.54*	*1.29*	*1.13*	*0.67*
Govt—shares your values (0–4)	*0.69*	*1.08*	*0.44*	*1.05*	*0.93*	*0.51*
Govt—follow through on promises (0–4)	*0.89*	*1.22*	*0.56*	*1.33*	*1.22*	*0.67*
Govt—willing to address your concerns (0–4)	*0.80*	*1.17*	*0.59*	*1.17*	*1.08*	*0.66*
Govt—ability to act without bias (0–4)	*0.80*	*1.15*	*0.53*	*1.18*	*1.08*	*0.62*
Agriculture biotech industry GE trust scale (0–36)	7.19	8.10	5.14	10.32	9.53	5.88
AgBio—scientific and technical competence (0–4)	*1.30*	*1.39*	*1.00*	*1.88*	*1.87*	*1.08*
AgBio—understand social and ethical implications (0–4)	*1.03*	*1.30*	*0.85*	*1.38*	*1.31*	*0.97*
AgBio—willing to act in the public interest (0–4)	*0.78*	*1.16*	*0.54*	*1.12*	*1.07*	*0.64*
AgBio—honest about risks and benefits (0–4)	*0.76*	*1.16*	*0.48*	*1.08*	*0.97*	*0.60*
AgBio—act in open and transparent manner (0–4)	*0.70*	*1.11*	*0.47*	*1.00*	*0.90*	*0.52*
AgBio—shares your values (0–4)	*0.63*	*1.06*	*0.41*	*0.97*	*0.83*	*0.46*
AgBio—follow through on promises (0–4)	*0.77*	*1.17*	*0.49*	*1.13*	*1.04*	*0.61*
AgBio—willing to address your concerns (0–4)	*0.65*	*1.09*	*0.50*	*0.98*	*0.85*	*0.54*
AgBio—ability to act without bias (0–4)	*0.57*	*1.01*	*0.40*	*0.77*	*0.69*	*0.45*
Environmental organizations GE trust scale (0–36)	10.62	10.51	9.36	13.87	12.36	10.26
Envir—scientific and technical competence (0–4)	*1.16*	*1.35*	*1.09*	*1.45*	*1.27*	*1.18*
Envir—understand social and ethical implications (0–4)	*1.21*	*1.39*	*1.10*	*1.60*	*1.41*	*1.21*
Envir—willing to act in the public interest (0–4)	*1.40*	*1.46*	*1.22*	*1.83*	*1.68*	*1.34*
Envir—honest about risks and benefits (0–4)	*1.24*	*1.41*	*1.11*	*1.57*	*1.42*	*1.19*
Envir—act in open and transparent manner (0–4)	*1.19*	*1.39*	*1.00*	*1.56*	*1.39*	*1.12*
Envir—shares your values (0–4)	*1.12*	*1.41*	*0.95*	*1.48*	*1.27*	*1.07*
Envir—follow through on promises (0–4)	*1.22*	*1.43*	*1.03*	*1.65*	*1.49*	*1.13*
Envir—willing to address your concerns (0–4)	*1.15*	*1.39*	*1.04*	*1.52*	*1.38*	*1.12*
Envir—ability to act without bias (0–4)	*0.94*	*1.28*	*0.82*	*1.21*	*1.07*	*0.92*

(Continued on following page)

TABLE 1 | (*Continued*) Descriptive statistics for n = 2,000 adults in the U.S. in 2020.

Variable	Full sample		Willing to eat processed GEFs		Avoid buying GEFs	
	Mean	*SD*	*Mean (No)*	*Mean (Yes)*	*Mean (No)*	*Mean (Yes)*
GE food understanding scale (1–10)	4.33	1.97	4.06	5.18	4.75	4.35
Heard or read about GE foods (1–5)	*2.27*	*1.12*	*2.18*	*2.70*	*2.49*	*2.33*
Understanding of GE foods (1–5)	*2.06*	*1.04*	*1.87*	*2.47*	*2.25*	*2.01*
Personally care about GE foods (1–5)	2.80	1.20	3.14	2.60	2.44	3.27

SD, standard deviation.

TABLE 2 | Predicting willingness to eat and purposeful avoidance of gene edited foods for n = 1,988 adults in the U.S. in 2020.

	Willing to Eat Processed GE Foods		Willing to Eat Raw GE Foods		Avoid Buying GE Foods	
	Std. β	*SE*	*Std. β*	*SE*	*Std. β*	*SE*
Block 1: Demographics						
Age (years)	-0.069	(0.001)**	-0.095	(0.001)***	0.014	(0.001)
Women (ref = men)	-0.047	(0.046)*	-0.056	(0.046)**	0.039	(0.048)†
Minority (ref = white non-Hispanic)	-0.035	(0.050)†	-0.035	(0.051)	0.017	(0.053)
Health status, poor–excellent (1–5)	-0.037	(0.023)†	-0.028	(0.023)	0.041	(0.024)†
Incremental R^2	—	*0.052*	—	*0.056*	—	*0.027*
Block 2: Sociographics						
Educational attainment (1–6)	0.028	(0.017)	0.024	(0.017)	0.015	(0.018)
Family income (1–16)	0.080	(0.008)***	0.089	(0.008)***	-0.037	(0.008)
Incremental R^2	—	*0.027*	—	*0.030*	—	*0.008*
Block 3: General values						
Politics, liberal–conservative (1–5)	-0.049	(0.025)*	-0.048	(0.025)†	0.051	(0.026)*
Importance of religion (1–4)	-0.062	(0.021)**	-0.051	(0.022)*	0.064	(0.022)**
Incremental R^2	—	*0.024*	—	*0.020*	—	*0.027*
Block 4: Specific values						
Food beliefs importance scale (0–9)	-0.178	(0.011)***	-0.152	(0.011)***	0.138	(0.012)***
Food product importance scale (0–12)	0.018	(0.010)	0.003	(0.010)	0.017	(0.011)
Food nutrition importance (0–3)	0.064	(0.028)**	0.107	(0.029)***	-0.085	(0.030)**
Pro science and technology scale (0–18)	0.172	(0.005)***	0.152	(0.005)***	-0.213	(0.005)***
Incremental R^2	—	*0.077*	—	*0.069*	—	*0.093*
Block 5: Food information sources						
Friends and family important (1–5)	-0.034	(0.021)	-0.029	(0.022)	0.048	(0.023)*
Government agencies important (1–5)	0.015	(0.023)	0.015	(0.023)	-0.009	(0.024)
Food companies important (1–5)	0.007	(0.022)	0.011	(0.022)	0.006	(0.023)
Popular press important (1–5)	0.028	(0.023)	0.042	(0.023)†	-0.036	(0.024)
Social media important (1–5)	0.041	(0.023)†	-0.004	(0.023)	-0.042	(0.024)†
Incremental R^2	—	*0.013*	—	*0.011*	—	*0.009*
Block 6: Institutional trust of GE foods						
Government food regulators trust scale (0–36)	0.126	(0.004)***	0.136	(0.004)***	-0.094	(0.004)**
Agriculture biotech industry trust scale (0–36)	0.160	(0.004)***	0.178	(0.004)***	-0.158	(0.004)***
Environmental organizations trust scale (0–36)	-0.080	(0.003)**	-0.082	(0.003)**	0.133	(0.003)***
Incremental R^2	—	*0.059*	—	*0.066*	—	*0.045*
Block 7: GE food awareness						
GE food understanding scale (1–10)	0.217	(0.013)***	0.181	(0.013)***	-0.125	(0.014)***
Personally care about GE foods (1–5)	-0.211	(0.021)***	-0.212	(0.022)***	0.295	(0.023)***
Incremental R^2	—	*0.052*	—	*0.043*	—	*0.062*
Block 8: State fixed effects						
49 States	Y	—	Y	—	Y	—
Incremental R^2	—	*0.023*	—	*0.021*	—	*0.018*
$F_{(71,1916)}$	13.099***	12.395***	10.935***	—	—	—
White's $\chi^2_{(329)}$	329.280*	343.400**	347.830**	—	—	—
R^2	0.327	0.315	0.288	—	—	—

Std. β = standardized beta. SE, standard error. †p< .10, *p< .05, **p< .01, ***p< .001.

RESULTS

Descriptive Statistics

Table 2 presents the descriptive statistics of people in the sample. The average age of respondents was 48 years old, slightly over half were women, 36 percent identified as non-white or Hispanic, and most reported to be in good health. The typical degree obtained was some college beyond high school, but no degree; and the typical family income ranged between $50,000 to $59,999 annually. For politics, most identified as moderates who fell between liberal and conservative ideologies. Many said religion was not a very important part of their life. In making decisions about food, the most important considerations were the characteristics of the food product itself, especially its safety and taste (score of 73.8 of 100, calculated by dividing the scale mean of 8.86 by 12). The nutritional content of food was also important (67.0 of 100), while food beliefs were less important in decisions (40.9 of 100). People had mixed views on the role of science and technology in society. Most disagreed with cutting research funding, disagreed that technology made society worse off, and disagreed that science created more problems than it solved. On the other hand, more tended to agree that scientists hide the truth and exaggerate the truth for their own gain.

With regard to GE foods specifically, most people had heard or read very little about the topic, and most had only a fair understanding of the technology. Many were ambivalent about GE foods, with most saying they only somewhat care about the issue. When asked how much they trust the institutions overseeing GE foods, more people thought environmental organizations were more trustworthy than government or industry (29.5 of 100, calculated by dividing the scale mean of 10.62 by 36). Government food regulators scored lower (21.8 of 100), especially having on less technical competence. Agricultural biotechnology firms also scored lower (20.0), but were seen as having more technical competence. However, people saw industry as more likely to act with bias, less likely to share their values, and unwilling to address the public's concerns.

Regression Models

Results of the OLS regression models, presented in **Table 1**, show that the standardized correlates of willingness to eat both processed and raw GE foods are very similar. Both models account for about one-third of the variance in processed (R^2 = 0.327) and raw (R^2 = 0.315) foods. People who are more willing to eat have a better understanding of GE foods (b = 0.181 to 0.217), place greater trust in agricultural biotech companies who develop and commercialization GE foods (b = 0.160 to 0.178), and are more trusting of government food regulators who oversee these foods (b = 0.126 to 0.136). To a lesser degree, people are also more willing to consume GE foods if nutritional content is an important part of food decision-making (b = 0.064 to 0.107), and if they have higher incomes (b = 0.080 to 0.089). Information sources about food risks and benefits play a minimal role.

On the other hand, people who are less willing to eat are those who personally care a great deal about the issue of GE foods (b = −0.181 to -0.217), and those whose food beliefs are very important in their food decisions (b = −0.152 to −0.178). Although the effects are weaker, those less willing to eat view environmental organizations as more trustworthy (b = −0.080 to −0.082). Being older (b = −0.069 to −0.095), more religious (b = −0.051 to −0.062), a woman (b = −0.047 to −0.056), and more politically conservative (b = −0.048 to −0.049) all reduced one's willingness to eat GE foods, albeit the effects are small. Interestingly, people of color and those in better health tend to be less willing to eat processed GE foods, although the results are weak and marginally significant. This may be attributable to these cohorts eating less processed foods generally, with people of color doing so for cultural reasons (e.g., ethnic cuisines) and the health conscious to maintain physical well-being.

Purposeful avoidance means that, given the choice, people would avoid buying foods made with GE crops. Our model accounts for 29 percent of the variance in this outcome. The most important factors driving avoidance is whether people personally care about the issue of GE foods, which increased avoidance by b = 0.295. People who say that food beliefs (e.g., ethics, where food comes from, etc.) are important in food decisions also avoid GE foods (b = 0.138), as are people those who highly trust environmental organizations to monitor this new technology (b = 0.133). Others who are likely to avoid GE foods are religious people (b = 0.064), political conservatives (b = 0.051), those who rely on family and friends to get information about food risks and benefits (b = 0.048), people in good physical health (b = 0.041), and women (b = 0.039)—although the last two are marginally significant.

Conversely, people are less likely to avoid GE foods if they view science and technology as positive for society (b = −0.213), if they highly trust agricultural biotech companies (b = −0.158), and if they possess a good understanding of GE food technology (b = −0.125). Avoidance is also reduced when people trust government food regulators (b = −0.094), when people place importance on nutritional content when making food decisions (b = −0.085), and when people rely on social media for food information (b = −0.042, but marginally significant).

DISCUSSION

From our analysis, we find that social values, institutional trust, and awareness are the most important factors in why Americans would choose to either eat or avoid GE foods. Surprisingly, the public's attitudes about the tangible characteristics of food (such as safety, cost, taste, and appearance) had no bearing on GE food perceptions. This helps explains why the American public makes little distinction between willingness to eat processed or raw foods made with GE crops. We expected people to be more willing to eat processed and less willing on raw GE foods, but the results from both models are nearly identical. We also find that food information sources play a minimal role in people's decisions about GE food products. Given the newness of the

technology, we expected the public to rely more on information channels to make food choices. Instead, our findings indicate that social values about technology and food ethics are the main reasons driving willingness to eat and purposeful avoidance of GE foods.

Those willing to buy and consume GE foods are those who embrace technology generally, both for themselves and those who develop such technology. This group sees science and technology as a valuable part of society, making everyone's life better off. It is likely they make no distinction between GE foods and other technological innovations. GE food adopters are also much more aware of the technology, having read much about it and report a good understanding of the topic. Perhaps due to a high level of awareness, most do not think GE foods is a matter of great public concern and care little about the issue. This group also trusts government and industry scientists who develop, commercialize, and regulate GE foods. This trust likely stems from their pro-technology attitudes and knowledge of the subject. Levels of trust are double that for GE food skeptics, except that even pro-technology people do not trust government and industry to understand the social and ethical implications of GE foods. Consistent with other technology adopters (Peters et al., 2007; Lang, 2013), this group tends to be dominated by younger generations (Generation Z and Millennials under 30 years if age) and those with upper middle class incomes (above $125,000 annually).

On the other hand, those who choose to not buy or eat GE foods are people who place greater value on their own personal beliefs than on science. When making food choices, GE skeptics say ethics and beliefs are important in their decisions, suggesting an ethical or moral objection to GE foods. Given the importance of values, it is unsurprising that this group cares deeply about the issue of GE foods. These values about food correlate with strong religious beliefs and conservative political orientations compared to GE adopters. The combination of ethical concerns and anti-technology orientations is what likely accounts for lower trust in government and industry on all measures of competency and accountability. Instead, GE skeptics more highly trust environmental organizations to monitor GE food development. Such organizations are more attuned to the ethical and social impacts of this GE technology, a major concern among people who are cautious about these foods.

Lastly, those hesitant to buy or consume GE foods tend to be members of more vulnerable groups, such as senior citizens, women, people of color, and those with lower incomes. The gender divide is particularly stark, with roughly 60 percent of women being unwilling to eat and purposefully avoiding GE foods. About 40 percent of older Americans in the Silent and Boomer generations (generally over 60 years of age) avoid eating and buying, compared to only 22 percent among Millennials and Generation Z. Among low to moderate income Americans (earning $40,000 to $45,000 annually), only 25 percent are willing to eat. Willingness increases to 42 percent for upper middle income people (about $125,000 to $149,000), and reaches nearly 70 percent among upper Americans earning over $250,000. People of color are slightly less likely to eat GE foods than white non-Hispanics (25 versus 31%), but are just as likely as whites to avoid buying these foods.

CONCLUSION

There is considerable uncertainty regarding the degree to which the public in the United States and elsewhere will accept or purposefully avoid GEF products as more products enter the consumer marketplace. However, from this representative survey study, we clearly demonstrate that individuals' willingness to eat, and purposeful avoidance of GEFs are primarily driven by their existing social values about food, science and technology, institutional trust, and awareness of GE foods. These antecedent, and more deeply seated core values supersede more immediate and topical concerns and opinions on the safety, cost, taste, and appearance of GEF products. Thus, this study provides a more holistic, yet granular depiction of the most influential factors which more robustly explain and predict GEF attitudes than previous studies which investigated only a partial view of what drives the one's willingness to eat, and purposeful avoidance of GEFs. GE adopters, those willingness to eat and not avoid GEFs, are generally pro-technology, knowledgeable about GE foods, and trust government and industry actors to oversee GEF products as they enter the commercial marketplace. This group also trends as younger and having higher than average household income. Conversely, GE skeptics, those not willing to eat and who plan to avoid GEFs, tend to be driven by food ethics and beliefs, are more likely to hold strong religious beliefs, and identified as more politically conservative. This group largely distrusts government and industry actors to oversee GEF products and instead place greater trust in environmental organizations who may better represent their values with regards to food. This group also tends to be comprised women, senior citizens, and to a lesser degree people of color.

As a populous, the American public made no distinction between raw and processed GE foods. This likely indicates that the qualities of final product itself do not influence acceptance/avoidance as much as one's values associated with GE technologies more generally. This provides further theoretical insights into how people may come to judge GE food products in the future as social values demonstrate exceeding importance in food decisions.

This study highlights a need for better consumer-focused communication and offers a scientific baseline of current U.S. public opinion regarding people's willingness to eat, and purposeful avoidance of GE foods. Moving forward, we expect that the U.S. public's willingness to eat and purposeful avoidance of gene edited food will change as they are engaged more readily on the developmental process and products in this area. Further study of what drives consumer preference will be warranted as more products enter the commercial marketplace and more communication reaches broader audiences.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Iowa State University IRB. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CC and DP contributed equally to the design, analysis, and writing of this report.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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APPENDIX

Table A1 | Variable response scales.

Variable	Response scale
Willing to eat processed GE foods	1 = Definitely not; 2 = Probably not; 3 = Possibly; 4 = Probably yes; 5 = Definitely yes
Willing to eat raw GE foods	1 = Definitely not; 2 = Probably not; 3 = Possibly; 4 = Probably yes; 5 = Definitely yes
Would avoid buying GE foods	1 = Definitely not; 2 = Probably not; 3 = Possibly; 4 = Probably yes; 5 = Definitely yes
Health status	1 = Poor; 2 = Fair; 3 = Good; 4 = Very good; 5 = Excellent
Educational attainment	1 = No high school; 2 = High school; 3 = Some college; 4 = 2-years college degree; 5 = 4-years college degree; 6 = Graduate degree
Family income	1 = Under $10k; 2 = $10–19k; 3 = $20–29k; 4 = $30–39k; 5 = $40–49k; 6 = $50–59k; 7 = $60–69k; 8 = $70–79k; 9 = $80–99k; 10 = $100–119k; 11 = $120–149k; 12 = $150–199k; 13 = $200–249k; 14 = $250–349k; 15 = $350–499k; 16 = $500k or more
Politics, liberal–conservative	1 = Very liberal; 2 = Liberal; 3 = Moderate; 4 = Conservative; 5 = Very conservative
Importance of religion	1 = Not at all important; 2 = Not too important; 3 = Somewhat important; 4 = Very important
Food beliefs/product/nutrition scale items	0 = Not or slightly important; 1 = Somewhat important; 2 = Moderately important; 3 = Extremely important
Pro science and technology scale items	0 = Strongly agree or agree; 1 = Neutral; 2 = Disagree; 3 = Strongly disagree
Food information sources items	1 = Not at all important; 2 = Slightly important; 3 = Somewhat important; 4 = Moderately important; 5 = Extremely important
Institutional trust of GE foods scale items	0 = Very low, low, low-moderate; 1 = Moderate; 2 = High-moderate; 3 = High; 4 = Very high
Heard or read about GE foods	1 = Nothing; 2 = Very little; 3 = Some; 4 = A fair amount; 5 = A great deal
Understanding of GE foods	1 = Poor; 2 = Fair; 3 = Good; 4 = Very good; 5 = Excellent
Personally care about GE foods	1 = Not at all; 2 = Very little; 3 = Somewhat; 4 = A fair amount; 5 = A great deal