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RESEARCH ARTICLE

Are consumers ready to accept gene-edited crops? Evidence from a choice experiment for CRISPR-edited tomatoes in Spain

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Abstract

Aim of the study: Understand consumer acceptability and willingness to pay for CRISPR-edited food and explore how production method, production origin and pesticide reduction affected their acceptance.

Area of Study: Aragón (Spain)

Material and Methods: We used a pre-registered online survey with a discrete choice experiment (DCE) implemented on 521 consumers. Consumers choose their preferred option when purchasing tomatoes, which differed in the breeding method (traditional vs. CRISPR), price, pesticide reduction, production method (conventional vs organic), and origin (European Union (EU) vs. non-EU). As context information for the analysis, we elicit consumers' perceptions, knowledge and trust regarding different breeding technologies (including gene modification and editing) and food technology neophobia.

Main Results: Spanish consumers generally trust EU food safety but display high neophobia towards new food technologies, with limited knowledge of plant breeding methods. They also prefer EU-sourced and organically produced tomatoes, with solid support for those produced while reducing pesticide use. However, CRISPR-edited tomatoes face considerable resistance, with consumers requiring a discount to accept them. This price discount could be eliminated if the CRISPR-edited tomato is grown with at least a 67% reduction in pesticide use.

Research highlights: While the proposal for the regulation of CRISPR provides a valuable entry point to enable its adoption in the EU, findings indicate that Spanish consumers are not ready to accept the CRISPR-edited tomatoes at face value, requiring additional assurances or specific benefits before acceptance.

Keywords: choice experiment; consumer behaviour; CRISPR; Spain; willingness to pay.

¿Están los consumidores preparados para aceptar cultivos editados genéticamente? Evidencia de un experimento de elección con tomates editados con CRISPR en España

Resumen

Objetivo del estudio: Comprender la aceptabilidad del consumidor y la disposición a pagar por alimentos editados con CRISPR, y explorar cómo el método de producción, el origen de la producción y la reducción de pesticidas afectan su aceptación.

Área de estudio: Aragón (España).

Material y métodos: Realizamos una encuesta en línea pre-registrada que incluyó un experimento de elección discreta (EED) aplicado a 521 consumidores. Los participantes debían elegir su opción preferida al comprar tomates, que se diferenciaban en el método de cultivo (tradicional vs. CRISPR), precio, reducción de pesticidas, método de producción (convencional vs. orgánico) y origen (Unión Europea (UE) vs. fuera de la UE). Para complementar el análisis, recopilamos información contextual sobre las percepciones, el conocimiento y la confianza de los consumidores respecto a diferentes tecnologías de mejora genética (incluyendo la modificación y edición genética), y medimos la neofobia hacia tecnologías aplicadas a los alimentos.

Principales resultados: Los consumidores españoles confían en la seguridad alimentaria de la UE, pero muestran una marcada neofobia hacia las nuevas tecnologías alimentarias y tienen un conocimiento limitado de los métodos de mejora genética. Además, prefieren los tomates de origen europeo y de producción orgánica, apoyando especialmente aquellos que reducen el uso de pesticidas. Sin embargo, los tomates editados con CRISPR generan una notable resistencia, ya que los consumidores exigen un descuento en el precio para aceptarlos. Este descuento podría eliminarse si el tomate editado con CRISPR se cultiva con una reducción de al menos un 67% en el uso de pesticidas.

Aspectos destacados de la investigación: Aunque la propuesta para regular CRISPR ofrece una vía valiosa para facilitar su adopción en la UE, los hallazgos indican que los consumidores españoles aún no están preparados para aceptar los tomates editados con CRISPR y exigen garantías adicionales o beneficios específicos.

Palabras clave: comportamiento del consumidor; CRISPR; disposición a pagar; España, experimento de elección.

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Introduction

Ensuring proper nutrition and food security remains a crucial global challenge, especially considering how climate change will impact crop production. Advanced biotechnologies in plant breeding provide promising solutions to this challenge. Traditional plant breeding techniques, such as crossbreeding and induced mutations through chemicals or radiation, have long been used to develop new plant varieties (Van de Wiel et al., 2010). These methods face particular challenges, such as high costs and lengthy development times, with an average of 13 to 15 years to develop a new crop variety, with unpredictable genetic outcomes and undesirable traits due to random mutations (Singer et al., 2021).

Genetically modified (GM) technology, also known as genetically modified organisms (GMO), was developed as an alternative that allowed to speed up the process, lower costs and improve the variety’s traits like herbicide tolerance and resistance to insects and plant viruses. This process involves transferring genes (foreign or not) from one organism to another (Brookes, 2022; Sendhil et al., 2022), resulting in crops with transgenic (genes taken from a different species) or cisgenic (genes taken from the same species) known traits. While GM crops have provided various benefits, including improved nutrition (Diaz & Ortiz, 2013) and reduced pesticide use (Brookes & Barfoot, 2020), concerns about the environmental and human health impacts of transgenes have contributed to the rejection of GM foods, particularly in Europe (Macilwain, 2015). Numerous studies indicate that consumers generally prefer conventional over GM foods (Lusk, 2011; Frewer et al., 2013), and in the EU, a lack of consumer and farmer acceptance led even to the withdrawal of a GM potato variety approved for industrial use (Kanter, 2012).

Recent advancements in biotechnology include new genomic techniques (NGTs). Within NGTs, several genome editing (GE) technologies aim to improve productivity and develop desirable crop traits more efficiently (Hu et al., 2022). Among these GEs, the Clustered Regularly Interspaced Short Palindromic Repeat (CRISPR) has gained popularity as it allows removing, adding, or altering specific DNA regions without using transgenes (Hu et al., 2022). It is currently the most straightforward, fastest, most flexible, and most accurate method for genetic manipulation (Pacesa et al., 2024). Friedrichs et al. (2019) estimated that CRISPR experiments in the agri-food sector could be completed much faster (often within a year) compared to traditional breeding or GMO methods. Additionally, they projected that production costs could be as low as €10. Similar to GM technology, CRISPR can lead to varieties that offer disease resistance (Schneider et al., 2023), tolerance to environmental stresses (Kumar et al., 2020), enhanced nutrition features (Jouanin et al., 2018), and increased yields (Rengasamy et al., 2024). However, unlike GM, CRISPR-edited foods are transgene-free and indistinguishable from traditional plant breeding methods. While this benefit may raise scepticism, it could also reduce public resistance to CRISPR-derived foods and enhance consumer acceptance.

From a policy perspective, in 2018, the Court of Justice of the European Union (CJEU) issued a judgment classifying NGTs as GMOs. This classification subjects them to stringent pre-market risk evaluations (CJEU, 2018; Vives-Vallés & Collonnier, 2020). While this decision disappointed many in the scientific community, more recent growing debates about the potential of NGTs to contribute to sustainable food systems have led to discussions about the need for a more differentiated regulatory approach for these crops (Wesseler et al., 2022). Several studies suggest that facilitating their approval compared to GMOs could bolster key agricultural initiatives, including the EU's Farm to Fork strategy, European Green Deal, and efforts to achieve Sustainable Development Goals (Lemarié & Marette, 2022; Smyth, 2022). Motivated by these potential benefits and concerned about falling behind in the bioeconomy revolution driven by NGTs, the European Commission (EC) proposed a new regulation proposal in July 2023. This proposal aimed to treat GE varieties similarly to those that could occur naturally or be developed through conventional breeding, enabling their development and market introduction while ensuring high environmental, human and animal health protection (EC, 2023). These new rules would apply to so-called Category-1 NGT plants, considered equivalent to those that could occur naturally or through conventional breeding. Therefore, they should not be treated differently from traditional varieties and would not be subject to GMO legislation. NGT crops that do not meet these criteria are labelled Category-2 and will be regulated as GMOs. The regulatory framework for NGT advanced further when the European Parliament voted to favour the EC's proposal on NGTs (European Parliament, 2024a). Notable amendments include the requirement to publish lists of Category-1 NGT plants online, the prohibition of NGTs in organic farming, and the non-patentability of all Category-1 NGT plants (European Parliament, 2024b). Some critics have raised concerns about this proposal (Puchta, 2023), but it aligns with a letter signed by 37 Nobel Laureates and over 1,500 scientists urging policymakers to consider the scientific evidence for NGTs in the EU's best interest (WePlanet, 2024). As of October 2024, the future of this proposal depends on the European Council's decision. Irrespective of the legislative changes, the long-term market success of NGT-derived foods will ultimately depend on consumers' willingness to purchase and consume them.

From a consumer behaviour perspective, as far as we know, the first analysis of consumer attitudes and valuations regarding GE varieties was conducted in 2018 (Shew et al., 2018), and since then, interest has surged, with over 50 peer-reviewed papers published by October 2024 (Jouanin et al., 2018; Kumar et al., 2020; Vives-Vallés & Collonnier, 2020; Nguyen et al., 2021; Hu et al., 2022; Lemarié & Marette, 2022; Wesseler et al., 2022; Schneider et al., 2023; Atimango et al., 2024; Rengasamy et al., 2024, among others). These studies indicate that consumers are poorly informed about GE, GMOs and NGTs. Specifically, the review of Lemarié & Marette (2022) highlighted that the general population's limited knowledge of GE is commonly lower than that of GMOs. However, despite this limited knowledge, GE appears to have a more favourable image among consumers than GMOs. Nevertheless, consumers are only willing to purchase gene-edited crops if sold at a discount compared to conventional options. This discount can be partly or even fully offset if the gene-edited variety benefits consumers (e.g. improved nutritional profile) and the environment (e.g. reduced use of pesticides). The authors suggested that enhanced awareness of the differences between gene-edited products and GMOs would facilitate acceptance and explicit signalling of the benefits of the gene-edited varieties. Similarly, Nguyen et al. (2021) emphasised that GE developers face consumer knowledge deficits as the public struggles to distinguish between GE and GM technologies. In the EU, a European Food Safety Authority (EFSA) survey from a representative sample of EU citizens showed that only 36% of Europeans had heard of NGTs (EFSA, 2022a). Despite the lack of awareness and likely a more significant lack of knowledge, those who believe NGTs will positively impact outnumber those who expect adverse outcomes across six of the seven domains surveyed. The only domain where negative beliefs slightly (by one percentage point) prevail is the one related to human health. In contrast, favourable perceptions regarding climate change resistance and food production quantity exceed negative ones by over 45 percentage points.

Regarding consumer valuation of varieties developed with gene editing, studies on Canadian consumers reported similar valuations for GE and GM foods (Muringai et al., 2020; Yang & Hobbs, 2020; Vasquez et al., 2022). Recent research in the EU and other countries indicated that consumers view GE foods more favourably (Bašinskienėa & Šeinauskienėb, 2021; Bearth et al., 2022; Atimango et al., 2024; Bearth et al., 2024; Deng et al., 2024). Studies also show that consumers perceive GE as safer (Son & Lim, 2021; Uddin et al., 2022) and are willing to pay more for GE than GM foods (Deng et al., 2024). Summing up, while the literature exploring consumer preferences for GE food remains limited compared to studies examining consumer acceptance of GE and GM plant breeding technologies (Shew et al., 2018; Götz et al., 2022; Deng et al., 2024), consumer knowledge about GE technologies is low (Caputo et al., 2020; Götz et al., 2022; Deng et al., 2024). Additionally, consumer evaluation between GE and GM foods are mixed (Shew et al., 2018; Gatica-Arias et al., 2019; Caputo et al., 2020; Marette et al., 2021a, 2021b; Götz et al., 2022; Hu et al., 2022; Tadich & Escobar-Aguirre, 2022; Baum et al., 2023; Deng et al., 2024).

Given these aforementioned general conclusions, further research is needed to understand consumers' acceptance of GE foods, particularly regarding preferences in understudied regions (such as the Mediterranean), specific traits that might enhance the appeal of GE crops (such as reduced pesticide use), and interaction with other valued food characteristics (like origin and organic production methods) to provide valuable insights for academic research, GE food developers, and policymakers.

This paper will provide further evidence on consumer acceptance and choice behaviour regarding CRISPR-edited tomatoes in Spain. Since foods modified using NGTs are not yet available on the EU market, we rely on a hypothetical discrete choice experiment (DCE) to assess consumer preferences and willingness to pay (WTP). We used tomatoes as the reference product to examine preferences for GE versus traditional alternatives, focusing on the most prevalent GE technique, CRISPR. The DCE also considered four additional attributes: pesticide reduction (a potential benefit of the new GE variety), production method (conventional vs organic)[1], and origin (European Union (EU) vs non-EU), and price.

This research makes several critical contributions to the growing literature on consumer acceptance of GE food. First, this study is the first to measure consumer preferences and WTP for GE food in Spain. Second, while previous EU studies examined consumer preferences for GE food before the EU's regulatory advancements (i.e., July 2023), this study is the first to analyse consumer behaviour after the EC put forward these changes. Bearth & Siegrist (2016) found that regulatory bans on new technologies (e.g., GMO and GE) may signal risks to citizens. Furthermore, scientists in public institutions and consumer organisations were identified as the EU's most trusted sources of food risk information (EFSA, 2022b). Since many EU citizens are likely aware of these regulatory developments supported by scientific evidence (Ichim, 2024), we expect to provide novel and more representative insights regarding consumers' valuation of GE food. Our findings offer valuable insights to policymakers, marketers, farmers, and plant breeders, helping them communicate more effectively with consumers and citizens.

Materials and methods

To achieve our objectives, we conducted a DCE via an online survey. Given that GE foods are not yet available in the EU market, we employed a hypothetical DCE where consumers were presented with various attributes and levels of products. This approach was chosen for its capacity to evaluate multiple food attributes simultaneously, grounded in the random utility theory (McFadden, 1974), and its ability to simulate actual market purchasing behaviour (Adamowicz et al., 1998). In line with the journal's editorial policy (Barreiro-Hurle, 2021), the study was pre-registered before data collection[2], and here we focus on the analysis of the pooled data to test the six hypotheses summarised in Table 1.

[1] We are aware that under the EC legislative proposal, the use of NGTs remains prohibited for organic farming. However, the organic sector's position regarding this ban is not homogenous, nor is it shared among the different EU countries in their Council discussions. Therefore, taking advantage of the hypothetical nature of our study, we can provide some evidence on how this ban is seen by consumers.

[2] AsPredicted is a platform designed to facilitate the pre-registration of studies by researchers while also providing an easy way for others to access and assess those pre-registrations. To pre-register a study on AsPredicted, a researcher responds to nine straightforward questions regarding their research design and analysis methods. The platform generates a time-stamped, one-page PDF document that contains a unique URL for verification purposes. The study was pre-registered on 3/14/24 on the *aspredicted.org* platform before starting the data collection (#166206). The preregistered form is available online at: https://aspredicted.org/96x5-84qs.pdf

Table 1. Pre-registered hypotheses and how they are tested.

Hypotheses	Results	Supported / Not supported
1. Negative valuation of CRISPR technology, all else being equal, regarding other characteristics of food products.	See the coefficient of the CRISPR variable in Table 5.	Supported
2. Positive valuation of reductions on pesticide use	See the coefficient of the PESTICIDE variable in Table 5.	Supported
3. Negative valuation of CRISPR by consumers can be mitigated by reduction in pesticide use	Total WTP calculation in table 6.	Supported
4. EU Local food products are preferred over imports	See the coefficient of the EU variable in Table 5.	Supported
5. Negative valuation of imports versus EU products could benefit from the claim of a reduction in the use of pesticides	See the coefficient of EU-PESTICIDE interaction in Table 5. Total WTP calculation in table 6.	Not supported
6. Negative valuation of CRISPR by consumers can be mitigated by use in organic farming	See the coefficient of CRISPR-ORGANIC interaction in Table 5.	Not supported

Source: AsPredicted.org pre-registration.

Data collection

Data collection targeted consumers in Aragón (north-eastern Spain) in April 2024. This sample comprised household food shoppers over 18 who consumed tomatoes at home. Consumers were stratified by gender and age. We collected responses from 550 individuals. However, we excluded 29 individuals who consistently chose the no-buy option in all tasks (serial status quo choosers) of the DCE, as they might not have been interested or willing to engage with this part of the survey (a detailed profile of this group is shown in Supplementary material, Table S1. Therefore, the final sample consisted of 521 consumers[3]. Table 2 provides the socio-demographic description with comparisons to Spanish population data where available.

The sample is representative of the population in Aragón, followed by the representativeness of the Spanish population, as there are no differences in gender and age. The sample is moderately biased towards more educated respondents (53% hold a university degree compared to 41% of the population) ($p<0.05$). This is a consistent pattern from samples taken from online panels. Income data reveal that a fifth of respondents did not declare their income; for those that did, the largest share of respondents falls within the middle-income range of € 1500 and € 3000 a month (34.6%), and the lowest earn over € 5000 (4.4%). Assuming missing observations are equally distributed across income intervals, the difference between the sample and the population is not statistically significant. Likewise, the average monthly income[4] is similar: € 3,086 in the sample versus € 2,902 in the Spanish population (INE, 2023). The average household size is 2.6, slightly over ($p<0.05$) the population figure of 2.5, and 29% of respondents live in households with children.

Table 3 shows the sample's purchasing and consumption habits and perceptions of EU food safety aspects. Most respondents are primarily responsible for household food purchases, with 57% always and 35% very often in charge. Over half (54%) reported purchasing organic products within the year before the survey.

[3] This final sample size for a confidence level of 95.5% (k = 2) when estimating proportions for the more conservative scenario (p = q = 0.5) results in a sampling error of ± 4.3%.
[4] Using income data in the sample available for 11 intervals and multiplying the respective proportions by the mid-point value in the interval, we approximate an average monthly income.

Table 2. Description of the sociodemographic characteristics of the sample (N = 521 individuals).

Variable	Indicator	% sample	% Aragón population [a]	% Spanish population [b]
Gender [b]	Male	48.2	49.4	49.0
	Female	51.8	50.6	51.0
Age [b]	18-34 years old	20.5	21.0	22.2
	35-44 years old	16.9	16.2	17.1
	45-54 years old	23.0	19.3	19.6
	≥ 55years old	39.5	43.6	41.1
Education**	Up to compulsory school (primary, secondary)	20.2	32.6	36.3
	High school or equivalent	26.5	24.1	23.0
	University	53.4	43.3	40.7
Net household income (€/ month)**,[c]	≤ € 1500 per month	15.2 [19.0]	28.3	28.3
	€ 1501-3000 per month	34.6 [43.3]	43.6	43.6
	€ 3001-5000 per month	25.7 [32.2]	21.9	21.9
	> € 5000 per month	4.4 [5.5]	6.2	6.2
	n.a.	20.1 [0.0]	-	-
Household size**	Average size (std. deviation)	2.6 (1.06)	2.4	2.5
Household composition	With children (<18 years old)	28.8	25.7	-
	With retired persons (>65 years)	20.7	-	-
	Only adults (18-65 years old)	52.6	-	-

Source: Own elaboration.
Notes: ** stands for significant differences between sample and population according to the Chi-2 test (t-test in the case of household size). [a] Population figures for gender and age in Aragón in 2023, from INE (2024a); [b] Sources for the population are: INE (2024a) for gender and age (year 2023); EUROSTAT (2023) for education (year 2022); INE (2024b) for income (year 2023); INE(2024c) for household size (year 2024). [c] When non-reported values are considered, the population has significant differences. Non-significant differences are found, however, when the non-reported values are spread equally across categories (percentages in brackets).

The EU is perceived as a guarantor of food safety and a strict regulator regarding pesticide allowances. Participants believe to a greater extent that the EU impose higher requirements on pesticides and food safety standards than third countries (Mean score: 4.1 and 4.0, respectively). In contrast, there is mistrust of imported food products, showing in general disagreement with third countries imposing equivalent pesticides and food safety regulations (mean: 2.1 and 2.2, respectively). Finally, the EU origin as a quality marker received an average of 3.1.

Around 65% purchase tomatoes at least once a week, and 64% buy them year-round. Compared to the national average fresh tomato consumption (200g weekly, MAPA, 2024), 41% consume more and 39% consume at the average. The average price is € 2.6 per kg, with a median of € 2.5 per kg, while 75% of the respondents pay € 3 or less. About 25% purchase organic tomatoes, though only 2% exclusively purchase organic.

Table 3. Consumers' food and tomato purchase and consumption habits.

Variable	Indicator	% of respondents
Food purchases		
Respondent responsible for purchases	Always	57.4
	Often	34.7
	Sometimes	7.3
	Seldom	0.6
Organic food purchases	Yes	54.1
EU food safety perceptions: mean (std dev): 1-5 scale		
Higher pesticide requirements in the EU than in third countries		4.1 (0.91)
EU origin is a signal of quality		3.1 (1.14)
Imported food complies with EU pesticide requirements pesticides		2.1 (1.18)
Higher food safety standards in the EU than in third countries		4.0 (0.92)
Imported food complies with EU food safety standards		2.2 (1.20)
Tomatoes purchasing and consumption		
Tomato purchasing frequency	At least once a week	64.7
	Once or twice a month	30.7
	Never	4.6
Tomato purchasing seasons	Spring	16.7
	Summer	30.1
	Autumn	7.5
	Winter	6.5
	All seasons	63.9
Tomato consumption	Below average	20.3
	Average	39.0
	Above average	40.7
The price paid for tomatoes (€/kg)	Mean	2.6
	Median	2.5
	Percentile 75	3.0
Purchase of organic tomatoes	Organic	23.8
	Organic & conventional	20.9
	Organic only	1.7

Source: Own elaboration

Survey description

Before distributing the final survey, a pilot study with 60 respondents assessed the clarity of questions and the time required for completion. The survey was distributed by a specialised marketing research company with over 20 years of experience. This company has maintained a representative consumer panel since 2005, certified by ISO 20252 (International Organisation for Standardisation).

The survey comprised several parts. The first part included questions on food shopping, organic food purchasing, and attitudes towards organic food. The second part addressed subjective knowledge of plant breeding technologies (PBT) and perceptions of EU food safety. The third part focused on participants' tomato shopping and eating habits. In the fourth part, the DCE choice questions were included. Before completing the choice tasks, participants were provided information about PBT and EU regulations (Suppl. material, Annex-General information)[5].

Subjective knowledge was measured by asking participants to rate various breeding techniques, such as traditional, cisgenic, CRISPR, and transgenic (GMO), using a four-point scale (none, low, medium or high knowledge). Cisgenic and CRISPR are considered GE technologies that fall under the NGT regulation. Additionally, we assessed perceptions of the benefits and risks of CRISPR gene editing by evaluating 12 items (six benefits and six risks) using a five-point Likert scale (1 = totally disagree to 5 = totally agree), adapted from Baum et al. (2023) and Farid et al. (2020) along with participants' trust in various institutions (scientists, farmers, regulators, companies, media and social networks) using a five-point Likert scale (Farid et al., 2020; Uddin et al., 2022). Food technology neophobia was assessed using an abbreviated Borrello et al. (2021) scale and measured on a five-point Likert scale. Finally, background questions, including socio-demographics (i.e. gender, age, family size, income and education level), were asked. Since this study was part of a larger project, the questionnaire included additional sections not discussed in this paper.

Choice experiment design

The tomato was chosen as the product for our study as it is the most consumed vegetable in Spain, with a per capita home consumption of 11.2 kg/year in 2023 (MAPA, 2023). Spain was the most significant EU producer in 2023, producing over 1.5 million tonnes for fresh consumption (EC, 2024). In addition to the PBT attribute, which is the study's primary focus, four other attributes were considered: production method, pesticide reduction, origin and price. The production method (organic or conventional) was included to evaluate consumers' support for banning GE in organic production (see footnote #1 in the Introduction). In addition, we want to observe the effect of the organic attribute on CRISPR tomatoes. The reduction in pesticide use was incorporated to represent a potential environmental benefit that GE could deliver. We chose this attribute for two main reasons. First, this is one of the traits that have been shown in the past to reduce consumer resistance to gene-edited crops (Jones & Brown, 2023; Götz et al., 2022; Muringai et al., 2020; Paudel et al., 2023; Uddin et al., 2023; Vasquez et al., 2022). Second, pesticide reduction is relevant as the EU's "Farm to fork" strategy aims to halve pesticide use and risk by 2030. This target is also set at the global level in the Kunming – Montreal Global Biodiversity Framework, adopted by the Convention on Biological Diversity. As one of its 22 targets, this framework includes the reduction of pollution risks and the negative impact of pollution to levels that are not harmful to biodiversity and ecosystem functions. One of the pollution impacts explicitly mentioned for reduction is the overall pesticide risk. Moreover, the impact assessment of the NGT legislative proposal put forward by the EC was included as one of the case studies to highlight the benefits of modifying the regulation of NGT two varieties with pest resistance as a trait introduced via CRISPR (Schneider et al., 2023). The origin of production (EU versus non-EU) was selected to capture consumer reluctance to purchase fresh products from non-EU countries (Enthoven & Van den Broeck, 2021; Bouwman et al., 2024). Price was included as the last attribute to estimate each attribute's WTP. We collected data from different supermarkets and grocery stores to determine price levels. The tomato prices ranged between € 1.5 and € 6 per kg. These prices were the lowest and highest, with two additional intermediate levels, each increasing by € 1.5 per kg. Table 4 presents the selected attributes and their levels.

To further explore consumer valuations of CRISPR, our design also allowed us to estimate three two-way interaction effects. First, we investigated the interaction between CRISPR gene editing and pesticide reduction (CRISPR*Pesticide), with our hypothesis being that pesticide reductions enabled by this technology could mitigate negative perceptions of CRISPR. Second, we examined the interaction between CRISPR and the production method (CRISPR*Organic) to explore if organic production could soften negative perceptions (see footnote #1 in the Introduction), with our hypothesis being that its use in organic production could mitigate negative perceptions of CRISPR. Finally, we investigated the interaction between the origin of production and pesticide reduction (EU*Pesticide), considering whether a preference for domestic products arises from the perception that imported goods have higher pesticide levels. As an alternative hypothesis not directly related to CRISPR technology, we test whether claims of reduced pesticide use could mitigate this negative view of imports.

[5] The DCE included a between-subject design to test the impact of different types of additional information provided. However, in this study, we carry out a pooled analysis as we focus on the hypothesis that does not relate to the information treatment.

Table 4. Attributes, levels and coding used in the choice experiment.

Attribute	Levels	Variable name	Coding
Plant breeding technology (PBT)	Traditional CRISPR	CRISPR	One if PBT is CRISPR, zero otherwise
Production method (PROD)	Conventional Organic	ORGANIC	One if PROD is ORGANIC, zero otherwise
Pesticide reduction	0% 25% 50% 75%	PESTICIDE	Continuous
Origin of production	European Union Rest of the World	EU	One if the origin is EU, zero otherwise
Price	€ 1.5 kg-1 € 3.0 kg-1 € 4.5 kg-1 € 6.0 kg-1	PRICE	Continuous

Source: Own elaboration

The choice sets for the main and interaction effects were generated using efficient designs via NGENE software. The design produced choice cards with three alternatives (two hypothetical products and a 'no-buy' option), resulting in 24 combinations. To avoid overwhelming participants, these combinations were randomly divided into three blocks. Each respondent evaluated eight choices, with alternatives presented without a specific label (Alternatives A and B). An example of a choice card is provided in Figure 1.

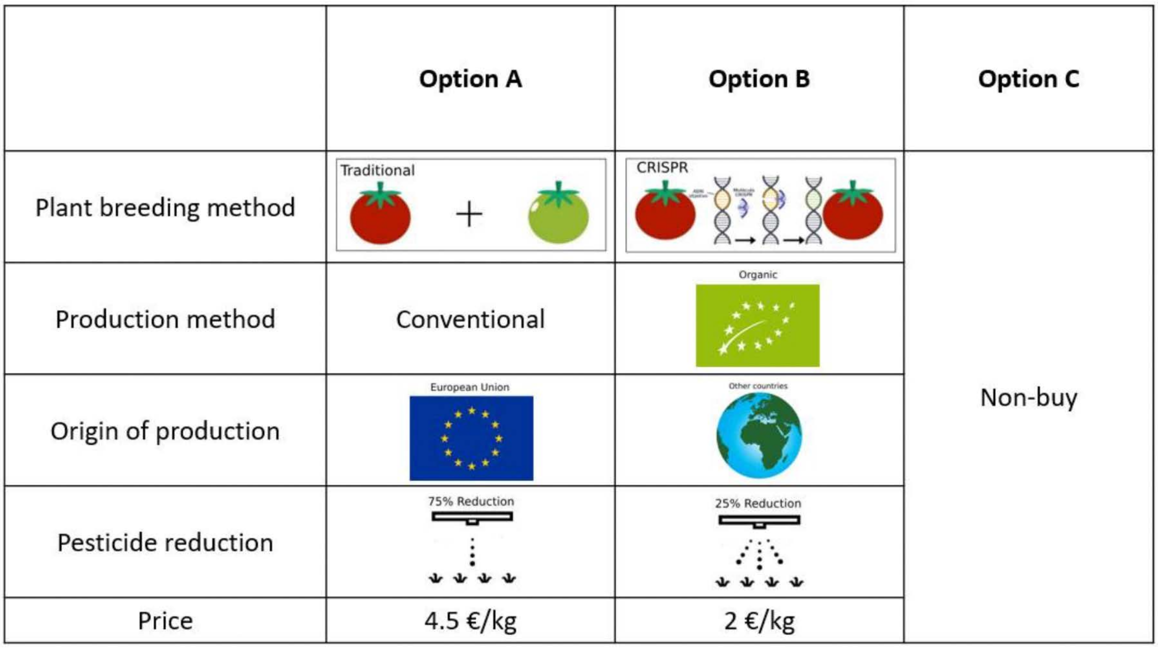

Figure 1. Example of a choice set.

Note: Translated version. Source: Own elaboration.

Model specification and estimation

In the DCE, consumers select their most preferred option among products described by varying attributes and levels; this option is assumed to be the one that maximises their utility. Therefore, the data collected can be modelled using Lancaster's consumer utility maximisation theory. According to this theory, consumers derive utility from product attributes rather than the product itself, where the total utility of a product is the sum of the separate utilities of its attributes (Lancaster, 1966). While this utility is known to the consumer, it remains partially observable by the researcher, who only observes specific characteristics, with the remaining utility treated as random, following the random utility theory (McFadden, 1974).

Consequently, utility is considered a stochastic variable. Our utility function for respondent *n* choosing alternative *j* from a set of *J* alternatives in each of *t* choice sets is defined as:

$$\begin{aligned} U_{njt} = NO - BUY + \beta_{PRICE} PRICE_{njt} + \beta_{CRISPR} CRISPR_{njt} + \beta_{ORG} ORGANIC_{njt} + \\ \beta_{PEST} PESTICIDE_{njt} + \beta_{EU} EU + \beta_{CRISPR\_PEST} CRISPR * PESTICIDE_{njt} + \\ \beta_{CRISPR\_ORG} CRISPR * ORGANIC_{njt} + \beta_{EU\_PEST} EU * PESTICIDE + \varepsilon_{njt} \end{aligned} \quad (1)$$

Here, the variable "NO-BUY" is coded as a dummy variable which values one if the no-buy option is selected and zero otherwise. We expect the coefficient on "NO-BUY" to be negative and significant, indicating that consumers derive less utility from the no-buy option than the alternatives (A and B), as they are regular tomato consumers. PRICE and PESTICIDE are continuous variables, reflecting the respective levels (see Table 4). CRISPR, ORGANIC and EU take the value one if the alternative has been developed using CRISPR technologies, produced following organic methods or produced in the EU, respectively. If that is not the case, they take the value 0. Interaction effects were calculated by multiplying the relevant attribute-specific variables (e.g. CRISPR*PESTICIDE, CRISPR*ORGANIC and EU*PESTICIDE). Finally, the error term ε_{njt} is independent and identically distributed over time, respondents, and alternatives.

As mentioned in the pre-registration the modelling of the DCE data will be done in a manner that we take account for heterogeneity in consumer preferences. From the three models mentioned and consistent with previous DCE studies, we estimated a Random Parameters Logit (RPL) model to obtain each parameter's means and standard deviations (Train, 2003). All coefficients, except PRICE, were assumed to follow a normal distribution. The model was estimated using STATA 18 (StataCorp LLC, 2023).

From the model results, we calculate the marginal and partial WTPs. The marginal WTP for an attribute/level m is calculated as the ratio of the attribute's utility to the marginal utility of income, as follows:

$$\mathrm{WTP_m} = -\frac{\beta_m}{\beta_{PRICE}} \quad (2)$$

The marginal WTP for an attribute interacted with another is calculated using either specific values for the interacted variables or the mean. For instance, the marginal WTP for a 1% reduction in PESTICIDE use is calculated as:

$$\mathrm{WTP_{PESTICIDE}} = -\frac{(\beta_{PEST} + \beta_{CRISPR\_PEST} * CRISPR + \beta_{EU\_PEST} * EU)}{\beta_{PRICE}} \quad (3)$$

CRISPR and EU can take a specific value (e.g. EU = 0, 1) or the average. To get marginal WTP for each of the possible levels of PESTICIDE, equation (3) evaluated at mean values of EU and CRISPR is multiplied by 0,25,50 or 75.

Likewise, the partial WTP for a combination of attribute levels is calculated by evaluating the attributes at specific values. For instance, the partial WTP for CRISPR at alternative values of pesticides is:

$$\mathrm{WTP_{CRISPR\ \&\ PESTICIDE}} = -\frac{(\beta_{CRISPR} + \beta_{CRISPR\_PEST} * PESTICIDE + \beta_{PEST} * PESTICIDE)}{\beta_{PRICE}} \quad (4)$$

Where PESTICIDE = 0, 25, 50 and 75. We use the term 'partial' so as not to be mistaken with the 'total' WTP, as strictly speaking, the total WTP should compare the monetary value of a product defined by selected values of all attributes with that of the no-buy value (Hensher, Rose and Greene, 2015).

WTP can be calculated using either the mean coefficients estimated (population WTP) or using specific coefficients for each consumer (conditional WTP) following Revelt & Train's (2000) proposal. We only present the conditional WTP (mean, median) for brevity, which varies marginally from population WTP.

Results

Knowledge of plant breeding technologies

Figure 2 presents the respondent's knowledge of CRISPR compared to other plant breeding technologies. Knowledge levels were generally deficient, with less than 5% of consumers declaring high knowledge of any technology. GMOs appeared somewhat better known than gene-editing alternatives. Traditional breeding was the least known. The lowest percentages of knowledge were seen with cisgenics (64%) and CRISPR (55%).

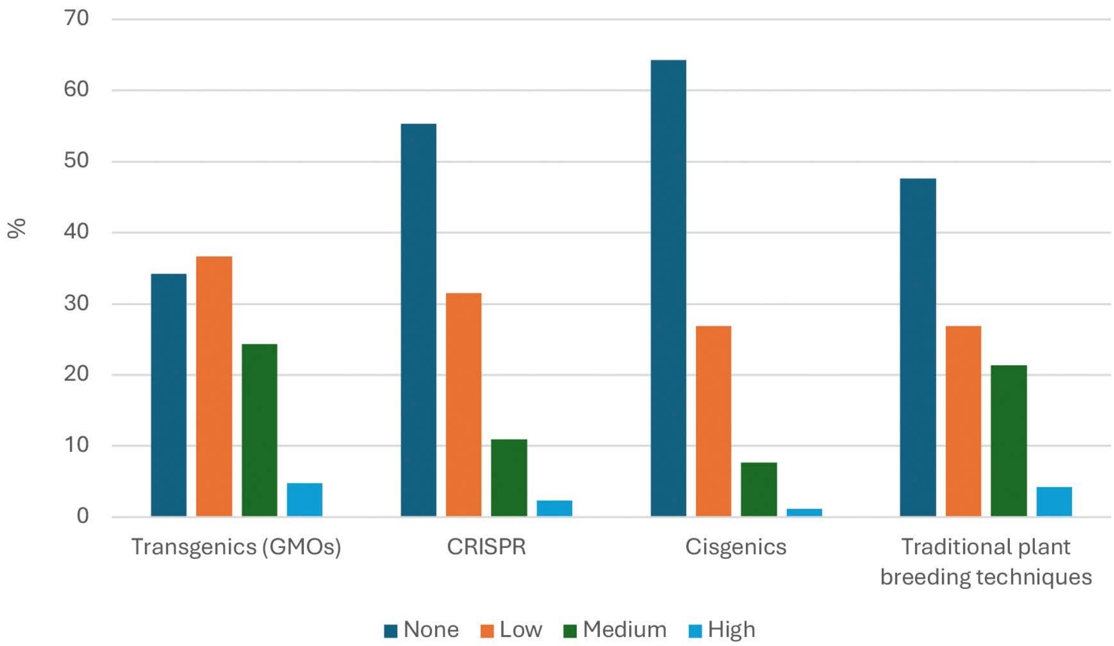

Figure 2. Declared knowledge of plant breeding technologies (% of respondents).

Source: Own elaboration.

Perceptions of potential benefits and risks associated with CRISPR

When evaluating perceptions of CRISPR and other new technologies through Likert scales (covering perception benefits, risks, trust in institutions, and food technology neophobia), instead of using the media for all the participants to provide results, we interpreted the percentage of participants for each point in the scale because the median was, in most cases, close to 3 which represents indifference. To provide a single value for each scale used for further analyses (e.g. independent variables for WTP estimations), responses (1 = "totally disagree" to 5 = "totally agree") of the different items in the scales were summed and mean, and median values are reported in Figures 3 to 5.

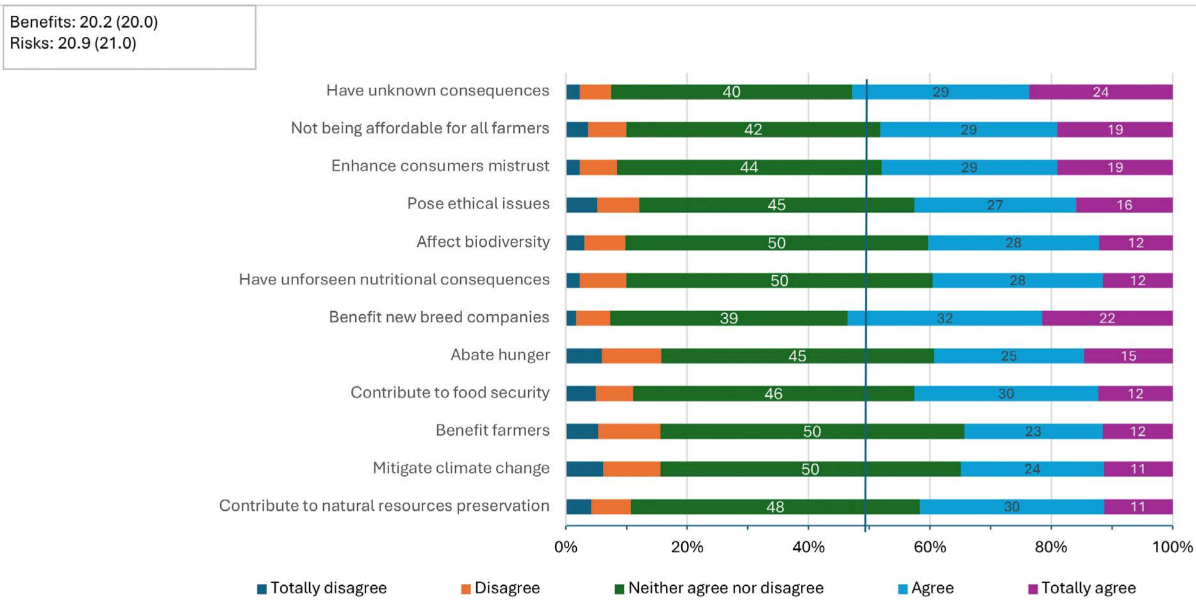

Figure 3. Perceptions about gene-editing technology (CRISPR) (% of respondents).

Source: Own elaboration. Notes: In the top left corner, the mean (median) of the aggregate score was obtained by adding up the valuations (between 1 "totally disagree" to 5 "totally agree") of the 6 items related to benefits and 6 to risks, respectively. The range of the aggregated score is 6-30.

Figure 3 summarises consumer beliefs about the benefits and risks of CRISPR. This question was posed after receiving some basic information that preceded the DCE (see Materials and Methods). Our results show that, on average, perceptions about gene-editing techniques were not favourable, aligning with findings that EU consumers may struggle to identify benefits and risks due to unfamiliarity (EFSA, 2022a; Dendler et al., 2023). For each of the 12 statements, the most common response was "neither agree nor disagree" (ranging from 39% to 50% of the response depending on the item), a pattern that reflects either uncertainty or lack of knowledge. Among the benefits, the percentage of respondents with the highest level of agreement (agree and totally agree) was more than 40% for three of them: 'benefits developer companies' (54%), 'contribute to food security' (43%) and 'contribute to natural resource conservation' (42%), with a minority of people stating disagreement (disagree and totally disagree), 7%, 11% and 11% of respondents, respectively. For the rest of the benefits, the percentage of respondents that agree lied between 34% and 39%. For the perceived risks, the highest percentage of respondents that agreed correspond to 'have unknown consequences" (53%), 'enhance consumers mistrust' and 'not being affordable for all farmers" (48%). On the other side, the level of disagreement was low for the three mentioned risks (7%, 8% and 10%, respectively). For the other three risks, the percentage of respondents with a higher level of agreement (agree and totally agree) ranged from 40% to 43%.

Trust in CRISPR-Related Institutions

Figure 4 reports respondents' level of trust in institutions that provided information about CRISPR. Between 40-49% selected the midpoint on the scale, indicating neither agree nor disagree. Scientists and regulations received the highest support (43% and 31% agree and totally agree). At the same time, social networks and media were the least trusted sources for CRISPR information, with 17% and 15% of respondents expressing their agreement or total agreement. Farmers and companies were in the middle position, who agreed (29%) or totally agreed (25%).

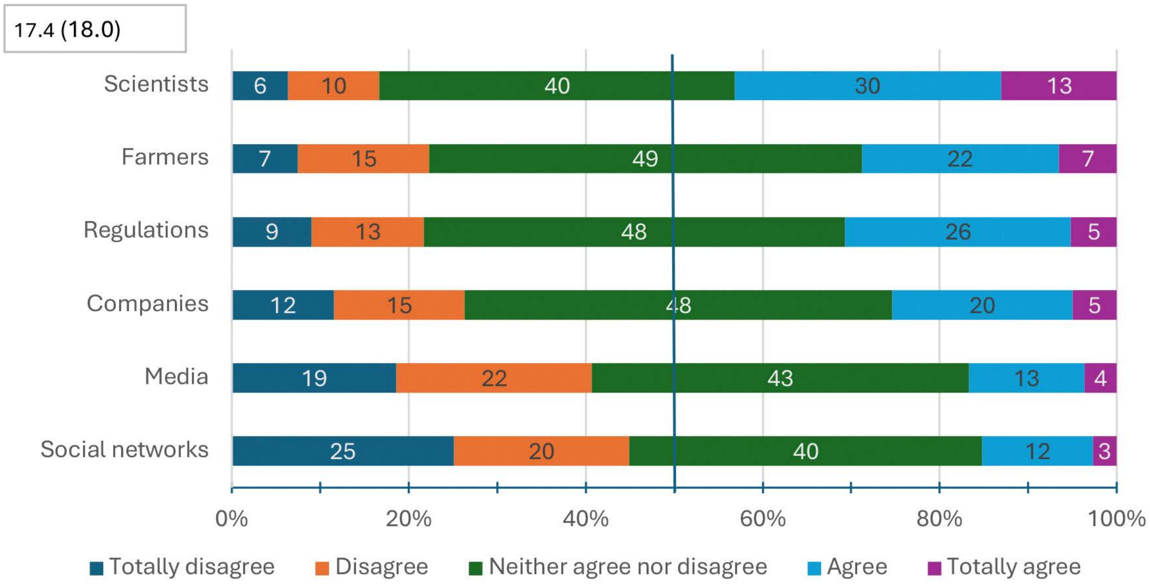

Figure 4. Trust in institutions that provide information about CRISPR (% of respondents).

Notes: In the top left corner, the mean (median) of the aggregate score was obtained by adding up the valuations (between 1 "totally disagree" to 5 "totally agree") of the 6 items. The range of the aggregated score is 6-30. Source: Own elaboration.

Food technology Neophobia Scale

Figure 5 details responses to the food technology neophobia scale, where agreement indicated reluctance towards new technologies. Most respondents selected the midpoint, though over 40% showed some degree of rejection of new technologies for most items.

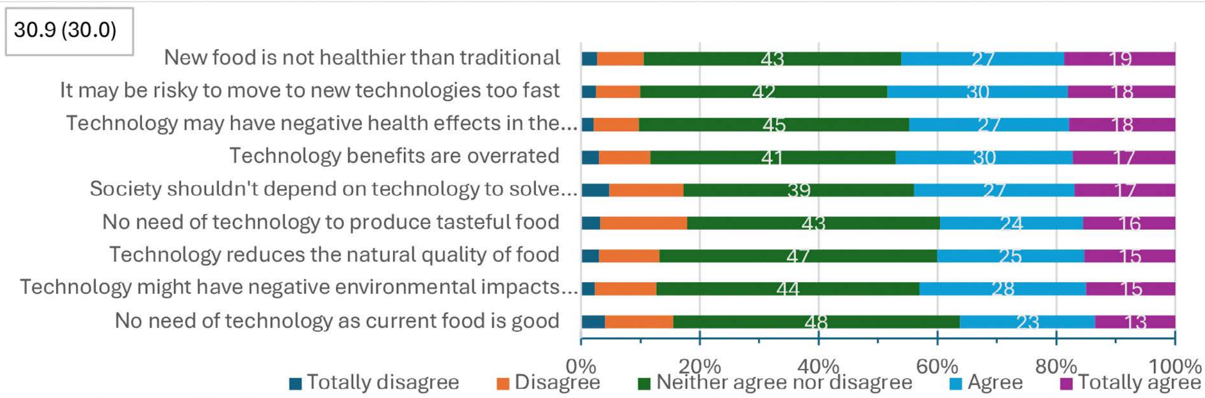

Figure 5. Scale of Phobia to new food technologies.

Source: Own elaboration.

Notes: In the top left corner, the mean (median) of the aggregate score was obtained by adding up the valuations (between 1 "totally disagree" to 5 "totally agree") of the 6 items. The range of the aggregated score is 9-45.

Estimation results

Table 5 presents the estimation results of the DCE for equation (1) using a RPL model. A more restrictive conditional logit and a RPL model without attribute interactions were also included for comparison. The main effects of the attribute levels were all statistically significant across models, and main implications were also common. Choosing the “no-buy” option was not preferred over the two alternatives, and utility increased as the price decreased. Confirming our hypotheses, traditional breeding was preferred over CRISPR technology (hypothesis #1), EU origin over imports (hypothesis #4), and utility raised as pesticide reduction increased (hypothesis #2). In addition, organic production was preferred over conventional methods.

Table 5. Estimation results of the RPL model.

	CL	RPL	RPL-interactions
		Means	
CRISPR	-0.376*** (0.054)	-0.554*** (0.088)	-0.503*** (0.119)
ORGANIC	0.335*** (0.047)	0.582*** (0.092)	0.551*** (0.100)
PESTICIDE	0.007*** (0.001)	0.012*** (0.002)	0.012*** (0.002)
EU	0.922*** (0.051)	1.300*** (0.108)	1.162*** (0.140)
PRICE	-0.377*** (0.015)	-0.586*** (0.040)	-0.586*** (0.040)
CRISPR* PESTICIDE			-0.004** (0.002)
CRISPR* ORGANIC			0.165 (0.126)
EU* PESTICIDE			0.004** (0.002)
NO-BUY	-1.305*** (0.076)	-2.010*** (0.141)	-2.028*** (0.141)
		Standard deviations	
CRISPR	--	1.261*** (0.119)	-1.231*** (0.115)
ORGANIC	-	1.309*** (0.091)	1.340*** (0.101)
PESTICIDE	-	0.024*** (0.002)	0.025*** (0.002)
EU	-	1.498*** (0.117)	1.478*** (0.113)
CRISPR* PESTICIDE			0.000 (0.002)
CRISPR* ORGANIC			-0.246 (0.345)
EU* PESTICIDE			-0.002 (0.002)
N	12504	12504	12504
No. choices	4168	4168	4168
No. individuals	521	521	521
R-square	0.15	0.24	0.24
LR	-	723.54 [0.000]	723.115 [0.000]
LL	-3689.124	-3327.353	-3327.566

Source: Own elaboration.
Notes: Robust standard errors per choice (individual and choice set) in parentheses. ***, ** and * are significant at 1, 5 and 10%, respectively. [a] Normal distribution is assumed for the random coefficients. McFadden Pseudo $R^2 = 1 - (LL/L0)$, where L0 is the log-likelihood in the intercepts-only model. LLR is the log-likelihood ratio to test for joint significance of standard deviations in the RPL (p-value in brackets).

Model fit improved when parameters were treated as random because the standard deviations of the parameter’s estimates were statistically different from zero. The Likelihood Ratio (LR) supports the joint significance across all four standard deviations. Therefore, we concluded that preferences were heterogeneous across individuals for each attribute considered.

Of the three interactions tested, only CRISPR*PESTICIDE (hypothesis #3) and EU*PESTICIDE (hypothesis #5) were statistically significant at a 5% significance level. The standard deviations of these interactions were not statistically significant, indicating that consumers’ preferences for these variables were homogeneous. The negative interaction term between CRISPR and PESTICIDE suggested that the utility of pesticide reduction decreases if this was associated with a CRISPR-developed variety. Therefore, while supporting this hypothesis, the capacity to compensate for disutility associated with the CRISPR technology used to develop pesticide resistance traits only leaded to acceptance at very high levels of pesticide reduction (around 63%)[6]. This reduction was at the higher end of evidence for field trials for potatoes and apples (Schneider et al. 2023), signalling the challenge developers face if they want market acceptance without price discounts.

On the other hand, the positive sign of the coefficient of the interaction EU*PESTICIDE suggested that preferences for each of these two characteristics were reinforced mutually when combined. In other words, EU production can enhance the positive valuation of higher pesticide reduction levels. Thus, both characteristics (EU origin and less use of pesticides) for tomatoes are complementary, and both can be used to reach consumers, but this was not the case for imported products, thus rejecting hypothesis 5.

As the interaction between CRISPR and ORGANIC was not significant, we fail to support our last hypothesis as the negative utility associated with the technology is not mitigated if used for organic production.

WTP estimates

Table 6 presents the marginal WTPs for each attribute, evaluated at mean values of the interacted variables as explained in the methodological section. The mean WTP for the EU origin was the highest, amounting to € 2.149 per kg, followed by the organic production, with a WTP of € 0.945 per kg. Consumers were willing to pay € 0.02 per kg for each per cent point of pesticide reduction. Thus, for a kg of tomato with a 75% reduction of pesticides, WTP would reach an average of € 1.5. In contrast, purchasing CRISPR gene-edited tomatoes would require a refund of € 1.048 per kg to gain consumer acceptance.

The lower panel in Table 6 shows the partial WTP for specific combinations of attribute levels. Thus, WTP for CRISPR was € -0.86 per kg if the developed variety had no impact on pesticide use, decreasing to € -0.53 and € -0.21 per kg if the variety leaded to a 25% and 50% reduction in pesticide use, respectively, and to 0 if the variety reached 75% in pesticide use (note that the reported value +0.11 was not statistically, significantly different from 0). At around 67% pesticide reduction, the WTP for CRISPR become null on average. This result suggested that consumers' negative valuation of CRISPR could be mitigated by pesticide reduction, which this technology could bring but would require a substantial reduction.

Considering that the EU*PESTICIDE interaction was positive, the WTP for pesticide reduction was higher for EU tomatoes (€ 0.025 per 1% pesticide reduction) than for tomatoes from other countries (0.018). Likewise, the value attached to the EU origin increased significantly with the reduction in pesticides: from €1.97 at a 0% reduction to €4.1 at a 75% reduction. In comparison, the value attached to non-EU tomatoes would range between 0 and €1.5 at 0% and 75% pesticide reduction, respectively.

Table 6. Willingness to pay (RPL with interactions).

	CRISPR	ORGANIC	PESTICIDE	EU origin
Marginal WTP				
Mean [a]	-1.048***	+0.945***	+0.020***	+2.149***
Median [a]	-0.830	+0.958	+0.023	+1.947
At Pest = 0 [b]			0.000	
At Pest = 25 [b]			+0.512***	
At Pest = 50 [b]			+1.023***	
At Pest = 75 [b]			+1.535***	
At EU = 1 [b]	-	-	+0.025***	-
At EU = 0 [b]	-	-	+0.018***	-

[6] Based on coefficients in Table 5 and solving: -0.503 + x*0.012 – x*0.004≥0. Later, we calculate this value exactly using the individual coefficients for each respondent, which leads to 67%.

Partial WTP (on a combination of attribute-levels)			
	CRISPR & PESTICIDE		**EU & PESTICIDE**
At Pest = 0 ^{c}	-0.856 ***	-	+1.969*** [0.000]
At Pest = 25 ^{c}	-0.532***	-	+2.664*** [0.515***]
At Pest = 50 ^{c}	-0.209**	-	+3.360*** [1.031***]
At Pest = 75 ^{c}	+0.115	-	+4.056*** [1.546***]

Source: Own elaboration.
Notes: Conditional WTP calculates specific coefficients for each individual using Revelt and Train's (2000) proposal and are obtained in Stata with the mixlbeta command (with 200 Halton draws and 15 burned elements) after estimation with mixlogit. Then, WTP is calculated as the quotient between the attribute and the price coefficient (changed of signed). a Marginal WTP for an attribute/level evaluated at mean values of the interacted variables. b Marginal WTP for pesticide reduction (either 1% or alternative values) calculated as in equation (4). c WTP for CRISPR for alternative values of PESTICIDE calculated as in equation (5). Similarly, WTP for EU & PESTICIDE uses both the coefficients on the main effects and the interactions for values of PESTICIDE indicated in the first column as in equation (5).
***, **, * stand for significance at 1, 5 and 10%, respectively, according to the means comparison one-sample t-test.

Profile of Consumers Less Reluctant to CRISPR

To get further insights about the rejection of CRISPR technology, the individual conditional WTP was crossed with socio-demographic characteristics, food and organic food purchase, EU food safety perceptions, tomato purchase and consumption habits, knowledge of CRISPR, perceptions of CRISPR's benefits and risks, trust in CRISPR-related institutions and new technology phobia. Table 7 only reports those associations that were found statistically significant.

The first significant finding was that WTP for CRISPR-edited tomatoes without any additional benefit was negative for all consumer profiles. Nevertheless, we can see that resistance to CRISPR (as measured by negative WTP) varied significantly depending on education and income, with higher reluctance to the technology associated with higher levels of studies attained and higher incomes. Other socio-demographic variables, such as gender and age, were not statistically related to the CRISPR WTP. Interestingly, food and tomato consumption habits like the intensity of consumption, the frequency of purchases and the regularity of consumption throughout the year were not significantly associated with the WTP for CRISPR technology.

The WTP for CRISPR was positively correlated with the perception of the beneficial effects of such technology and negatively correlated with the perceptions of risks. In other words, consumers with a more positive perception of the possible benefits of the technology also demand a lower discount to accept CRISPR-edited varieties (0.708 and 1.298 for consumers above and below the median score of perceived benefits, respectively). Likewise, the higher the perception of risks derived from the technology, the lower (more negative) the WTP: the average WTP for CRISPR with a value of -1.237 and -0.911, when the negative perception was above and below the median, respectively. On the other hand, trust in the institutions related to CRISPR was positively correlated with WTP, with a significant gap between those consumers who trusted more (above the median) and less, with respective WTP of -0.623 and -1.274. Finally, consumers more phobic towards new food technologies were also more reluctant to use CRISPR, showing a lower WTP. Thus, on average, consumers with phobia above the median score had a mean WTP for CRISPR of -1.255, while the mean WTP was -0.85 for those consumers with phobia levels below the median.

Table 7. Conditional WTP for CRISPR per subgroup of consumers (€/kg).

Panel a. Categorical variables: Kruskal-Wallis non-paremetric test (KW) [p-value].		
Variable	**Indicator**	**WTP (mean)**
Education *	Compulsory (primary, secondary)	-0.779
	High school or equivalent	-1.053
	University	-1.147
	KW [pval]	4.995 [0.082]
Income*	≤ € 1500 per month	-0.738
	€ 1501 - 3000 per month	-1.026
	€ 3501-5000 per month	-0.958
	> € 5000 per month	-1.518
	n.a.	-1.332
	KW [pval]	11.800 [0.019]
Panel b. Continuous variables: Spearman correlation (CORR) [p-value]		
Variable	**Indicator**	**WTP (mean)**
Perceptions about gene-editing technology: benefits***	Above median score	-0.708
	Below median score	-1.298
	CORR [pval]	0.196 [0.000]
Perceptions about gene-editing technology: risks ***	Above median score	-1.237
	Below median score	-0.911
	CORR [pval]	-0.117 [0.008]
Trust in CRISPR-related institutions ***	Above median score	-0.623
	Below median score	-1.274
	CORR [pval]	0.228 [0.000]
New technology phobia***	Above median score	-1.255
	Below median score	-0.850
	CORR [pval]	-0.169 [0.000]

Source: Own elaboration based on conditional WTP estimated with Model RPL-interactions in Table 4.
Notes:***, ** and * denote significant differences at 1, 5 and 10%, respectively, according to panel a) the Kruskal-Wallis (KW) non-parametric test across subgroups of consumers defined by variable indicators; panel b) the Spearman correlation between the WTP and the variable.

Discussion

This is the first EU study to analyse consumer behaviour towards CRISPR-edited food after the EU's regulatory advancements (July 2023), it aims to provide more representative insights into the consumer valuation of such products. In overall, purchasing CRISPR gene-edited tomatoes in Spain would require a €1.048 per kg discount to gain consumer acceptance. This finding aligns with several studies that have reported significant discounts for food products developed using GE (Muringai et al., 2020; Yang & Hobbs, 2020; Borrello et al., 2021; Marette et al., 2021a; 2021b; McFadden et al., 2021; Martin-Collado et al., 2022; Ortega et al., 2022; Ufer et al., 2022; Hao et al., 2024). However, a positive WTP for CRISPR was observed when pesticide reduction reached 67%, indicating that consumers' negative valuation of CRISPR could be mitigated by the pesticide reduction benefit that this technology could offer (Deng et al., 2024).

These findings reveal a complex landscape where consumer preferences are deeply rooted in cultural identity, ethical considerations, and trust in regulatory frameworks.

Cultural perspectives

The findings highlight a strong cultural preference among Spanish consumers for EU-grown food products, driven by perceptions of higher safety standards and stricter regulations. This reflects a broader European cultural identity tied to trust in institutional frameworks and a preference for locally sourced products (EFSA, 2022b; European Parliament, 2024c). The emphasis on origin labelling, supported by 93% of EU respondents, underscores a cultural value placed on transparency and traceability in food production. This cultural inclination is further reinforced by the rise of organic farming, which aligns with growing environmental consciousness and a preference for "natural" food production methods (Edenbrandt et al., 2017; Edenbrandt, 2018; Götz et al., 2022; Tran et al., 2023). However, the low awareness and negative perceptions of GE technologies like CRISPR reveal a cultural conservatism towards novel food technologies. This neophobia is not unique to Spain but is consistent across the EU, where consumers tend to be more sceptical of innovations in food production compared to regions like the U.S. or Japan (Marette et al., 2021a; Bearth et al., 2022; Kato-Nitta et al., 2022). Cultural narratives around food safety, tradition, and naturalness play a significant role in shaping these attitudes. For instance, participants expressed risk perceptions and mistrust, agreeing with statements that GE technologies 'can have unknown consequences', 'may not be affordable for all farmers', and 'enhance consumers' mistrust' (EFSA, 2022a; Dendler et al., 2023; Strobbe et al., 2023).

Ethical Perspectives

Ethical concerns are central to consumer hesitancy towards GE technologies. Participants expressed fears about "unknown consequences" and the potential for these technologies to exacerbate inequalities, such as making them unaffordable for smaller farmers. These concerns reflect broader ethical debates about the role of technology in agriculture, including questions of equity, sustainability, and the precautionary principle (Siddiqui et al., 2022). The preference for organic products, even when GE alternatives offer similar benefits (e.g., pesticide reduction), suggests that consumers prioritise ethical considerations over purely utilitarian outcomes. This aligns with the ethical framework of "naturalness," where organic farming is perceived as more aligned with ecological and moral values (Edenbrandt et al., 2017; Edenbrandt, 2018). Additionally, the mistrust of third-country imports highlights ethical concerns about global trade practices and the potential exploitation of weaker regulatory frameworks in non-EU countries. Reports from EFSA and the media have noted that while the risk to consumer health from pesticide residues is low, imports from third countries are four times more likely to exceed recommended levels, necessitating close monitoring (EFSA, 2023; Fortuna, 2024).

Legal Perspectives

From a legal standpoint, the EU's stringent regulatory environment for food safety and pesticides is a key factor shaping consumer trust. The EU's precautionary approach to GE technologies, which requires rigorous safety assessments and labelling, contrasts with more permissive regulatory frameworks in countries like the U.S. This legal context influences consumer perceptions, as evidenced by the higher trust in scientists and regulatory bodies compared to journalists or influencers (Martin et al., 2016; EFSA, 2022b; Cummings & Peters, 2022). However, the lack of familiarity with GE technologies also points to a gap in public communication and education about the legal safeguards in place. The EU's regulatory framework for CRISPR and other GE technologies is often perceived as overly restrictive, which may hinder innovation while simultaneously reinforcing consumer skepticism (De Marchi et al., 2021). Legal mandates for origin labelling and transparency in food production further reflect the EU's commitment to consumer rights and informed choice, which resonates strongly with public sentiment (European Parliament, 2024c).

In summary, targeted communication strategies that address cultural values, ethical concerns, and legal safeguards are essential. For instance, emphasising the environmental and social benefits of GE technologies, such as reduced pesticide use and enhanced food security, could help align these innovations with consumer values (Yang et al., 2022; Baum et al., 2023). Additionally, transparent labelling and educational campaigns could mitigate fears and build more trust in the regulatory framework (De Marchi et al., 2021; Deng et al., 2024).

Study limitations

This study has several limitations. Firstly, measuring stated preferences (WTP) through an online survey may be subject to hypothetical bias (Murphy et al., 2005) and social desirability bias (Fisher, 1993). Additionally, self-selection bias (Berk, 1983) may have influenced our results. We may have also overlooked other essential factors in consumer preferences, such as sensory aspects (e.g. taste), which can affect perceptions of GE-derived foods (Uddin et al., 2022; Orivri et al., 2023). We acknowledge that one possible limitation is the inclusion of market combinations that may currently be perceived as unrealistic (e.g., CRISPR and organic). While this was likely permitted due to the hypothetical nature of the experiment, it is important to note that the combination of CRISPR and organic is actively being discussed by researchers and the food industry. In fact, this combination has already been studied in the US, where organic certification currently excludes GMOs, but it may have future implications if regulatory changes allow for its inclusion (Caputo et al., 2025). While our estimated price premiums may not perfectly reflect real-world valuations, they maintain a consistent relative result compared to existing literature, providing valuable insights.

Practical implications

The results provide valuable insights that can inform strategies for labelling GE foods in the EU. For instance, labels for GE foods should clearly indicate the origin of the products, emphasizing EU-grown ingredients where applicable. This aligns with consumer preferences for locally sourced products and reinforces trust in EU safety standards. Labels should emphasize compliance with EU safety standards and regulatory approvals. This may alleviate consumer concerns about the safety of GE foods. Labels should also clearly communicate the specific benefits of the GE technology used, in consumer-friendly language and visuals (e.g., icons or infographics) such as “Reduced Pesticide Use by 75%” or “This CRISPR-edited tomato uses 75% fewer pesticides, protecting the environment.” Labels should address ethical and environmental concerns by highlighting how GE technologies contribute to sustainable agriculture and fair practices. That can be done by including statements like “Supports Sustainable Farming” or “Helps Small Farmers Reduce Costs.” Labels might also reference trusted sources, such as scientific institutions or regulatory agencies (e.g., “Developed in collaboration with [University/Research Institution]”), to validate claims about GE foods. Additionally, labels should be part of broader educational campaigns that explain GE technologies, their safety, and their benefits.

Overall, labels can play a crucial role in enhancing the acceptance of CRISPR-edited foods by promoting transparency, safety, benefits, and trust while addressing consumer concerns and supporting educational campaigns. This labelling approach, combined with pricing strategies aligned to pesticide reduction levels (e.g., neutral pricing for 67%+ reductions), can be a penetration pricing strategy to build CRISPR acceptance and facilitate initial market entry without relying on a discounted price. These strategies should be tailored to EU consumers’ specific needs and preferences, ensuring that GE foods are perceived as safe, beneficial, and aligned with their values.

Conclusions

This study sheds light on consumer behaviour and willingness to pay (WTP) for CRISPR-edited tomatoes among consumers in Northern Spain. The results show that gene-edited tomatoes would need to be sold at a significant discount in the absence of environmental co-benefits. However, this discount could diminish significantly if the GE tomatoes were marketed, highlighting environmental co-benefits such as pesticide use reduction. Findings also reveal that consumers prefer tomatoes grown within the EU and those produced organically. Overall, while the revised regulatory frameworks may facilitate the development of CRISPR-edited varieties in the EU, our findings suggest that Spanish consumers remain cautious and would need additional beneficial characteristics to accept CRISPR-edited tomatoes readily. Breeders will need to focus on developing traits that consumers value to capture a premium in the market to recover the investments in research and development. While our study focused on Spanish consumers, our findings can inform consumer acceptance of CRISPR-edited food products in other regions and parts of the world.

The findings highlighted that consumer acceptance of CRISPR-edited food increases when positive information about the benefits of this technology is highlighted. Hence, further research should focus on selecting information addressing critical global challenges, such as environmental and health benefits, to explore their influence on consumer preferences and WTP. Such information will aim to develop more effective communication strategies and public policies.

Supplementary material (Table S1 and Annex-General Information): accompanies the paper on SJAR's website.

Data availability: The authors have full access to the data reported in the manuscript and will provide them upon request.

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