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U.S. adult viewers of information treatments express overall positive views but some concerns about gene editing technology

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Abstract

Gene editing techniques (GET) may add precision and speed to the genetic improvement process. However, some adults remain skeptical. We examined U.S. consumer sentiment and concerns about foods derived from GET following information treatments. Randomly assigned participants viewed either: an industry-based video, a food blogger video, or a written article. We coded sentiment and themes of open-ended survey responses. Most responses were in favor of GET after intervention; the industry video produced the most negative attitudes; and technical benefits, concerns, and effects emerged among themes. Our research will help design engagement to boost consumer understanding of GET risks and benefits.

Keywords

Public engagement with science and technology; Public perception of science and technology

DOI

https://doi.org/10.22323/2.22040202

Submitted: 8th June 2022
Accepted: 3rd May 2023
Published: 10th July 2023

Introduction

The family of emerging *gene editing* techniques (GET) may add precision and speed to the genetic improvement process. With GET, scientists can turn off, delete, substitute, or add desired genes without addition of DNA sequences typically transferred in traditional genetic engineering technologies. The result of GET is a custom product identical to one that could have been produced via traditional breeding over years, decades, or centuries, if appropriate gene variants were available. GET is considered so revolutionary that one technique, CRISPR/Cas9, was awarded the 2015 Breakthrough of the Year in *Science* [Travis, 2015]. The emergence of this versatile technology has opened the doors for other relevant applications that impact the global food system. For example, traits that reduce pesticide demand by interfering with the molecular basis of pathogen susceptibility may be created in crop plants. Similarly, genes that expedite the spoilage of raw products can be deleted to extend the shelf life of perishable foods. As GET research continues to gain momentum, specifically within the context of the agricultural commodities market, we must also provide consumers with the information to make informed purchasing decisions.

Consumer acceptance is necessary for the technology to maximize impact on both production and human health [MacFie, 2007]. American adults have reported GET has initial support in the context of research into direct human genetic modification in a therapeutic or preventative context [Weisberg, Badgio & Chatterjee, 2017], and a Twitter analysis from 2018–19 indicated high engagement and general positivity toward gene editing in agriculture, suggesting positive attitudes among those users [Hill, Meyers, Li, Doerfert & Mendu, 2022]. We can learn from U.S. public opposition to current genetic *engineering* technology, a broader category that includes GET, to improve communication and education that will positively influence consumer perception. We know from consumer studies with multiple technologies and issues that simply providing scientific information about safety is not sufficient to win public trust or motivate action [e.g. Bolderdijk, Gorsira, Keizer & Steg, 2013; Bultitude, Rodari & Weitkamp, 2012; Chazdon, Horntvedt & Templin, 2016; Kraft, Lodge & Taber, 2015; Lundgren et al., 2019]. As such, this study explores the components of effective science communication to improve public perception as one of the principal factors that may increase public engagement with science and promote consumer acceptance by establishing mutual good faith among scientists and public audiences.

In this study, we sought to understand U.S. consumer sentiment toward and concerns about GET, specifically. This research aims to gain insight into the motivations behind consumer decisions and examine consumer attitudes regarding food ingredients from crops enhanced with GET. The study also sought to identify factors that shape the perception of GET from the lens of U.S. adults, thereby highlighting areas of priority for future educational strategies. Our research is part of a larger effort to design programs and communication to help these consumers weigh the relative risks and benefits of GET, both for themselves and in broad application. Equipped with this understanding, we hope consumers will contribute to larger ethical discussions about technology use in food with more scientifically-aligned information.

Context

Consumer attitudes towards GET are crucial to consider in the widespread implementation of gene editing technology in agricultural production. GET such as CRISPR/Cas are still emerging, and ours is among the first work related to consumer acceptance of GET in the context of food that has been conducted in the U.S. Therefore, we take inspiration and direction from work with *genetically modified organisms* (GMO) or *genetic engineering* (GE) food studies, both within and outside the U.S. These reports examined sentiment as applied to transgenic technologies, a more invasive and less precise form of genetic engineering than GET.

While more than 280 scientific and technical institutions support the use of ingredients from genetically engineered crops in food [Norero, 2017], overwhelmingly, U.S. consumers thought labeling of such food should be mandatory [McFadden & Lusk, 2016]. In 2015, only 37% of U.S. consumers believed that ingredients from genetically engineered crops were safe for consumption, while 88% of scientist members of the American Association for the Advancement of Science considered human consumption safe [Funk, Rainie & Page, 2015]. We also know that U.S. consumers oppose statements about the safety of genetically engineered food for human consumption when compared to other statements about the advantages and disadvantages of the technology [Ruth & Rumble, 2019].

The basis of most attitudes towards genetically engineered foods may lie in risk and benefit perceptions [Scott, Inbar, Wirz, Brossard & Rozin, 2018]. McFadden and Lusk [2015, 2016] demonstrated that U.S. adult audiences were uniformly divided among *safe*, *unsafe*, and *not sure*, when asked about safety of food ingredients from genetically engineered crops. People may worry about these foods possibly causing allergies or cancer [Scott et al., 2018]. Consumers may view ingredients from GET-modified crops as safer than those from transgenic (a.k.a. genetically *modified*) crops, because the introduction of transgenes from another organism is not required in GET [Ishii & Araki, 2016]. A large-scale multinational survey suggested consumers were more willing to consume food with ingredients from crops which had been genetically edited with CRISPR than food from genetically modified (transgenic) crops [Shew, Nalley, Snell, Nayga & Dixon, 2018]. Among participants of Shew et al.'s [2018] study who preferred to consume food produced with only one biotechnology method, 15% of U.S. participants preferred CRISPR produced food while only 8% preferred genetically modified food. Additionally, 40.1% of American participants considered CRISPR-produced food safe for consumption, while just 5.5% considered food from genetically modified crops safe.

Trust in institutions may also influence consumer perception of risks and benefits of and their willingness to accept GE foods [E. Diamond, Bernauer & Mayer, 2020; Siegrist, 2000]. Trust is often influenced by whether or not the institution's values align with the consumer's, and a greater level of trust could lead to higher acceptance of gene technology [Brondi, Pellegrini, Guran, Fero & Rubin, 2021; Landrum, Hilgard, Lull, Akin & Hall Jamieson, 2018]. A study with Tennesseeans noted those who used more scientific information channels had more positive-leaning perceptions than those who relied on more casual sources such as family and friends [Gibson, Greig, Rampold, Nelson & Stripling, 2022]. Consumers tend to believe that genetic engineering only benefits farmers and seed companies rather than themselves, and this leads to an increased likelihood of rejection of GE technology [Landrum et al., 2018; Scott et al., 2018]. However, approval of genetic modification increased significantly when people were informed [Scott, Inbar & Rozin, 2016] of how specific products derived from genetically modified crops could directly benefit the consumers, such as the use of gene technology in the development of more nutritious grain, which can be used to feed those in developing countries [Hallman, Adelaja, Schilling & Lang, 2002]. Additionally, consumers stated that they often felt uninformed about GM technology in general. Sharing research broadly on the topic of genetically engineered crops could allow for consumers to consider risks and benefits more rationally, possibly leading to a more positive view of genetic modification. Indeed, people who felt that they were more well informed about science and GM technology were more likely to support foods produced from GM crops [Lucht, 2015]; other work suggests even incidental exposure to science may increase factual knowledge on gene editing [Anderson, Howell, Xenos, Scheufele & Brossard, 2021]. However, simply discussing basic scientific knowledge or providing some informational material related to biotechnology has not been effective in changing consumers' perspectives if they are already informed or have opinions. Instead, it may be more beneficial to work toward increasing consumers' trust in scientific institutions and allowing for more public involvement in decision making [Lucht, 2015]. Malyska, Bolla and Twardowski [2016] suggests that interactive seminars could be a useful platform for this purpose since this method would involve more direct engagement with the public. Communicators and facilitators should take consumers' concerns seriously and address them with reason when communicating with their publics.

An increasing interest in natural, organic foods may influence attitudes toward genetically engineered foods [Scott et al., 2018], as may environmental concerns toward food production [Rose, Brossard & Scheufele, 2020; Stofer & Schiebel, 2017]. Consumers prefer food that has been minimally altered, and they may perceive genetic modifications as violating such naturalness, even disgusting or more risky [Chinn & Hasell, 2021]. In 2013, a majority of American adults reported opposition to genetically engineering plants and animals, with a large portion of those opposed reporting so-called moral absolutists who felt that food produced from genetically modified crops was unacceptable since it violated basic moral principles. Since consumers' attitudes are largely affected by these moral institutions, Scott et al. [2018] suggests shifting moral opposition to food from GE crops by informing consumers of other moral or ethical situations which would actually benefit from food produced from GE. This could include discussions of how food derived from GE crops can improve human health and reduce world hunger [Jamil, 2012]. Regarding environmental concerns, a 2018 study found that 8.2% of U.S. participants believed that genetically modified rice could help solve environmental issues, while 5.5% of participants believed that CRISPR technology in rice would be helpful to the environment. Though these personal and ethical factors can have a large impact on consumers' perceptions of risks and benefits, current discussions related to agricultural biotechnology rarely address these ideas. Including these factors in such discussions can make them much more effective [Lucht, 2015].

However, the participants' familiarity with various technologies also influences their opinions on both human and environmental safety [Calabrese, Featherstone, Robbins & Barnett, 2021; Stofer & Schiebel, 2017]. Information treatments can move skeptics more in line with scientific consensus [E. Diamond et al., 2020]. U.S. adults were generally unfamiliar with genetic engineering in 2017, though familiarity increased if they had experience in agriculture [Stofer & Schiebel, 2017]. U.S. participants who were more familiar with genetic modification technology were less willing to pay for foods made with genetically modified ingredients, while participants who were more familiar with CRISPR were more willing to buy CRISPR-produced food [Shew et al., 2018]. Finally, we know from nanotechnology communication [Gilbert & Lin, 2013; Macoubrie, 2006] that, compared to than playing catch up, proactively engaging consumers with the technology and working to address their concerns for use is more likely to allow the technology to benefit those who need it. Using a variety of communication and education channels and strategies might also affect consumer preferences [Besley, Newman, Dudo & Tiffany, 2021; Brondi et al., 2021]. When anti-science forces heavily influence narratives, as is happening with vaccines [J. Diamond et al., 2016; Jee, Uttal, Spiegel & Diamond, 2015] and other genetic modification technologies

[Fernbach, Light, Scott, Inbar & Rozin, 2019], these technologies may face obstacles to widespread adoption. Ultimately, we posit that increasing broad consumer acceptance of the scientific consensus toward adopting GET technology, the topic we explore in the current study, should contribute also toward improved critical discussions of science involving people outside the research community.

Conceptual framework

We used a primarily pragmatic framework [Thayer, 1982], choosing existing, off-the-shelf information treatments that we used previously to explore consumer attitudes and learning preferences for GET through focus groups [McFadden et al., 2021; Thiel et al., 2022]. Our pragmatic conceptual framework relies on no particular theory but instead addresses questions of interest [Thayer, 1982]; in this case, we aim to understand U.S. adult perceptions of gene editing, particularly of existing media on the topic. Such understanding will contribute to our larger goal to design media specifically for experimental studies to examine effectiveness of media and particular elements for changing perceptions. To further explore consumer reactions to the treatments with a larger population, in this study we used an inductive qualitative coding approach to explore post-information treatment attitude and sentiments, with participants randomly assigned to one of three treatment groups [Campbell, Stanley & Gage, 1963]. The inductive approach allowed us to draw themes from participants' own words given limited published studies on consumer reactions to gene editing technology.

Reflexivity statement

The first and second authors completed the primary coding for this study with support from Author 3. The first author was a second year Ph.D. student and graduate research assistant who had taken courses in qualitative research. They also had three years' experience in Extension education. The first author researches Cooperative Extension education to provide solutions to people's everyday lives in the form of research-based educational programs. The second author was a project Co-PI with authors 3 and 4 and the lead for the education research perspective. The second author is a faculty member in agricultural education with over 10 years' experience with qualitative data analysis. The second author researches public engagement with a variety of scientific topics with an aim to help audiences use research-based knowledge in their decision-making. Author 3, who reviewed the codebook development, is a faculty member in agricultural communication with over 10 years' qualitative data analysis experience. The first and second authors' epistemological perspectives are that of education professionals and researchers without explicit ties to gene editing technology. The author team's funding is intended to explore ways to help consumers grow in their acceptance of the scientific facts of gene editing technology; however, we do not feel this stance biases us toward searching for acceptance but rather orients us to seek out criticisms with the hope of qualitatively understanding areas of alternative conceptions.

Purpose and objectives

The purpose of this research was to 1) assess U.S. adults' reactions to information treatments about regulation and consumption of food and ingredients derived from gene-edited crops; and 2) examine reactions across type of treatment. We had the following research questions:

1. What are the participants' reactions to gene edited crops after the information treatment?
2. Do different information treatments result in different participant reactions?
3. What themes emerged in participants' open-ended reactions after information treatment?

Methods

Data collection

We used a Qualtrics opt-in, quota based survey panel to recruit and present an online survey to U.S. adults Dec. 13–19, 2019. Such surveys using non-probability sampling have limitations, including that they are not statistically random, introducing different assumptions into the process of analysis. For example, for non-random samples, "the relationship between the sample and the population is unknown so there is no theoretical basis for computing or reporting a margin of sampling error and thus for estimating how representative the sample is of the population as a whole" [Pew Research Center, n.d., para. 6]. In addition, the need for participants to have internet connectivity and awareness of and time to sign up for a panel to be considered for survey recruitment also limit the population available to be sampled. As of 2019, almost 90% of U.S. adults are estimated to use the internet; making internet connectivity increasingly less of an issue Both of the previous issues are typically partially addressed through use of quotas on demographics or other measures such as offline survey data recruitment using telephone or door-to-door sampling [Pew Research Center, n.d.] or mail-based surveys to mimic the population of interest, though limitations remain for any method or even combination of methods. Another option is to screen opt-in respondents before the survey to match your population demographics, which again does not remove the internet access requirement. However, the ability to collect truly random samples of large populations has always been limited even via random-digit telephone dialing when parts of the population do not have access to or do not answer the phone when caller identification provides a caller they do not recognize [Dillman, Smyth & Christian, 2009]. Therefore, despite their limitations, non-probability sampling surveys are considered one standard method for large-scale opinion research while investigation of methodological strengths and weaknesses are ongoing [Baker et al., 2013; Pew Research Center, n.d.].

We used screening questions to match participant demographics to U.S. Census Bureau categories on age, sex, and income. Survey questions included seven items assessing trust in science [National Science Board, 2018] as Likert-scale responses to prompts such as "Developments in science help make society better", and "overall, modern science does more good than harm". Overall, we designed the survey to complement focus group discussions we also carried out in Fall 2019, with a similar structure to facilitate cross-method analysis. This limited our ability to ask open-ended questions both pre- and post- information treatment also to keep the length of the survey manageable. We report here on a single question about the treatments while the survey itself encompassed additional areas of gene editing as explored in the focus groups.

We first asked about participants' familiarity with both conventional breeding and gene editing, whether they had and opinion on the technology and if so, their ideas about the technology's benefits and concern (open-ended). Next, we offered the National Library of Medicine's definition of gene editing and then asked another open-ended question about benefits and concerns after reading the definition. We also asked knowledge questions related to gene editing's similarities to "traditional GMOs", selective breeding, U.S. regulations of the technology, and benefits of gene editing, among others. Finally, the survey platform randomly assigned participants to an information treatment, and we followed the treatment viewing with the same question asked of focus group participants, "What are your thoughts after viewing the [treatment]?", an open-ended question designed to understand broad ideas about the treatments rather than specifically solicit benefits and concerns as asked prior to treatment. Given the non-specific and qualitative nature of the question following the treatment, difference from the questions offered before the treatment, as well as the knowledge questions as confounds between the original opinions and the treatments, we felt we were unable to design a pre-post comparison on the treatments and instead analyzed the post-treatment question alone for sentiment and themes. Participants were not required to answer either the questions on benefits and concerns before treatment or the question on thoughts after the treatment. Finally, we repeated the knowledge questions and collected additional demographics. The University of Delaware, McFadden's former institution, IRB approved the survey, and the online panel provider compensated respondents. Full survey instrument and treatments are available here: https://osf.io/qena3/?view_only=052ab8eaa1dd486b82860d5434d9e2f0. More detail on the treatments and their use in the focus groups can also be found in Thiel et al. [2022].

Treatments

The survey platform randomly assigned participants to one of three information treatments: and industry-based video, a food blogger educational video, and a written article from a scientist. We used edits of off-the-shelf, publically available videos to represent existing gene editing educational materials to guide our ultimate work to design research-informed communication materials. The video from an industry-based organization featured facts and graphics accompanied by a voiceover, while the blogger video produced by a non-profit, non-lobbying interest group featured a food blogger interviewing a scientist, and a two-page written article from a scientist. Our edits captured pros and cons of GET as similarly as possible. We could not find an existing article; therefore, the fifth author wrote the article to present the pros and cons of GET, and the second, third, and fourth authors all reviewed it and suggested revisions. We did not reveal the sources of the industry treatment to participants, but a logo for the non-profit appeared in the video with the food blogger. Treatment videos were less than five minutes long, and we designed the article to be the same approximate length. Participants had up to 10 min to read the article.

Data analysis

For this study, we examined only the open-ended responses after the information treatment. We started with all 1,375 valid survey responses exported to Excel. The first and second authors then categorized open-ended responses as: unintelligible or blank, related to gene editing, or intelligible but unrelated. During this process, the first author realized that some participants were giving comments on GMOs and using GMOs interchangeably with gene editing. Therefore, we assigned those responses a separate category. We ended up with 1,049 responses related to gene editing; 48 GMO related, 138 intelligible but unrelated, and 143 unintelligible or blank.

The first author coded 50 responses chosen at random from the 1,049[1] related responses for positive, negative, or neutral sentiment and also used open coding [Saldaña, 2016] to categorize the content of responses beyond sentiment, creating the initial codebook. Each participant's response got a single sentiment code to align with another dataset we are investigating for the project in Thiel [2020]; we coded a response as neutral if the participant had either 1) an overall response that expressed both positive and negative sentiments without a clear position, such as when they made one positive statement and one negative statement or 2) a single lack of position or sentiment in one or more statements. However, participants' responses could have more than one thematic code as these were coded at the statement or phrase level rather than the overall participant level. For example, one participant's response was coded as *positive* and *both good and bad*:

> "it is interesting and I think the way of the future. I feel it needs heavy regulation and oversight to make sure that bad is not done. But to be able to increase food supply, eradicate disease and generally helping the earth and population I see as a good thing." (Article)

That response was also coded as *ethics*: "I feel it needs heavy regulation and oversight to make sure that bad is not done" and *benefits to humans*: "to be able to... eradicate disease". On the other hand, a participant who was marked as *neutral* and *both good and bad* said, "While the benefits are clear there are also so many accidental dangers and this whole process could be used as a weapon" (as well as *ethics* and *general benefits*). Given small numbers of responses in some themes and variation across richness of participant responses, we did not attempt to examine sentiment by theme.

The primary coder worked from the focus group protocol and subsequent survey questions as well as from discussions with the first and third author to determine initial thematic codes. The primary coder first examined the data on their own as the least immersed in the topic of gene editing among the researchers who would code the data. The first and third author were co-authors on overarching grant proposal to develop gene editing communication materials; thus, they directed the literature review for both the focus group and current survey study and used those findings to guide the primary coder through subsequent codebook discussions described next.

The second author used the initial codebook to code the same set of initial responses. The first and second authors then discussed, added, and revised the codebook. The larger project team also reviewed and agreed with the codebook. Thematic codes included whether the response covered agriculture or human health contexts, as previous research has found U.S. adults tend to think of these technologies in human health contexts more often. Thematic codes also included

[1] In contrast to the analysis for Rumble et al. [2023], here we included all participants' responses, regardless of level of trust in science.

concerns, benefits, confusion, and knowledge gained. The first author then coded the remaining responses, using MaxQDA20 for the open coding. Both first and second authors worked together to discuss themes of the responses from coding, and the first author was the primary writer of the qualitative results. Full codebook is in Table 1.

Table 1. Final codebook.

Theme	*Code*	*Code description*	*Examples*
Sentiment	Postive	Participant had an overall response that was positive to GE technology or the format. This includes responses like "interesting"	"I think the process has many benefits" and "it was very informative without too much technical jargon"
	Negative	Participant had an overall response that didn't favor GE technology or the format. This includes responses like "bad".	"That it's still playing God with DNA and it's wrong." and "Boring"
	Neutral	Participant had an overall response that was indifferent to GE technology or the format. This includes responses like "I didn't learn anything new". Or, participant expressed both a positive statement and a negative one without coming down clearly on one side.	Example 1: "It's a good plan to remove the sianide [sic] from the plant to grow for the hungry countries. As long as we stick to food and medicine and do not try to recreate humans or animals" Example 2: "It changed my mind"
Concerns	Fear of GE	Participants mentioned they are afraid or fearful of GE technology.	"It's [sic] seems like its pretty Co [sic] but seems like it can be alarming at the same time with all the modifications options"
	Beneficial but needs more research done	Participants expressed seeing the benefit of GE technology but stated more research or testing was needed.	"I think that when used properly and without making error it could help human diseases. Still not sure what the longterm effects would be."
	Scary, needs more research	Participants expressed doubt coupled with a request for more research	"I hope there is plenty of research"
	Efficacy	Participants question does it work	"Sounds good if it's safe and works"
	Safety	Participants mentioned issues of safety and or not causing harm	"Gene editing has the potential to make food safer. Science can solve big problems if used properly."
	Good and bad	Participants acknowledge both good and bad	"I'm still not convinced this is a good thing in some instances it may be but there may be bad repercussions as well only time will tell." And "it is interesting and I think the way of the future. I feel it needs heavy regulation and oversight to make sure that bad is not done. But to be able to increase food supply, eradicate disease and generally helping the earth and population I see as a good thing."
	Ethics	Participants mentioned the need for regulations or proper use	"Wow. This science and technology cannot fall into the hands of evil-doers; it must be closely regulated for the good of humanity."

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Table 1. *Continued from the previous page.*

Theme	*Code*	*Code description*	*Examples*
Effect	Future generations effects	Participants mentioned how this may affect future generations of people.	"I think it is amazing how much Scientists are doing for all of humanity and our futures." And
	Agriculture effects	Participants discuss effects on agriculture or component industries	"This process is beneficial to producing food"
	Intersection	Participants discuss other social issues discussed in conjunction, such as overpopulation	When used properly, genetic research can do amazing things by helping to create better foods, diminish disease, and eliminate malnourishment and poverty.
Emotions[1]	Lack of interest in subject	Participants express lack of interest or care for GE Technology.	"It's hard for me to focus on this kind of subject. It doesn't really interest me all that much."
	Inspiring	Participants discuss not just thinking but more action-oriented besides learning more	(No reponses fit this code)
Knowledge	Knowledge gain	Participants expressed increase of knowledge on GE technology.	"I didn't know that they could improve how a plant works by editing their DNA."
	Amount of info	Participant mentions a lot of information/didn't know as much as they had thought	"I learned more than I ever knew about how it affects it all"
	Desire to learn more	Participant mentions specific desire to learn more	"Would like to research it more very interesting"; On the other hand "Very interested in this process" was not coded with desire to learn more.
	Confusion remains	Participant mentions they have questions or confusion still	"That's ALOT to take. It's hard for me to completely understand tons like that."
	Thought-provoking/new perspective	Participant mentions new idea that is not related to content knowledge	"Very interesting and provocative"
	It's real	Participants talking about how the technology is new/different/realistic with some elements of surprise	"It is very different then what I understood genetic editing to be" and "I think it's cool this kind of advancement is real"
Technical benefit	Benefits to developing countries	Participants felt this could help the world in some way like helping developing countries.	"It's a good plan to remove the sianide [sic] from the plant to grow for the hungry countries."
	Human health	Participants mentioned better human health or things related to health such as decrease diseases, etc.	"Editing could be used to supply better food and help fight deceases. [sic]"
	Better food nutrition	Participants mentioned things relating to nutrition like food allergies or removing things such as gluten.	"Its [sic] about how to improve vegetables for those who has [sic] allergies"
	Environmental benefit	Participants mentioned something related to global impact like reducing climate change.	"Probably needed for the future because of global warming"
	General/non-specific effect	Response does not mention a specific benefit except benefit to people or plants and animals	"Sounds really helpful to all people"

Note. [1] The theme of emotions resulted in a small number ($n = 14$) of ideas and was therefore excluded from reporting and further analysis.

To determine how many responses we coded with thematic as well as sentiment codes, we viewed all valid participants' categorized responses in Excel for ease of readability from the MaxQDA output. A unique participant response coded with one or more thematic codes would show up multiple times in the spreadsheet. Therefore, by identifying and separating responses which had duplicates, all responses could be classified into two groups: responses with only sentiment codes, and responses with thematic codes. Then we used Excel filters to highlight participants who had provided responses with thematic codes to enumerate the sentiments of the thematic-coded responses. Similar filtering produced numbers for each treatment. Finally, we used Pearson's Chi-square analysis in R, Version 4.0.5 (2021-03-31), to examine the hypothesis that the sentiment distribution varied across information treatment. Upon finding that we rejected the null hypothesis of no difference across treatment, we conducted a Bonferroni post-hoc analysis (packages "devtools" version 2.4.0, library "chisq.posthoc.test", method = bonferroni) of sentiment with treatment as the independent variable.

This study purposely removed some aspects of data collection that allows for true rigorous qualitative analysis in favor of collecting a larger number of responses, especially across different types of media. While standards for research quality vary, we submit that our methods follow principles toward establishing credibility [Lincoln & Guba, 1985; Dooley, 2007]. Our team of researchers has been working on understanding consumer responses to GET and earlier technologies for over five years. The large number of responses allows us to understand the phenomenon in depth, providing a form of persistent observation to accompany our deep experience in the subject area. While recognizing the limits of triangulation using a single data source but multiple investigators [Lincoln & Guba, 1985], our collaboration provides multiple perspectives on our data. Our detailed explanations of methods satisfy criteria for dependability, and we provide descriptions of our qualitative data to the extent possible for transferability [Dooley, 2007]. Finally, our conclusions can be traced back to our original data for confirmability [Dooley, 2007].

Results

Of our 1049 valid responses, the sum of participants' trust in science scores ranged from 7 (low trust, all 1's on a 1–7 scale) to 35 (high trust, all 7's on a 1–7 scale). Based on screening questions aiming to match to national demographics, participant household income resulted in the following: $50,000–$99,999 (32%), with under $25,000 (18%) and $25,000–$49,999 (22%). Participants were roughly equally distributed among three age groups: 18–34 (29%), 35–54, 55 and up (36%), and slightly fewer males than females (52%). Regarding demographics that were not matched to national distributions, overwhelmingly, we had White participants (799, 77%), with Black participants close to national demographics (126, 12%), and Hispanic/Latino (6%) and Asian participants (3%) underrepresented in our final sample compared to national demographics. Participants were roughly equally distributed among three age groups: 18–34 (29%), 35–54, 55 and up (36%), and slightly fewer males than females (52%). Participant household income skewed slightly to $50,000–$99,999 (32%), with under $25,000 (18%) and $25,000–$49,999 (22%) categories underrepresented of the four. For completed education level, participants reported high school (35%), some college/trade school (27%), and bachelor's degree (22%) most frequently. 40% of participants reported full-time employment, 22% were retired, and 13% were stay-at-home parents/spouses; the remainder were students, part-time employees, or seeking full-time employment. Almost 42% of participants lived in the South, compared to roughly 20% each in the Northeast, Midwest, and West; these regions were designated to match our focus groups from Thiel et al. [2022]. Overall, our 1049 participants with valid open-ended responses did not obviously differ from the 1375 total survey participants.

Sentiment

The first research question sought to determine adults' reactions to gene edited crops after an information treatment. Most participants ($n = 790$, 75%) with valid responses had an overall positive response after viewing one treatment on gene editing. Neutral responses accounted for 127 (12%) of responses. A similar number, 131 (12%), of the total participants opposed gene editing or had overall negative responses. See Table 2.

Table 2. Responses and sentiment, overall and by treatment.

	Overall		*Blogger video*		*Industry video*		*Written article*	
	Total	Percent	Total	Percent[1]	Total	Percent[1]	Total	Percent[1]
Unique participants with a valid response	1049	100[1]	363	35	377	36	309	28
Positive responses overall	787	75[2]	295	37	277	35	216	27
Negative responses overall	131	12	31	24	57	44	43	33
Neutral responses overall	130	12	37	28	43	33	50	38

Note. [1] Rows across present percent of total valid responses. [2] Columns present totals by treatment. Totals may not sum to 100 due to rounding.

For research question 2, we wanted to determine if the particular information treatments produced different reactions. We found that the two videos had roughly similar percentages of positive responses among viewers of each treatment, 35–37%, However, the industry video had a higher percentage of negative responses than the food blogger video, with 43% of viewers rating their view of GET negative after the industry video compared to 24% of food blogger video viewers. The written article received the smallest proportion of positive responses at 27%. More article readers were neutral overall toward GET after treatment than either positive or negative. See Table 2.

Chi-square analysis of sentiment revealed a significant difference of observed vs. expected values in our dataset overall, $X^2(df = 4, N = 1049) = 15.5$, $p < .01$. Therefore, having rejected our null hypothesis of equivalent expected and observed values, Bonferroni post-hoc analysis showed that the blogger video was significantly more likely to result in positive comments ($p < .01$), and significantly less likely to provoke neutral or negative responses than expected. Neither the industry video nor the article produced other statistically significant differences in observed vs. expected sentiment values, except for the written article, which had a marginal ($p < .10$) significantly lower than expected value for positive responses. See Table 3.

Table 3. Chi-square results, sentiment by treatment.

	Blogger video		*Industry video*		*Written article*	
	Residuals	Expected value	Residuals	Expected value	Residuals	Expected value
Positive	3.4	273**	−0.9	283	−2.5	232
Negative	−2.8	45*	1.9	47	0.9	39
Neutral	−1.6	45	−0.7	47	2.4	38

Note. * $p < .05$, ** $p < .01$.

Themes

Research Question 3 concerned the content of open-ended responses to GET after treatment. From 501 unique participants who provided responses that could be coded based on content, we had a total of unique 638 coded responses. See Table 4. Knowledge, technical benefits, concerns, and domains for effectiveness all emerged as themes, with knowledge, benefits, and concerns expected as they were likely primed by questions in the survey before the treatments. In this section we discuss each theme in detail. There were nearly equal numbers of responses coded as human health, better food nutrition, and agricultural effects.

Table 4. Sentiment and number of thematic codes.

Total content codes[1]	*Positive content responses*	*Negative content responses*	*Neutral content responses*
638	485	77	76

Note. [1] Participants could have more than one content code per response.

The most common code that emerged from the participants was that they learned something new and/or wanted to learn more about gene editing, resulting in 117 (19%) of the statements or phrases that were coded beyond sentiment. Knowledge was the most prevalent theme, at 38%. The themes of *Effects* and *Technical Benefits* were overwhelmingly part of positively-coded responses, perhaps unsurprisingly due to the definitions for the benefits, but perhaps surprisingly for effects, which was not defined as positive or negative. Themes of *Knowledge* and *Concerns* were also largely part of positive overall responses, but these themes were associated with more negative and neutral overall responses as well. Participants mentioned benefits and concerns with approximately equal frequency. See Table 5.

Table 5. Sentiment by thematic codes.

Theme	*Positive*	*Negative*	*Neutral*	*Total*
Concerns	77	33	47	157
Effect	65	2	2	69
Knowledge	199	28	18	245
Technical benefit	141	1	3	145

Codes relating to the theme Knowledge covered *knowledge gained*, *desire to learn more*, mentions of the *amount of information*, *confusion remains*, *thought-provoking or new perspective*, and *realization that the technology is real*. One participant's response related to knowledge gain was "Very educational. Learned things I never knew existed in regards to the genetics in food," (blogger video (BV)) while another said, "I was unaware of a lot of what was explained in the video" (industry video (IV)). Other participants stated an explicit desire to learn more, calling gene editing "promising" (BV), or noting gene editing "could be very beneficial to the health of humanity. I'd like to learn more about the different ways it's being used" (BV). Another said they were unfamiliar with the term CRISPR but would definitely seek out more research (BV). Some participants who were still confused noted the amount of information also, as they tried to "understand all the things that's being said in [the article]", though others reported the article (A) was "thorough" and provided new information. Others revealed the information was thought-provoking (A) and "opens the mind to more positive possibilities" (BV). One participant's expression of realizing the technology existed was, "I didn't know that they could improve how a plant works by editing [its] DNA" (IV).

For technical benefits, participants described how the technology itself could be beneficial. They mentioned benefits to developing countries, such as "I especially liked that crisper [*sic*] technology can help feed people in 3rd world countries" (BV). Others mentioned human health benefits, including better nutrition, as in this quote, "It can help countries that struggle with food insecurity to create sustainable and nutritious food while also removing allergens so that all of the world can be more safe" (BV). Participants also mentioned environmental benefits, including, "Seems like it will be useful for the environment for a long time" (IV).

The theme of concern included codes such as *mixed thoughts* in general, and *concerns about safety*, *potentially beneficial but needing more research*, *fear*, and *ethical use*. Many codes in this theme overlapped considerably. One participant stated their mixed thoughts, writing, "I think scientists are making amazing discoveries each and every day. I however am one to be concerned about stuff mutating and taking over the world. I don't know. Maybe I've seen one too many zombie movies" (A). Another mixed thoughts response concerned a lack of discussion of potential downsides in the information treatment, saying, "It addresses one of the positive uses of CRISPR technology, but does not acknowledge any of the potential consequences" (BV). In terms of safety, some people agreed gene editing is safe, saying: "Gene editing is [a] way to increase [quality], yield, and resistance to disease while maintaining safety for the customer. We should expand its use" (IV). Others brought up safety concerns, "pretty radical stuff. Extreme changes but also [very] scary and potentially dangerous" (A). Another participant was in favor of gene editing but shared some concerns about needing more research,

> I tend to agree with the use of that technology. My one and only worry is whether we can demonstrate that in the long run — say 10 or 20 years — we don't cause any unforeseen adverse side effects, which are common to so many changes that are not THOROUGHLY [*sic*] researched. (BV)

Some participants expressed fear, saying things including, "i feel uncomfortable just reading this" (A); and, "I believe she is on the right track. But it is scary to think about the dangers that lie ahead. Especially if this leads to human gene modifications" (BV). For some, the dangers and fear were for potential consequences: "That doesn't sound so bad. But what about long term? They said vaping was a better solution to smoking, now look. I understand [CRISPR is] good. But food plays a big part in our overall development and health" (I).

Several participants brought up ethical concerns, such as one who wrote:

> It appears as though there are more benefits than serious problems after the process, but the process seems to be driven by only a few large companies, countries and big money people who control the process and that is not good or acceptable. People from all countries and governments should come together to monitor this situation to ensure proper outcomes. (A)

Participants also discussed the potential domains for effects, including on: future generations, agriculture, human health, and intersections with other social issues. For future generations, for example, one respondent wrote, "I think it is amazing how much Scientists are doing for all of humanity and our futures" (A). Another went further, incorporating both ethical issues and intersections with other social issues such as family planning:

> It's absolutely fascinating that this technology could make such a difference in people's lives, specifically that of children. ... it's important though that it be used in an ethical manner and that societal changes occur at the same time. If a family is used to having as many children as possible because some of them don't live..., it's important that family planning is introduced when every child is healthy. (BV)

Another wove together ethical concerns and human health, saying, "When used properly, genetic research can do amazing things by helping to create better foods, diminish disease, and eliminate malnourishment and poverty." (BV). Several respondents discussed effects on agriculture such as eliminating poisons from produce (BV, the only source to mention this), increasing efficiency of crop production (IV), and longer shelf life for fruits and vegetables (IV, A). Other participants mentioned addressing allergies with gene editing; all of these came from the blogger video, which was the only source to mention allergies. The other social issues that participants mentioned intersecting with gene editing included overpopulation, and reduction of poverty.

Discussion

The largest number of participant responses were positive after information treatment on GET, though we cannot tell if the treatment itself influenced those opinions in any direction. This includes responses that were positive explicitly toward the technology, explicitly toward the treatment, and those that were positive but unclear about what aspect or aspects. While the off-the-shelf videos did not allow for highly controlled and comparable inferences, we did note also a few deviations from expected results across treatments. The industry video produced a higher percentage, though not significant, of negative attitudes than the food blogger video and the written article. The blogger video showed more positive responses than expected compared to both the neutral and negative responses and the industry video and article, and responses to the article were slightly less positive than expected. This is a somewhat different pattern, with more skew toward positivity for the blogger video compared to our findings among just participants who had a trust in science score higher than average, reported in Rumble et al. [2023]. Notwithstanding our lack of control in the design, it is also noteworthy that the explicitly balanced article that we did design to present both pros and cons resulted in the highest number of neutral responses; public audiences do report wanting balanced information about GET [McFadden, Rumble, Stofer & Folta, 2023]. However, the question of what constitutes balance remains murky; presenting pros and cons without an assessment of whether experts consider the benefits to outweigh the risk may leave public audiences with a feeling that there is no consensus from experts. This could be an explanation for the neutrality elicited by the article. Another explanation to consider would be the perceived neutrality of the source as a scientist and relative trust of the source. Finally, overall low media literacy could influence reactions to the blogger versus the scientist. These alternatives are worth further consideration.

Of those participants who responded further, many reported learning something new about GET and CRISPR. The participants made connections between GET and both health and agriculture, in line with other findings about context and these technologies [Stofer & Schiebel, 2017; McFadden et al., 2021; McFadden et al., 2023]. Another common theme reflected participants seeing GET's benefits but still wanting more research as well as concerns about ethical use and safety, especially in the long-term. Participants mentioned aspects of the technology that seemed accessible to them, such as removing poison and allergens and increasing yield and shelf life for food. A small number of participants did not want gene editing to happen at all.

As participants viewed only one treatment each, we have little evidence as to why they viewed particular treatments more favorably or negatively than others. The survey question makes it difficult to disentangle thoughts about the technology itself from the medium, nor could we directly assess the thoughts on our sources: an everyday person, an industry group, or a scientist. Instead, we tackle those in our related studies using focus groups and other experimental designs [McFadden et al., 2023; Thiel, 2020; Thiel et al., 2022]. However, positive aspects people commented on were the clarity and amount of information, the discussion of risks as well as benefits, and relevance to their lives such as when discussing food allergies, which could guide communicators in content choices. Concerns people brought up seemed to center on the technology and the clarity or amount of information. Overall, all formats received a majority of comments that were positive, and all received some critiques. However, only about half of the participants commented at all. More research to ask participants about the aspects of the format separately from the technology could assist in clarifying format preference; our own focus group work has explored participant preferences when comparing all three formats and found similar preferences for the blogger video [Thiel et al., 2022]. Our future work involves creating and testing more identical communication tools to more precisely vary and thus compare the variables of format, source, and even context that we could not when using off-the-shelf tools.

A communication gap between experts and public audiences' understanding of scientific topics is a common issue. Our study helps scientists and science communicators gain a better understanding of how U.S. adults may feel towards GET in order to create effective and creative educational messaging. The themes revealed here can guide communications to include what resonated with people as well as addressing what concerns they expressed or areas they wished had been addressed. However, overall, our research suggests consumers may be more open to GET than public audiences are or were to so-called GMO foods.

Creative messaging can be in various forms that may be appealing for the specific audience such as storytelling, infographics, analogies, using visual aids, and asking your audience open-ended questions. We now have ample evidence that storytelling can be a powerful way to nurture engagement with science [Dahlstrom, 2014] and that stories help people to understand, process and recall science-related information [ElShafie, 2018; Joubert, Davis & Metcalfe, 2019]. The simplicity of a science infographic can be helpful in communicating information to non-academic audiences through news articles, brochures, or posters; however, scientists can also use infographics to communicate their research with peers without the formalities of a journal article [The University of Queensland, n.d.]. For example, for those participants who had concerns but wanted more research, communicators could use infographics or visual representations of research to show adults how much research has been conducted on GET.

Our research has some attendant limitations. For one, we used an external panel for survey recruitment, which brings both self-selection of panel enrollees and ultimate survey participants. However, these panels are standard for public opinion research, and we matched participants to U.S. adult demographic categories to address sample representation. Our qualitative coding also presents limitations in terms of generalizability and validity due to the nature of the analysis. However, by presenting a detailed description of our researchers' qualifications and thick, rich descriptions and participants' voices wherever possible for data, we addressed the standards of analysis as laid out by Dooley [2007].

Recommendations

Future research could separate responses to the open-ended questions after treatment based on initial responses, level of trust in science, response changes after the definition, or responses that changed after treatment, especially given larger sample sizes to collect more open-ended responses per treatment and sentiment. We also did not compare themes across treatments in this study due to the variation in content resulting from the use of off-the-shelf videos. Each of these studies could give us further insights into particular audiences and help inform best practices for Extension and educational programming and communication to improve participants' understanding of the technology's benefits, remaining concerns, and the extent of the research behind the technology to date. We could also examine the relation of knowledge on the participants' attitudes both before and after the treatment.

Future research could also examine more closely the role of trust in science and the correlation of high trust with sentiment. Through the process of coding, the researchers discovered that some participants were using the terms *gene editing* and *GMOs* interchangeably, despite the presentation of the definition of gene editing. Based on this finding, there was confusion among participants about the difference between GET and the imprecise catch-all "GMOs". Future research could examine U.S. adults' understanding of the similarities and differences between GET and so-called GMOs and their related technologies. One set of audiences specifically that deserves further attention is those people with disabilities, especially those people whose disabilities have a genetic component, because of potential benefits, risks, and additional ethics considerations related to use of GET for medical applications.

This research specifically gives science communication and education practitioners a better understanding of the opinions of a broad group of U.S. adults on gene editing as of Fall 2019. Since the majority of U.S. adults surveyed had positive remarks regarding gene editing in foods and in agricultural production after treatment, we suspect many people may be open to learning more about gene editing and its benefits. However, we also noted that participants had some concerns, mainly related to resistance to technology more broadly in the context of genetic-level interventions for agriculture and human medicine. Practitioners must understand specifics about their audience to help tailor their communication strategies around GET, such as their trust in science overall and trust in the practitioners themselves. For example, U.S. Cooperative Extension agents, with their history in and connection to agricultural and rural communities, could prove to be a more trusted source for messaging than industry in some contexts, but certainly food bloggers are also likely influential in shaping attitudes.

Practitioners could create messaging and programs to address separately both those already interested in learning more and using the technology's benefits, and those who are skeptics following principles of audience segmentation. For the first group, a champion such as the food blogger may be encouraging and result in positive attitudes, and practitioners could follow with an ask for the first group to become champions to their family and friends in turn. For the skeptics, offering opportunities to discuss their concerns and highlight the benefits and extent of research behind the technology using techniques such as motivational interviewing rather than potentially evoking negative sentiment through an information-only presentation may be more effective to produce converts. However, there may also be a group with little information and few strong opinions to start with in the context of food [Thiel et al., 2022]. For these people, education facilitators could take advantage of people's interest in gene editing in the related context of health to make a connection to the agricultural aspects of gene editing technology. In Extension, family and community science or horticulture educators could facilitate meaningful discussion to compare multiple technologies and what that means to the food we eat. Practitioners could also create displays for tabling events at farmers markets or food festivals to share with shoppers more about gene editing technology and its effects on agriculture and human nutrition. Communicators could use social media to share videos as well as written articles while creating conversations around gene editing and how it may benefit humans and the environment. Proactively discussing this emerging technology may allow us to increase familiarity and comfort, capitalizing on existing positive orientations toward gene editing while addressing continued concerns, allowing GET to ethically benefit those who could be helped most.

Acknowledgments

This research was supported by the intramural research program of the U.S. Department of Agriculture, National Institute of Food and Agriculture, AFRI program, 2018-67023-29795, Hatch/Multistate 1020926, and Hatch 1020898. The findings and conclusions in this preliminary publication have not been formally disseminated by the U.S. Department of Agriculture and should not be construed to represent any agency determination or policy.

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How to cite

Stofer, K. A., Turner, S., Rumble, J., McFadden, B., Folta, K., Jeevan, A., Ouncap, T., Hecht, K., Cummins, C. and Thiel, R. (2023). 'U.S. adult viewers of information treatments express overall positive views but some concerns about gene editing technology'. *JCOM* 22 (04), A02. https://doi.org/10.22323/2.22040202.

ISSN 1824-2049. Published by SISSA Medialab. jcom.sissa.it