Q Open, 2023, **3**, 1–30
https://doi.org/10.1093/qopen/qoad008
Advance access publication date: 21 March 2023
Article

OXFORD

Consumers' willingness to accept gene-edited fruit—An application to quality traits for fresh table grapes

Azhar Uddin[1], R. Karina Gallardo [2,*], Bradley Rickard[3], Julian Alston [4] and Olena Sambucci[4]

[1]Institute for Research and Education to Advance Community Health (IREACH), Washington State University, Pullman, WA, USA
[2]School of Economic Sciences, Puyallup Research and Extension Center, Washington State University, Puyallup, WA, USA
[3]Charles H. Dyson School of Applied Economics and Management, Cornell University, Ithaca, NY, USA
[4]Department of Agricultural and Resource Economics, University of California, Davis, CA, USA

*Corresponding author: School of Economic Sciences, Puyallup Research and Extension Center, Washington State University, 2606 W. Pioneer Ave., Puyallup, WA 98371, USA. E-mail: karina_gallardo@wsu.edu

Received: October 1, 2022. **Accepted:** March 14, 2023

Abstract

Given the increasing number of applications in agriculture of gene editing, specifically CRISPR, it is important to understand consumers' perceptions of this breeding technology. We estimate consumers' willingness to pay (WTP) for selected quality attributes of table grapes developed using either conventional breeding or CRISPR. Results show that the willingness-to-pay values for the selected table grape attributes were ranked in the same order for both breeding technologies. We found a slight discount in the overall WTP for table grapes produced using CRISPR compared with conventional breeding, but this discount was neither economically nor statistically significant. Our findings highlight consumers' preferences for eating-experience attributes—e.g. sweetness and crispness. Results in this study advance the understanding of consumers' perceptions, contributing to strategies for promoting broader acceptance of CRISPR in the marketplace.

Keywords: Consumer preferences, CRISPR, Plant breeding, Table grapes, Choice experiment, Willingness to pay.
JEL codes:Q13, Q16

1. Introduction

Consumers are increasingly attentive to the food technologies used to develop, produce, process, and preserve foods (Lusk, Roosen, and Bieberstein 2014). While some food technologies (such as freezing, pasteurization, and chemical and biological preservatives) that have faced strong resistance by consumers are generally accepted today, others (such as food irradiation and genetic engineering) continue to experience significant and longstanding market resistance (Wunderlich and Gatto 2015; Yang and Hobbs 2020). Despite the scientific community having established that specific new technologies are safe and effective, many consumers exhibit aversion and mistrust and are said to perceive the technologies themselves or the foods they are used to produce as risky, unethical, or unnatural (Frewer 2003; Siegrist, Hartmann, and Keller 2013).

Genetic engineering is a prime example of a technology facing resistance in the marketplace. Genetic engineering is a laboratory-based process of altering an organism's DNA, in which a gene from one species may be introduced to an organism from a different species to produce a desired trait (Smith 2022). Several studies have assessed whether consumers are more prone to tolerate risks associated with new technologies if they perceive that the technologies bring them direct benefits rather than benefitting agricultural producers and input suppliers. In other words, consumers will less easily accept novel products or technologies that do not directly bring a tangible benefit to them (Frewer 2003; Lusk, Roosen, and Bieberstein 2014; Lusk, McFadden, and Rickard 2015).

Interest among scientists, policymakers, and industry in new plant breeding technologies extends beyond genetic engineering. This study centers on consumer acceptance of gene editing, specifically CRISPR-Cas9, where CRISPR stands for 'clustered regularly interspaced palindromic repeat' and Cas9 is a CRISPR associated protein (hereafter CRISPR). Gene editing enables scientists to manipulate DNA by removing, inserting, or replacing portions of the DNA of living organisms. But unlike genetic engineering, gene editing will not add a gene from one species to an organism from a different species to produce a desired trait. With gene editing, the manipulated DNA can be induced by four systems, of which CRISPR is one (Doudna and Charpentier 2014). CRISPR is simpler, faster, cheaper, and more accurate than older gene-editing methods; hence, many scientists who employ gene-editing tools now use CRISPR (Doudna and Charpentier 2014).

The feasibility of using gene editing in plant-breeding programs has shown abundant promise. Multiple gene-editing applications have been studied in the production of rice, tomato, maize, wheat, potato, soybean, citrus, and livestock, with a focus on influencing agronomic traits, food and feed quality, and biotic stress tolerance (Zhang et al. 2018; Menz et al. 2020).

The US regulations on the release and commercialization of gene-edited crops and animals are mixed and come from multiple agencies, suggesting that the nature and extent of regulations may vary on a case-by-case basis (Parrott 2022). The Environmental Protection Agency has shown an intention to regulate gene-edited plants that have a pesticidal property for pest resistance. The US Food and Drug Administration released the 'Plant and Animal Biotechnology Innovation Plan' to clarify its policies regarding food safety evaluations of foods containing ingredients from gene-edited crops (Entine et al. 2021). The US Department of Agriculture's Animal and Plant Health Inspection Service approved the release of gene-edited organisms without further regulation only if they do not pose any plant or animal pest risk; beyond this, gene-edited organisms are subject to regulatory status review (Entine et al. 2021). The US Department of Agriculture's Agricultural Marketing Service released the 'National Bioengineered Food Disclosure Standard,' stipulating that foods containing gene-edited ingredients would not be subject to disclosure requirements so long as those gene-edited ingredients do not contain novel DNA combinations that could not be created through conventional breeding or found in nature (Entine et al. 2021).

Conventional breeding and gene editing differ in the extent to which genetic innovation is controlled. Conventional breeding entails crossing existing varieties or the offspring of previous breeding programs that have the desired plant traits. This results in hundreds or thousands of potentially desirable plants that must be whittled down by selection to identify the best candidates for commercial use, with uncontrolled variation in multiple genes occurring all at once. Gene editing enables scientists to alter specific genes while holding other genes constant, without introducing genes from any other sources. Gene editing can target specific DNA sequences in the genome for slight modification, which can improve plant traits (VitisGen2 2018).

Given the exponential increase in the number of applications and the expectation that many gene-edited crops will soon be commercialized, it is important and timely to assess consumers' perceptions of this new plant-breeding technology. Considering consumers' significant rejection of genetically engineered crops, it is important to know whether consumers will take a similarly negative view of gene-edited crops or will come to perceive gene-editing as different from genetic engineering, allowing its products to be more widely accepted.

This study aims to assess the differences in willingness to pay (WTP) for selected fruit eating quality attributes of table grapes, described as being developed using either conventional breeding or CRISPR. Past studies concluded that consumers tend to perceive new plant breeding technologies more favorably if the benefits from using such technology are direct and tangible to consumers (Lusk, Roosen, and Bieberstein 2014). Therefore, our results contribute toward a better understanding of how preferences for consumer-oriented traits (in this instance, traits affecting eating quality attributes of fresh produce) vary according to the plant breeding technique used. In addition, our findings can help inform the phenotyping and genetics research community about consumer demand for specific traits in new table grape cultivars (VitisGen2 2018).

The rest of this article is organized as follows. Section 2 provides an overview of related literature. Section 3 discusses the design of the survey used to collect data for our study, and Section 4 describes research methods, including the empirical approach used in the article. We describe and discuss the results from the survey, the estimation of models, and their implications in Section 5. Section 6 concludes the article.

2. Literature review

Peripherical to the central research question on WTP for gene editing, in this study we asked survey respondents to identify the quality attributes of table grapes that are important for consumer acceptance; the importance of food labels to their decisions to purchase food and table grapes; how strongly they would trust different sources of information when making food purchase decisions; what they know about how new varieties are created; and their general perceptions of different plant breeding methods.

Some previous studies suggest that taste-related attributes such as sugar/acid ratio, acidity, and sweetness are positively correlated with consumer acceptance (Crisosto and Crisosto 2002; Jayasena and Cameron 2008). In general, there is evidence that taste- and texture-related attributes (taste, odor, and texture) are more important than appearance-related attributes (color and cleanliness) (Ma et al. 2016). However, the importance of particular bundles of quality attributes differed between green and red grape varieties: visual appearance and taste matter more for green grape varieties; texture (crunchiness) and flavor-related (intense berry aroma) for red grape varieties (Chironi et al. 2017). In this study, we focus on green table grapes.

None of the previous studies compared the importance of the bundle of label information (breeding technique-related, origin-related, or chemical application-related) for table grape purchase decisions. Food labels serve a role in informing consumers about different product features that may influence their purchases and the way food manufacturers and agribusinesses market products (Lim and Page 2022). Similarly, none of the previous studies evaluated the influence on their food purchasing decisions of consumers using different sources of information (social media and media, consumer-oriented groups, producer-oriented groups, government, universities, and scientific groups) to learn about technology and food safety.

A related point is relevant to our study: how attention paid by consumers to different sources of information related to their food purchase decisions might influence public acceptance of genetically engineered foods. The findings in previous studies are diverse. Distrust of the government as a regulatory institution was identified as a contributor to the negative perception of genetic engineering (Ishii and Araki 2016; Anders et al. 2021). While the US public may overall trust the scientific community (Pew Research Center 2022), poor communication from the scientific community about the risks and benefits of genetic engineering has deterred public acceptance of genetically modified foods (Ishii and Araki 2016). On the mass media's influence on the acceptance of genetic engineering, studies conclude that news coverage is not supportive of the application of biotechnology to agriculture (Walker and Malson 2020). Regarding the influence of social media, findings are mixed, suggesting that the influence varies among social media outlets (i.e. Twitter versus Facebook) and with the extent of public engagement in the discussions. A study in Japan found that Twitter posts about gene-edited food reflected an overall negative sentiment (Tabei et al. 2020), whereas a study in the USA suggested positive sentiments for using gene editing in agriculture. It should be noted that individuals in the US study were more engaged in the discussion (Hill et al. 2022). A study analyzing Facebook users' discussions of gene editing showed that this subset of the population perceived gene editing as a challenge to their religious faith and conflated it with genetic engineering (Walker and Malson 2020).

Regarding the influence of the general level of knowledge on public acceptance of gene editing or genetic engineering, there is evidence that limitations on knowledge contribute to a negative public perception of breeding technologies (Ishii and Araki 2016; Pew Research Center 2020; Yang and Hobbs 2020). Regarding perceptions of gene editing and genetic engineering, one study found that the US public considers genetically engineered foods unsafe to eat (Pew Research Center 2020); another, unnatural (Walker and Malson 2020).

Numerous studies have been published about consumers' WTP for genetically engineered crops. These studies showed that consumers are willing to pay price premiums to avoid foods that use ingredients from genetically engineered plants and animals (Lusk et al. 2005; Dannenberg 2009). Studies of acceptance of genetically engineered foods are less abundant for foods produced from fresh fruits compared to other crops; however, Costanigro and Lusk (2014) found that consumers were willing to pay a price premium to avoid genetically engineered apples. Relative to conventional forms of the same product, consumers applied a larger discount for genetically engineered fresh foods than for genetically engineered processed foods. They also required a larger discount for genetically engineered beef compared to genetically engineered corn and apples (Lusk, McFadden, and Rickard 2015). Another study found that the presence of 'genetically engineered' labels boosted the demand for unlabeled apples, strawberries, and potatoes, but the presence of the non-GE label did not exert a negative effect on the demand for the unlabeled foods (Yeh, Gomez, and Kaiser 2019).

Previous studies analyzing consumers' WTP for foods from gene-edited crops have found that individuals were willing to pay more for gene-edited foods than genetically engineered foods. However, consumers' WTP was lower for foods produced from both gene-edited and genetically engineered plants and animals than for foods from conventionally bred plants and animals. These findings applied to gene-edited canola oil (An, Lloyd-Smith, and Adamowicz 2019), rice (Shew et al. 2018), apples (Yang and Hobbs 2020; Marette, Disdier, and Beghin 2021), frozen French fries (Muringai, Fan, and Goddard 2020), and milk from gene-edited cows (Kilders and Caputo 2021).

Unlike the studies cited above, our research examines whether the breeding method used (conventional breeding versus gene editing) affects consumers' WTP for improvements in selected fruit quality attributes in table grapes. For example, are these improved attributes so valuable to consumers that they will be willing to pay more regardless of the breeding method? Or do negative consumer perceptions of the breeding methods overshadow the importance of specific attributes and thus varietal traits?

The contribution of this study is to provide some granularity to the evidence of how consumers value individual benefits that may result from different breeding technologies. The broader question that we seek to address is whether some consumers are willing to pay enough for specific attributes that were improved using non-conventional breeding technologies to more than outweigh any discounts they may require to accept the use of the new breeding methods.

3. Data collection

We chose to target table grape consumers in our study for three reasons. First, some evidence suggests consumers of fresh products (compared to highly processed products) are more thoughtful about the production methods used (Lusk, McFadden, and Rickard 2015). Second, table grapes are a very important fruit crop in the USA; table grapes are one of the few fruit crops that have experienced growth in consumer demand over the past four decades (U.S. Department of Agriculture-Economic Research Service 2019). Third, the production of table grapes in the USA is heavily concentrated in a relatively small geographical area with a significant amount of integration across firms in the industry, where new varietal technologies can often be adopted widely among producers. California produces over 95 per cent of the table grapes grown commercially in the USA (California Table Grape Commission 2022). In 2020, California's 122,000 bearing acres of table grapes produced 1.19 million tons of table grapes valued at 1.47 billion dollars at the farm gate (U.S. Department of Agriculture-National Agricultural Statistics Service 2021). Of all the types and varieties of table grapes, this study focuses on green table grapes.

Online choice experiments were administered to a nationwide sample of US consumers to collect information about how consumers value specific attributes in green table grapes. The data were collected online via the survey platform Qualtrics during April 2020. The IRB approval number for the survey was '*Not shown for review Name of the institution*' 18186-001. The researchers requested Qualtrics to recruit subjects who were at least 18 years old, were in charge of grocery shopping for the household, and had purchased table grapes in the past 3 months. Also, the selection criteria were designed to recruit a pool of subjects conforming to a reasonable representation of the US adult population in terms of age, household income, and geographical location. After incomplete responses were removed, the survey included responses from a total of 2,873 participants.

A between-subjects design was used to examine the effect of the breeding technique on respondents' WTP for table grape quality attributes. Two versions of the survey were developed, and they were distributed randomly among respondents, resulting in almost equal-sized samples for the two versions. Survey version 1 (with a focus on table grapes developed from a conventional breeding program) had 1,422 respondents, and survey version 2 (with a focus on table grapes developed using CRISPR) had 1,451 respondents. The only difference between the two survey versions was that, before being presented the discrete choice experiment questions, respondents were informed that the products they would evaluate were from one specific breeding technique for table grapes (either conventional breeding or CRISPR). Both versions of the survey presented a brief description of the two breeding technologies (Appendix A).

Each respondent was presented with eight scenarios, each of which was designed to mimic a grocery shopping experience and a decision whether to buy one pound of green table grapes as described in a specific offer. Before the scenarios were presented, the subjects were informed as to whether the table grape variety was developed by conventional breeding or CRISPR. A scenario consisted of purchase options for green table grapes, where each option presented a different, randomly assigned combination of price (1.98$/lb vs. 2.98$/lb) and quality attributes: fruit size (small vs. large), skin color (50 per cent amber/yellow blush vs. 100 per cent green), crispness (crisp vs. not crisp), sweetness (not sweet vs. sweet), and flavor (neutral vs. fruity). In each scenario, subjects were asked to select only one option from among three: they could choose option A, option B, or neither A nor B (which was labeled as option C in each scenario). Table 1 presents the list of attributes and the set of alternative possibilities for each attribute. An example of a choice scenario is presented

Table 1. List of attributes and options used in the discrete choice experiment.

Green table attributes and descriptions	Alternative possibilities available for each attribute	
Fruit size Size of one grape berry	Smaller than a dime (less than 3/4 inch)	Larger than a dime (more than 3/4 inch)
Uniform skin color Grape external color	100 per cent green color	Green background with 50 per cent amber/yellow blush color
Crispness Acoustic sensation detected by the ear during the fracturing of crisp foods	Crisp	Not crisp
Sweetness Taste-related attribute: Perception of sweet is similar to the perception of acid, bitter, or salt	Not sweet	Sweet
Overall flavor Non-taste related attribute fruity, neutral floral, honey, perfumed, and cotton candy	Fruity	Neutral
Price ($/lb)	1.98	2.98

in Fig. 1. The selected list of table grape quality attributes was based on previous sensory-related studies (Crisosto and Crisosto 2002; Jayasena and Cameron 2008; Ma et al. 2016; Chironi et al. 2017) and on consultations with table grape breeders and industry experts.

The JMP® software was used to generate a fractional factorial design with random combinations of attributes in each scenario. Including all possible combinations of attribute settings in a full factorial design would have yielded $2^6 = 64$ scenarios, and this would have been expected to create respondent fatigue and compromise the reliability of findings (Krosnick and Alwin 1987). Therefore, we opted for a fractional factorial design. The algorithm used by the software gives a design that minimizes the number of scenarios, resulting in eight, while ensuring orthogonality, balance, and a maximized D-efficiency.[1] We acknowledge that we did not include mitigation techniques for the hypothetical bias often associated with discrete-choice experiments. We base our decision on previous studies stating that discrete choice experiments do fairly well when predicting market shares, but the hypothetical bias does more damage when estimating responses to marginal changes in quality attributes (Louviere, Hensher, and Swait 2000; Lusk and Schroeder 2004).

In addition to the discrete-choice questions, respondents were asked about their table grape consumption, including consumption frequency, reasons for not consuming table grapes more often, preferred grape packaging, and color of grape most often bought. Respondents were also asked to rate the importance of different table grape attributes, including appearance (e.g. uniformity of the berry color, size of the berry, freedom from defects, color of the stem, uniformity of the size and shape of the berries, freshness, ripeness), taste and texture (e.g. thickness of berry skin, crispness, firmness, juiciness, unique flavor, aroma, tartness, sweetness), and phytonutrient content. The rating was measured on a 1–5 scale, where 1 = very unimportant and 5 = very important.

Other questions in the survey asked respondents to rate the importance of different food labels, including private brand, local origin, domestic product, name of the grape variety, seedless, organic, sustainable agriculture, non-GMO, eco-label, and pesticide-free. Here, the same 1–5 scale was also used, where 1 = very unimportant and 5 = very important.

Attributes	Option A 	Option B 	Option C
Fruit size Size of one grape berry	Smaller than a dime (less than ¾ inch) 	Smaller than a dime (less than ¾ inch) 	Neither option A nor option B
Skin color Grape external color	Green background with 50% amber/yellow blush color	Green background with 50% amber/yellow blush color	
Crispness Acoustic sensation detected by the ear during the fracturing of crisp foods	Crispy	Not crispy	
Sweetness Taste related attribute: Perception of sweet is similar to the perception of acid, bitter, or salt	Not sweet	Sweet	
Overall flavor Non-taste related attribute fruity, neutral floral, honey, perfumed, cotton candy	Fruity	Fruity	
Price ($/lb)	1.98	1.98	
	I would choose Option A ○	I would choose Option B ○	I would choose Option C ○

Figure 1. Example of a discrete choice scenario included in the survey.

Furthermore, respondents were asked to rate how trustworthy they considered different sources of information, including scientific groups such as medical professionals (e.g. your primary physician), scientific associations (e.g. American Association for the Advancement of Science), and scientific journals (e.g. Nature); producer-oriented groups such as individual farmers, farmer organizations (e.g. California Table Grape Commission), food manufacturers (e.g. Nestle, General Mills), and food retailers (e.g. Walmart, Safeway); local government (e.g. local mayor) and government agencies (e.g. US Department of Agriculture); consumer-oriented groups such as activist groups (e.g. Green America), consumer organizations (e.g. American Council of Consumers); and social media, media (e.g. newspaper, TV, magazines), family, and friends. The ratings were measured using a 1–5 scale, where 1 = strongly do not trust and 5 = strongly trust.

Respondents were also asked to rate the extent of their knowledge of two breeding technologies (genetic engineering and CRISPR) and the extent to which they perceived food to be safe to eat, natural, and ethically or morally acceptable, depending on whether it was produced using genetic engineering or CRISPR, and whether it was produced organically or conventionally. Finally, respondents were asked a series of questions about their sociodemographic details.

4. Conceptual framework and empirical approach

The conceptual framework stems from Lancaster's theory of demand, which postulates that consumers derive utility from the attributes inherent to the good rather than the good itself (Lancaster 1966), and random utility theory, which represents the utility derived by the consumer when consuming a good as comprising a deterministic component, reflecting the good's attributes, and a random component, reflecting the effects of unobserved factors (McFadden 1974).

The standard econometric model used to estimate WTP in preference space is the mixed logit model. This model assumes that the non-price parameters are normally or log-normally distributed, while the price parameter is fixed. Under this assumption, WTP can be estimated by dividing the non-price parameter by the price parameter, assuming a fixed price implies that consumers have homogeneous preferences for price. We use the Generalized Multinomial Logit (G-MNL) model proposed by Fiebig et al. (2010) that yields parameter estimates in WTP space. The G-MNL model allows for 'scale' heterogeneity, which allows the scale of the idiosyncratic error term to vary among consumers. In other words, the choice behavior is more random for some consumers compared to others, as the scale of the error term is inversely related to the error variance (Fiebig et al. 2010).

The G-MNL model extends the mixed logit model with the following specification:

$$U_{njt} = [\sigma_n\beta + \gamma\eta_n + (1-\gamma)\,\sigma_n\eta_n]x_{njt} + \varepsilon_{njt}, \tag{1}$$

where U_{njt} is the utility derived by individual n from choosing alternative j in choice scenario t, σ_n is the scale heterogeneity for each individual n, β is a vector of mean attribute utility weights, γ is a scale parameter between 0 and 1, η_n is the vector of n-specific deviations from the mean, x_{njt} is the vector of observed attributes, and ε_{njt} is the idiosyncratic error term, the observations of which follow an independent and identical extreme value distribution. The variable σ_n is given by

$$\sigma_n = exp\,(\bar{\sigma} + \theta z_n + \tau v_n)\,, \tag{2}$$

where z_n is a vector of characteristics associated with individual n and v_n follows a standard normal distribution (0,1); $\bar{\sigma}$ is a normalizing constant such that σ_n is equal to 1 when $\theta = 0$.

The G-MNL model gives the probability of respondent i choosing alternative j in choice scenario t as

$$\Pr\,\left(choic\,e_{it} = j|\beta_i\right) = \frac{e^{\beta_i' x_{itj}}}{\sum_{K=1}^{J} e^{\beta_i' x_{itj}}}\,, \tag{3}$$

$$\text{for } i = 1,\ldots,N;\, t = 1,\ldots,T;\, j = 1,\ldots,J$$

where x_{itj} is a vector of observed attributes of alternative j and β_i is a vector of individual-i-specific parameters, which are defined as follows:

$$\beta_i = \sigma_i\,\beta + \{\gamma + \sigma_i\,(1-\gamma)\}\,\eta_i. \tag{4}$$

Here, β_i depends on a constant vector β, a scalar parameter γ, a random vector η_i distributed with multivariate normal distribution (MVN $(0,\ \Sigma)$), and the individual-specific scale of the error, σ_i (Fiebig et al. 2010). We report the results from GMNL model Type I (or GMNL-I), which assumes $\gamma = 1$, such that the standard deviation of taste heterogeneity is proportional to the scale parameter.[2]

Vector x_{njt} is represented by the table grape quality attributes of sweetness, crispness, skin color, flavor, and fruit size, as well as the price associated with each alternative and the alternative specific constant. The regression was conducted using the combined dataset of observations from survey version 1 and survey version 2.

To assess the effect of the plant breeding technique on consumers' preferences and WTP for each fruit quality attribute, we include variables to represent the interaction of the effects of fruit quality attributes and those of the plant-breeding technique. Here, the plant-breeding technique is represented by an indicator variable, equal to 1 for conventional breeding and 0 for gene editing. The variable representing the interaction effect was created by multiplying the plant-breeding indicator variable with the measures of each quality attribute, price, and the alternative specific constant.

To compare WTP for the quality attributes between the two breeding methods, bootstrap vectors of estimated WTP for each attribute were calculated for each breeding method. Next, a *t*-test was used to test whether WTP differs depending on the breeding technique used. The aggregated premium in the WTP for one pound of green table grapes, produced using conventional breeding versus CRISPR, was also estimated using the bootstrapped WTP estimates for each quality attribute and price ($2.98/lb was used as a reference price).

4.1. Latent class model

The latent class model captures consumers' heterogeneity in their choices and identifies classes (or groups) within the sample of survey respondents. Preferences across groups are heterogeneous, but preferences within each group are assumed to be homogeneous (Greene and Hensher 2003). Mathematically, the probability that individual n will choose alternative i in choice scenario j for a latent group c is

$$\Pr\left(nij|c\right) = \frac{\prod_{j=1}^{J} e^{\beta_c x_{nij}}}{\sum_{i=1}^{I} e^{\beta_c x_{nij}}}, \quad (5)$$

where x_{nij} is the vector of observed attributes associated with alternative i, β_c is the coefficient estimate for the group-specific utility (parameter vector), which captures preference heterogeneity among groups, and j is the choice scenarios available to individual n. A fractional multinomial logit model is used to estimate the probability that individual n belongs to group c:

$$\Pr\left(c\right) = \frac{e^{\theta_c m_n}}{1 + \sum_{c=1}^{C-1} e^{\theta_c m_n}}, \quad (6)$$

where m_n is the set of observable individual characteristics that affect the group membership vector θ_c, (c^{th} parameter vector is normalized to zero to ensure identification of the model). In our choice experiment, each respondent was asked to make choices for eight different scenarios. The observation of repeated choices by the respondents helps us to examine how changes in particular attributes affect individual utility and a comparison across scenarios with a priori expectations (Greene and Hensher 2003).

To identify the number of groups, we use the following criteria: measures of goodness of it, interpretability of results, and classification diagnosis (Nylund-Gibson and Choi 2018). The commonly used measures of fit, the AIC and BIC, are presented in Table 2 (where lower values for AIC and BIC indicate a superior fit). The BIC decreases between models with four and five classes, and the prediction accuracy is higher for four rather than five classes. Therefore, we opted for four groups, or latent classes, in both sub-samples of respondents.

5. Results and discussion

This section presents the results from the statistical analysis of the survey responses. Before discussing the results of the choice experiments, we present descriptive statistics for the

Table 2. Goodness-of-fit criteria used to select the number of groups in the latent class model.

Classes	Parameters	Likelihood function	AIC	BIC	Prediction accuracy
		Conventional breeding survey version			
2	37	−11,064.14	22,202.27	22,396.89	0.953
3	67	−10,898.25	21,930.5	22,282.91	0.895
4	97	−10,565.75	21,325.51	21,835.71	0.912
5	127	−10,486.47	21,226.94	21,894.94	0.887
		Gene editing survey version			
2	37	−11,189.26	22,452.53	22,647.89	0.966
3	67	−10,753.41	21,640.83	21,994.59	0.956
4	97	−10,597.75	21,389.5	21,901.66	0.901
5	127	−10,532.91	21,319.82	21,990.38	0.895

sociodemographic characteristics of the survey respondents. Here we see that the two groups of respondents were similar and reasonably representative of the broader US population.

5.1. Sociodemographic characteristics of respondents

Table 3 presents the sociodemographic characteristics of the survey respondents and compares them with the corresponding information from the US Census data (U.S. Census Bureau 2018). Overall, across both survey versions, 59 per cent of the respondents in the sample are female; the average age of the respondents is 42 years; the average household size is three individuals; and on average, respondents have less than one child that is 18 years old or less; 75 per cent of the respondents are of white ethnicity; 30 per cent have obtained a 4-year college degree; the average annual household income is $99,922; 18 per cent of the respondents live in a rural area (the three options were rural, urban, and suburban areas); 17 per cent are vegetarian; and 26 per cent of the respondents have worked or lived on a farm or ranch. Some non-negligible differences in demographic characteristics were observed between the samples of respondents to the two versions of the survey: compared to the respondents to the gene-editing version of the survey, the respondents to the conventional breeding version had a larger percentage of households with children under 18, a larger percentage of vegetarian respondents, and a larger percentage of respondents who worked/lived on a farm or ranch (Table 3). While these differences are worth noting, we argue that they do not impact the findings and conclusions. We used a pairwise *t*-test comparison between the two samples of respondents to analyze the differences in the key questions in this study, such as level of knowledge and perception of breeding methods, and did not find statistically significant differences between the two samples.

Compared with the 2018 US Census averages, our sample includes larger proportions of individuals who are female, white, and have at least a 4-year college degree; and the survey respondents on average have higher income (U.S. Census Bureau 2018). However, our survey respondents follow the profile of individuals who tend to be more responsive to surveys (Curtin, Presser, and Singer 2000).

5.2. Respondents' shopping and eating habits

The survey asked about the frequency distribution of the respondents' grape purchasing habits (see results in Fig. 2). The average annual purchase frequency was nine for the respondents in our sample. Given that the average quantity of table grapes they bought per grocery shopping trip is 2.65 lb and that the average number of individuals per household is 2.9 members, the estimated average per capita consumption of table grapes in our sample is 8.6 lb per year. Considering that the per capita consumption of fresh grapes in 2019

Table 3. Demographic characteristics of survey respondents compared to US Census, categorical variables.

Demographic characteristics	Unit	Survey version 1 (*N* = 1,422)	Survey version 2 (*N* = 1,451)	Survey sample (*N* = 2,873)	Difference between survey 1 and survey 2 (Chi-square/ *t*-test *P* value)	US Census 2018
Female	per cent	59.3	58.1	58.7	0.519[a]	50.8
Age	Year	42.2 (15.9)[4]	42.5 (15.9)	42.4 (15.9)	0.695[b]	38.2
Race						
White/Caucasian, European-American	per cent	76.6	74.1	75.4	0.414[a]	75.5
Asian, Asian-American		7.6	8.8	8.2		5.4
Black, African American		7.8	7.7	7.7		14.0
Hispanic or Latino-American		6.2	6.8	6.5		17.8
American Indian or Alaskan Native		0.7	1.2	1.0		1.7
Middle Eastern, Middle Eastern-American		0.4	0.7	0.6		—
Pacific Islander		0.3	0.1	0.2		0.4
Other (Mixed, Spain, Greek, etc.)		0.4	0.6	0.5		—
Education						
4-year degree	per cent	30.7	28.4	29.5	0.385[a]	19.4
Postgraduate degree		22.4	25.0	23.7		12.1
Some college		15.6	15.3	15.5		20.6
High school graduate		15.6	15.1	15.4		27.1
2-year degree		8.4	9.7	9.1		4.2
Professional degree		5.8	5.3	5.6		4.2
Less than high school		1.5	1.2	1.3		12.4
Other (certificate, dropped out)		0.0	0.1	0.1		—
Income distribution						
Less than $25,000	per cent	8.1	9.2	8.6	0.002[a]	20.2
$25,000–$34,999		8.4	4.9	6.6		9.3
$35,000–$49,999		4.9	6.6	5.7		12.6
$50,000–$74,999		18.4	19.9	19.1		17.5
$75,000–$99,999		15.2	15.0	15.1		12.5
$100,000–$149,999		20.7	21.5	21.1		14.6
$150,000–$199,999		9.3	10.7	10.0		6.3
More than $200,000		10.1	8.6	9.4		7.0
Prefer not to answer		4.9	3.8	4.3		—
Household annual income	$	100,175 (62,482)	99,618 (60,694)	99,922 (61,543)	0.813[b]	63,179
Region						
Northeast	per cent	26.0	26.4	26.2	0.310[a]	17.4
Midwest		18.9	18.5	18.7		21.1
South		31.4	33.9	32.7		37.9
West		23.8	21.2	22.5		23.7
Individuals per household	Count	2.9 (1.3)	2.9 (1.3)	2.9 (1.3)	0.411[b]	2.6
Households with children under 18	per cent	49.4	46.1	47.7	0.080[a]	41.5

Table 3. Continued.

Demographic characteristics	Unit	Survey version 1 ($N = 1,422$)	Survey version 2 ($N = 1,451$)	Survey sample ($N = 2,873$)	Difference between survey 1 and survey 2 (Chi-square/ t-test P value)	US Census 2018
Children under 18 per household	Count	0.8 (1.0)	0.8 (1.0)	0.8 (1.0)	0.489[b]	
Vegetarian	per cent	19.5	14.3	16.9	0.000[a]	–
Worked/lived in a farm or ranch	per cent	28.1	24.0	26.0	0.011[a]	–

[a] P-value of the chi-square test to measure the difference between the distribution of a set of discrete variables.
[b] P-value of the t-test to measure the difference between the distribution of two continuous variables.
Source: U.S. Census Bureau (2018). American Community Survey. Retrieved from https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/2018/.
Note: The value in parenthesis is the standard deviation.

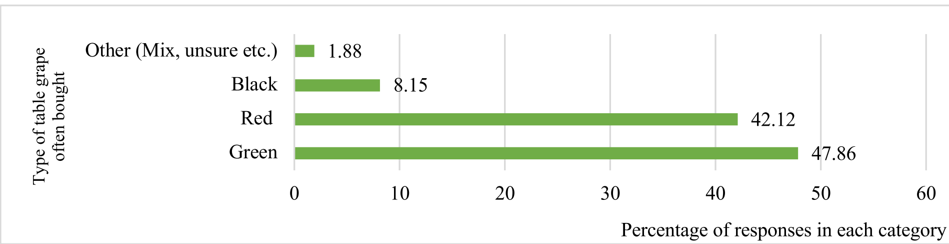

Figure 2. Frequency distribution of respondents describing table grape purchases ($N = 2,873$).

was 7.7 lb per person per year (U.S. Department of Agriculture-Economic Research Service 2021b), the respondents in our sample consume more grapes than the national average. Based on the responses from the survey, the top three reasons for not buying table grapes more often than other fruits were: prefer other fruit, too expensive, and availability/access to table grapes. Overall, 59 per cent of the respondents said they preferred pre-bagged table grapes (across the packaging options), while 48 per cent indicated that their favorite type of table grape is green (across the options of green, red, and black). Purchase frequency details are shown in Fig. 2.

5.3. Respondents' preferences for different attributes of table grapes

Respondents were asked to rate selected table grape attributes on a scale of 1–5: 1 = very unimportant and 5 = very important in terms of their importance to them when making decisions about buying grapes. The full set of results is shown in Fig. 3. The attributes with the highest rating scores were freshness (4.53) and ripeness (4.33) of the fruit. The second tier of the most important attributes includes those that directly relate to the eating experience and appearance, and these include juiciness (4.31), freedom from external defects (4.27), firmness (4.23), sweetness (4.18), and crispness (4.16). The next tier of important attributes includes seedlessness (4.16), uniform and attractive skin color (3.9), green-colored stems (3.83), phytonutrient content (3.79), fruit berry size (3.71), uniform size and shape of berries (3.61), and thickness of the berry skin (3.58). The least important considerations for the subjects in our sample included sensory attributes such as aroma (3.5), tartness (3.45), and unique flavor (3.32). These results align with previous findings showing that eating experience and appearance-related attributes are relatively highly ranked by consumers

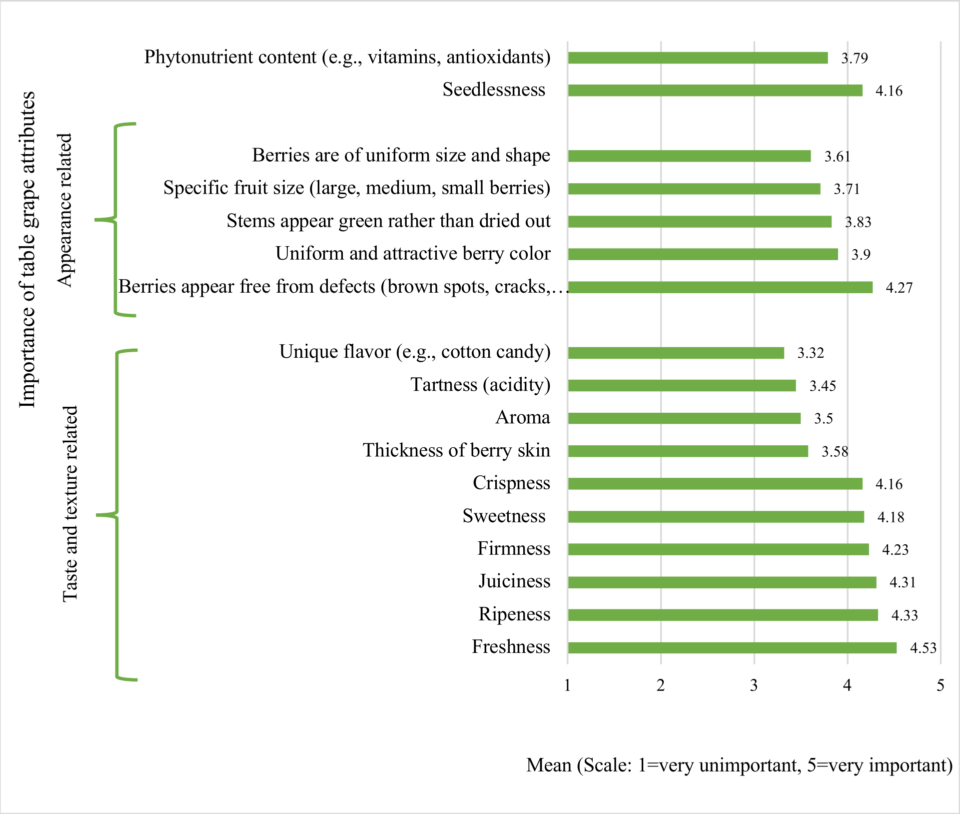

Figure 3. Ratings of importance of table grape attributes.

(Crisosto and Crisosto 2002; Jayasena and Cameron 2008; Ma et al. 2016; Chironi et al. 2017). In addition, some previous work also found that attributes related to the freshness and ripeness of fruit are highly important to consumers.

5.4. Respondents' attitudes to food labels

The survey asked respondents to rate the importance of information displayed on labels when making food purchase decisions on a scale of 1–5: 1 = very unimportant and 5 = very important. The results are highlighted in Fig. 4. The most important label information for survey respondents was 'seedless' (4.05). This is interesting because most fresh grape varieties offered in the USA are already seedless, yet respondents consider this trait to be the most important information presented on labels. 'Pesticide-free' (3.81) is the second-most important piece of information presented on a label. Being pesticidefree is particularly relevant for fresh grapes, as they have edible skin. Interestingly, 'organic' (3.27) was rated below 'pesticide-free' in importance, suggesting that respondents to this survey might not realize that 'organic' effectively encompasses 'pesticide-free'. Origin of the fruit (local origin, 3.32; domestic product, 3.52) is also an important label for the subjects in our survey. The USA is the world's largest importer of fresh grapes, mostly from Mexico, Chile, and Peru (U.S. Department of Agriculture-Economic Research Service 2021a), and mainly during the winter months when there is no US table grape production. Fairly low ratings of importance were given for 'non-GMO' labels (3.44) and labels describing environmentally friendly (eco-label, 3.36) production practices. The name of the grape variety (3.16) and the

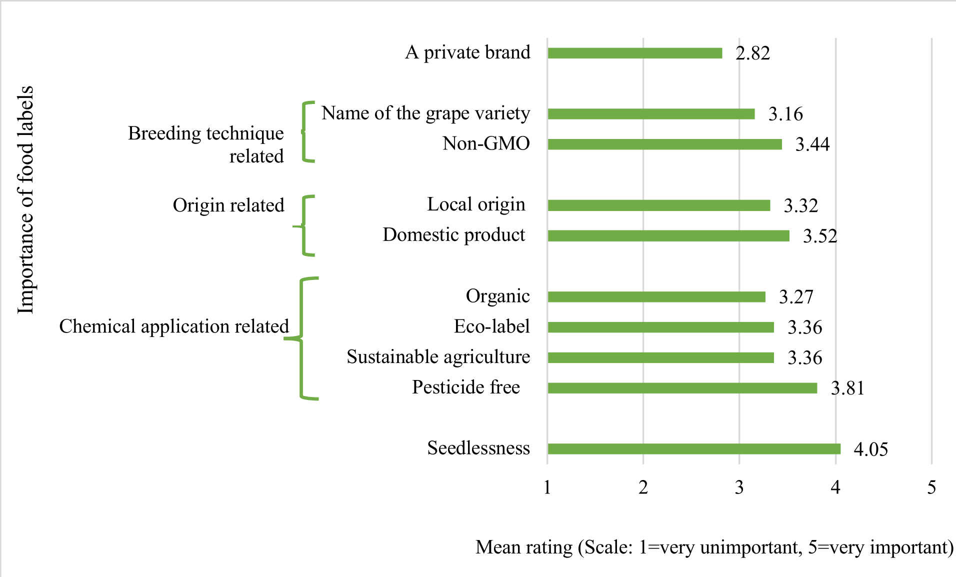

Figure 4. Ratings of importance of table grape food labels.

name of the private brand (2.82) were the least important types of label information to our subjects.

5.5. Respondents' trust in different information sources

The survey also included questions asking respondents to rate how strongly they trust different sources of information when making food purchase decisions on a scale of 1–5: 1 = very unimportant and 5 = very important (Fig. 5). Respondents assigned the highest ratings of importance to scientific groups (3.88). Similar results were found in a nationwide US survey conducted by the PEW Research Center, with respondents selecting medical professionals and scientists as the group most likely to act in the public's best interests, over military, police officers, public school principals, religious leaders, journalists, business leaders, and elected officials (Pew Research Center 2022). The next highest-ranked sources of trustworthy information were universities (3.72), then producer-oriented groups (3.71), followed by government-related institutions (3.51), and consumer-oriented groups and organizations (3.48). The lowest-ranked sources of trusted information were social media, family, and friends (3.3).

5.6. Respondents' knowledge about and perception of plant breeding technologies

The final section of our survey included questions asking respondents about their knowledge of plant breeding technologies on a scale of 1–5: 1 = completely uninformed and 5 = completely informed. Results are presented in Fig. 6. Respondents claimed to be most informed about genetic engineering technologies (3.25), with scores higher than conventional breeding (3.22) and CRISPR (3.02). When asked if they thought genetic engineering and CRISPR were different, 58 per cent of respondents indicated there was a difference, 27 per cent of them thought these two were different, but they did not know what the difference was, and 15 per cent thought there was no difference between these two breeding methods. Given 58 per cent of respondents indicated that genetic engineering and CRISPR were different

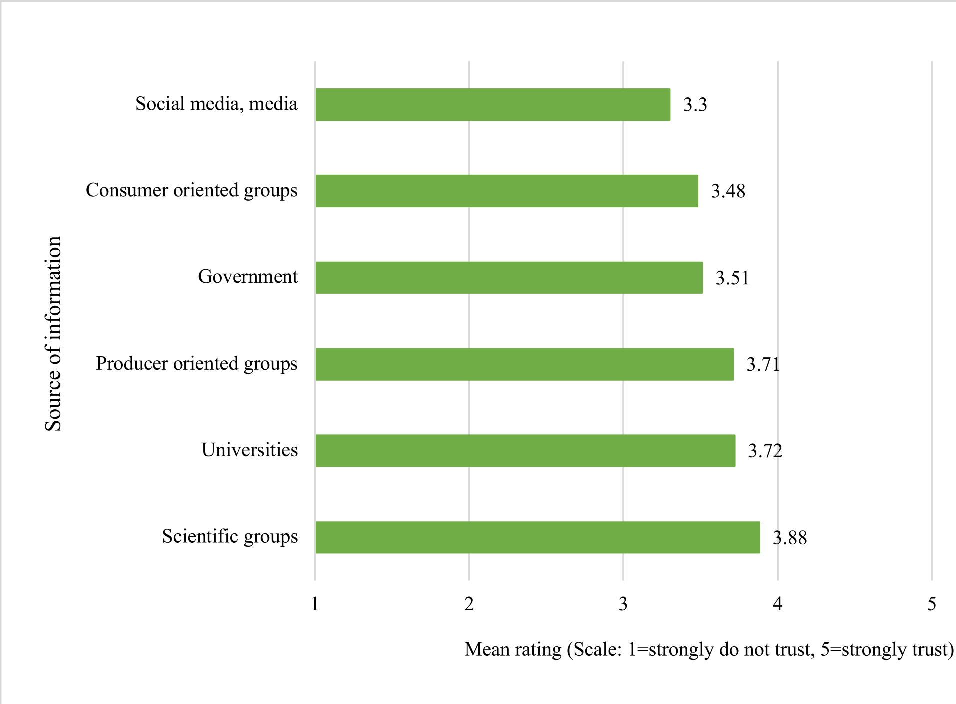

Figure 5. Rating of trust for sources of information. *Note*: Scientific groups include medical professionals (e.g. your primary physician), scientific associations (e.g. American Association for the Advancement of Science), scientific journals (e.g. Nature, Science). Producer-oriented groups include individual farmers, farmer's organizations (e.g. California Table Grape Commission), food manufacturers (e.g. Nestle, General Mills, food retailers (e.g. Walmart, Safeway). Government includes local government (e.g. local mayor), and government agencies (e.g. US Department of Agriculture). Consumer-oriented groups include activist groups (e.g. Green America) and consumer organization (e.g. American Council of Consumers). Social, media, family, and friends include newspaper, TV, magazines, friends, and family members.

shows that this sample of individuals is reasonably knowledgeable about breeding methods, and therefore may be more receptive to new breeding technologies than the less knowledgeable general population (Ishii and Araki 2016; Pew Research Center 2020; Yang and Hobbs, 2020). Respondents were asked to rate their perceptions about how safe, natural, ethical, and morally acceptable they considered various plant breeding technologies. Here, organic farming received the highest scores for safety and being natural, ethical, and morally acceptable, followed by conventional breeding, CRISPR, and genetic engineering. This is consistent with findings that the US public considers genetically engineered foods unsafe to eat (Pew Research Center 2020) and unnatural (Walker and Malson 2020).

5.7. G-MNL results

We estimated the G-MNL regression using the pooled sample, and the results are presented in Table 4. The estimated coefficients are interpreted directly as the premium that consumers are willing to pay for each of the quality attributes. As such, the estimated coefficient on price with CRISPR is negative and statistically significant, indicating that the utility of respondents decreases as price increases. The coefficient estimates with CRISPR for the other attributes—sweet versus not sweet, crisp versus not crisp, 100 per cent green (uniform skin color) versus 50 per cent amber fruit color (non-uniform skin color), and fruity flavor

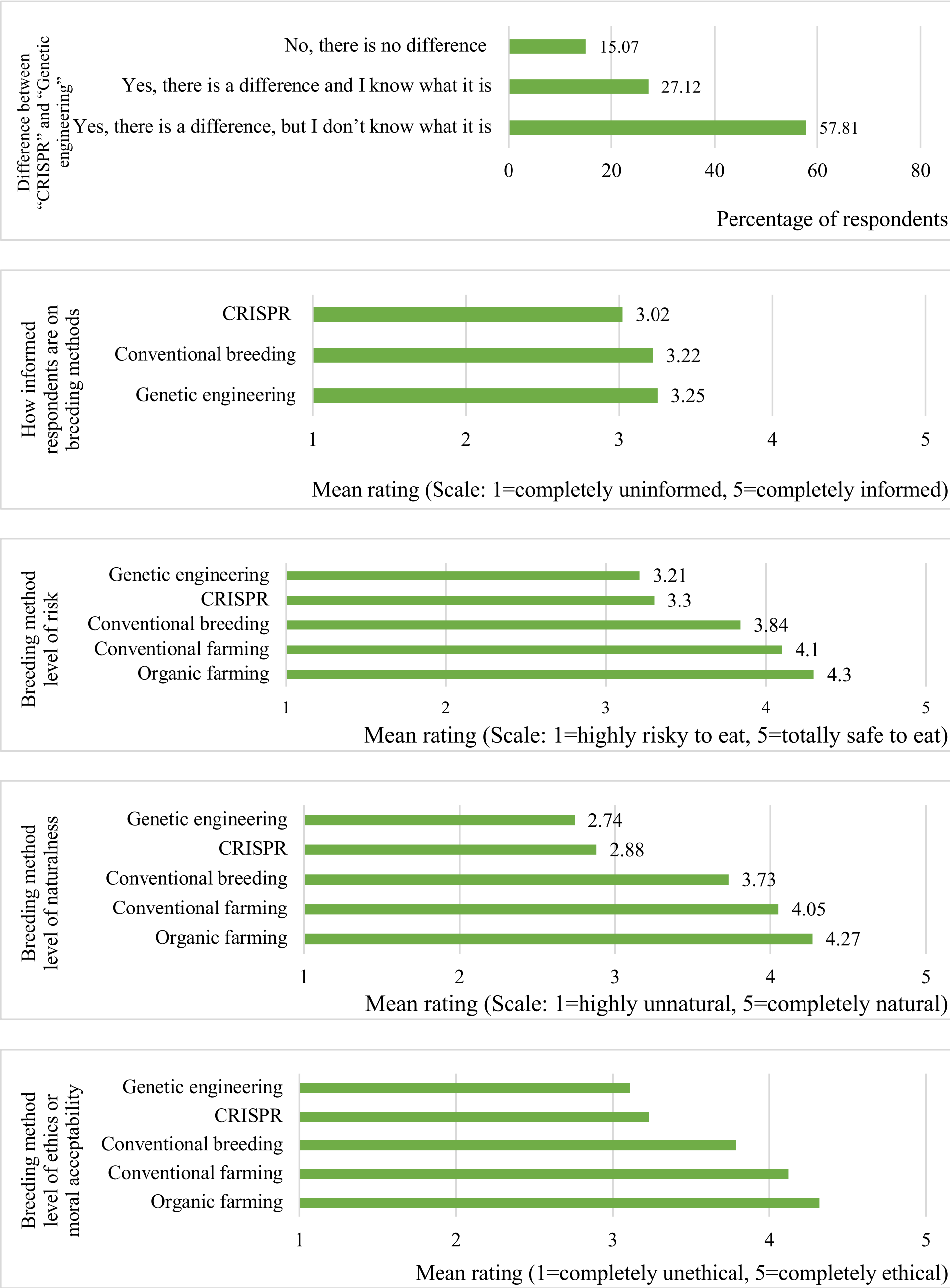

Figure 6. Respondents' perceptions on production methods and breeding methods.

versus neutral flavor—are all positive and statistically significant, indicating that respondents derive greater utility when table grapes are sweet, crisp, 100 per cent green, and display a fruity flavor. The coefficient for fruit size is not statistically significant. These results are consistent with those from previous studies showing that consumers prefer table grapes that are flavorful, sweet, and crisp (Crisosto and Crisosto 2002; Jayasena and Cameron 2008;

Table 4. Coefficient estimates for the generalized multinomial logit model, for selected table grape quality attributes, and considering two different breeding methods.

Variable	Mean	Standard deviation
Price	–1.57*** (0.41)	
Sweetness (Sweet vs. not sweet)	3.06*** (0.57)	0.25*** (0.09)
Crispness (Crisp vs. not crisp)	2.61*** (0.55)	0.45*** (0.05)
Uniform skin color (100 per cent green vs. 50 per cent amber)	1.59*** (0.41)	0.07 (0.14)
Flavor (Fruity vs. neutral)	0.61** (0.26)	0.04 (0.17)
Size (Larger vs. smaller than a dime)	0.33 (0.25)	0.08 (0.11)
Alternative specific constant-none option	0.37 (0.38)	1.97 (0.05)
Price × conventional breeding	–0.15 (0.38)	
Sweetness × conventional breeding (Sweet vs. not sweet)	0.15 (0.51)	0.02 (0.15)
Crispness × conventional breeding (Crisp vs. not crisp)	0.30 (0.49)	0.02 (0.19)
Uniform skin color × conventional breeding (100 per cent green vs. 50 per cent amber)	0.21 (0.38)	0.02 (0.15)
Flavor × conventional breeding (Fruity vs. neutral)	–0.18 (0.39)	0.16 (0.16)
Size × conventional breeding (Larger vs. smaller than a dime)	–0.09 (0.38)	0.10 (0.13)
Alternative specific constant-none option × conventional breeding	–0.22 (0.53)	0.04 (0.17)
Scale heterogeneity variance (τ)	3.16*** (0.22)	

Notes: Standard errors in parentheses. *, **, *** indicate statistical significance at the 10 per cent, 5 per cent, and 1 per cent level.

Ma et al. 2016; Chironi et al. 2017). The coefficient on the interaction of price with the indicator variable for conventional breeding is not statistically significant; likewise, the interaction terms for the various fruit quality attributes and the indicator variable for conventional breeding are all not statistically significant.

The estimates for the alternative specific constants (ASC) representing the no-purchase options for both CRISPR and conventional breeding are not statistically significant. This result implies that the share of subjects selecting 'none' is not significantly different from the share of subjects that select one of the options with attributes listed. Overall, we feel this is a reasonable outcome, as subjects do not necessarily buy grapes every time they have the option to buy them (i.e. they do not always buy grapes on every trip to the grocery store). Furthermore, the estimated standard deviations are statistically significant for sweetness and crispness, indicating heterogeneity of preferences among respondents for these quality attributes. The variance of the scale heterogeneity measure (τ) is positive and statistically significant, indicating substantial heterogeneity among respondents.

Table 5. Bootstrapped WTP estimates and confidence intervals for selected table grape attributes.

Variable	WTP estimates ($/lb)		$WTP_{conventional\ breeding} - WTP_{CRISPR}$ ($/lb)	
	Conventional breeding	CRISPR	Difference	*t*-value
Sweetness (Sweet vs. not sweet)	3.20 [1.81, 4.60]	3.06 [1.94, 4.18]	0.15	0.16
Crispness (Crisp vs. not crisp)	2.91 [1.53, 4.28]	2.61 [1.53, 3.68]	0.30	0.34
Uniform skin color (100 per cent green vs. 50 per cent amber)	1.79 [0.81, 2.78]	1.59 [0.79, 2.39]	0.21	0.32
Flavor (Fruity vs. neutral)	0.44 [−0.13, 1.00]	0.61 [0.11, 1.12]	−0.18	−0.46
Size (Larger vs. smaller than a dime)	0.25 [−0.32, 0.81]	0.33 [−0.17, 0.83]	−0.09	−0.23
Aggregated table grape	2.88 [2.10, 3.66]	2.75 [2.12, 3.39]	0.13	0.25

Note: *t*-statistics of the difference in WTP for different table grape attributes under conventional breeding and CRISPR. 95 per cent confidence intervals are shown in brackets.

To compare the WTP for grape attributes across the two breeding methods, estimates of individual WTP for each respondent were bootstrapped (Table 5). Regardless of the breeding method for table grapes, attribute by attribute, consumers are willing to pay the largest price premium for sweetness, followed by crispness, uniform skin color (recall that this study only considered green grape varieties), fruity flavor, and larger berry size (compared to the reference point of 3/4 inch diameter). The bootstrapped means were compared using a *t*-test, and the *t*-test results shown in Table 5 suggest that WTP values are not statistically significantly different between the two breeding methods at the 1 per cent level of significance for each of the attributes.

The WTP estimates aggregated across all selected quality attributes are also presented in Table 5. The point estimates suggest that consumers are willing to pay a slightly higher price for green table grapes developed using conventional breeding rather than CRISPR ($2.88/lb vs. $2.75/lb), but this difference is not statistically significant. This finding is aligned with results from previous studies (Shew et al. 2018; An et al. 2019; Muringai, Fan, and Goddard 2020; Yang and Hobbs 2020; Marette, Disdier, and Beghin 2021) that found a price discount for crops developed using gene editing compared to conventional breeding. Our findings suggest no significant differences in WTP between the two breeding methods. However, this may be because of the hypothetical nature of the study and the relatively small sample size.

5.8. Latent class results

In the latent class model, the sample of respondents was divided into two sub-samples. The first sub-sample included respondents who were informed that the green table grapes were bred by conventional breeding, and the second sub-sample included respondents who were informed that table grapes were bred by CRISPR. Parameter estimates obtained from the latent class model for both survey versions are presented in Table 6. In each of the two survey sub-samples, four latent class groups of consumers were identified based on their sensitivity to price. Respondents from groups 1 to 4 vary in their sensitivity to price, group

Table 6. Parameter estimates for the latent class model to represent heterogeneity of preferences for table grape attributes produced using conventional breeding and CRISPR.

Variable	Latent class model parameter estimates							
	Respondents who received the survey version considering conventional breeding $N = 1,422$				Respondents who received the survey version considering CRISPR $N = 1,451$			
	Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4
Number of respondents in each group	299	640	313	171	609	334	189	319
Share of respondents in each group (per cent)	21	45	22	12	42	23	13	22
Sweetness	0.63***	0.03	3.48***	1.78***	0.06	0.57***	0.99***	3.52***
(Not sweet vs. sweet)	(0.10)	(0.05)	(0.28)	(0.23)	(0.06)	(0.09)	(0.27)	(0.20)
Crispness	0.44***	0.17***	2.84***	1.17***	0.04	0.28***	1.55***	2.61***
(Not crisp vs. crisp)	(0.11)	(0.06)	(0.26)	(0.21)	(0.06)	(0.10)	(0.29)	(0.18)
Uniform skin color	0.31***	0.06	1.30***	0.83***	0.14***	0.28***	0.85***	1.13***
(50 per cent amber vs. 100 per cent green)	(0.07)	(0.05)	(0.14)	(0.21)	(0.05)	(0.07)	(0.25)	(0.13)
Flavor	1.22***	0.09	1.88***	0.83***	–0.01	0.59***	0.59**	1.22***
(Neutral vs. fruity)	(0.25)	(0.06)	(0.33)	(0.23)	(0.07)	(0.22)	(0.25)	(0.23)
Size	1.04***	–0.01	1.13***	0.44**	0.03	0.38**	0.98***	0.16
(Smaller vs. larger than a dime)	(0.21)	(0.06)	(0.33)	(0.21)	(0.06)	(0.18)	(0.24)	(0.22)
Price	–0.16**	–0.24***	–1.14***	–2.15***	–0.09*	–0.22***	–1.04**	–1.56***
	(0.07)	(0.05)	(0.13)	(0.29)	(0.05)	(0.07)	(0.31)	(0.14)
Alternative specific constant-none option	–12.03	–0.89***	3.06***	0.17	–0.41***	–3.13***	3.39***	1.15***
	(103.60)[a]	(0.13)	(0.51)	(0.52)	(0.52)	(0.61)	(0.59)	(0.35)

[a] We have run multiple checks to investigate the magnitude of the standard error of the none option for this group of respondents. The large standard error is most likely due to the fact that no one chose option C in this group in any of the choice scenarios. Classes were defined based on the various 'membership' variables and not based on their choices. While there was enough variability in the choices in the other groups.

Notes: Standard errors in parentheses. *, **, *** indicate statistical significance at the 10 per cent, 5 per cent, and 1 per cent level.

1 being the least sensitive and group 4 being the most sensitive. We refer to these groups in these terms: group 1 is *least* price sensitive, group 2 is *least-to-moderately* price sensitive, group 3 is *moderately-to-highly* price sensitive, and group 4 is *highly* price sensitive.

The demographic descriptions of the four different groups of respondents in each of the latent class models are included in Tables 7 and 8. Table 7 refers to those groups among respondents who were informed that the grapes were bred by conventional breeding (hereafter conventional breeding version), and Table 8 refers to those groups among respondents who were informed that the grapes were bred by CRISPR (hereafter CRISPR version). The demographic characteristic for the least price-sensitive group (group 1) in both survey versions, includes a larger percentage of males compared to all other groups (Tables 7 and 8).

In both survey versions, compared with other groups of respondents, the least price-sensitive group reported the highest ratings of trust for all sources of information included: scientific groups, producer-oriented groups, universities, government, consumer-oriented groups, and finally social media, media, friends, and family members (Tables 7 and 8). Also, for both survey versions, the least price-sensitive group scored the highest on the respondents' self-assessed level of knowledge of both genetic engineering and CRISPR, and the least-to-moderately price-sensitive group scored the second highest. There was a significant difference in the self-assessed level of knowledge between the least-to-moderately and moderately-to-highly price-sensitive groups. However, there were no significant differences in the self-assessed level of knowledge between the moderately-to-highly and the highly price-sensitive groups. Further, in both survey versions, compared more highly price-sensitive groups the least and least-to-moderately price-sensitive groups assigned higher ratings to CRISPR and genetic engineering for those methods being safe, natural, ethical, and morally acceptable.

6. Conclusion

Public acceptance of new plant-breeding technologies will be important for future global food security, especially in the least food-secure countries (Nes, Schaefer, and Scheitrum 2022). Our research estimated consumers' WTP for fruit quality attributes of green table grapes produced using either conventional breeding or CRISPR. Utilizing a US nationwide online survey of 2,873 consumers, we find that respondents prefer table grapes that are sweeter (compared to not sweet), crisp (compared to not crisp), with fruity flavor (compared to a neutral flavor), larger berries (larger than 3/4 inch compared to smaller than 3/4 inch), and more uniform skin color (100 per cent green compared to 50 per cent green and 50 per cent amber/yellow blush for green table grape varieties).

Our findings suggest that survey respondents ranked the green table grape quality attributes (sweet, crisp, flavor, size, and skin color) included in this study in the same order of importance for the two breeding methods: conventional breeding and gene editing. Moreover, we did not find a significant difference in the WTP for any of the quality attributes between the two breeding methods. While, on average, respondents in our sample were willing to pay slightly less for table grapes developed by gene editing ($2.75/lb vs. $2.88/lb), the difference of $0.13/lb is not statistically significant. Although the commercialization of CRISPR fresh fruits is still in its infancy, our findings are aligned with those from previous studies (An et al. 2019; Muringai, Fan, and Goddard 2020; Yang and Hobbs 2020; Marette, Disdier, and Beghin 2021) in that consumers are less accepting of food developed using CRISPR compared to conventional breeding, although in our study the implications of breeding method for WTP are not substantial.

Results from the latent class segmentation analyses suggest the existence of four groups that vary in their sensitivity to prices. Compared with the more highly price sensitive groups, the least and the least-to-moderately price-sensitive groups self-reported that they knew more about gene editing and genetic engineering; and assigned higher ratings to these

Table 7. Latent classes, conventional breeding sample: means of demographic variables and ANOVA comparisons across groups

	Mean				Analysis of variance comparison *P*-value					
Variable	Group 1	Group 2	Group 3	Group 4	Group 1 vs. 2	Group 1 vs. 3	Group 1 vs. 4	Group 2 vs. 3	Group 2 vs. 4	Group 3 vs. 4
Number of respondents in each group	299	640	313	171						
Share of respondents in each group (per cent)	21	45	22	11						
Sociodemographic variables (group-specific fraction of respondents in each category)										
Male	0.55 (0.50)	0.45 (0.50)	0.26 (0.44)	0.24 (0.43)	0.00	0.00	0.00	0.00	0.00	0.77
Millennial born after 1981	0.66 (0.48)	0.64 (0.48)	0.26 (0.44)	0.27 (0.44)	0.50	0.00	0.00	0.00	0.00	0.80
Income ≥ $99,922/year	0.40 (0.49)	0.47 (0.50)	0.49 (0.50)	0.40 (0.49)	0.04	0.02	0.92	0.59	0.10	0.06
White	0.81 (0.39)	0.69 (0.46)	0.84 (0.37)	0.83 (0.37)	0.00	0.33	0.53	0.00	0.00	0.87
Education ≥ bachelor's degree	0.62 (0.49)	0.58 (0.49)	0.62 (0.48)	0.48 (0.50)	0.21	0.91	0.00	0.18	0.03	0.00
Family size ≥ 3	0.51 (0.50)	0.57 (0.50)	0.55 (0.50)	0.54 (0.50)	0.10	0.27	0.52	0.71	0.58	0.81
Number of children under 18 ≥ 1	0.61 (0.49)	0.57 (0.49)	0.61 (0.49)	0.59 (0.49)	0.28	0.93	0.69	0.35	0.71	0.74
Frequency of consumption ≥ once/week	0.37 (0.48)	0.41 (0.49)	0.20 (0.40)	0.19 (0.40)	0.23	0.00	0.00	0.00	0.00	0.95

Table 7. Continued.

Variable	Mean				Analysis of variance comparison *P*-value					
	Group 1	Group 2	Group 3	Group 4	Group 1 vs. 2	Group 1 vs. 3	Group 1 vs. 4	Group 2 vs. 3	Group 2 vs. 4	Group 3 vs. 4
Respondents' ratings for the most trusted sources of information (1 = strongly do not trust, 5 = strongly trust)										
Scientific groups[a]	4.15 (0.72)	3.75 (0.85)	3.97 (0.71)	3.70 (0.80)	0.00	0.00	0.00	0.00	0.46	0.00
Producer-oriented groups[b]	3.99 (0.73)	3.67 (0.78)	3.64 (0.71)	3.52 (0.74)	0.00	0.00	0.00	0.51	0.02	0.10
Universities	4.06 (0.90)	3.68 (1.06)	3.69 (0.88)	3.38 (0.91)	0.00	0.00	0.00	0.88	0.00	0.00
Government[c]	3.89 (0.85)	3.47 (0.95)	3.39 (0.85)	3.33 (0.83)	0.00	0.00	0.00	0.22	0.09	0.48
Consumer-oriented groups[d]	3.88 (0.82)	3.45 (0.95)	3.34 (0.76)	3.16 (0.83)	0.00	0.00	0.00	0.08	0.00	0.04
Social media, media, friends, and family members[e]	3.74 (0.88)	3.37 (0.90)	2.94 (0.72)	2.98 (0.73)	0.00	0.00	0.00	0.00	0.00	0.68
Respondents' ratings for the level of knowledge about breeding technologies (1 = completely uninformed, 5 = completely informed)										
Knowledge of genetic engineering	3.66 (1.23)	3.44 (1.18)	2.75 (1.18)	2.73 (1.28)	0.01	0.00	0.00	0.00	0.00	0.82
Knowledge of CRISPR	3.38 (1.30)	3.24 (1.19)	2.50 (1.14)	2.47 (1.20)	0.10	0.00	0.00	0.00	0.00	0.82

Table 7. Continued.

Variable	Mean				Analysis of variance comparison *P*-value					
	Group 1	Group 2	Group 3	Group 4	Group 1 vs. 2	Group 1 vs. 3	Group 1 vs. 4	Group 2 vs. 3	Group 2 vs. 4	Group 3 vs. 4
Respondents' ratings on the perception of breeding technologies (1 = highly risky to eat, highly unnatural, completely unethical, 5 = totally safe to eat, completely natural, completely ethical)										
CRISPR is safe	3.51 (1.16)	3.38 (1.09)	3.16 (1.08)	2.98 (1.04)	0.08	0.00	0.00	0.01	0.00	0.08
Genetic engineering is safe	3.32 (1.29)	3.37 (1.19)	3.05 (1.20)	2.83 (1.22)	0.56	0.00	0.00	0.00	0.00	0.06
CRISPR is natural	3.18 (1.34)	3.09 (1.25)	2.38 (1.04)	2.45 (1.01)	0.31	0.00	0.00	0.00	0.00	0.58
Genetic engineering is natural	2.94 (1.34)	3.06 (1.32)	2.23 (1.10)	2.23 (1.10)	0.18	0.00	0.00	0.00	0.00	0.98
CRISPR is ethical and morally acceptable	3.44 (1.24)	3.36 (1.20)	3.03 (1.09)	2.91 (1.09)	0.30	0.00	0.00	0.00	0.00	0.30
Genetic engineering is ethical and morally acceptable	3.16 (1.34)	3.30 (1.26)	2.85 (1.23)	2.77 (1.26)	0.11	0.00	0.00	0.00	0.00	0.51

[a] Scientific groups include medical professionals (e.g. your primary physician), scientific associations (e.g. American Association for the Advancement of Science), and scientific journals (e.g. Nature, Science).
[b] Producer-oriented groups include individual farmers, farmer's organizations (e.g. California Table Grape Commission), food manufacturers (e.g. Nestle, General Mills), and food retailers (e.g. Walmart, Safeway).
[c] Government includes local government (e.g. local mayor) and government agencies (e.g. US Department of Agriculture).
[d] Consumer-oriented groups include activist groups (e.g. Green America) and consumer organization (e.g. American Council of Consumers).
[e] Social, media, family, and friends includes newspaper, TV, magazines, friends, and family members.
Note: Standard deviations are shown in the parentheses.

Table 8. Latent classes, gene-editing sample: means of demographic variables and ANOVA comparison across groups.

Variable	Mean				Analysis of variance comparison *P*-value					
	Group 1	Group 2	Group 3	Group 4	Group 1 vs. 2	Group 1 vs. 3	Group 1 vs. 4	Group 2 vs. 3	Group 2 vs. 4	Group 3 vs. 4
Number of respondents in each group	334	609	189	319						
Share of respondents in each group (per cent)	23	42	13	22						
Sociodemographic variables (group-specific fraction of respondents in each category)										
Male	0.51 (0.50)	0.46 (0.50)	0.28 (0.45)	0.31 (0.47)	0.16	0.00	0.00	0.00	0.00	0.44
Millennial born after 1981	0.61 (0.49)	0.69 (0.46)	0.27 (0.45)	0.22 (0.41)	0.01	0.00	0.00	0.00	0.00	0.18
Income ≥ $99,922/year	0.49 (0.50)	0.42 (0.49)	0.42 (0.50)	0.46 (0.50)	0.02	0.82	0.17	0.12	0.40	0.41
White	0.76 (0.43)	0.69 (0.46)	0.77 (0.42)	0.80 (0.40)	0.02	0.03	0.00	0.80	0.23	0.46
Education ≥ bachelor's degree	0.63 (0.48)	0.56 (0.50)	0.52 (0.50)	0.63 (0.48)	0.02	0.40	0.03	0.01	0.97	0.02
Family size ≥ 3	0.52 (0.50)	0.53 (0.50)	0.57 (0.50)	0.50 (0.50)	0.67	0.40	0.32	0.27	0.61	0.13
Number of children under 18 ≥ 1	0.61 (0.49)	0.60 (0.49)	0.62 (0.49)	0.50 (0.50)	0.82	0.62	0.00	0.77	0.01	0.01
Frequency of consumption ≥ once/week	0.46 (0.50)	0.41 (0.49)	0.19 (0.39)	0.20 (0.40)	0.09	0.00	0.00	0.00	0.00	0.82

Table 8. Continued.

Variable	Mean				Analysis of variance comparison *P*-value					
	Group 1	Group 2	Group 3	Group 4	Group 1 vs. 2	Group 1 vs. 3	Group 1 vs. 4	Group 2 vs. 3	Group 2 vs. 4	Group 3 vs. 4
Respondents' ratings for the most trusted sources of information (1 = strongly do not trust, 5 = strongly trust)										
Scientific groups[a]	4.04 (0.73)	3.77 (0.82)	3.64 (0.91)	3.97 (0.72)	0.00	0.07	0.00	0.00	0.26	0.00
Producer-oriented groups[b]	3.92 (0.77)	3.67 (0.78)	3.41 (0.84)	3.64 (0.72)	0.00	0.00	0.59	0.00	0.00	0.00
Universities	3.91 (0.93)	3.69 (0.95)	3.41 (1.03)	3.67 (0.93)	0.00	0.00	0.79	0.00	0.00	0.00
Government[c]	3.81 (0.85)	3.44 (0.95)	3.10 (0.98)	3.44 (0.83)	0.00	0.00	0.91	0.00	0.00	0.00
Consumer-oriented groups[d]	3.69 (0.91)	3.51 (0.84)	3.12 (0.93)	3.30 (0.82)	0.00	0.00	0.00	0.00	0.00	0.02
Social media, media, and friends, and family members[e]	3.61 (0.85)	3.38 (0.87)	2.89 (0.72)	2.94 (0.70)	0.00	0.00	0.00	0.00	0.00	0.49
Respondents' ratings for the level of knowledge about breeding technologies (1 = completely uninformed, 5 = completely informed)										
Knowledge of genetic engineering	3.62 (1.14)	3.46 (1.12)	2.73 (1.21)	2.72 (1.18)	0.04	0.00	0.00	0.00	0.00	0.94
Knowledge of CRISPR	3.47 (1.19)	3.27 (1.17)	2.43 (1.13)	2.37 (1.14)	0.01	0.00	0.00	0.00	0.00	0.60

Table 8. Continued.

Variable	Mean				Analysis of variance comparison *P*-value					
	Group 1	Group 2	Group 3	Group 4	Group 1 vs. 2	Group 1 vs. 3	Group 1 vs. 4	Group 2 vs. 3	Group 2 vs. 4	Group 3 vs. 4
Respondents' ratings on the perception of breeding technologies (1 = highly risky to eat, highly unnatural, completely unethical, 5 = totally safe to eat, completely natural, completely ethical)										
CRISPR is safe	3.61 (1.06)	3.34 (1.08)	2.55 (1.06)	3.28 (1.04)	0.00	0.00	0.42	0.00	0.00	0.00
Genetic engineering is safe	3.55 (1.15)	3.28 (1.18)	2.37 (1.11)	3.10 (1.16)	0.00	0.00	0.03	0.00	0.00	0.00
CRISPR is natural	3.25 (1.18)	3.11 (1.23)	1.99 (0.96)	2.49 (1.09)	0.07	0.00	0.00	0.00	0.00	0.00
Genetic engineering is natural	3.15 (1.26)	3.04 (1.31)	1.78 (0.90)	2.26 (1.07)	0.19	0.00	0.00	0.00	0.00	0.00
CRISPR is ethical and morally acceptable	3.59 (1.06)	3.29 (1.15)	2.50 (1.08)	3.07 (1.07)	0.00	0.00	0.01	0.00	0.00	0.00
Genetic engineering is ethical and morally acceptable	3.49 (1.14)	3.27 (1.23)	2.39 (1.13)	2.86 (1.20)	0.01	0.00	0.00	0.00	0.00	0.00

[a] Scientific groups include medical professionals (e.g. your primary physician), scientific associations (e.g. American Association for the Advancement of Science), and scientific journals (e.g. Nature, Science).
[b] Producer-oriented groups include individual farmers, farmer's organizations (e.g. California Table Grape Commission), food manufacturers (e.g. Nestle, General Mills), and food retailers (e.g. Walmart, Safeway).
[c] Government includes local government (e.g. local mayor) and government agencies (e.g. US Department of Agriculture).
[d] Consumer-oriented groups include activist groups (e.g. Green America) and consumer organization (e.g. American Council of Consumers).
[e] Social, media, family, and friends includes newspaper, TV, magazines, friends, and family members.
Note: Standard deviations are shown in the parentheses.

two plant breeding methods as being safe, natural, and ethically and morally acceptable. These results provide promise that CRISPR could present an opportunity for plant-breeding programs.

An important implication of our findings for breeding programs is that consumers prioritize attributes that directly affect their eating experience, such as sweetness and crispness. Another finding that is pertinent for breeding programs as well as agricultural producers and food retailers is that freshness and ripeness of grapes are important to consumers when they make their purchase decisions. Novel traits and post-harvest practices that preserve grape freshness in storage could be very valuable to consumers and producers.

Our work also identifies consumer segments that may be more accepting of new plant-breeding techniques, and there may be advantages in focusing on marketing efforts with these groups as a first step toward wider acceptance in the marketplace. The plant-breeding community may have an opportunity to develop varietal traits that will help the industry better provide the fruit quality attributes demanded by consumers as well as the agronomic traits demanded by growers to better cope with and adapt to an ever-evolving climate and regulatory environment.

One possible avenue for future work is to collect data that would allow for a closer identification of the consumer groups that are more accepting of new technologies and the reasons contributing to their acceptance. In this study, we were able to consider only a limited number of product quality attributes for table grapes. The generalizability of the results in this study could therefore be improved by extending the work to consider a greater range of fruit quality and production process attributes that are important to consumers, growers, food retailers, and plant breeders. Also, further research could explore consumer response with a larger sample and with the use of a laboratory or field experiment that is more reflective of market conditions and is incentive compatible. Further research could also examine the possible extent of hypothetical bias associated with the discrete-choice experiments and the potential benefits of employing mitigation techniques in this context.

Appendix A. Explanation of the plant breeding technologies provided to all survey respondents

- Conventional breeding: Plants with desirable traits are bred together, using existing varieties or the offspring of previous breeding programs that have the desired traits. This results in hundreds of potentially desirable plants that must be whittled down to the best candidates for commercial use. May be labeled as organic (if other production requirements are satisfied) or GMO-free.
- Gene editing (e.g. CRISPR): Specific genes can be altered without introducing genes from any other sources. Similar to editing a word in a novel, gene editing can target specific DNA sequences in the genome for slight modification, which can improve plant traits. The USDA recently proposed that plants produced using gene editing would be treated the same as conventionally bred plants. For this study, we can assume grapes produced using gene editing may be labeled as organic (if other production requirements are satisfied) or GMO-free.

Supplementary material

Supplementary data are available at *Q Open* online.

Funding

This work was supported in part by the USDA National Institute of Food and Agriculture – Specialty Crop Research Initiative project "VitisGEN2" (2017-51181-26829).

Acknowledgments

This work was supported in part by the USDA National Institute of Food and Agriculture—Specialty Crop Research Initiative project 'VitisGEN2' (2017-51181-26829).

Data availability

Data have been supplied to Q Open and are available as supplementary material.

End Notes

1 An orthogonal design implies that all estimable effects are uncorrelated, while a balanced design ensures that each setting of each attribute appears equally often. The D-efficiency is a measure of the goodness of a design relative to a hypothetical orthogonal design. These measures are based on the variance-covariance matrix of the vector of parameter estimates. An efficient design is one with a small variance matrix, with the eigenvalues of the inverse matrix providing measures of the design size. D-efficiency is a function of the geometric mean of the eigenvalues.

2 The Type I Generalized Multinomial Logit (GMNL-I) model assumes $\gamma = 1$, and the Type II Generalized Multinomial Logit (GMNL-II) model assumes $\gamma = 0$. That is, GMNL-I assumes that the standard deviation of the residual taste heterogeneity is independent of the scale, while GMNL-II assumes the standard deviation of the residual taste heterogeneity is proportional to the scale. Both model types were estimated using the 'gmnl' package in STATASE v. 17. When comparing the goodness-of-fit statistics—the Akaike information criterion (AIC), the Bayesian information criterion (BIC) and the value of the likelihood function—we find that the GMNL-I model outperforms the GMNL-II (with a lower AIC and BIC). Therefore, only the GMNL-I estimates are reported.

References

An H., Lloyd-Smith P. and Adamowicz W. L. (2019) 'Strategic behavior in stated preferences and the demand for gene-edited canola', in *Agricultural and Applied Economics Association Annual Meeting*. Atlanta, GA, USA: Agricultural and Applied Economics Association.

Anders S., Cowling W., Pareek A., Gupta K. J., Singla-Pareek S. L. and Foyer C. H. (2021) 'Gaining acceptance of novel plant breeding technologies', *Trends in Plant Science,* 26: 575–87.

California Table Grape Commission (2022) 'Grapes today', https://www.grapesfromcalifornia.com/all-about-grapes/, accessed 24 May 2022.

Chironi S., Sortino G., Allegra A., Saletta F., Caviglia V. and Ingrassia M. (2017) 'Consumer assessment on sensory attributes of fresh table grapes Cv 'Italia' and 'Red Globe' after long cold storage treatment', *Chemical Engineering Transactions*, 58: 421–6.

Costanigro M. and Lusk J. L. (2014) 'The signaling effect of mandatory labels on genetically engineered food', *Food Policy*, 49: 259–67.

Crisosto C. H. and Crisosto G. M. (2002) 'Understanding American and Chinese consumer acceptance of 'Redglobe' table grapes', *Postharvest Biology and Technology*, 24: 155–62.

Curtin R., Presser S. and Singer E. (2000) 'The effects of response rate changes on the index of consumer sentiment', *Public Opinion Quarterly,* 64: 413–28.

Dannenberg A. (2009) 'The dispersion and development of consumer preferences for genetically modified food—a meta-analysis', *Ecological Economics*, 68: 2182–92.

Doudna J. A. and Charpentier E. (2014) 'Genome editing. The new frontier of genome engineering with CRISPR-Cas9', *Science*, 346: 1258096.

Entine J., Felipe M. S. S., Groenewald J.-H., Kershen D. L., Lema M., McHughen A., Nepomuceno A. L., Ohsawa R., Ordonio R. L., Parrott W. A., Quemada H., Ramage C., Slamet-Loedin I., Smyth S. J. and Wray-Cahen D. (2021) 'Regulatory approaches for genome edited agricultural plants in select countries and jurisdictions around the world', *Transgenic Research*, 30: 551–84.

Fiebig Denzil G., Keane M. P., Louviere J. and Wasi N. (2010) 'The generalized multinomial logit model: accounting for scale and coefficient heterogeneity', *Marketing Science*, 29: 393–421.

Frewer L. (2003) 'Societal issues and public attitudes toward genetically modified foods', *Trends in Food Science & Technology*, 14: 319–32.

Greene W. H. and Hensher D. A. (2003) 'A latent class model for discrete choice analysis: contrasts with mixed logit', *Transportation Research Part B: Methodological*, 37: 681–98.
Hill N., Meyers C., Li N., Doerfert D. and Mendu V. (2022) 'How does the public discuss gene-editing in agriculture? An analysis of Twitter content', *Advancements in Agricultural Development*, 3: 31–47.
Ishii T. and Araki M. (2016) 'Consumer acceptance of food crops developed by genome editing', *Plant Cell Reports*, 35: 1507–18.
Jayasena V. and Cameron I. (2008) 'Brix/acid ratio as a predictor of consumer acceptability of crimson seedless table grapes', *Journal of Food Quality*, 31: 736–50.
Kilders V. and Caputo V. (2021) 'Is animal welfare promoting hornless cattle? Assessing consumer's valuation for milk from gene-edited cows under different information regimes', *Journal of Agricultural Economics*, 72(3):735–59.
Krosnick J. A. and Alwin D. F. (1987) 'An evaluation of a cognitive theory of response-order effects in survey measurement', *Public Opinion Quarterly*, 51: 201–19.
Lancaster K. J. (1966) 'A new approach to consumer theory', *Journal of Political Economy*, 74: 132–57.
Lim K. H and Page E. T. (2022) *Consumers' Interpretation of Food Labels with Production Claims Can Influence Purchases*. Amber Waves: U.S. Department of Agriculture, Economic Research Service.
Louviere J. J., Hensher D. A. and Swait J. D. (2000) *Stated Choice Methods: Analysis and Applications*. Cambridge: Cambridge University Press.
Lusk J. L., Jamal M., Kurlander L., Roucan M. and Taulman L. (2005) 'A meta-analysis of genetically modified food valuation studies', *Journal of Agricultural and Resource Economics*, 30: 28–44.
Lusk J., McFadden B. and Rickard B. (2015) 'Which biotech foods are most acceptable to the public?', *Biotechnology Journal*, 10: 13–6.
Lusk J., Roosen J. and Bieberstein A. (2014) 'Consumer acceptance of new food technologies: causes and roots of controversies', *Annual Review of Resource Economics*, 6: 381–405.
Lusk J. L. and Schroeder T. C. (2004) 'Are choice experiments incentive compatible? A test with quality differentiated beef steaks', *American Journal of Agricultural Economics*, 86: 467–82.
Ma C., Fu Z., Xu M., Trebar M. and Zhang X. (2016) 'Evaluation on home storage performance of table grape based on sensory quality and consumers' satisfaction', *Journal of Food Science and Technology*, 53: 1363–70.
McFadden D. (1974) 'Conditional logit analysis of qualitative choice behavior, in Zarembka, P. (ed.) *Frontiers in Econometrics*, pp. 105–42. New York, NY: Academic Press.
Marette S., Disdier A.-C. and Beghin J. C. (2021) 'A comparison of EU and US consumers' willingness to pay for gene-edited food: evidence from apples', *Appetite*, 159: 105064.
Menz J., Modrzejewski D., Hartung F., Ralf W. and Sprink T. (2020) 'Genome edited crops touch the market: a view on the global development and regulatory environment', *Frontiers in Plant Science*, 11: 586027.
Muringai V., Fan X. and Goddard E. (2020) 'Canadian consumer acceptance of gene-edited versus genetically modified potatoes: a choice experiment approach', *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, 68: 47–63.
Nes K., Schaefer K. A. and Scheitrum D. P. (2022) 'Global food trade and the costs of non-adoption of genetic engineering', *American Journal of Agricultural Economics*, 104: 70–91.
Nylund-Gibson K. and Choi A. Y. (2018) 'Ten frequently asked questions about latent class analysis', *Translational Issues in Psychological Science*, 4: 440–61.
Parrott W. A. (2022) *Gene-Edited Assisted Plant Breeding and the Regulatory Policy Regulating Its Use in the U.S. and Around the World*. Alexandria, VA: American Society for Horticultural Science.
Pew Research Center (2020) *Science and Scientists Held in High Esteem across Global Publics: Yet There is Ambivalence in Many Publics over Developments in AI, Workplace Automation, Food Science*. Washington, DC: Pew Research Center.
Pew Research Center (2022) *Americans' Trust in Scientists, Other Groups Declines*. Washington, DC: Pew Research Center.
Shew A. M., Durand-Morat A., Nalley L. L. and Ann-Kuenzel Moldenhauer K. (2018) 'Estimating the benefits of public plant breeding: beyond profits', *Agricultural Economics*, 49: 753–64.
Siegrist M., Hartmann C. and Keller C. (2013) 'Antecedents of food neophobia and its association with eating behavior and food choices', *Food Quality and Preference*, 30: 293–8.
Smith M. (2022) 'Genetic engineering', (updated 23 September 2022) https://www.genome.gov/genetics-glossary/Genetic-Engineering, accessed 24 August 2022.
Tabei Y., Shimura S., Kwon Y., Itaka S. and Fukino N. (2020) 'Analyzing twitter conversation on genome-edited foods and their labeling in Japan', *Frontiers in Plant Science*, 11: 535764.

U.S. Census Bureau (2018) *American Community Survey*. https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/2018/, accessed 24 August 2022.
U.S. Department of Agriculture-Economic Research Service (2019) *Food and Vegetable Availability*. USDA ERS.
U.S. Department of Agriculture-Economic Research Service (2021a) *Fruit and Tree Nuts Data, Imports and Exports*. USDA ERS.
U.S. Department of Agriculture-Economic Research Service (2021b) *Food Availability Data System*. USDA ERS
U.S. Department of Agriculture-National Agricultural Statistics Service (2021) *Noncitrus Fruits and Nuts 2020 Summary*. USDA NASS.
VitisGen2 (2018) 'Mapping the way to the next generation of grapes', https://www.vitisgen2.org/aboutvitisgen2/annual-project-reeport-2018/, accessed 24 May 2022.
Walker B. and Malson J. (2020) 'Science, God, and nature: a textual and frequency analysis of facebook comments on news articles about agricultural and environmental gene editing', *Environmental Communication*, 14: 1004–16.
Wunderlich S. and Gatto K. A. (2015) 'Consumer perception of genetically modified organisms and sources of information', *Advances in Nutrition*, 6: 842–51.
Yang Y. and Hobbs J. E. (2020) 'The power of stories: narratives and information framing effects in science communication', *American Journal of Agricultural Economics*, 102: 1271–96.
Yeh D. A., Gomez M. I. and Kaiser H. M. (2019) 'Signaling impacts of GMO labeling on fruit and vegetable demand', *PLoS ONE*, 14: e0223910.
Zhang Y., Massel K., Godwin I. D. and Gao C. (2018) 'Applications and potential of genome editing in crop improvement', *Genome Biology*, 19: 210.