Food Distribution Research Society

Journal of Food Distribution Research
Volume 56, Issue 3, pp. 42–74

Consumer Attitude and Willingness to Pay for GM and GE Edible and Ornamental Products: Implications from Choice Experiment and Structural Equation Modeling

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Abstract

Using choice experiments and structural equation modeling, we assess how positive and negative framing of genetically modified (GM) and gene edited (GE) information are associated with consumer attitudes and subsequent willingness to pay (WTP). We find consumer attitudes serve as an essential mediator, connecting information exposure and consumer characteristics to WTP for GM and GE products. Furthermore, the similarities between the WTP for GM and GE edible and ornamental products were identified. Another interesting finding is that information regarding one technology (GM or GE) is associated with attitudes toward the other, but GM information has a stronger information spillover effect on GE than the reverse. This study provides important implications for both policy making and marketing strategies related to GM and GE products.

Keywords: attitude, choice experiment, CRISPR, genetic modified, gene editing, mixed logit model, structural equation modeling, WTP

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Introduction

In recent years, there has been a growing body of literature in consumer behavior examining consumer willingness to pay (WTP) for foods made from genetic modification (GM) and gene editing (GE). For GM products, genes or modified genes are introduced to a crop from any plant or non-plant organism. Different from GM, GE (e.g., CRISPR) makes targeted changes to genes within a crop instead of introducing foreign genes. This distinction has raised questions about whether consumer attitudes toward GE foods are more favorable compared to their attitudes toward GM products (Son and Lim, 2021).

Revealed and stated preference studies have shown that consumers discount the price they are willing to pay for GM foods compared to conventional foods. In other words, consumers are willing to pay price premiums for non-GM alternatives in comparison to GM foods (Kolodinsky, Rose, and Danielsen, 2023). For example, Ortega et al. (2022) found that consumers are willing to pay about 20%–30% more for non-GM foods compared to GM foods. However, this premium is smaller when consumers are informed that the GM product provides benefits such as improved nutrition or taste. Additionally, consumers are more open to GM applications in plants compared to those in animals, and the premium for non-GM is lower for plants compared to animal products (Ding et al., 2023). As GM applications become more widely adopted, these price premiums for non-GM foods start to decrease (Vasquez, Hesseln, and Smyth, 2022), suggesting a gradual increase in consumer acceptance of GM technology. These studies have also shown there exists a substantial segment of consumers who remain unwilling to pay any premium for non-GM, indicating heterogeneity in consumer preferences.

Compared to GM foods, empirical studies have demonstrated that GE foods tend to have higher consumer acceptance in various countries. For instance, Son and Lim (2021) show that Korean consumers have greater acceptance of GE soybean oil compared to the GM counterpart. Similarly, Chinese consumers discount non-GE rice less than non-GM rice, which might reflect lower perceived risks associated with gene editing (Ding et al., 2023). Vasquez, Hesseln, and Smyth (2022) found Canadian consumers express a higher level of trust in GE than GM. These research findings around the globe imply that GE foods have less consumer resistance, which is potentially due to the perceived minor genetic alterations in GE compared to GM foods.

Attitudes As the Mediator between Information and Willingness to Pay

Consumer acceptance and willingness to pay for GM and GE foods are largely dependent on their attitudes toward biotechnology. The Theory of Planned Behavior (TPB) posits that consumer attitudes directly influence purchasing intentions, such as WTP, with knowledge and information serving as antecedents that form attitudes (Ajzen, 1991). Similarly, the Knowledge-Attitude-Practice Model (KAP) suggests that greater familiarity with GM and GE technologies improves attitudes, which in turn impacts WTP (Xie et al., 2024). Risk-benefit perception frameworks further support the mediating role of attitude, indicating that perceived benefits and risks impact consumer attitudes, which ultimately affect WTP (Bredahl, 2001).

Despite these theoretical foundations, few studies have systematically investigated how attitudes mediate the relationship between positive or negative information, knowledge, and WTP, particularly for both GM and GE products. While studies acknowledge the role of demographics in determining consumers' biotechnology acceptance, less attention has been given to how consumer demographics influence WTP indirectly via attitudes.

Information Spillover Effects

Information plays an essential role in influencing consumer attitudes toward technology. Among the aforementioned studies, Ding et al. (2023) showed participants informational videos describing GM versus GE technologies before eliciting WTP for rice; however, they did not include a control group in their analysis of how these videos impacted WTP. Similarly, Vasquez, Hesseln, and Smyth (2022) included explicit definitions of GE versus GM in their survey before eliciting willingness-to-consume responses, but the study did not test the effect of information on consumer valuations. Researchers who have investigated the effect of information on consumers' WTP for GM or GE products found mixed results. For example, Paudel et al. (2023) found that information about GE technology's health and environmental benefits positively impacts U.S. consumers' valuation for GE soybean oil but not for GE apples.

Consumers often form their opinion of one technology by drawing on their existing information or attitudes toward the other, which is often referred to as information spillover or attitudinal spillover effects. Past research has shown spillover effects for various technologies. For example, Akin et al. (2018) found that the risk perceptions of GM products are associated with support for labeling nano-enabled products. Otsuka (2021) surveyed Japanese consumers and found their attitudes toward GE are significantly influenced by their existing attitudes toward GM. Because GM and GE are both biotechnology, information spillover effects are likely to exist. Identifying and understanding the spillover effects shed light on the development of effective programs and strategies that clearly communicate the similarities and differences among technologies for policy makers and industry stakeholders. Effective communication programs minimize consumer misperceptions and help them make informed decisions. However, to the best of our knowledge, no study has systematically investigated the existence and nature of information spillover effects between GM and GE.

Beyond Food: The Perspective of Nonfood Products

Previous studies have extensively investigated consumer WTP for credence attributes in non-food products, such as organic cotton (Hustvedt and Bernard, 2008) and sustainably produced fibers (Ha-Brookshire and Norum, 2011). However, consumer acceptance of GM or GE non-food products is underexplored. This study directly addresses this gap by examining consumer response to GM and GE attributes across food (potatoes) and ornamental crops (petunias). Understanding consumer preference for biotechnology credence attributes in both non-edible products and foods provides valuable insights into the broader acceptance patterns and has important marketing and policy implications. A recent study examined producer responses and adoption intentions toward GE and GM ornamental and food products and showed the importance of producers' considerations related to profitability, risk management, regulatory perceptions, and market access (Abbey et al., 2025). Integrating insights from our consumer study with producer perspectives is very important because aligning the needs, perceptions, and acceptance levels of these two key market stakeholders can facilitate successful market introductions and policy developments for agricultural biotechnology.

Research Objectives

This study aims to fill these knowledge gaps using choice experiments and structural equation modeling (SEM) to analyze the direct and indirect effects of information, demographics, and psychographics on WTP for GM and GE products. By incorporating information treatments, we assess how positive and negative framing of GM and GE information affects consumer attitudes and subsequent WTP and whether there exist any spillover effects of GM information on GE acceptance and vice versa. We also explore how attitude acts as a mediator among information, consumer demographics, technology familiarity or knowledge, and consumer WTP. Furthermore, by comparing consumer attitudes and WTP between food (potatoes) and ornamental plants (petunias), we investigate whether information treatments on GM and GE elicit different levels of acceptance in different product categories.

Methods

Choice Experiments

We used a discrete choice experiment (DCE) to elicit consumer preferences and WTP for GM and GE products. DCEs are widely used to analyze consumer preferences and WTP for products, particularly when real market behavior data are unavailable for novel products (Yue, Hugie, and Watkins, 2012; Zhao and Yue, 2020; Lusk et al., 2022;). In a DCE, participants are presented with hypothetical choice scenarios and are asked to choose their preferred product option. These experiments are grounded in random utility theory, which assumes that consumers derive utility from product attributes and will choose the option that provides the highest utility (McFadden, 1980). By observing choices over various attribute combinations, we can derive the implicit value consumers place on specific attributes (e.g., GM or GE), which allows us to calculate the WTP premiums or discounts for those attributes.

The products we used in the choice experiment were potato (a popular edible crop) and petunia (a widely used ornamental crop). These two products were chosen because there are bioengineered potato and petunia in the marketplace. For example, Innate potato was commercialized by the J.R. Simplot Company and has disease resistance and reduced bruising. The bioengineered “African Sunset” petunia has a novel intense orange color. The potato attributes include plant type (conventional, GM, and GE), acrylamide level (low, medium, and high), non-browning (yes, no) and price ($3.50, $5.00, and $6.50 per 5 lbs). Acrylamide is a toxin that can be lowered using GM or GE. Non-browning is another benefit achieved by biotechnology. The attribute and attribute levels for petunia are plant type (conventional, GM, and GE), blooming time (season long and one month), flower color (novel-orange/blue or standard-purple/pink), price ($4, $6 and $8 per 6 pack).

The price levels were determined by checking the market price for the products in multiple market venues. Other attribute levels were chosen through a comprehensive literature review and by consulting industry experts. We designed the choice experiment to maximize D-efficiency. Each participant completed eight choice scenarios for each product.

To test how different types of information impact consumer choice and WTP, we included different types of information about GM and GE: positive information about GM, positive information about GE, negative information about GM, and negative information about GE (see Appendix). Participants were randomly assigned to read one of these types of information or were assigned to not read any information (control group).[1]

In addition to DCEs, we asked questions eliciting participants' perceived risk versus benefits and their familiarity with and knowledge level of GM and GE before they were assigned to read any information. After the information treatment, we asked a series of questions about participants' views about GM and GE products, the results of which were used to construct participants' latent attitudes toward GM and GE. Furthermore, questions about participants' willingness to take risks, their consideration for future outcomes, level of caring for the environment, if they consider themselves as more liberal or conservative, and demographics were included in the survey. We conducted a pretest of the survey with 50 participants. Based on their responses to the survey, we adjusted the questions and the choice design. Exploratory factor analyses with principal component extraction were conducted for those factors involving multiple questions.

Mixed Logit Model

We employed a mixed logit model to analyze the DCE data. The mixed logit model allows consumers' taste parameter to vary by some underlying distribution. Specifically, individual i is assumed to have a linear utility function as shown in equation (1):

$$U_{ijm} = \boldsymbol{x_{ijm}}\boldsymbol{\beta_i} + \varepsilon_{ijm} \tag{1}$$

In equation (1), individual i $(i = 1,2,\dots,N)$ chooses alternative j with their preferred option in J alternatives $(j = 1,2,\dots,J)$. The individual needs to make choices for m $(m = 1,2,\dots,M)$ choice scenarios. $\boldsymbol{x_{ijt}}$ denotes a vector of observed product attributes, such as price, GM, and GE, and $\boldsymbol{\beta_i}$ is the random coefficient vector following certain density function $f(\boldsymbol{\beta}|\boldsymbol{\theta})$, where $\boldsymbol{\theta}$ is a vector of the parameters that define the distribution. In this study, we assume the density function $f(\boldsymbol{\beta}|\boldsymbol{\theta})$ follows multivariate normal distribution. So $\boldsymbol{\theta}$ includes the mean vector and a variance matrix of the multivariate normal distribution, with variance matrix assumed to be diagonal. ε_{ijm} is the random error term that follows type I extreme value distribution and is assumed to be independently and identically distributed. y_{ijm} is a dummy variable denoting individual i

[1] In the experiment, we also included a free-choice treatment: Some participants were randomly assigned the option to choose whether to read the information, whereas others were assigned to read it. However, due to the scope of this study, the free-choice treatment was not included in the current analysis; it will be addressed in a separate paper. In this study, all participants who were either assigned to read the information or given the option to choose but ultimately read it were treated as having read the information.

choosing alternative j in choice scenario m. The probability of individual i choosing alternative j in choice scenario m given β_i is then given by equation (2).

$$L_i(\boldsymbol{y_i}|\boldsymbol{x_i},\boldsymbol{\beta_i}) = \Pi_{t=1}^{T}\Pi_{j=1}^{J}\left[\frac{exp(\boldsymbol{x_{ijm}\beta_i})}{\sum_{l=1}^{J} exp(\boldsymbol{x_{ljm}\beta_i})}\right]^{y_{ijm}} \quad (2)$$

Equation (3) defines the likelihood function.

$$L = \int_{\theta\in\Theta} L_i(\boldsymbol{y_i}|\boldsymbol{x_i},\boldsymbol{\beta_i})\, f(\boldsymbol{\beta_i}|\boldsymbol{\theta})d\boldsymbol{\beta_i} \quad (3)$$

In equation (3), $f(\cdot)$ is the density function of a normal distribution with parameter $\boldsymbol{\theta} \in \Theta$. The mixed logit models were estimated using Stata 16.

The WTP for attribute *a* is denoted as WTP_a in equation (4).

$$WTP_a = -\frac{\beta_a}{\beta_p} \quad (4)$$

In equation (4), β_a is the marginal utility of attribute a, and β_p is the marginal disutility from price.

Structural Equation Modeling (SEM)

To better understand the factors influencing consumer WTP for GM and GE food and ornamental products, we employed an SEM framework to simultaneously estimate multiple relationships among key variables, including demographics, attitudes, information exposure, prior knowledge, and perceived risks. SEM accounted for these factors' direct as well as indirect effects on WTP.

SEM is a widely used analytical method in consumer behavior research to investigate the complex relationships among beliefs, attitudes, and behavioral intentions. SEM is a multivariate statistical technique that allows researchers to build and test theoretical models involving latent constructs and observed indicators. SEM can simultaneously estimate a network of relationships, for example, how knowledge influences attitude and how attitude in turn impacts purchase intention, all in one model. In recent years, SEM has been employed to test frameworks such as the TPB and the KAP across a variety of contexts. SEM can incorporate measurement models (confirming that survey questions reliably measure the values of interest) and structural models (testing hypothesized causal paths among those latent constructs) within one analysis (Shin et al., 2017).

Some recent research has employed SEM to test conceptual models of what drives consumer attitudes and intentions of GM food. For instance, Ali et al. (2021) conducted a study on trust and risk perception determinants of GM food acceptance in China and the United States. The researchers developed a structural model where institutional trust, technology trust, perceived benefits, and perceived risks were predictors of overall trust in GM foods, which in turn affected acceptance. They found that GM-specific knowledge was a significant positive predictor of trust in GM foods in both samples.

The structure of our SEM analysis was explicitly informed by TPB and KAP. Our model captured the conceptual relationship of consumer attitudes toward GM and GE products, which worked as mediators that transferred the underlying consumer beliefs and knowledge into measurable WTP outcomes. Additionally, we integrated pre-information exposure (knowledge and familiarity) and information treatment effects into our SEM and explicitly modeled those variables as direct antecedents to consumer attitudes. Structuring our SEM framework around these two robust theories provided a clearer theoretical justification for the selected paths and causal relationships.

The mixed logit model and SEM were complementary in studying consumer preferences for GM and GE products. The mixed logit model directly captured consumer preferences and heterogeneity by estimating individual-level WTP values for specific product attributes, including the GM and GE technology attributes. SEM provided deeper insights into how the psychological and demographic factors impacted these WTP estimates. By combining these methodologies, we not only quantified consumer valuation through mixed logit but also explored the underlying attitudinal and psychological factors that influenced these valuations.

Our SEM model consisted of latent constructs estimated using factor analysis: Attitude toward GM (*AttitudeGM*), attitude toward GE (*AttitudeGE*), WTP latent construct (*WTPlatent*) to pay for GM and GE products, trust in others (*TrustOthers*), and consumer tendency to prioritize short-term versus long-term outcomes (*CFC*). The following observed variables were tested in the model: information exposure to positive or negative information about GM and GE (*ReadingPositiveGM, ReadingPositiveGE, ReadingNegativeGM,* and *ReadingNegativeGE*), demographics (Age, Gender, Income, and Education), pre-information risk perception of GM and GE, familiarity with GM and GE before information exposure (*FamiliarGM* and *FamiliarGE*), willingness to take risks (*RiskTaking*), care about environment (*CareEnvir*), and whether participants considered themselves more liberal or conservative (*Conservative*). We aimed to test the following paths: the direct effects of information exposure, risk perception, demographics, and knowledge on attitudes toward GM and GE; the effect of attitudes toward GM and GE on WTP; and the indirect effects of information exposure, risk perception, demographics, and knowledge on WTP, mediated through attitudes toward GM and GE, as shown in Figure 1.

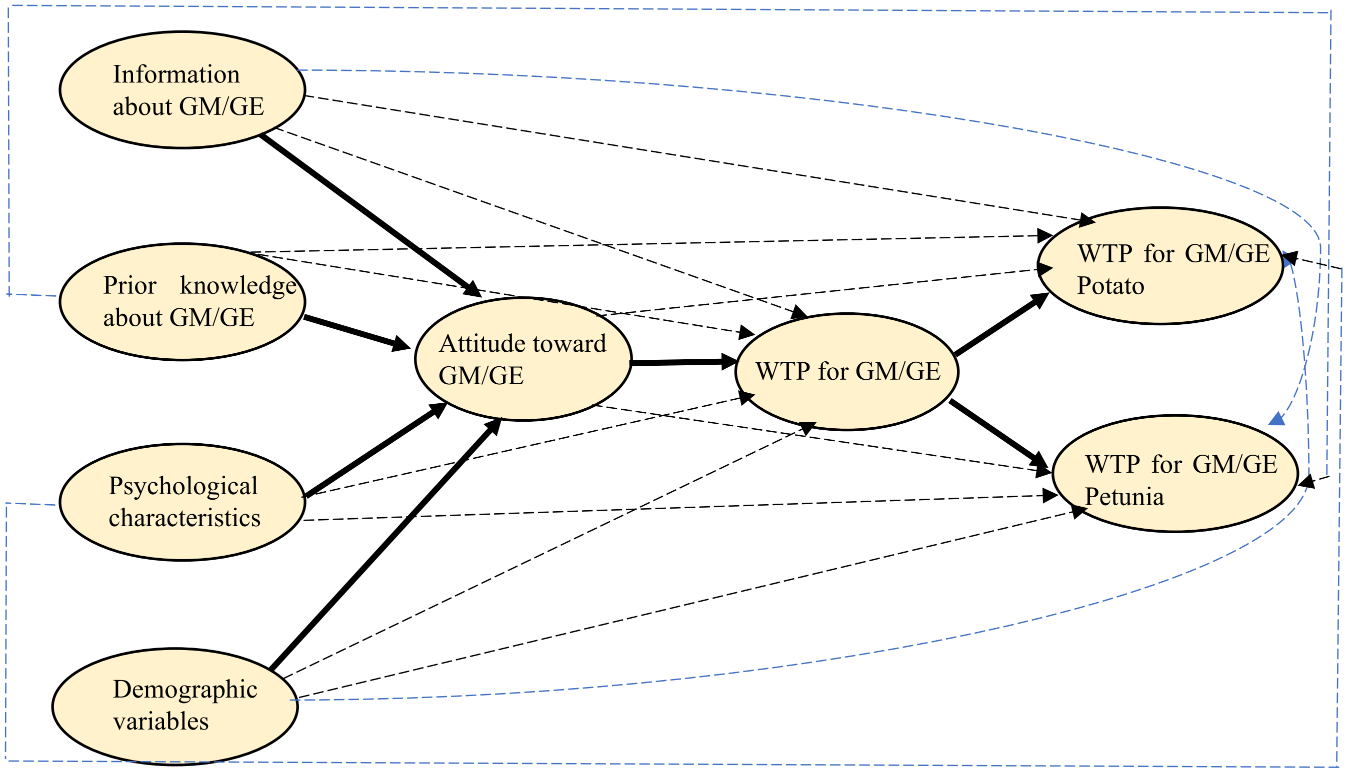

Figure 1. SEM framework (direct effect labeled as solid arrow and indirect effects labeled as dashed arrow)

Results

We collected these data using an online survey through Qualtrics, a professional survey company. To ensure that our sample was representative of decision makers for grocery shopping, we asked a screening question and only those who grocery shopped were allowed to participate. In total, 3,080 consumers from Minnesota, Wisconsin, North Dakota, and South Dakota completed all of the questions used in this analysis. The summary statistics of the demographic and psychographic variables are shown in Table 1. From the table, we can see the average age of participants was 45 years, 29% of participants were male, the income level was $50,000–$74,999, and the average education level was some college.

Table 1. Summary Statistics of Participants' Demographic and Psychographic Variables (N = 3,080)

Variable	Description	Mean	Std. Dev.
Age	Participants' age	45.228	17.444
Gender	Participants' gender: 1 if male, 0 otherwise	0.291	0.454
Income	1 = Less than $25,000 2 = $25,000 - $49,999 3 = $50,000 - $74,999 4 = $75,000 - $99,999 5 = $100,000 - $149,999 6 = $150,000 - $249,000 7 = More than $250,000	2.932	1.486
Edu	1 = Some high school 2 = High school diploma or equivalent 3 = Some college 4 = College degree 5 = Graduate degree	3.359	1.020
RiskTaking	Participants' willingness to take risks:1 = unwilling to take risks and 10 = fully prepared to take risks	5.321	2.172
CareEnvir	Level of agreement with the statement: Taking care of the environment is a big priority to me, 1 = Strongly disagree and 7 = Strongly agree	5.790	1.260
Conservative	Whether participant view him/herself as liberal or conservative, 1 = very liberal and 7 = very conservative	2.922	1.174
FamiliarGM	Participants' familiarity with GM before information treatment, 1 = not familiar at all, 5 = extremely familiar	2.551	1.232
KnowledgeGM	Participants' self-reported knowledge level of GM before information treatment, 1 = not knowledgeable at all, 5 = extremely knowledgeable	2.312	1.094
Prior_riskGM	Participants' perceived risks and benefits of GM before information treatment, 1 = benefit strongly outweighs risk, 5 = risk strongly outweighs benefit	3.227	1.235
FamiliarGE	Participants' familiarity with GE before information treatment, 1=not familiar at all, 5=extremely familiar	1.781	1.063
KnowledgeGE	Participants' self-reported knowledge level of GM before information treatment, 1=not knowledgeable at all, 5=extremely knowledgeable	1.653	0.960
Prior_riskGE	Participants' perceived risks and benefits of GE before information treatment, 1=benefit strongly outweighs risk, 5=risk strongly outweighs benefit	3.247	1.126

We found that before exposure to any information, participants thought they were more familiar with and knowledgeable of GM (mean values were 2.551 and 2.312, respectively) compared to GE (mean values were 1.781 and 1.653, respectively). The perceived risk of GM was about the same as that of GE before information exposure. We conducted *t*-tests between *FamiliarGM* and *FamiliarGE* and found participants' familiarities with GM and GE were significantly different ($p < 0.001$). As expected, participants showed a significantly higher familiarity with GM than GE. This result aligns with the longer history and greater public awareness of GM compared to GE.

Additionally, we divided participants into two groups based on their familiarity with GM or GE, using the mean levels of familiarity as thresholds. *T*-tests were conducted to test whether the perceived risks differed significantly between those who were more familiar with the technology and those who were not familiar. Interestingly, we found familiarity did not significantly impact the perceived risk for GM, but it did significantly impact the perceived risk for GE ($p < 0.001$). One possible explanation for this finding is that GM technology has long been subject to controversial public discourse, and consumers may have developed deeply ingrained risk perceptions that familiarity alone may not effectively reduce. In contrast, GE technology is newer, thus familiarity plays a stronger role in determining consumer risk perceptions. These results indicated the important role of information in consumer acceptance of emergent technologies such as GE.

Mixed Logit Model Results

The results of the mixed logit models are shown in Table 2. Dummy coding was used for categorical variables.

Table 2. Mixed Logit Estimation Results for Potato and Petunia

	Potato	
Variable	**Mean Coefficient**	**Std. Err.**
OptOut	-4.890***	0.093
GM	-0.889***	0.036
GE	-0.789***	0.035
Acrylamide	-0.726***	0.029
Non-browning	-0.123***	0.033
Price	-0.439***	0.012
	Std. Deviation Coefficient	**Std. Err.**
GM	1.384***	0.042
GE	0.905***	0.053
Acrylamide	0.945***	0.022
Non-browning	1.051***	0.038

Table 2 (cont.)

	Petunia	
Variable	**Mean Coefficient**	**Std. Err.**
OptOut	-2.402***	0.065
GM	-1.035***	0.044
GE	-0.990***	0.047
Bloomingtime	2.241***	0.055
Color	0.092***	0.035
Price	-0.309***	0.011
	Std. Deviation Coefficient	**Std. Err.**
GM	1.455***	0.049
GE	1.502***	0.050
Bloomingtime	2.473***	0.055
Color	0.764***	0.040

Price Sensitivity and Attribute Preference

For both potato and petunia, the coefficients of price were statistically significant, meaning participants were sensitive to price. For potato, reductions in acrylamide level (−0.726) increased participants' preferences. They did not like the non-browning trait (−0.123). For petunia, longer blooming time and novel color increased purchase likelihood, indicated by significant coefficients (2.241 and 0.092).

Consumer Acceptance of Biotechnology

Coefficients for GM potatoes and petunia were significant and negative, indicating participants did not like GM potatoes and petunia compared to conventional ones. GE potato had slightly less negative preferences compared to GM potato. Using the mixed logit model results, we estimated each individual participant's coefficient for the attributes and then estimated WTP for GM/GE potato and GM/GE petunia by calculating the ratio between an individual's coefficient of GM/GE and the coefficient of price (see Table 3).

Table 3. WTP Estimates for GM Potato, GE Potato, GM Petunia and GE Petunia, Using Conventional as the Base

Variable	**Mean**	**Std. Dev.**
WTPpotatoGM	-2.023	2.390
WTPpotatoGE	-1.820	1.139
WTPpetuniaGM	-3.279	3.152
WTPpetuniaGE	-3.250	3.248

The average WTP estimates were −$2.023, −$1.820, −$3.279, and −$3.250 for GM potato, GE potato, GM petunia, and GE petunia, respectively. Because the WTP for GM and GE from the same participant might be correlated, we conducted paired *t*-tests between GM versus GE potato and GM versus GE petunia. We found the WTP for GE potato was significantly higher than GM potato, but the WTP for GE petunia was not significantly different from GM petunia. These results indicated participants had a higher level of acceptance of GE than GM for edible products. Consumers may regard GE products as safer or more "natural" than those made from GM technology. This assumption reflects greater trust and potentially less regulatory concern associated with GE edible products compared to GM ones (Son and Lim, 2021; Ding et al., 2023).

Consumer Heterogeneous Preferences

Participants exhibited substantial variability in preferences for all attributes, indicated by significant standard deviations ($p < 0.001$). Figures 2 and 3 show the kernel density of WTP for GM and GE potato and petunia, respectively. One of the most obvious patterns we noted was the bimodal distributions, especially for GM products. A bimodal distribution indicated distinct groups: some participants were more open to GM products, whereas others were strongly against them. This finding highlighted the need for differentiated communication and marketing strategies targeting these segments. For example, groups opposed to GM or GE could be reassured through transparent information on regulatory safety assessments.

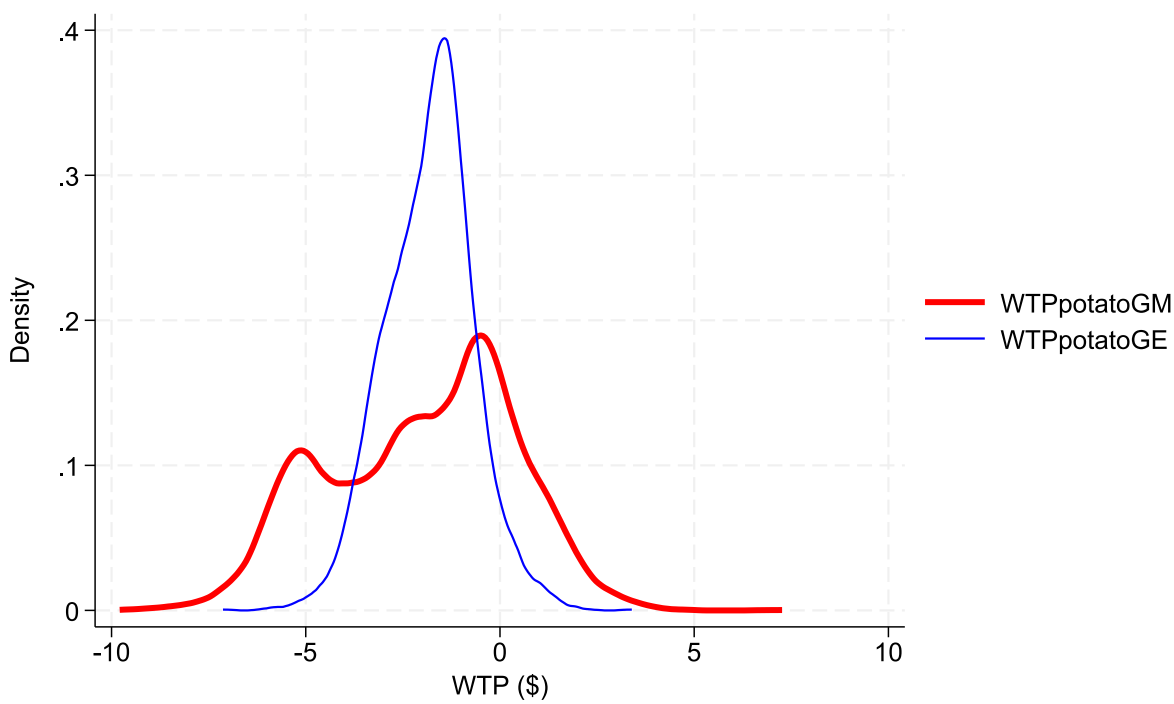

Figure 2. Kernal Density of Participants' WTP for GM and GE Potato

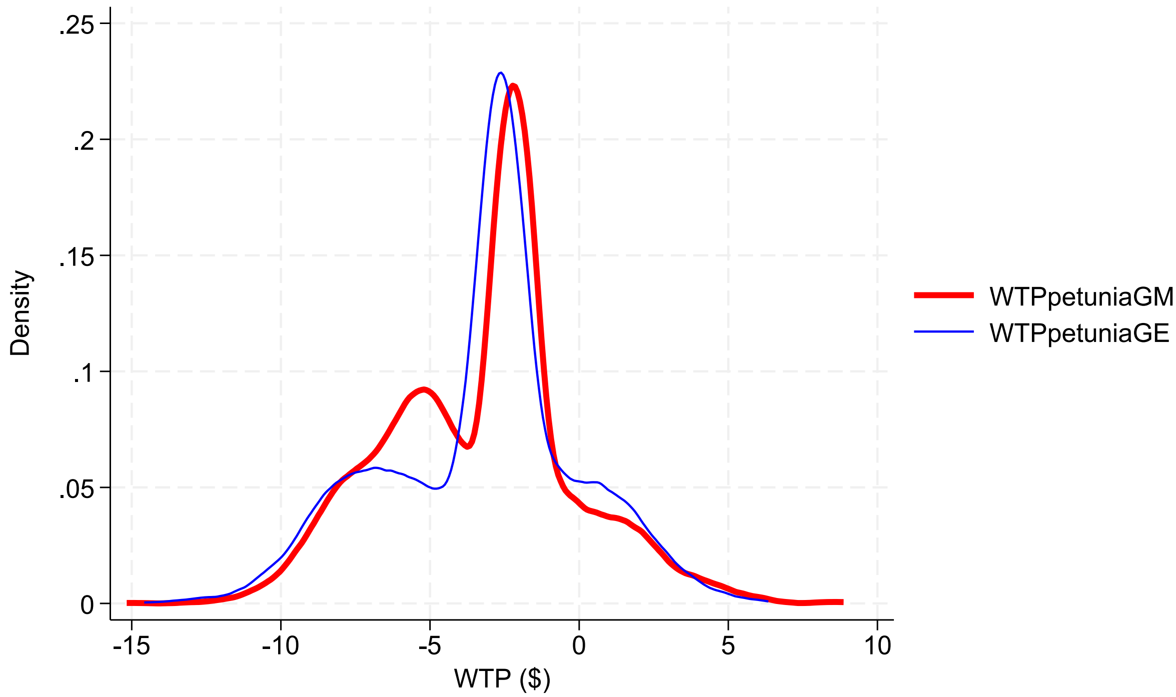

Figure 3. Kernal Density of Participants' WTP for GM and GE Petunia

For potato, the GM potato WTP curve showed bimodality. The GE potato curve was not bimodal and was more sharply peaked, indicating that participants' views of GE potato were less polarized compared to GM potato. The WTP for both GM and GE petunia also showed bimodality but with different intensities. The GM petunia curve had a broader spread, meaning that participants' WTP for GM petunia was more divergent than that of GE petunia. Some participants were neutral or accepting of GM petunia, but others rejected it. In contrast, the WTP for GE petunia was more centered and had a sharper peak near zero. This result implied a more homogeneous preference among participants. The distributions of WTP for GM and GE petunia were similar at the higher peaks. However, the GM curve had a higher secondary peak on the left, which indicated some participants had stronger rejection of GM petunia.

The observed bimodal distributions of WTP for GM products, especially evident in potatoes, suggested distinct consumer groups with different risk tolerance and acceptance levels. The stronger resistance against GM potatoes compared to petunias could be related to direct consumption and perceived health risks associated with edible products. Previous research suggests consumers have lower health concerns about ornamental or non-food crops, which leads to higher acceptance (Chandler and Sanchez, 2012).

Factor Analysis Results

We conducted factor analyses to identify underlying constructs associated with trust of others (*Trustothers*), consideration of future consequences (*CFC*), and attitudes toward GM and GE products (*AttitudeGM* and *AttitudeGE*) after participants read the GM/GE information. Specifically, we conducted exploratory factor analyses. Table 4 shows the questions asked. The table summarizes the mean, standard deviation, and factor loading. We used the threshold of 0.50 to retain the items.

For GM, participants agreed the most with, "I believe GM crops can help with world food security through increased yields," "GM foods need further research before approval for human consumption," and "I am concerned about the long-term environmental consequences of GM crops." For GE, participants agreed most with, "I believe GE crops can help with world food security through increased yields," "I am concerned about the long-term environmental consequences of GE crops," and "I am concerned about the long-term health consequences of GE foods." These results showed participants had reservations about GM and GE products.

The values of the Kaiser-Meyer-Olkin (KMO), which measures sampling adequacy, and Cronbach's Alpha, which measures reliability, are shown in Table 4. The values of Cronbach's Alpha and KMO for *AttitudeGM* were both 0.91. These values were also 0.91 for *AttitudeGE*. The Cronbach's Alpha and KMO values for *Trustothers* were 0.91 and 0.82, respectively, and they were 0.65 and 0.70, respectively, for *CFC*. These values were all close to or above the thresholds for Cronbach's Alpha (0.70) and KMO (0.70) and indicated that reliability and sampling adequacy were acceptable. The *p*-values for Bartlett's Test of Sphericity were significant ($p < 0.001$) for all of the factors, meaning there were appropriate correlations among items for factor analysis.

Table 4. Questions Used in Factor Analysis and the Factor Loadings and Test Statistics for Factor Analysis

Questions	**Mean**	**Std. Dev.**	**Factor Loading**	**Test Statistics**
AttitudeGM				
I believe GM crops can help with world food security through increased yields.	5.054	1.559	0.743	Cronbach's Alpha: 0.91
GM foods need further research before approval for human consumption.	5.366	1.530	-0.626	
Use of GM crops results in less use of pesticides and herbicides.	4.934	1.413	0.603	KMO: 0.91
GM crops have had a positive influence on environmental impacts of farming.	4.561	1.558	0.754	Bartlett's Test of Sphericity: $p < 0.001$
I have no hesitation in consuming GM foods.	4.202	1.880	0.837	
GM foods are safe for human consumption.	4.412	1.686	0.862	
GM technology is outside the natural order.	4.546	1.618	-0.629	
There are no negative consequences of growing or consuming GM crops.	3.193	1.473	0.714	

Table 4 (cont.)

Questions	Mean	Std. Dev.	Factor Loading	Test Statistics
There are no negative consequences of growing GM crops that will not be consumed by people (e.g., ornamental crops).	3.794	1.630	0.624	
I trust government agencies to determine if GM foods are safe (e.g., U.S. Department of Agriculture)	3.975	1.848	0.585	
I am concerned about the long-term health consequences of GM foods.	4.873	1.654	-0.704	
I am concerned about the long-term environmental consequences of GM crops.	5.008	1.595	-0.702	
AttitudeGE				
I believe GE crops can help with world food security through increased yields.	5.047	1.488	0.711	Cronbach's Alpha: 0.91
GE foods need further research before approval for human consumption.	5.311	1.457	-0.669	
Use of GE crops results in less use of pesticides and herbicides.	4.776	1.367	0.620	KMO: 0.91
GE crops have had a positive influence on environmental impacts of farming.	4.436	1.451	0.751	Bartlett's Test of Sphericity: $p < 0.001$
I have no hesitation in consuming GE foods.	3.946	1.812	0.838	
GE foods are safe for human consumption.	4.166	1.575	0.855	
GE technology is outside the natural order.	4.553	1.623	-0.608	
There are no negative consequences of growing or consuming GE crops.	3.372	1.423	0.739	
There are no negative consequences of growing GE crops that will not be consumed by people (e.g., ornamental crops).	3.774	1.572	0.682	
I trust government agencies to determine if GE foods are safe (e.g., U.S. Department of Agriculture).	3.868	1.828	0.541	
I am concerned about the long-term health consequences of GE foods.	4.827	1.623	-0.724	
I am concerned about the long-term environmental consequences of GE crops.	4.875	1.598	-0.720	
TrustOthers				Cronbach's Alpha: 0.91
Most people are basically honest.	4.438	1.563	0.909	
Most people are trustworthy.	4.369	1.543	0.928	KMO:0.82
Most people are basically good and kind.	4.745	1.427	0.898	Bartlett's Test of Sphericity: $p < 0.001$
Most people are trustful of others.	4.344	1.434	0.799	

Table 4 (cont.)

Questions	Mean	Std. Dev.	Factor Loading	Test Statistics
CFC				Cronbach's Alpha: 0.65 KMO: 0.70 Bartlett's Test of Sphericity: $p < 0.001$
I consider how things might be in the future and try to influence those things with my day to day behavior.	5.196	1.231	0.569	
Often I engage in a particular behavior in order to achieve outcomes that may not result for many years.	4.679	1.407	0.567	
I only act to satisfy immediate concerns, figuring the future will take care of itself.	3.512	1.581	-0.808	
My behavior is only influenced by the immediate (i.e. a matter of days or weeks) outcomes of my actions.	3.545	1.631	-0.814	
My convenience is a big factor in the decisions I make or the actions I take.	4.595	1.432	-0.559	

Note: In the factor analysis, the threshold for item retention is 0.50.

SEM Results

Direct and Indirect Influences on WTP

The SEM results, as shown in Tables 5.1 and 5.2, provided detailed insights into the factors associated with participants' attitudes and WTP for GM potato and GM petunia. *AttitudeGM* was significantly associated with WTP for GM petunia and GM potato. Specifically, a strong positive relationship was observed between *AttitudeGM* and the latent WTP construct (*WTPlatent*), with a highly significant coefficient (1.134). *AttitudeGE* also had a significantly positive relationship with the latent WTP construct for GE products.

Table 5.1. SEM Estimation Results for GM Products-Direct effect

	Variable	Bootstrap Coefficient	Bootstrap Std. Err.
Structural	WTPlatent		
	AttitudeGM	1.134***	0.050
Measurement	WTPpetuniaGM		
	WTPlatent	1(constrained)	
	WTPpotatoGM		
	WTPlatent	1.072***	0.048
Structural	AttitudeGM		
	ReadpositiveGM	0.468***	0.047
	ReadnegativeGM	-0.348***	0.043
	ReadpositiveGE	0.102**	0.046
	ReadnegativeGE	-0.205***	0.042
	RiskTaking	0.046***	0.007
	CareEnvir	-0.050***	0.014

Table 5.1 (cont.)

	Variable	Bootstrap Coefficient	Bootstrap Std. Err.
	Trustothers	0.136***	0.017
	Age	-0.003***	0.001
	Gender	0.199***	0.034
	Income	0.038***	0.011
	Edu	-0.009	0.015
	FamiliarGM	0.004	0.021
	KnowledgeGM	0.027	0.024
	Prior_riskGM	-0.358***	0.014
	CFC	-0.114***	0.018

Table 5.2. SEM Estimation Results for GM Products—Indirect Effect

	Variable	Bootstrap Coefficient	Bootstrap Std. Err.
Structural	WTPlatent		
	ReadpositiveGM	0.531***	0.059
	ReadnegativeGM	-0.395***	0.053
	ReadpositiveGE	0.115**	0.053
	ReadnegativeGE	-0.232***	0.048
	RiskTaking	0.052***	0.009
	CareEnvir	-0.057***	0.016
	Conservative	-0.060***	0.016
	Trustothers	0.154***	0.020
	Age	-0.003***	0.001
	Gender	0.226***	0.040
	Income	0.043***	0.012
	Edu	-0.010	0.017
	FamiliarGM	0.005	0.023
	KnowledgeGM	0.030	0.028
	Prior_riskGM	-0.406***	0.024
	CFC	-0.129***	0.021
Measurement	WTPpetuniaGM		
	AttitudeGM	1.134***	0.050
	ReadpositiveGM	0.531***	0.059
	ReadnegativeGM	-0.395***	0.053
	ReadpositiveGE	0.115**	0.053
	ReadnegativeGE	-0.232***	0.048
	RiskTaking	0.052***	0.009
	CareEnvir	-0.057***	0.016
	Conservative	-0.060***	0.016
	Trustothers	0.154***	0.020

Table 5.2 (cont.)

	Variable	Bootstrap Coefficient	Bootstrap Std. Err.
	Age	-0.003***	0.001
	Gender	0.226***	0.040
	Income	0.043***	0.012
	Edu	-0.010	0.017
	FamiliarGM	0.005	0.023
	KnowledgeGM	0.030	0.028
	Prior_riskGM	-0.406***	0.024
	CFC	-0.129***	0.021
	WTPpotatoGM		
	AttitudeGM	1.216***	0.035
	ReadpositiveGM	0.569***	0.060
	ReadnegativeGM	-0.423***	0.054
	ReadpositiveGE	0.124**	0.056
	ReadnegativeGE	-0.249***	0.051
	RiskTaking	0.055***	0.009
	CareEnvir	-0.061***	0.017
	Conservative	-0.064***	0.017
	TrustOthers	0.166***	0.021
	Age	-0.003***	0.001
	Gender	0.243***	0.041
	Income	0.046***	0.013
	Edu	-0.011	0.018
	FamiliarGM	0.005	0.025
	KnowledgeGM	0.032	0.030
	Prior_riskGM	-0.435***	0.021
	CFC	-0.139***	0.022
Goodness of Fit Statistics	RMSEA	0.033	
	CFI	0.965	
	TLI	0.944	
	SRMR	0.016	

WTPlatent had a significant positive relationship with WTP for GM petunia (constrained path coefficient = 1) and GM potato (path coefficient = 1.072). A smaller magnitude was observed for GE potato (0.356). The smaller magnitudes for GE potato compared to petunia indicated stronger participant hesitance toward food products made from biotechnology relative to ornamental plants, which is consistent with previous findings showing consumers are more accepting of biotechnology in ornamental plants compared to food products (Chandler and Sanchez, 2012).

The indirect effects showed that information exposure was significantly related to WTP through attitudes. Reading positive GM information had an indirect positive association with WTP (0.531), whereas reading negative GM information was negatively associated with WTP (−0.395). Demographics were also indirectly associated with WTP: Older participants tended to have lower WTP compared to younger ones (−0.003). Participants with higher income (0.043) and being male (0.226) tended to have a positive indirect relationship with WTP. These results aligned with previous literature showing male consumers, younger consumers, and those with higher income are more accepting of GM or GE products (Moerbeek and Casimir, 2005; Cummings and Peters, 2022). Participants' willingness to take risks (*RiskTaking*) had a significant indirect positive relationship with WTP for GM products (0.052). Caring for the environment (*CareEnvir*) had an indirect negative association with WTP (−0.057). Having more conservative views (*Conservative*) was indirectly linked to WTP for GM products in a negative way (−0.060). These indirect effects were similar for the GE model.

Demographic and Psychographic Determinants of Consumer Attitudes

Participants' demographics had significant associations with attitudes toward GM products. Older participants were less likely to have positive attitudes toward GM compared to younger ones (−0.003). Male participants showed more favorable attitudes toward GM than female participants (0.199). Participants with a higher income level also had significantly more positive attitudes compared to those with a lower income level (0.038). Education did not have a significant association with participants' attitudes toward GM.

Regarding participants' characteristics, those who thought the risk of GM technology outweighed the benefit (*Prior_riskGM*) were positively linked to having negative attitudes toward GM (−0.358). Thus, it is important to address risk perceptions proactively through clear communication on safety evaluations and long-term research outcomes of GM technology. Participants who placed more weight on future consequences (*CFC*) held unfavorable attitudes toward GM (−0.114). Additionally, trust in others (*Trustothers*) was associated with GM attitudes in a positive way (0.136). Participants who were more willing to take risks (*RiskTaking*) were significantly likely to have positive attitudes toward GM directly (0.046). These results aligned well with previous research showing consumers with higher trust in others tend to have positive GM attitudes, and individuals with higher risk propensity are likely to have higher acceptance of GM or GE products (Lu, Xie, and Xiong, 2015; Meerza et al., 2024). Caring for the environment (*CareEnvir*) was negatively associated with GM attitudes directly (−0.050), which indicated that participants associated GM products with negative environmental impacts. Conversely, having more conservative views (*Conservative*) was negatively linked to GM attitudes directly (−0.053).

Similar results were observed for the GE model (see Tables 6.1 and 6.2). The only difference we noticed was the significant coefficients of *FamiliarGE* in the GE model and the insignificant *FamiliarGM* in the GM model. This finding echoed our earlier results on participants' familiarity with GM and GE and might reflect differences in public familiarity with the two technologies. As discussed earlier, GM technology has been extensively discussed, and most consumers may have established attitudes regardless of their level of self-reported familiarity. In contrast, GE technology is newer and consumers are less aware of it. Thus, we saw a stronger connection between consumers' self-perceived familiarity and their attitudes. These results indicated that greater familiarity with GE could reduce uncertainty and enhance positive attitudes.

Table 6.1. SEM Estimation Results for GE Products—Direct Effect

	Variable	Bootstrap Coefficient	Bootstrap Std. Err.
Structural	WTPlatent		
	AttitudeGE	1.292***	0.056
Measurement	WTPpetuniaGE		
	WTPlatent	1 (constrained)	
	WTPpotatoGE		
	WTPlatent	0.356***	0.018
Structural	AttitudeGE		
	ReadPositiveGE	0.320***	0.018
	ReadNegativeGE	-0.245***	0.045
	ReadPositiveGM	0.377***	0.042
	ReadNegativeGM	-0.324***	0.046
	RiskTaking	0.058***	0.045
	CareEnvir	-0.065***	0.008
	Conservative	-0.059***	0.014
	Trustothers	0.139***	0.015
	Age	-0.002**	0.018
	Gender	0.166***	0.001
	Income	0.030***	0.035
	Edu	0.004	0.011
	FamiliarGE	0.050**	0.015
	KnowledgeGE	0.004	0.024
	Prior_riskGE	-0.353***	0.027
	CFC	-0.096***	0.015

Table 6.2. SEM Estimation Results for GE Products--Indirect Effect

	Variable	Bootstrap Coefficient	Bootstrap Std. Err.
Structural	WTPlatent		
	ReadPositiveGE	0.413***	0.061
	ReadNegativeGE	-0.317***	0.057
	ReadPositiveGM	0.487***	0.063
	ReadNegativeGM	-0.419***	0.063
	Risktaking	0.075***	0.011
	CareEnvir	-0.084***	0.019
	Conservative	-0.076***	0.019
	TrustOthers	0.179***	0.024

Table 6.2 (cont.)

	Variable	Bootstrap Coefficient	Bootstrap Std. Err.
	Age	-0.003**	0.001
	Gender	0.215***	0.046
	Income	0.039***	0.015
	Edu	0.006	0.020
	FamiliarGE	0.065**	0.031
	KnowledgeGE	0.006	0.035
	Prior_RiskGE	-0.456***	0.029
	CFC	-0.124***	0.023
Measurement	WTPpetuniaGE		
	AttitudeGE	1.292***	0.056
	ReadPositiveGE	0.413***	0.061
	ReadNegativeGE	-0.317***	0.057
	ReadPositiveGM	0.487***	0.063
	ReadNegativeGM	-0.419***	0.063
	Risktaking	0.075***	0.011
	CareEnvir	-0.084***	0.019
	Conservative	-0.076***	0.019
	Trustothers	0.179***	0.024
	Age	-0.003**	0.001
	Gender	0.215***	0.046
	Income	0.039***	0.015
	Edu	0.006	0.020
	FamiliarGE	0.065**	0.031
	KnowledgeGE	0.006	0.035
	Prior_RiskGE	-0.456***	0.029
	CFC	-0.124***	0.023
	WTPpotatoGE		
	AttitudeGE	0.460***	0.019
	ReadPositiveGE	0.147***	0.021
	ReadNegativeGE	-0.113***	0.020
	ReadPositiveGM	0.173***	0.022
	ReadNegativeGM	-0.149***	0.022
	Risktaking	0.027***	0.004
	CareEnvir	-0.030***	0.007
	Conservative	-0.027***	0.007
	TrustOthers	0.064***	0.009
	Age	-0.001**	0.0004
	Gender	0.076***	0.016
	Income	0.014***	0.005
	Edu	0.002	0.011
	FamiliarGE	0.023**	0.010

Table 6.2 (cont.)

	Variable	Bootstrap Coefficient	Bootstrap Std. Err.
	KnowledgeGE	0.002	0.008
	Prior_riskGE	-0.162***	0.019
	CFC	-0.044***	0.021
Goodness of fit statistics	RMSEA	0.029	
	CFI	0.967	
	TLI	0.947	
	SRMR	0.014	

Information Framing and Cross-Technology Spillover Effects

We found that reading positive information about GM had a significantly positive association with attitudes toward GM (0.468), whereas negative information about GM was adversely associated with attitudes (−0.348). Interestingly, we found that reading positive and negative information about GE technologies also had spillover effects on attitudes toward GM. Specifically, reading positive GE information was positively related to GM attitudes (0.102), and reading negative GE information was negatively associated with GM attitudes (−0.205). We observed similar indirect spillover effects from GE information.

We compared the spillover effects of GM and GE information and found that positive GM information had a stronger spillover effect on attitudes toward GE than positive GE information had on attitudes toward GM. Specifically, the results showed that positive GM information had a significantly positive association with attitudes toward GE (0.377) at the 1% significance level, but positive GE information had a smaller (0.102) and less significant effect on GM attitudes at the 5% significance level, which indicated that when participants read positive information about GM, they were more likely to generalize their positive perception to GE. In contrast, learning about the benefits of GE did not lead to a positive increase in GM attitudes that was as strong. This asymmetry may arise from differences in how these technologies are perceived: GM technology has existed for decades and many consumers have established skepticism about it, whereas GE is often framed as a more precise and "natural" innovation. As a result, positive information about GM may increase the credibility of biotechnology, but the impact of GE-related information on GM remains relatively limited.

A similar asymmetry was observed for negative information effects. Negative GM information was negatively associated with attitudes toward GE (−0.324), but negative GE information had a slightly smaller but still significant negative association with GM attitudes (−0.205). This result shows that negative perceptions of GM are more likely to spill over concerns about GE. Participants who were exposed to negative GM information may have associated similar risks with GE products, as they might perceive GE as a subset or improved version of GM. Conversely, negative information about GE, while still harmful to GM attitudes, did not generate an impact that was as large. The stronger spillover effect of GM information onto GE indicated that well-established or familiar biotechnologies significantly impacted perceptions of newer related technologies. Our results mirrored broader research on technology spillover, where consumers rely on established perceptions of GM to frame new technologies like GE, particularly when GM is seen as familiar or controversial (Akin et al., 2018). As a result, positive (and negative) GM information was more strongly associated with GE attitudes than GE information was with GM attitudes, reflecting both asymmetry and anchoring in public perception.

Goodness of Fit of the Models

To test the goodness of fit for the models, we calculated several test statistics. The results for the GM model were as follows: the Root Mean Square Error of Approximation (RMSEA) was 0.033, the Comparative Fit Index (CFI) equaled 0.965, the Tucker-Lewis Index (TLI) was 0.944, and the Standardized Root Mean Squared Residual (SRMR) equaled 0.016. These statistics suggested an excellent goodness of fit for the model. The overall model fit statistics for the GE model were also excellent, with an RMSEA of 0.029, a CFI of 0.967, a TLI of 0.947, and an SRMR of 0.014, indicating strong model specification.

Conclusions and Discussion

Using choice experiments and analysis methods, such as factor analysis, mixed logit models, and SEM, this research studied how information about biotechnology and its key factors were associated with consumer attitudes and WTP for GM and GE potato and petunia. The similarities between the WTP for GM and GE technologies and edible and ornamental products were identified. Based on these results, this study provides several important implications for both policy making and marketing strategies related to GM and GE products.

The findings highlighted that consumer attitudes served as an essential mediator connecting information exposure and consumer characteristics to WTP for GM and GE products. This mediation effect suggests information is associated with purchasing behavior indirectly through consumer attitudes, meaning that information is linked to consumers' underlying attitudes, which in turn is associated with their economic valuations and choices. An important implication for policy makers and marketers is that they might not solely focus on informational content. Instead, they can carefully consider how the provided information influences consumer attitudes, given that attitudes translate strongly and directly into economic decisions. Additionally, understanding consumer demographics and other characteristics (e.g., trust of others, risk preferences, environmental concerns, and political ideologies) is very important because these factors influence attitudes, which subsequently impact WTP.

The significant associations of positive and negative information with attitudes highlighted the important role communication strategies play in shaping consumer underlying attitudes. These results are consistent with previous findings that have shown positive information increases consumers' WTP, but negative information decreases WTP (Lusk and Coble, 2005; Frewer, Howard, and Shepherd, 2013). Therefore, policy makers and suppliers of GM and GE products could provide clear, accurate, and positive information dissemination in order to encourage informed acceptance of GM and GE products among consumers.

An interesting finding was that information regarding one technology (GM or GE) was associated with attitudes toward the other, that is, the information spillover effect (Martin-Collado et al., 2022). We found positive GM information had a positive relationship with consumer perceptions of GE technology and vice versa, suggesting that a positive message of one technology can potentially have broader beneficial impacts. Similarly, negative messages about one technology can possibly be detrimental to the other. This information spillover effect has been observed by other related studies. For example, a recent study on gene-edited meat found that many consumers' views on GE mirrored their stance on GM foods. The observed information spillover effect indicates that it is important to use holistic and well-coordinated communication strategies when introducing new biotechnologies to consumers. Additionally, we found that even though the information about one influenced perception of the other, GM information had a stronger information spillover effect on GE than the reverse.

Because improving consumer attitudes toward GM can significantly enhance attitudes toward GE, positive GM information could serve as a gateway to achieving broader biotechnology acceptance. Because the negative GM information spilled over strongly onto GE attitudes, efforts can be focused on correcting misinformation about GM to indirectly increase the acceptance of GE technologies. If the goal is to increase GE adoption independently of GM, communications could emphasize its differences from GM, particularly in how it is more precise and does not involve transgenic modification.

Consumers showed consistently greater acceptance and higher WTP for GE-edible products compared to GM ones. The results indicate that GE technology may face fewer consumer-related adoption barriers. As mentioned earlier, unlike GM, GE does not involve the introduction of foreign DNA, so consumers might associate GE with a greater sense of naturalness, and thus a lower perceived risk. Risk perception and technological familiarity might impact the perceived "naturalness" and the adoption of GE. Risk perception is consumers' evaluation of the potential risks of a technology. Technological familiarity refers to the extent to which consumers have experience with a technology. Lower risk perception associated with GE technologies may promote moral licensing because consumers feel morally justified by choosing the seemingly "natural" GE products, and thus their caution about GE products' risks is reduced. Similarly, as consumers become more familiar with GE products, the moral licensing effect can be intensified. When consumers believe that GE foods are safe or familiar, they will unlikely try to verify whether these foods are safe. Food safety narratives need to carefully balance GE's benefits with the transparent communication of ongoing food safety research.

We also found consumers were more accepting of GE food products compared to GM products, but their preferences for GM and GE ornamental products were not significantly different from each other. One possible explanation for this finding is that consumers are more cautious about food products because what they eat directly affects their health. As a result, they prefer GE, which is perceived as more "natural" and less risky than GM. Consumers do not directly consume ornamental plants, so the perceived health risks from GM or GE are low. This assumption weakens the concerns about the distinction between GM and GE, leading to similar levels of acceptance. The results imply that marketing strategies of GE foods can focus on their distinction from GM foods, and that premium pricing for GE foods relative to GM counterparts may be feasible. For ornamental crops, marketing should emphasize product attributes (novel color, longer bloom, disease resistance, etc.) achieved by GM or GE rather than the technologies themselves.

We found a significant relationship between demographics (age, gender, income) and attitudes toward GM and GE. Thus, targeted campaigns can effectively reach specific groups. Younger, higher income, and male consumers are more open to these technologies, which is consistent with previous findings (McFadden and Lusk, 2017; Cummings and Peters, 2022). Communications can be developed to target specific demographic segments with less favorable attitudes (e.g., older consumers, lower-income groups, or female in the case of GE) to enhance their acceptance of the technologies.

Furthermore, we found that consumers who focus on future consequences were less inclined to favor GM and GE products, which aligns with findings in behavioral economics that suggest individuals who discount the future heavily may be more responsive to immediate advantages rather than long-term risks (Günden et al., 2024). Since GM and GE crops often provide immediate benefits, such as reduced pesticide use, longer shelf life, better taste, and lower food prices, consumers who regard short-term outcomes as more important may be more willing to trade off perceived risks for short-term gains. For marketing and public communication, emphasizing the short-term, tangible benefits of GM and GE technologies could be an effective way to increase acceptance by present-focused consumers. Framing GM/GE foods around long-term sustainability or global food security will resonate more strongly with future-focused consumers.

Our study had several limitations. First, although potatoes and petunias were both frequently purchased products by consumers, they may still differ widely in consumer familiarity, risk perception, and frequency of purchase. These asymmetries could affect comparability across product categories. Second, participants in our study were from four Midwestern states. The generalization of our results to national or international populations should be made with caution. Further studies can be conducted to validate the applicability of our results to other regions or countries. Third, when we estimated mixed logit model, we assumed normal distribution for the random parameters. We acknowledge that different distribution assumptions might yield different WTP estimates. Lastly, our sample was skewed toward female participants. Including only grocery shoppers in the screening of survey participants that resulted in a sample consisting of more female than male participants. Based on previous research, the majority of grocery shoppers in a household are female (Schaeffer, 2019); most of the plant purchasers are also female (Statista, 2023). From this perspective, our sample is more representative of decision makers for grocery shopping than a gender-balanced sample. However, readers should consider that this demographic distribution may influence our results, particularly because gender significantly affected attitudes and WTP in our analysis.

Due to the scope of this study, we did not conduct subgroup analysis despite some demographic and psychographic variables having significant effects. Further studies could explore how results differ among age, gender, or psychographic groups. Additionally, the significant standard deviation coefficients and the kernel distributions indicated the existence of consumer segments in terms of their attitudes toward GM and GE food or ornamental crops. Our future effort will focus on exploring consumer heterogeneity and consumer segmentation in terms of their preferences for GM and GE ornamental and food crops.

Acknowledgment

This research was funded by the Minnesota Department of Agriculture. Grant Number:184955-3000037455.

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Appendix

Positive information about GM

How does it work?

- DNA or modified genes are added to a crop from any plant or non-plant organism.
- Adding non-plant genes to a crop triggers a regulatory process.
- In most cases the genes for a new trait may be modified from their original form and may contain more than one modified gene from any organism.

Health and safety

- The US Department of Agriculture (USDA) has determined GM food crops are safe for consumption and the environment.
- The US Environmental Protection Agency (EPA) has determined there are no negative environmental impacts of growing GM crops.
- The US Food and Drug Administration (FDA) has determined GM food crops are safe for consumption and determined GM foods equivalent to conventional foods.
- GM food crops show fewer toxins, carcinogens, and allergens when compared to conventional food crops of the same variety.
- GM foods are grown with less pesticide, herbicide, and fertilizer than conventional foods.
- GM makes food healthier by enhancing nutrients and reducing unhealthy chemicals.

Environment:

- GM crops tolerate drought, frost, and other environmental stressors, making production less uncertain.
- GM crops produce more food with less pesticide, feeding the world's growing population while decreasing the costs to health and environment.
- GM crops that are herbicide-tolerant are grown with less synthetic insecticides using conservation tillage (less or no-till farming) which reduces greenhouse gases and increases soil health.
- The environmental and human health impact of synthetic pesticides can be dramatically lowered using GM crops that produce their own natural pesticides.
- GM crops are grown using less fuel, reducing greenhouse gas emissions and can be used as renewable fuels and biodegradable plastic.
- GM crops can trap carbon capturing CO_2 emissions and increasing soil health.

Business Practices

- GM crops increase yield and profitability for farmers, ensuring food security, and lowering costs to consumers.
- GM crops are used by large and small farms equally providing economic opportunity for all.
- As GM crops are increasingly used and accepted, growers and consumers will share in the economic benefits stimulating creation of even more beneficial crops to increase farm profits while protecting the environment and human health.

Summary

- The benefits of GM crops could save the planet from climate change, make food healthier, and feed the world. Throwing out this technology could be throwing out a brighter future.

- GM crops have been grown and consumed for over 25 years without any significant negative impacts and many benefits.

Negative information about GM

How does it work?

- DNA or modified genes are added to a crop from any plant or non-plant organism.
- Adding non-plant genes to a crop triggers a regulatory process.
- In most cases the genes for a new trait may be modified from their original form and may contain more than one modified gene from any organism.

Health and safety

- Despite government approval of some GM food crops for farming and consumption, many possible health issues related to growing and consuming GM food crops have not been and cannot be fully tested.
- Genetic modification can create unintentional issues like producing new allergens, toxins, or carcinogens in food.
- There may be unanticipated health side effects that cannot be predicted or easily and quickly detected.
- Bacteria exposed to GM plants could acquire antibiotic resistance that could in turn spread antibiotic resistant bacteria.
- While the use of GM crops may lower the use of some pesticides and herbicides, the use of the pesticide glyphosate has risen, and glyphosate was classified as "probably carcinogenic to humans" in 2015.

Environment

- Increased yields are listed as a main benefit of GM crops, but data has shown mixed evidence of increased yields.
- We have seen evidence of one unanticipated consequence already as nature responded to GM herbicide-tolerant crops with herbicide-resistant superweeds; the emergence of super-weeds increases pesticide use and decreases yields.
- One of the biggest purported benefits of GM crops, the ability to use no-till farming, is not exclusive to growing GM crops having been used for thousands of years in organic and conventional farming.
- GM crops that produce their own natural insecticide can negatively affect other insects.
- GM crops may have dire effects on biodiversity.
- GM crops are produced and sold by large corporations with poor environmental records that also sell herbicides and pesticides, such as glyphosate.

Business practices

- GM crops are more expensive due to patents and licensing.
- High prices lead to consolidation and more corporate factory farms as small farms drop out of the market, reducing farmer profits and increasing food costs for consumers.
- Costs for neighboring conventional or organic farms increase due to the burden of protecting conventional crops from irreversible genetic pollution from neighboring crops using GM technology.

Summary

- We can’t know for sure what effect GM crops will have on the environment or our health, and after releasing them across the country it is too late to reverse course.

- Adding altered DNA from any organism outside a crop species is not natural. This process takes millions of years in nature, how can we know the consequences of making these changes overnight?

Positive information about GE

How does it work?

- Specific targeted changes to DNA are made within a crop.
- Since no new DNA is added to genetically edited crops, and similar gene changes could be achieved by conventional plant breeding no regulation is required for genetically edited crops to be grown.

Health and safety

- The US Department of Agriculture (USDA) has determined genetically edited food crops are safe for consumption and the environment since they do not contain new genetic material.
- The US Environmental Protection Agency (EPA) and the US Food and Drug Administration (FDA) regulate genetically edited food crops that are sent to them the same way they regulate conventional food crops.
- Genetically edited crops compared to conventional crops of the same variety show fewer toxins, carcinogens and allergens.
- Genetically edited crops are grown with less pesticide, herbicide and fertilizer than conventional crops.
- Genetic editing makes food healthier by enhancing nutrients and reducing toxins.

Environment:

- Genetically edited crops tolerate drought, frost, and other environmental stressors, making crop yields less uncertain.
- Genetically edited crops produce more food with less pesticides, feeding the world's growing population while decreasing the costs to health and the environment.
- Genetically edited crops that are herbicide-tolerant are grown with less synthetic insecticides using conservation tillage (less or no-till farming) which reduces greenhouse gases and increases soil health.
- The environmental and human health impact of synthetic pesticides can be dramatically lowered using genetically edited crops that produce their own natural pesticides.
- Genetically edited crops are grown using less fuel, reducing greenhouse gas emissions and can be used as renewable fuels and biodegradable plastic.
- Genetically edited crops can trap carbon capturing CO_2 emissions and increasing soil health.

Business Practices

- Genetically edited crops increase yield and profitability for farmers, ensuring food security, and lowering costs to consumers.
- Genetically edited crops are used by large and small farms equally providing economic opportunity for all.
- Genetically edited crops are regulated the same way as conventional crops, facilitating easier adoption by farmers and consumers.

- As genetically edited crops are increasingly used and accepted, growers and consumers will share in the economic benefits stimulating creation of even more beneficial crops to increase farm profits while protecting the environment and human health.

Summary

- The benefits of genetically edited crops could save the planet from climate change, make food healthier, and feed the world. Throwing out this technology could be throwing out a brighter future.
- Altering DNA through genetic editing removes the need to introduce DNA from other organisms, thus the USDA considers genetically edited crops conventional and not needing approval.

Negative information about GE

How does it work?

- Specific targeted changes are made within a crop.
- Since no new DNA is added to genetically edited crops, and similar gene changes could be achieved by conventional plant breeding no regulation is required for genetically edited crops to be grown.

Health and safety

- The US Department of Agriculture (USDA) has determined genetically edited (CRISPR) food crops are not required to go through the regulation process because they do not contain introduced genetic material.
- Genetically edited food crops do not go through any approval processes unless businesses volunteer to have their crops analyzed, so unhealthy changes that might occur may not be identified by a regulatory process.
- Even though no new genetic material is added, genetic editing can create unintentional issues like producing new allergens, toxins, or carcinogens in food through off-target effects.
- There may be unanticipated health effects that cannot be predicted or easily and quickly detected that thus are and will remain untested.
- While use of genetically edited crops may lower use of some pesticides and herbicides, use of the pesticide glyphosate has risen, and glyphosate was classified as "probably carcinogenic to humans" in 2015.

Environment

- Increased yields are listed as a main benefit of genetically edited products but data has shown mixed evidence of increased yields.
- We have seen evidence of unanticipated consequences with herbicide-resistant superweeds, which increases pesticide use and decreases yields.
- One of the biggest purported benefits of genetically edited crops, the ability to use no-till farming, is not exclusive to growing genetically edited crops having been used for thousands of years in organic and conventional farming.
- Genetically edited crops that produce their own natural insecticide can negatively affect other insects.
- Genetically edited crops may have dire effects on biodiversity.

- Genetically edited crops are produced and sold by large corporations with poor environmental records that also sell herbicides and pesticides, such as glyphosate.

Business practices

- Genetically edited crops are more expensive due to patents and licensing.
- High prices lead to consolidation and more corporate factory farms as small farms drop out of the market, reducing farmer profits, and increasing food costs for consumers.
- Costs for neighboring conventional or organic farms increase due to the burden of protecting conventional crops from irreversible genetic pollution from neighboring crops using genetic editing technology.

Summary

- Even though the USDA considers genetic editing safe since no DNA is added from outside the species, this process is not natural. DNA changes take millions of years in nature, how can we know the consequences of making these changes overnight?
- We can't know for sure what effect genetically edited crops will have on the environment or our health, and after releasing them across the country it is too late to reverse course.