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U.S. Adult Attitudes about Biotechnology and Risk Aversion to Gene Editing

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While attitudes toward genetically modified (GM) foods have a long study history, there is still much to learn about U.S. adults' attitudes toward gene edited (GnEd) food. We combine results from two online surveys; one study of 1,331 respondents used a randomized approach to compare views between GnEd and GM foods, and the other study of 1,442 respondents used a framing approach to compare GnEd and fungicide as a solution to combat an agricultural fungus. Overall, respondents viewed GnEd and GM similarly. However, the results provide hints that there are more positive attitudes about the capability of GnEd to positively impact the food system. There was no obvious preference for using either GnEd or fungicide to combat an agricultural disease; however, there were some small framing effects. Combined, our results show some differences emerging in the discussion of GnEd versus GM and reduced some of the risk aversion for GnEd compared to fungicide use.

Keywords: Gene editing versus genetic modification, Prospect theory, risk aversion to biotechnology

1. Introduction

Gene editing (GnEd) is the familiar name given to changes in DNA created through site-specific nucleases, enzymes that tailor discrete changes in DNA. The application of GnEd to combat pests and diseases in agriculture has received renewed attention since the invention of CRISPR, a GnEd technique, which *Science* magazine named the breakthrough of the year in 2015 (Travis, 2015). To what extent GnEd applications will reach their commercial potential in combatting pests and disease depends partly on consumers' concerns and ultimate acceptance or rejection of this technology. Early research hints that consumers may have a similar aversion to GnEd as genetic modification (Shew et al., 2018).

The literature on U.S. consumer acceptance of food containing ingredients originating from genetically engineered crops provides important lessons that may be extended to consumer perceptions of GnEd foods. For example, consumer preferences are influenced more by country of origin than whether a food contains ingredients from genetically modified (GM) plants (Hu, House, McFadden, & Gao, 2021), and consumers are more accepting of manufactured foods with GM crop ingredients, such as sugar or oil than GM whole foods, such as sweet corn (Lusk, McFadden, & Rickard, 2015). Other research postulates different reasons for varying attitudes toward GM and related technology, such as lack of understanding or familiarity with the terms *GM* (Hallman, Cuite, & Morin, 2013) or *genetic engineering* (Stofer & Schiebel, 2017), or differences between concerns about the technology's effects on human health versus the environment (Stofer & Schiebel, 2017).

Although consumer aversion to previously introduced genetic engineering techniques, particularly ingredients derived from GM crops, has been well documented (Frewer et al., 2013; Gaskell, Bauer, Durant, & Allum, 1999; Lusk et al., 2005; McFadden & Lusk, 2016; McFadden & Smyth, 2019), there is some early evidence that consumers may be more amenable to GnEd solutions for issues like combatting plant disease (McFadden, Anderton, Davidson, & Bernard, 2021). There is also evidence that consumers perceive GnEd somewhat differently than GM. For example, consumers associate GnEd more with medical applications rather than agricultural applications (McFadden et al., 2021). However, the presentation of the technology to consumers may matter as they consider gains and losses. Previous research suggests that the gain or non-loss may not matter if presented on food labeling (Abrams, 2015). Abrams (2015) found no significant difference in consumer attitudes toward a chicken product when presented with different labeling treatments claiming gains or non-losses. Further, previous research concluded that loss-framing about technology that enhances food safety was more influential on consumer perceptions of safety and willingness to pay than gain-framing (Britwum & Yiannaka, 2019a, 2019b).

Using data from two separate surveys administered to different sets of respondents in the U.S., this paper builds on concepts applied to GM and in other agricultural contexts to provide insight into societal views about GnEd. In one survey, data were collected from 1,331 U.S. respondents to examine whether attitudes held toward GnEd were similar to attitudes held toward GM. In another survey, data were collected from 1,442 U.S. respondents and a well-founded theoretical framework, Prospect Theory, was used to examine attitudes toward a GnEd application compared to increased pesticide application (i.e., fungicide) and potential framing effects on attitudes. Taken together, these results provide insight into how GnEd is perceived relative to previous genetic engineering techniques and pesticide use. The results of this study add to the emerging literature examining differences in U.S. adults' attitudes about GnEd versus GM in food and how consumers may be willing to make tradeoffs between using GnEd versus pesticides to combat agricultural pests.

The remainder of this paper is organized as follows. The next section is a literature review that broadly discusses the previous studies relied upon to develop the survey questions used in this study. Section 3 provides details of two online survey studies, including the U.S. adult samples for the data, the specific questions used in each. Survey 1 involved no experimentation and only asked about attitudes but compared GM and GnEd directly, while Survey 2 presented hypothetical scenarios randomized for subgroups of participants based on Prospect Theory. We also share more details about the questions used in the previous studies that our questions rely upon in Section 3, and the statistical tests estimated to examine responses and compare experimental scenarios. Section 4 presents the results from the statistical tests, and Section 5 provides conclusions drawn from the results and aligns the results with previous research.

2. Literature Review

Data collected for one of the research questions in this study expanded on the set of questions previously used by Ruth and Rumble (2019). Ruth and Rumble (2019) examined the attitudes and beliefs of Florida residents toward different GM messaging strategies, with the primary goal of exploring uncertainty and perceived health risks associated with GM foods. The study used a quantitative survey consisting of two questions to explore the range of attitudes and beliefs individuals held toward GM food and the messaging surrounding them. A majority of respondents perceived GM foods not to be sufficiently well understood and to be riskier for consumption than conventional foods (Ruth & Rumble, 2019). However, while consumers were shown to be skeptical and concerned about GM food safety overall, the results pointed toward somewhat polarized views of this technology: When asked which statements least aligned with their views, the majority of participants selected the statement claiming that GM foods were safe to eat. At the same time, the second most rejected statement was that GM foods cause cancer. We introduced an additional question that used the same format and message wording but replaced GM with GnEd. This novel approach allowed us to directly determine similarities and differences between attitudes toward GnEd and GM.

Data collected for the other research question in this study closely followed Prospect Theory, a framework put forward by Kahneman and Tversky (1979). Prospect Theory posits that people respond differently to the framing of outcomes as a gain or a loss. This behavioral phenomenon, referred to as *loss aversion*, implies that people are more comfortable with risk when the potential outcome is presented as a loss to be avoided rather than an equal gain to be realized. The desire to avoid losses may also delay the adoption of unfamiliar technologies, even when some technologies offer well-established benefits (Liu, 2013). For example, *Bacillus thuringiensis* (Bt) applications can reduce reliance on broad-spectrum insect control strategies, reducing effects on non-target insects, the high cost of application, and potential toxicity to applicators (Ahmed, Hoddinott, Abedin, & Hossain, 2021; Kouser & Qaim, 2013). Yet, some producers remain hesitant to adopt Bt applications (Liu, 2013).

Loss aversion has been applied in a range of disciplines, including economics, finance, politics, international relations, and strategic management (Abdellaoui, Bleichrodt, & Kammoun, 2013; Barberis, 2013; Bromiley & Rau, 2022; Farnham, 1994; Levy, 1992; Vis, 2011). A recent meta-analysis by Brown, Imai, Vieider, and Camerer (2021) concluded that people's aversion to losses is about twice as strong as their attraction to gains. This framework has also been applied to agricultural producer decision-making, showing that producers' risk attitudes are consistent with loss aversion (Zhao & Yue, 2020), and agricultural producers' risk attitudes are consistent with the estimate of aversion to losses being twice as strong compared to gains (Bocquého, Jacquet, & Reynaud, 2014). While there is not much evidence surrounding the effects of loss aversion on technology adoption for consumers, McDermott, Fowler, and Smirnov (2008) suggest that the risk and loss preferences underlying Prospect Theory are consistent with models of evolutionary psychology explaining adaptive problems like procuring a sufficient amount of food for survival. Our application of Prospect Theory is novel as it seeks to understand consumer aversion to GnEd relative to pesticide use. GnEd applications in agriculture are often designed to replace or reduce pesticide use. Thus, exploring how consumers make tradeoffs between aversion to GnEd versus pesticide use and how framing effects influence relative aversion provides valuable information about communicating the benefits of GnEd applications targeted at replacing or reducing pesticide use.

3. Materials & Methods

This paper examines responses to two lines of questions: 1) respondents selected the messages that most and least aligned with views about either GnEd or GM food, and 2) respondents selected either GnEd or fungicide as a solution to combat a fungus outbreak in apple trees in questions that varied by framing (Prospect Theory). More details are provided in the subsequent subsections and the specific wording of the questions asked are presented in Appendix Figures 1 and 2.

These two lines of questions build on the conceptual framework of previous research. The first line of questions builds on the framework used by Ruth and Rumble (2019) by collecting data on attitudes about GnEd and GM foods, not just GM foods. Further, our study expands the population sampled to the entire U.S., whereas Ruth and Rumble (2019) focused on respondents residing in Florida. Therefore, our study provides information about U.S. adult attitudes towards GnEd and GM and allows us to test for any differences between GnEd and GM attitudes. The second line of questions builds on the Prospect Theory put forth by Tversky and Kahneman (1981) by using the framework to examine framing effects and risk aversion to a practical outcome (i.e., reducing the impact of an agricultural disease), rather than using the framework for theory testing. Our application of Prospect Theory provides information about risk perceptions to the use of a biotechnology response (i.e., GnEd) relative to a chemical response (i.e., fungicide) to an agricultural disease and the impacts of framing effects on risk perceptions.

3.1 Data

Data for the two questions examined in this paper were collected from separate online surveys administered to a sample of adults residing in the U.S. Both studies were approved by the Institutional Review Board at [*masked for review*] and respondents provided informed consent before answering any questions. Qualtrics® online survey-design software was used to develop the survey instruments, and the sample respondents were reached via online panels maintained by Qualtrics®. Quota-based sampling was used to ensure that respondent characteristics matched the U.S. population based on age, education, income, and sex. The first line of questions in this paper were asked in a survey that was fielded between February 11 and 17, 2021, and collected 1,331 responses. The average respondent age was approximately 47 years old, about 31% had a Bachelor's degree or higher, the average household income was around $70,000, and 50% were female. The second line of questions in this study were asked in another survey of 1,442 respondents fielded between February 2 and March 1, 2021. The average respondent age was approximately 44 years old, about 33% had a Bachelor's degree or higher, the average household income was around $68,000, and 51% were female. The means of these demographic characteristics by groups and treatments for each study are presented in Appendix Table 1. There were no significant differences between groups across the demographic characteristics, as determined by multivariate analysis of variance (MANOVA).

3.2 Survey Questions of Interest

Question One: Gene Editing versus Genetic Modification

For the first question, respondents were randomly assigned to a GnEd or GM group and only selected the messages that most and least aligned with views about one of the technologies. There were 670 and 661 respondents randomized to the 'GnEd Group' and 'GM Group', respectively, totaling 1,331 observations. A similar question formatting has been used to determine consumer preferences for food products (Liu, Li, Steele, & Fang, 2018), food attributes (Massaglia et al., 2019), perceptions about the food safety responsibility of actors along the food value chain (Erdem, Rigby, & Wossink, 2012), and food policies (Caputo & Lusk, 2020).

The messages that respondents could select from were adapted based on common perspectives of GM food found in Mahgoub's (2016) book and previously used in a study of messages about GM food by Ruth and Rumble (2019). The messages presented to respondents to select from include:

- GnEd/GM food can cause cancer in humans
- GnEd/GM food contributes to the prevalence of antibiotic resistant bacteria
- Potential risks of GnEd/GM food related to health have not been adequately investigated
- GnEd/GM foods might be riskier to consume than traditional food
- GnEd/GM foods are safe for human consumption
- GnEd/GM food increases the food available for me to purchase
- GnEd/GM food can provide me with improved nutrition compared to traditional food (e.g., increased vitamin C)
- GnEd/GM food can be used to increase the safety of certain foods (e.g., remove toxins or allergens)

Question Two: Gene Editing versus Pesticide

For the second question, we adapted a question introduced by Tversky and Kahneman (1981) to show the existence of framing effects. Tversky and Kahneman (1981) described a hypothetical scenario involving a deadly disease outbreak and offered two unspecified programs with given outcomes as potential solutions. The framing of the solutions varied between two groups of respondents to determine how individuals respond to solutions framed as gains (lives saved) versus losses (lives lost). The original context presented in Tversky and Kahneman (1981) was: "Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimate of the consequences of the programs are as follows:

Response options for 'Group 1':

A. If Program A is adopted, 200 people will be saved.
B. If Program B is adopted, there is 1/3 probability that 600 people will be saved, and 2/3 probability that no people will be saved.

Response options for 'Group 2':

C. If Program C is adopted 400 people will die.
D. If Program D is adopted there is 1/3 probability that nobody will die, and 2/3 probability that 600 people will die. Which of the two programs would you favor?"

The expected values are the same for all programs: 200 people are spared. However, Programs B and D (risk-seeking) involve more uncertainty than Programs A and C (risk-averse). While Programs A and C are identical except for their framing, there is evidence that a majority of individuals in Group 1 (gain frame) chose Program A, and while Programs B and D are the same except for framing, a majority of individuals in Group 2 (loss frame) chose Program D. Given the difference in framing, this observed pattern is consistent with risk aversion in gains, but risk-seeking behavior in losses.

We adapted this framework to explore how subjects' perceptions of GnEd and alternative approaches vary with the framing of a question to solve a hypothetical fungal disease outbreak in trees. In our survey, response options were framed by the number of acres saved (a gain) versus the number of acres destroyed (a loss). The number of acres saved or destroyed used was similar to that in Tversky and Kahneman (1981), except the magnitude of the numbers was increased (e.g., 60,000 acres instead of 600 people). Further, this study deviates from the format used by Tversky and Kahneman (1981) in two major ways. First, we explicitly 'label' the solutions rather than describing the possible outcomes of unspecified programs. The solutions provided to respondents included either gene-editing the tree or spraying fungicide on the tree to reduce the impact of the hypothetical fungal disease.

Second, we expanded the number of groups to six, referred to as Treatments 1-6 hereafter. Some respondents made decisions for both the gain and loss framing (Treatments 1 and 4) to yield a within-subject framing effect, while other respondents made a single decision (Treatments 2, 3, 5, and 6) as in Tversky and Kahneman (1981) to provide a between-subject framing effect. There were 403 and 399 respondents randomized to Treatments 1 (T_1) and 4 (T_4), respectively, while 160 respondents each were randomized to Treatments 2, 3, 5, and 6, for a total of 1,442 observations.

Treatments 1 and 4 were oversampled, which is not typical for within-subjects measures; however, this allows us to determine if a learning effect generates different responses than the between-subjects measures. A learning effect could occur if the program selected for the acres saved question influences the program selected for the acres destroyed question. Testing for a learning effect tells us whether results are sensitive to asking respondents both the gain and loss questions compared to only asking one of the questions. Programs A (P_A) and C (P_C) were labeled "gene editing" for some respondents (T_1 - T_3) and labeled "spraying fungicide" for other respondents (T_4 - T_6). These designations allow us to test whether framing effects persist between respondents and whether there is indeed an order effect associated with the risk-averse or risk-taking decisions.

The hypothetical scenario concerning an agricultural fungal disease outbreak for T_1 - T_3 was:

Imagine the U.S. is preparing for an outbreak of a fungus, which is expected to kill 60,000 acres of apple trees. Two alternative programs to combat the fungus have been proposed. **Program A (C)** involves gene editing the tree, while **Program B (D)** involves spraying fungicide on the tree. Assume that the exact scientific estimates of the consequences of the programs are as follows:

GnEd was the risk-averse solution for programs for T_1 - T_3 (P_AG and P_cG), and fungicide was the risk-seeking solution (P_BF and P_DF). The programs presented to T_1 and T_2 were:

P_AG. If program A is adopted (gene editing the tree), 20,000 acres will be saved.

P_BF. If program B is adopted (spraying fungicide on the tree), there is a one-third probability that 60,000 acres will be saved and a two-thirds probability that no acres will be saved.

The programs presented to T_1 and T_3 were:

P_cG. If program C is adopted (gene editing the tree), 40,000 acres will be destroyed.

P_DF. If program D is adopted (spraying fungicide on the tree), there is a one-third probability that no acres will be destroyed and a two-thirds probability that 60,000 acres will be destroyed.

T_4 - T_6 were shown the same hypothetical scenario about an agricultural fungal-disease outbreak; however, fungicide was the risk-averse solution for programs for T_4 - T_6 (P_AF and P_cF), and GnEd was the risk-seeking solution (P_BG and P_DG). The programs presented to T_4 and T_5 were:

P_AF. If program A is adopted (spraying fungicide on the tree), 20,000 acres will be saved.

P_BG. If program B is adopted (gene editing the tree), there is a one-third probability that 60,000 acres will be saved and a two-thirds probability that no acres will be saved.

The programs presented to T_4 and T_6 were:

P_cF. If program C is adopted (spraying fungicide on the tree), 40,000 acres will be destroyed.

P_DG. If program D is adopted (gene editing the tree), there is a one-third probability that no acres will be destroyed and a two-thirds probability that 60,000 acres will be destroyed.

Comparisons between subjects in T_2 and T_3 and between subjects in T_5 and T_6 estimate the usual gain/loss framing effects in the context of gene editing and fungicide spraying respectively, while comparisons between subjects in T_2 and T_5 and between subjects in T_3 and T_6 allow us to estimate the persistence of this effect as we vary which type of treatment is listed first.

3.3 Statistical Tests

The first set of statistical tests determined whether the messages that most or least aligned with views varied by genetic engineering technique (i.e., GnEd vs. GM). First, we examined whether there was a difference between the frequency of messages selected as most or least aligned for GnEd and GM (e.g., $GnEd_{MostAligns}$ vs. $GM_{MostAligns}$). To do so, messages selected as most or least aligned were coded as a 1 and messages not selected were coded as a 0, and a Chi-Square test of independence was estimated to determine if there was a difference between the number of times messages were selected for GnEd and GM.

Next, we examined which messages most or least aligned with views. For this analysis, messages that most aligned with views were coded as 1, least aligned were coded as -1, and messages not selected were coded as 0. This creates a difference variable, of sorts, for each message that varies from -1 to 1 (e.g., $GnEd_{Diff}$ = $GnEd_{MostAligns}$ minus $GnEd_{LeastAligns}$). This allowed us to test differences in means across messages and group messages by frequency of selection, and the Bonferroni *p*-value correction method was used to adjust for the multiple comparisons of means across messages. Lastly, we used a difference-in-differences approach (i.e., $GnEd_{Diff}$ minus GM_{Diff}) to conduct between-group Chi-Square tests of independence for each message. This allowed us to determine the grouping of relative differences in selecting messages that most and least aligned between the GnEd and GM groups. The second set of statistical tests examined data from the Prospect Theory questions to determine *framing* and *order effects* on the sensitivity of selecting a gene editing or fungicide solution. Framing effects could occur due to communicating the yield protection provided by gene editing or pesticide use as a gain (i.e., acres saved) or a loss (i.e., acres destroyed). To determine the presence of framing effects, tests of equality were conducted for the proportion of risk-averse options selected for each Program (i.e., P_AG vs. P_CG and P_AF vs. P_CF). Then, we examined differences in proportions between respondents who answered both questions and respondents who only answered one question (e.g., P_AG for T_1 vs. P_AG for T_2). Lastly, we examined the presence of program order effects by testing differences in proportions of solutions selected based on which was presented as Programs A and C (e.g., P_AG for $T_1 – T_3$ vs. P_BG for $T_4 – T_6$).

4. Results

Table 1 presents the results for the most/least aligned questions. There was not a significant difference between the frequencies of messages selected that as most aligned were selected for GnEd and GM, nor was there a difference between the frequencies for messages that least aligned. Surprisingly, messages that were often selected as "most aligns" by some participants were also often selected as "least aligns" by other participants. This was the case for the messages: potential risks related to health have not been adequately investigated; might be risker than traditional food; and safe for human consumption. Perhaps this highlights the dichotomy in attitudes toward genetic engineering techniques.

Figure 1 illustrates differences across messages for both GnEd and GM and the letters above the bars in the graph denote the grouping of means that have been adjusted for multiple comparisons using the Bonferroni-correction method. Within grouping for $GnEd_{Diff}$ and GM_{Diff} are denoted using capital letters (e.g., A) and lowercase letters (e.g., a), respectively. The data used to produce this figure are presented in Appendix Tables 2 and 3. Positive differences, meaning a message was chosen as "most aligns" more frequently than "least aligns," for both GnEd and GM were: increases the food available; potential risks related to health have not been adequately investigated; and can increase the safety of certain foods. GnEd also had positive differences for: can provide improved nutrition; and safe for human consumption, while GM also had positive differences for: might be risker than traditional food; and contributes to the prevalence of antibiotic-resistant bacteria. 'Can cause cancer in humans' was the message with the largest negative difference for GnEd and GM, indicating it was the message that least aligned with views for both genetic engineering techniques. It is interesting that there is not much concern about GM foods causing cancer but there are concerns about safety and risk. Thus, there is likely some other mechanism(s) that prompts concerns about GM. Moreover, there appears to be more variation in views about GnEd, as there are more groups of messages for GnEd than GM.

Figure 2 illustrates the difference-in-differences between GnEd and GM. While none of the relative differences were significantly different from zero, as determined by Chi-Square tests, the figure does provide some insight. For example, there appear to be more favorable attitudes toward GnEd's ability to improve nutrition and increase the availability of food, and there is relatively heightened concern about the risk associated with GM. Taken together, these results appear to hint at a more positive attitude toward GnEd compared to GM and potential optimism about the possible solutions that GnEd may provide.

The frequency that GnEd and fungicide were selected in the Prospect Theory questions are presented by treatment in Table 2. Respondents mostly chose the more risk-averse program options, (P_AG vs. P_CG and P_AF vs. P_CF) for all treatment variations. Unlike Tversky and Kahneman (1981), we do not find the familiar reversal between T_2 and T_3 or T_5 and T_6 as the frame changes from gains to losses. Instead, subjects seem to always gravitate toward the option with lower overall uncertainty. Suggesting that they are risk averse both in the domain of gains and in the domain of losses, which is inconsistent with loss aversion (Britwum & Yiannaka, 2019a, 2019b).

Table 3 presents details and results of the different tests conducted to determine framing and order effects. P_AG was selected more often than P_CG and P_AF was selected more often than P_CF, indicating a small framing effect of preference for the gains frame. However, these differences do not persist for between-treatment tests (e.g., P_AG vs. P_CG). It is important to note that the within test has more power, and therefore the lack of significance for the between measures could be a result of relatively smaller sample sizes in those treatments. The only significant differences in proportions between treatments in which respondents answered both questions and treatments in which respondents only answered one of the questions was P_CF for T_4 versus P_CF for T_6. Thus, there was not a strong learning effect that influenced subsequent responses.

Since there were no significant differences between responses to questions within groups, treatments were combined to determine if there was an order effect associated with the type of risk tolerance presented first. For example, the proportions program P_AG was selected by T_1 or T_2 was combined to compare with the proportion P_BG was selected by T_4 and T_5. There were obvious order effects, as the risk-averse programs were always presented first and were selected more often. Tests of proportions confirm that respondents were more likely to select the risk-averse program presented despite varying the solution and framing associated with the program.

The fact that respondents gravitated strongly toward the more risk-averse program in each case and did not update their choice, even in a within-subject setting that provided the possibility for learning, suggests that risk aversion to the outbreak of a hypothetical deadly disease was more influential than framing effects or the mechanism of yield protection (i.e., a GnEd approach versus a pesticide-use approach). More research is needed to unpack how risk and loss aversion affect the acceptance of alternative solutions.

5. Conclusions

This paper used data from two separate surveys in the U.S. to investigate risk perceptions of GnEd compared to GM foods and examine consumer preference between a GnEd and fungicide solution to a plant disease. The results provide a better understanding of how emerging GnEd technology is perceived relative to a standard alternative of chemical use.

Results indicate that the public viewed GnEd similar to previous genetic engineering techniques, as messages that most or least aligned with views for GnEd were similar to views about GM. Like the previous results in Ruth and Rumble (2019), respondents appear to be concerned by 1) a perceived lack of investigation into the potential risks of GM, and 2) risks of GM foods to consumers. Concern about a perceived lack of investigation into potential risk was slightly higher for GnEd than GM; however, respondents do not show concern about the risk of consuming food produced from GnEd crops. Also like in Ruth and Rumble (2019), similar proportions of respondents selected several messages as either most or least aligning with views. Respondents do perceive GnEd to have some positive impacts on the food system; for example, 'the ability of GnEd food to increase food availability,' 'food safety,' and 'provide improved nutrition' were selected as most aligned more often than least aligned. Thus, while GnEd and GM were viewed similarly overall, there are hints that U.S. adults have a generally more favorable attitude toward GnEd and are less concerned about consumption risk than GM.

We also used Prospect Theory as a method to examine the influence of risk aversion on preferences for GnEd and pesticide solutions for agricultural disease. There was not an obvious preference for either solution, which further supports McFadden et al. (2021) conclusion that the public does not oppose GnEd solutions for combatting plant disease. Framing programs as a gain or loss induced large changes in the selection of programs in previous studies (Bocquého, Jacquet, & Reynaud, 2014; Brown, Imai, Vieider, & Camerer, 2021). While we identify some small framing effects, our findings, like Abrams' findings (2015), are not consistent with the loss aversion literature. Instead, our results may suggest that the perceived risk associated with the agricultural disease dominated the risk perceptions associated with GnEd or fungicide solutions. Our results may also be reflective of consumers' heightened desire for certainty in an increasingly uncertain world than original prospect theory work (1979). Also, the lack of large changes in the selection of programs due to framing effects may be due to differences between risk perceptions for human lives lost used by Tversky and Kahneman (1981) and acres lost used by this study.

The use of GnEd in crop production has occurred, and these results may be helpful in devising communication strategies to adjust public perception and acceptance. Transparency and precision about the actual risks and the remedies to mitigate them may allay the concerns that this is a new technology that is available without sufficient safety testing (Zhao & Wolt, 2017). Our results show some differences emerging in the discussion of GnEd versus GM and present the opportunity for researchers and communicators to capitalize on the conversation surrounding GnEd technologies.

Observations of reduced perceived risk and more positive attitudes provide the opportunity to move the technology to consumer acceptance and encourage adoption. Furthermore, our findings that deviated from loss aversion literature present the opportunity to further explore how consumers consider risk and loss related to GnEd technologies and if this varies between products or the phase of production in which the loss is presented (e.g., loss of acres versus loss of food in the grocery store). Future research should consider how consumers weigh risk, loss framing, and potential solutions related to GnEd technologies when presented in a food consumption scenario. Finally, we could explore consumers' overall desire for certainty in the world as a potential variable in their decision-making.

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References

Abdellaoui, M., Bleichrodt, H., & Kammoun, H. (2013). Do financial professionals behave according to prospect theory? An experimental study. *Theory and Decision*, *74*, 411-429. doi: https://doi.org/10.1007/s11238-011-9282-3

Abrams, K. M. (2015). Loss aversion and regulatory focus effects in the absence of numbers: Qualitatively framing equivalent messages on food labels. *Journal of Applied Communications*, *99*(3), 3. doi: https://doi.org/10.4148/1051-0834.1054

Ahmed, A. U., Hoddinott, J., Abedin, N., & Hossain, N. (2021). The impacts of GM foods: results from a randomized controlled trial of Bt eggplant in Bangladesh. *American Journal of Agricultural Economics*, *103*(4), 1186-1206. doi: https://doi.org/10.1111/ajae.12162

Barberis, N. C. (2013). Thirty years of prospect theory in economics: A review and assessment. *Journal of Economic Perspectives*, *27*(1), 173-196. doi: https://doi.org/10.1257/jep.27.1.173

Bocquého, G., Jacquet, F., & Reynaud, A. (2014). Expected utility or prospect theory maximisers? Assessing farmers' risk behaviour from field-experiment data. *European Review of Agricultural Economics*, *41*(1), 135-172. doi: https://doi.org/10.1093/erae/jbt006

Britwum, K., & Yiannaka, A. (2019a). Consumer willingness to pay for food safety interventions: The role of message framing and issue involvement. *Food Policy*, *86*, 101726. doi: https://doi.org/10.1016/j.foodpol.2019.05.009

Britwum, K., & Yiannaka, A. (2019b). Shaping food safety perceptions: The influence of informational nudges. *Journal of Behavioral and Experimental Economics, 81*, 139-151. doi: https://doi.org/10.1016/j.socec.2019.06.007

Bromiley, P., & Rau, D. (2022). Some problems in using prospect theory to explain strategic management issues. *Academy of Management Perspectives, 36*(1), 125-141. doi: https://doi.org/10.5465/amp.2018.0072

Brown, A. L., Imai, T., Vieider, F., & Camerer, C. (2021). Meta-analysis of Empirical Estimates of Loss Aversion. *Journal of Economic Literature*. Retrieved from https://rationality-and-competition.de/wp-content/uploads/2021/01/275.pdf

Caputo, V., & Lusk, J. L. (2020). What agricultural and food policies do US consumers prefer? A best–worst scaling approach. *Agricultural Economics, 51*(1), 75-93. doi: https://doi.org/10.1111/agec.12542

Erdem, S., Rigby, D., & Wossink, A. (2012). Using best–worst scaling to explore perceptions of relative responsibility for ensuring food safety. *Food Policy, 37*(6), 661-670. doi: https://doi.org/10.1016/j.foodpol.2012.07.010

Farnham, B. (1994). *Avoiding losses/taking risks: Prospect theory and international conflict*. University of Michigan Press. doi: https://doi.org/10.3998/mpub.7763

Frewer, L. J., van der Lans, I. A., Fischer, A. R., Reinders, M. J., Menozzi, D., Zhang, X., et al. (2013). Public perceptions of agri-food applications of genetic modification–a systematic review and meta-analysis. *Trends in Food Science & Technology, 30*(2), 142-152. doi: https://doi.org/10.1016/j.tifs.2013.01.003

Gaskell, G., Bauer, M. W., Durant, J., & Allum, N. C. (1999). Worlds apart? The reception of genetically modified foods in Europe and the US. *Science, 285*(5426), 384-387. doi: https://doi.org/10.1126/science.285.5426.384

Hallman, W. K., Cuite, C. L., & Morin, X. (2013). *Public Perceptions of Labeling Genetically Modified Foods*. Rutgers University. doi: https://doi.org/10.7282/T33N255N

Hu, Y., House, L. A., McFadden, B. R., & Gao, Z. (2021). The Influence of Choice Context on Consumers' Preference for GM Orange Juice. *Journal of Agricultural Economics*, *72*(2), 547-563. doi: https://doi.org/10.1111/1477-9552.12416

Kahneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, *47*(2), 263-292. doi: https://doi.org/10.2307/1914185

Kouser, S., & Qaim, M. (2013). Valuing financial, health, and environmental benefits of Bt cotton in Pakistan. *Agricultural Economics*, *44*(3), 323-335. doi: https://doi.org/10.1111/agec.12014

Levy, J. S. (1992). Prospect theory and international relations: Theoretical applications and analytical problems. *Political Psychology*, *13*(2), 283-310. doi: https://doi.org/10.2307/3791682

Liu, C., Li, J., Steele, W., & Fang, X. (2018). A study on Chinese consumer preferences for food traceability information using best-worst scaling. *PloS One*, *13*(11), e0206793. doi: https://doi.org/10.1371/journal.pone.0206793

Liu, E. M. (2013). Time to change what to sow: Risk preferences and technology adoption decisions of cotton farmers in China. *Review of Economics and Statistics*, *95*(4), 1386-1403. doi: https://doi.org/10.1162/REST_a_00295

Lusk, J. L., Jamal, M., Kurlander, L., Roucan, M., & Taulman, L. (2005). A Meta-Analysis of Genetically Modified Food Valuation Studies. *Journal of Agricultural and Resource Economics*, *30*(1), 28-44. Retrieved from https://www.jstor.org/stable/40987259

Lusk, J. L., McFadden, B. R., & Rickard, B. J. (2015). Which biotech foods are most acceptable to the public? *Biotechnology Journal*, *10*(1), 13-16. doi: https://doi.org/10.1002/biot.201400561

Mahgoub, S. E. O. (2016). *Genetically modified foods: Basics, applications, and controversy*. CRC Press. doi: https://doi.org/10.1201/b18642

Massaglia, S., Merlino, V. M., Borra, D., Bargetto, A., Sottile, F., & Peano, C. (2019). Consumer attitudes and preference exploration towards fresh-cut salads using best–worst scaling and latent class analysis. *Foods*, *8*(11), 568. doi: https://doi.org/10.3390/foods8110568

McDermott, R., Fowler, J. H., & Smirnov, O. (2008). On the evolutionary origin of prospect theory preferences. *The Journal of Politics*, *70*(2), 335-350. doi: https://doi.org/10.1017/S0022381608080341

McFadden, B. R., Anderton, B. N., Davidson, K. A., & Bernard, J. C. (2021). The effect of scientific information and narrative on preferences for possible gene-edited solutions for citrus greening. *Applied Economic Perspectives and Policy*, *43*(4), 1595-1620. doi: https://doi.org/10.1002/aepp.13154

McFadden, B. R., & Lusk, J. L. (2016). What consumers don't know about genetically modified food, and how that affects beliefs. *The FASEB Journal*, *30*(9), 3091-3096. doi: https://doi.org/10.1096/fj.201600598

McFadden, B. R., Rumble, J. N., Stofer, K. A., Folta, K. M., Turner, S., & Pollack, A. (2021). Gene editing isn't just about food: comments from US focus groups. *GM Crops & Food, 12*(2), 616-626. doi: https://doi.org/10.1080/21645698.2021.1919485

McFadden, B. R., & Smyth, S. J. (2019). Perceptions of genetically engineered technology in developed areas. *Trends in Biotechnology, 37*(5), 447-451. doi: https://doi.org/10.1016/j.tibtech.2018.10.006

Ruth, T. K., & Rumble, J. N. (2019). Consumers' evaluations of genetically modified food messages. *Journal of Applied Communications*, *103*(1), 5. doi: https://doi.org/10.4148/1051-0834.2193

Shew, A. M., Nalley, L. L., Snell, H. A., Nayga Jr, R. M., & Dixon, B. L. (2018). CRISPR versus GMOs: Public acceptance and valuation. *Global Food Security*, *19*, 71-80. doi: https://doi.org/10.1016/j.gfs.2018.10.005

Stofer, K. A., & Schiebel, T. M. (2017). US Adults with Agricultural Experience Report More Genetic Engineering Familiarity than Those Without. *Journal of Agricultural Education*, *58*(4), 160-174. doi: https://doi.org/10.5032/jae.2017.04160

Travis, J. (2015, 17 Dec). *And Science's 2015 Breakthrough of the Year is... CRISPR genome-editing technology shows its power*. Science News Staff. Retrieved from https://www.science.org/content/article/and-science-s-2015-breakthrough-year

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science, 211*(4481), 453-458. doi: https://doi.org/10.1126/science.7455683

Vis, B. (2011). Prospect theory and political decision making. *Political Studies Review, 9*(3), 334-343. doi: https://doi.org/10.1111/j.1478-9302.2011.00238.x

Zhao, H., & Wolt, J. D. (2017). Risk associated with off-target plant genome editing and methods for its limitation. *Emerging Topics in Life Sciences, 1*(2), 231-240. doi: https://doi.org/10.1042/ETLS20170037

Zhao, S., & Yue, C. (2020). Risk preferences of commodity crop producers and specialty crop producers: An application of prospect theory. *Agricultural Economics, 51*(3), 359-372. doi: https://doi.org/10.1111/agec.12559

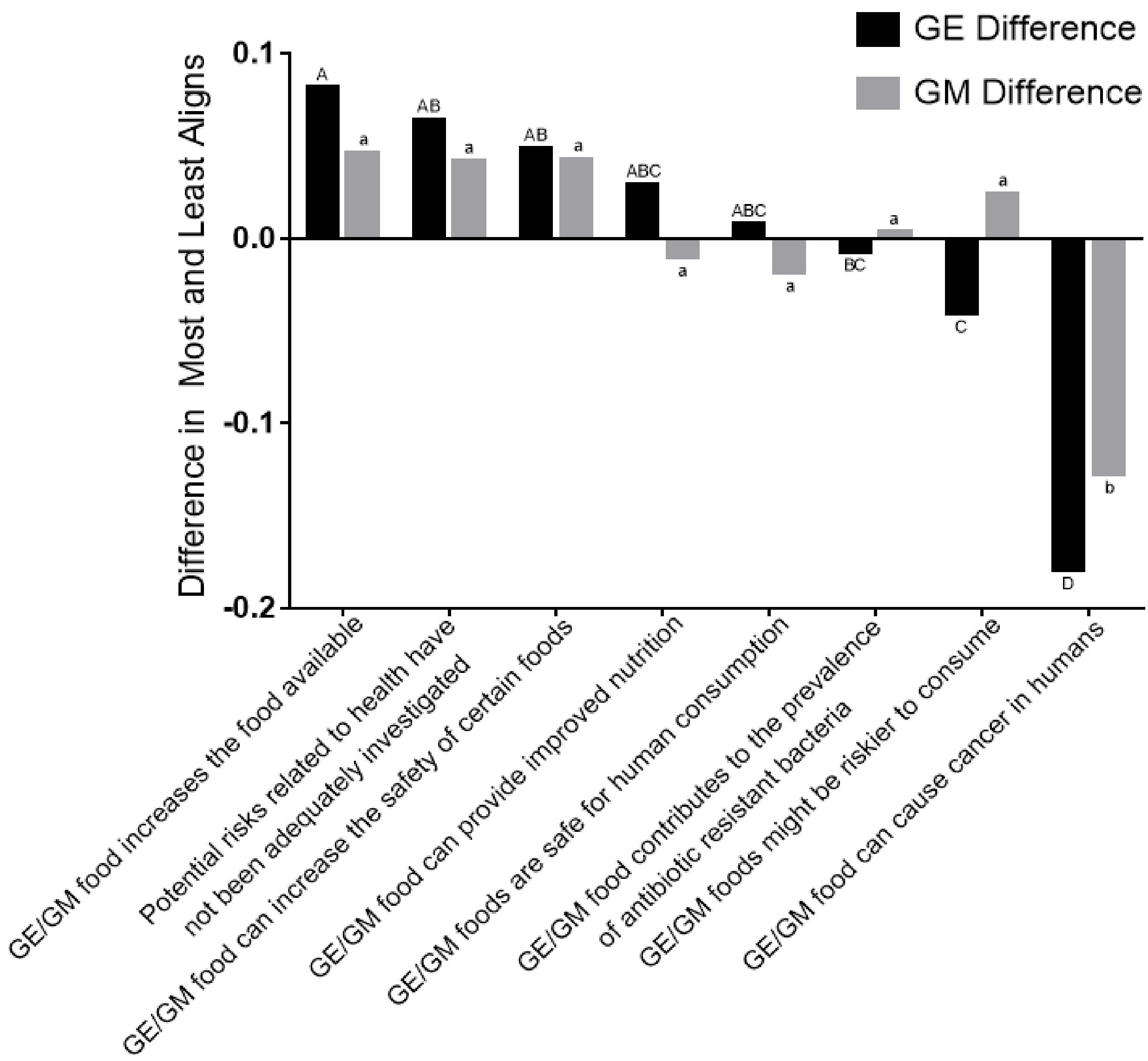

Figure 1. Difference in Messages that Most and Least Align for Gene Edited and Genetically Modified Foods
Note: Capital letters (e.g., A) denote Bonferonni-adjusted groups for GnEd Diff and lowercase letters (e.g., a) denote the groups for GM Diff.

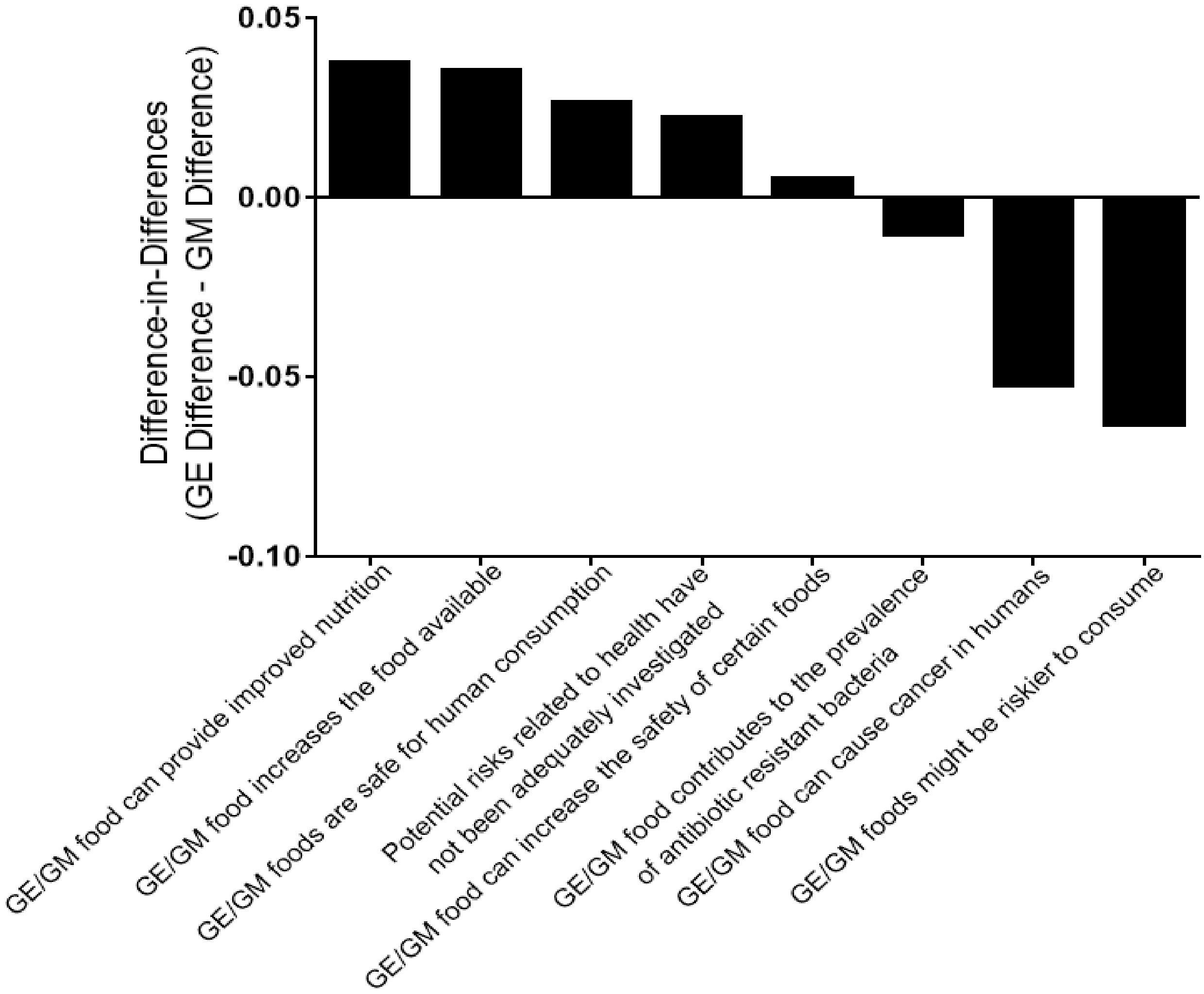

Figure 2. Difference-in-Differences between Messages that Most and Least Align for Gene Edited and Genetically Modified Foods

Table 1. Proportions that Messages were Selected as Most or Least Align with Views for GnEd and GM Foods

	Most Aligns		Least Aligns	
Messages	**GnEd**	**GM**	**GnEd**	**GM**
GnEd/GM food can cause cancer in humans	0.081	0.103	0.260	0.230
GnEd/GM food contributes to the prevalence of antibiotic resistant bacteria	0.076	0.086	0.084	0.083
Potential risks of GnEd/GM food related to health have not been adequately investigated	0.187	0.159	0.124	0.118
GnEd/GM foods might be riskier to consume than traditional food	0.122	0.148	0.163	0.126
GnEd/GM foods are safe for human consumption	0.136	0.136	0.128	0.154
GnEd/GM food increases the food available for me to purchase	0.164	0.141	0.084	0.095
GnEd/GM food can provide me with improved nutrition compared to traditional food (e.g., increased vitamin C)	0.118	0.106	0.090	0.115
GnEd/GM food can be used to increase the safety of certain foods (e.g., remove toxins or allergens)	0.116	0.121	0.069	0.079

Note: n=670 and 661 for the GnEd and GM groups, respectively. Chi-Square tests were used to determine differences in frequencies that messages were selected as either most or least aligns between GnEd and GM. There was not a significant difference for messages that most aligned (Chi-Square statistic = 7.04, *p*-value = 0.43) or least aligned (Chi-Square statistic = 9.14, *p*-value = 0.24).

Table 2. Proportions that GnEd and Fungicide Use Programs were Selected as Solutions to a Fungus Outbreak

	GnEd as Risk-Averse Solution				Fungicide as Risk-Averse Solution		
	Treatment 1	**Treatment 2**	**Treatment 3**		**Treatment 4**	**Treatment 5**	**Treatment 6**
Gain Frame				Gain Frame			
P_AG	0.707	0.706		P_AF	0.629	0.656	
P_BF	0.293	0.294		P_BG	0.371	0.344	
Loss Frame				Loss Frame			
P_CG	0.618		0.638	P_CF	0.554		0.644
P_DF	0.382		0.363	P_DG	0.446		0.356
n	403	160	160	n	399	160	160

Table 3. Effect Testing for the Prospect Theory Questions

Within Comparisons	Between Comparisons	Treatment(s)	Risk-Averse Solution	Frame	Number of Respondents	Difference in Proportions	Test Statistic (H_0: difference=0)
Framing Effects							
P_AG vs. P_CG		T_1	Gene editing	Gain vs. Loss	403	0.089	z = 2.86 p-value < 0.01
	P_AG vs. P_CG	T_2 vs. T_3	Gene editing	Gain vs. Loss	160	0.069	z = 1.31 p-value = 0.19
P_AF vs. P_CF		T_4	Fungicide	Gain vs. Loss	399	0.75	z = 2.16 p-value = 0.03
	P_AF vs. P_CF	T_5 vs. T_6	Fungicide	Gain vs. Loss	160	0.013	z = 0.23 p-value = 0.81
Learning Effects							
	P_AG vs. P_AG	T_1 vs. T_2	Gene editing	Gain vs. Gain	403 vs. 160	0.001	z = 0.02 p-value = 0.98
	P_CG vs. P_CG	T_1 vs. T_3	Gene editing	Loss vs. Loss	403 vs. 160	-0.020	z = 0.43 p-value = 0.66
	P_AF vs. P_AF	T_4 vs. T_5	Fungicide	Gain vs. Gain	399 vs. 160	-0.027	z = 0.60 p-value = 0.55
	P_CF vs. P_CF	T_4 vs. T_6	Fungicide	Loss vs. Loss	399 vs. 160	-0.090	z = 1.95 p-value = 0.05
Program Order Effects							
	P_AG vs. P_BG	$T_1 + T_2$ vs. $T_4 + T_5$	Gene editing vs. Fungicide	Gain vs. Gain	563 vs. 559	0.070	z = 2.50 p-value = 0.01
	P_CG vs. P_DG	$T_1 + T_3$ vs. $T_4 + T_6$	Gene editing vs. Fungicide	Loss vs. Loss	563 vs. 559	0.044	z = 1.50 p-value = 0.13

APPENDIX

Which message most aligns and least aligns with your view on **gene edited (GE) food**? Please drag and drop only one item on the left into each box on the right.

Items

GE foods are safe for human consumption
GE food increases the food available for me to purchase
GE food can be used to increase the safety of certain foods (e.g. remove toxins or allergens)
GE food contributes to the prevalence of antibiotic resistant bacteria
GE food can provide me with improved nutrition compared to traditional food (e.g. increased vitamin C)
Potential risks of GE food related to health have not been adequately investigated
GE food can cause cancer in humans
GE foods might be riskier to consume than traditional food

Most Aligns

Least Aligns

Which message most aligns and which least aligns with your view on **genetically modified (GM) food**? Please drag and drop only one item on the left into each box on the right.

Items

GM foods are safe for human consumption
Potential risks of GM food related to health have not been adequately investigated
GM food contributes to the prevalence of antibiotic resistant bacteria
GM food can be used to increase the safety of certain foods (e.g. remove toxins or allergens)
GM foods might be riskier to consume than traditional food
GM food increases the food available for me to purchase
GM food can cause cancer in humans
GM food can provide me with improved nutrition compared to traditional food (e.g. increased vitamin C)

Most Aligns (Pick 1)

Least Aligns (Pick 1)

Appendix Figure 1. Specific Wording for Question One: Gene Editing vs. Genetic Modification

Imagine the U.S. is preparing for an outbreak of a fungus, which is expected to kill 60,000 acres of apple trees. Two alternative programs to combat the fungus have been proposed. Program A involves gene editing the tree, while Program B involves spraying fungicide on the tree.

Assume that the exact scientific estimates of the consequences of the programs are as follows:

- **If program A is adopted (gene editing the tree), 20,000 acres will be saved.**
- **If program B is adopted (spraying fungicide on the tree), there is a one-third probability that 60,000 acres will be saved and a two-thirds probability that no acres will be saved.**

Which of the two programs would you favor?

- ◯ Program A: gene editing the tree to combat the fungus.
- ◯ Program B: spraying fungicide on the tree to combat the fungus.

Imagine the U.S. is preparing for an outbreak of a fungus, which is expected to kill 60,000 acres of apple trees. Two alternative programs to combat the fungus have been proposed. Program A involves gene editing the tree, while Program B involves spraying fungicide on the tree.

Assume that the exact scientific estimates of the consequences of the programs are as follows:

- **If program A is adopted (gene editing the tree), 40,000 acres will be destroyed.**
- **If program B is adopted (spraying fungicide on the tree), there is a one-third probability that no acres will be destroyed and a two-thirds probability that 60,000 acres will be destroyed.**

Which of the two programs would you favor?

- ◯ Program A: gene editing the tree to combat the fungus.
- ◯ Program B: spraying fungicide on the tree to combat the fungus.

Imagine the U.S. is preparing for an outbreak of a fungus, which is expected to kill 60,000 acres of apple trees. Two alternative programs to combat the fungus have been proposed. Program A involves spraying fungicide on the tree, while Program B involves gene editing the tree.

Assume that the exact scientific estimates of the consequences of the programs are as follows:

- **If program A is adopted (spraying fungicide on the tree), 20,000 acres will be saved.**
- **If program B is adopted (gene editing the tree), there is a one-third probability that 60,000 acres will be saved and a two-thirds probability that no acres will be saved.**

Which of the two programs would you favor?

- ◯ Program A: spraying fungicide on the tree to combat the fungus.
- ◯ Program B: gene editing the tree to combat the fungus.

Imagine the U.S. is preparing for an outbreak of a fungus, which is expected to kill 60,000 acres of apple trees. Two alternative programs to combat the fungus have been proposed. Program A involves spraying fungicide on the tree, while Program B involves gene editing the tree.

Assume that the exact scientific estimates of the consequences of the programs are as follows:

- **If program A is adopted (spraying fungicide on the tree), 40,000 acres will be destroyed.**
- **If program B is adopted (gene editing the tree), there is a one-third probability that no acres will be destroyed and a two-thirds probability that 60,000 acres will be destroyed.**

Which of the two programs would you favor?

- ◯ Program A: spraying fungicide on the tree to combat the fungus.
- ◯ Program B: gene editing the tree to combat the fungus.

Appendix Figure 2. Specific Wording for Question Two: Gene Editing vs. Pesticide

Appendix Table 1. Demographic Characteristics by Groups for Both Studies

	Study 1		**Study 2**	
	GnEd Group	**GM Group**	**Gain Group**	**Loss Group**
Age	48.084	46.870	43.786	43.314
Education	3.545	3.589	3.545	3.495
Income	6.793	6.759	6.696	6.384
Sex	1.510	1.536	1.550	1.566

Note: There were not significant differences across the demographic variables between groups within studies, as determined by estimating a MANOVA (Study 1: Wilks' lambda = 0.998, p-value = 0.60; Study 2: Wilks' lambda = 0.998, p-value = 0.57). Age is number of years, Education ranged from 1=less than high school,…, 6=graduate or professional degree, Income ranged from 1=less than $10,000,…, 12=$150,000 or more, and the response options for Sex were 1=male, 2=female, 3=non-binary, and 4=prefer not to say.

Appendix Table 2. GnEd Diff and Bonferroni-corrected groups

Messages	**Mean GnEd Difference**	**Bonferroni Group**
GnEd/GM food increases the food available for me to purchase	0.081	A
Potential risks of GnEd/GM food related to health have not been adequately investigated	0.063	AB
GnEd/GM food can be used to increase the safety of certain foods (e.g., remove toxins or allergens)	0.048	AB
GnEd/GM food can provide me with improved nutrition compared to traditional food (e.g., increased vitamin C)	0.028	ABC
GnEd/GM foods are safe for human consumption	0.007	ABC
GnEd/GM food contributes to the prevalence of antibiotic resistant bacteria	-0.007	BC
GnEd/GM foods might be riskier to consume than traditional food	-0.040	C
GnEd/GM food can cause cancer in humans	-0.179	D

Appendix Table 3. GM Diff and Bonferroni-corrected groups

Messages	Mean GM Difference	Bonferroni Group
GnEd/GM food increases the food available for me to purchase	0.045	A
GnEd/GM food can be used to increase the safety of certain foods (e.g., remove toxins or allergens)	0.042	A
Potential risks of GnEd/GM food related to health have not been adequately investigated	0.041	A
GnEd/GM foods might be riskier to consume than traditional food	0.023	A
GnEd/GM food contributes to the prevalence of antibiotic resistant bacteria	0.003	A
GnEd/GM food can provide me with improved nutrition compared to traditional food (e.g., increased vitamin C)	-0.009	A
GnEd/GM foods are safe for human consumption	-0.018	A
GnEd/GM food can cause cancer in humans	-0.127	B