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

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Running title: Are Consumers in Spain Ready for Gene-Edited Crops? Insights from a CRISPR Tomato Study.

Topic: Agricultural economics.

Six tables and seven figures

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 chose 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 Spanish consumers are not ready to accept the CRISPR-edited tomatoes at face value, requiring additional assurances or specific benefits before acceptance.

Keywords: Consumer behaviour, CRISPR, choice experiment, willingness to pay, Spain.

Abbreviations used: CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats); DCE (Discrete Choice Experiment); EC (European Commission); EU (European Union); GE (Genome Editing); GM (Genetically Modified); GMO (Genetically Modified Organisms); NGTs (New Genomic Techniques); WTP (Willingness to Pay).

Título: ¿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 enfrentan 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, experimento de elección, disposición a pagar, España.

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 can be completed in just a few days, with production costs 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 European Court of Justice clarified that NGT varieties fall under EU GMO regulations (Vives-Vallés & Collonnier, 2020). Subsequently, the potential of NGTs to support the transition to sustainable food systems has raised a debate regarding the need for a differentiated approach to regulating these crops (Wesseler *et al.*, 2022). Indeed, several studies suggest that facilitating their approval compared to GMOs could bolster key agricultural initiatives, including the EU's Farm to Fork strategy and 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 (European Commission, 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 on 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.

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 European consumers are poorly informed about NGTs. An EU-wide survey run by EFSA on 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 the valuation of varieties developed with gene editing, while earlier studies reported similar consumer valuation for GE and GM foods among Canadian consumers (Muringai *et al.*, 2020; Yang & Hobbs, 2020; Vasquez *et al.*, 2022), more 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). 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).

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). Despite mixed results on consumers preferences (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) and farmers attitudes (Ferrari, 2021), studies revealed limited consumer knowledge about GE technologies (Caputo *et al.*, 2020; Götz *et al.*, 2022; Deng *et al.*, 2024).

Evidence of consumer attitudes and preferences for gene-edited food is still scarce, primarily focused on the US and Canada. Lemarié & Marette (2022) highlighted that the general population's limited knowledge of GE is generally 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). 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. Nguyen *et al.* (2021) emphasised that GE developers face consumer knowledge deficits as the public struggles to distinguish between GE and GM technologies. Consequently, labelling could help gene-edited products gain wider consumer acceptance. Overall, a system that generates consumer trust would improve the likelihood of market success for gene-edited crops. Another factor significantly affecting consumer acceptance of gene editing is the ownership of the developed traits. Lusk *et al.* (2018) found that support for resistance to genetically engineered food or crops is higher when academic institutions or the state creates the varieties.

Despite these 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 three 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).

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 European Commission 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

[1] We are aware that under the legislative proposal of the Commission use of NGTs remains prohibited for organic farming. However, the position of the organic sector regarding this ban is not homogenous nor 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.

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). The study was pre-registered before data collection, and here we focus on the analysis of the pooled data to test the six hypotheses described in section 2 of the pre-registration, which are summarised in table 7[2].

Data Collection and Survey Description

The DCE was executed 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). Data collection occurred in Aragón, north-eastern Spain, in April 2024. The target population consisted of household food shoppers over 18 years old who consumed tomatoes at home. Consumers were stratified by gender and age.

A pilot survey with 60 respondents assessed the clarity of questions and the time required for completion before distributing the final questionnaire. 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 (see Annex I)[3].

[2] The study was pre-registered on 3/14/24 on the *aspredicted.org* platform before starting the data collection (#166206).

[3] As mentioned in the pre-registration, 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 pre-registered hypothesis that does not relate to the information treatment.

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 2022 (MAPA, 2023). Spain was the most significant EU producer in 2023, producing over 1.5 million tonnes for fresh consumption (European Commission, 2024). In addition to the PBT attribute, which is the study's primary focus, four other attributes were considered: production method, pesticide reduction and origin. The production method (organic or conventional) was included to evaluate consumers' support for banning GE in organic production (see footnote #1). 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). Last, 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 1 presents the selected attributes and their levels.

{Approximate position of Table 1}

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 pre-registered 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), with our pre-registered 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 a related pre-registered hypothesis not directly related to CRISPR technology, we test whether claims of reduced pesticide use could mitigate this negative view of imports.

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.

{Approximate position of Figure 1}

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:

$$U_{njt} = \alpha + \beta_{PRICE} PRICE_{njt} + \beta_{CRISPR} CRISPR_{njt} + \beta_{ORG} ORGANIC_{njt} + \beta_{PEST} PESTICIDE_{njt} + \beta_{EU} EU + \beta_{CRISPR\_PEST} CRISPR * PESTICIDE_{njt} + \beta_{CRISPR\_ORG} CRISPR * ORGANIC_{njt} + \beta_{EU\_PEST} EU * PESTICIDE + \varepsilon_{njt} \quad (1)$$

Here, coefficient α represents the alternative-specific constant, coded as a dummy variable with 1 for alternatives A and B and 0 for the no-buy option. We expect α to be positive and significant, indicating that consumers derive more utility from the alternatives (A and B) than the no-buy option, as they are regular tomato consumers. PRICE and PESTICIDE are continuous variables, reflecting the respective levels (see Table 1). 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 εnjt 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 total 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:

$$\mathrm{WTP_m} = -\frac{\beta_\mathrm{m}}{\beta_\mathrm{PRICE}} \quad (3)$$

The WTP is calculated using specific values for the interacted variables to incorporate interactions between attributes. For simplicity, we use the mean. For instance, the marginal WTP for EU origin is calculated as:

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

Where PESTICIDE takes any particular value or for instance the average.

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

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

Where PESTICIDE = 0, 25, 50 and 75. 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

The sample

We collected responses from 550 individuals. However, as stated in the pre-registration, we excluded 29 individuals who consistently chose the no-buy option in all tasks (serial status quo choosers) as they might not have been interested or willing to engage with the survey. These 29 individuals were predominantly females (72%), respondents over 55 years old, and those with a high education level (55%). A significant portion (38%) opted not to disclose household income. Most belong to households with adults between 18 and 65 years old (52%) and purchase tomatoes twice a month (35%). Many lack knowledge about traditional tomato breeding (69%) and CRISPR technology (79%). For a detailed profile, refer to Annex II. As the

DCE results do not substantially change when excluding these individuals, the rest of this section relates to the sample of 521 consumers[4]. Table 2 provides the socio-demographic description with comparisons to population data where available.

The sample is representative of Aragon's population in terms of gender. Age distributions match the population closely for those up to 44 years old, but the sample slightly under-represents individuals aged over 55 years (39.5% versus 43.6%). The sample is also moderately biased towards more educated respondents (53% hold a university degree compared to 43% of the population). This is a consistent pattern from samples taken from online panels; however, the differences in age and education between the sample and population are not statistically significant. 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, we find an upward income bias. However, the average monthly income[5] remains comparable: € 3,086 in the sample versus € 2,919 in the population (INE, 2023). The average household size is 2.6, consistent with the population, and 29% of respondents live in households with children.

{Approximate position of Table 2}

Purchasing, Consumption and Perception Analysis

The sample's purchasing and consumption habits and perceptions of EU food safety aspects are shown in Table 3. 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.

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). 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

[4] 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%.

[5] 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.

2.2). Finally, the EU origin as a quality marker received an average of 3, but with a large dispersion.

{Approximate position of Table 3}

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.

Knowledge of plant breeding technologies

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

{Approximate position of Figure 2}

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 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 are 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) is 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 lies between 34% and 39%. For the perceived risks, the highest percentage of respondents that agree 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 is 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) ranges from 40% to 43%.

{Approximate position of Figure 3}

Trust in CRISPR-Related Institutions

Figure 4 reports respondents’ trust level in institutions associated with 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 are in the middle position, who agree (29%) or totally agree (25%).

{Approximate position of Figure 4}

Food Technology Neophobia Scale

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

{Approximate position of Figure 5}

Estimation Results

Table 4 presents the estimation results of the DCE for equation (1) using a Random Parameter Logit (RPL) model. A more restrictive conditional logit and an RPL model without attribute interactions are also included for comparison. The main effects of the attribute levels are all statistically significant across models, and main implications are also common. Choosing any of the two alternatives with specific attributes (α) is preferred over the no-buy option, and utility increases as the price decreases. Confirming our pre-registered hypothesis, traditional breeding is preferred over CRISPR technology (pre-registered hypothesis #1) EU origin over imports (pre-registered hypothesis #4) and utility rises as pesticide reduction increases (pre-registered hypothesis #2). In addition, organic production is preferred over conventional methods.

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

Of the three pre-registered interactions tested, only CRISPR*PESTICIDE (pre-registered hypothesis #3) and EU*PESTICIDE (pre-registered hypothesis #5) are statistically significant at a 5% significance level. The standard deviations of these interactions are not statistically significant, indicating that consumers' preferences for these variables are homogeneous. The negative interaction term between CRISPR and PESTICIDE suggests that the utility of pesticide reduction decreases if this is 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 leads to acceptance at very high levels of pesticide reduction (around 63%)[6]. This reduction is 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 suggests that preferences for each of these two characteristics are 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 while this is not the case for imported products, thus rejecting hypothesis 5.

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

[6] Based on coefficients in Table 4 and solving: $-0.503 + x*0.012 - x*0.004 \geq 0$. Later, we calculate this value exactly using the individual coefficients for each respondent, which leads to 67%.

{Approximate position of Table 4}

WTP estimates

Table 5 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 is the highest, amounting to € 2.149 per kg, followed by the organic production, with a WTP of € 0.945 per kg. Consumers are 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 5 shows the total WTP for specific combinations of attribute levels. As mentioned, the interaction CRISPR*PESTICIDE is negative, highlighting consumers' negative valuation for CRISPR as the percentage of pesticide reduction increases to a specific point. Thus, WTP for CRISPR is € -0.86 per kg if the developed variety has no impact on pesticide use, decreasing to € -0.53 and € -0.21 per kg if the variety leads to a 25% and 50% reduction in pesticide use, respectively. Consumers would be willing to pay a premium for CRISPR-developed varieties if these led to a reduction in pesticide use of 75% (+0.11). At around 67% pesticide reduction, the WTP for CRISPR becomes positive on average. This result suggests 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 is positive, the WTP for pesticide reduction is higher for EU tomatoes (0.025) than for tomatoes from other countries (0.018). Likewise, the value attached to the EU origin increases 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.

{Approximate position of Table 5}

Figure 6 shows the distribution of WTP for the attributes/levels. This distribution shows the heterogeneity of preferences towards the CRISPR technology; the median for CRISPR (-0.83) is remarkably larger than the mean (-1.048); thus, preferences towards the CRISPR technology are left skewed. While on average, WTP is negative, around 20% of the consumers in the sample would be willing to pay a positive amount (€ 0.80 on average).

{Approximate position of Figure 6}

Profile of Consumers Less Reluctant to CRISPR

To get further insights about the rejection of CRISPR technology, the individual conditional WTP is 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 6 only reports those associations that were found statistically significant.

{Approximate position of Table 6}

The first significant finding is that WTP for CRISPR-edited tomatoes without any additional benefit is negative for all consumer profiles. Nevertheless, we can see that resistance to CRISPR (as measured by negative WTP) varies 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, are 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 are not significantly associated with the WTP for CRISPR technology.

The WTP for CRISPR is 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 is above and below the median, respectively. On the other hand, trust in the institutions related to CRISPR is positively correlated with WTP, with a significant gap between those consumers who trust more (above the median) and less, with respective WTP of -0.623 and -1.274. Finally, consumers more phobic towards new food technologies are also more reluctant to use CRISPR, showing a lower WTP. Thus, on average, consumers with phobia above the median score have a mean WTP for CRISPR of -1.255, while the mean WTP is -0.85 for those consumers with phobia levels below the median.

Discussion

Numerous scientific studies highlight the potential advantages of CRISPR technology in meeting the world's growing food demands sustainably. However, public acceptance is essential for the widespread adoption of CRISPR in food production (Wolter & Puchta, 2017; Gao, 2018; Shew *et al.*, 2018), particularly in Europe, where using any NGT for human food production is prohibited. Currently, literature specifically addressing consumer behaviour towards CRISPR-edited food is limited compared to studies on consumer acceptance of GE and GM plant breeding technologies (Shew *et al.*, 2018; Götz *et al.*, 2022; *Deng et al.*, 2024). This is mainly because CRISPR is a relatively new technology (Caputo *et al.*, 2020; Götz *et al.*, 2022; Deng *et al.*, 2024). As 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.

Our results suggested that Spanish consumers generally view EU food products as safe. Participants expressed confidence that the EU enforces stricter regulations on pesticides and food safety standards than non-EU countries. This sentiment is reflected in their mistrust of imported food products, with many believing that third countries do not comply with the same pesticide and food safety regulations as the EU (Table 3). This aligns with data indicating that 70% of respondents across the EU are 'personally interested' in food safety issues and that awareness of food safety is high within the EU (EFSA, 2022b). Reports from EFSA and the media may have influenced these views, noting that while the risk to consumer health from pesticide residues is low, imports from third countries need close monitoring as they are four times more likely to exceed recommended levels (EFSA, 2023; Fortuna, 2024).

Regarding knowledge and perceptions of plant breeding technologies and institutional trust, Spanish consumers report deficient knowledge (Figure 2). Surprisingly, GMOs are slightly better known than GE alternatives, while traditional breeding is the least recognised technology. This finding aligns with studies by Hu *et al.* (2022) in the U.S. and Dendler *et al.* (2023) across three EU countries, which found a significant lack of familiarity with GE compared to GMOs. According to EFSA's 2022 report, only 29% of respondents had heard of GE, and 25 % had heard of nanotechnology in food production, ranking them as the lowest in awareness (EFSA, 2022b). Although few studies compare consumer perspectives on GE and GMO foods (Atimango *et al.*, 2024), consistent findings suggest that knowledge and awareness of GE technologies are notably lower than those of GMOs, especially in the EU (EFSA, 2019).

The results indicate that, on average, participants have an unfavourable perception of GE techniques, including CRISPR (Figure 3). This outcome is expected, as EU consumers may struggle to identify benefits due to a lack of familiarity, awareness and knowledge of these techniques (EFSA, 2022a; Dendler *et al.*, 2023; Strobbe *et al.*, 2023). 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'. Conversely, over 40% of consumers (less than 50%) recognised potential benefits, such as 'contributing to food security' and 'natural resource preservation'. However, less than 40% believed these technologies could mitigate climate change or provide economic benefits for farmers. This low positive perception of GE aligns with previous studies that found EU consumers to have less favourable perceptions and more significant concerns about GE technologies compared to consumers in the U.S., Japan, and the U.K. (Marette *et al.*, 2021a; Bearth *et al.*, 2022; Kato-Nitta *et al.*, 2022). Consumer interest and positive perceptions may improve by disseminating relevant information about the benefits of GE technology (Yang *et al.*, 2022). It is essential to provide consumers with information about GE's benefits and target traits, as this can influence their perceptions and address risk concerns. Understanding the benefits of GE has been shown to positively affect consumer attitudes and intentions towards the technology (Baum *et al.*, 2023). For instance, a study involving Italian consumers found that more individuals were willing to pay for GE fungus-resistant grapes when provided with specific positive details about GE technology (Borrello *et al.*, 2021).

Whilst the degree of trust in the assurance of CRISPR safety information from institutions seems generally low (Figure 4), information from scientists and regulations is the most trusted source (43% and 31% of respondents, respectively). These findings are consistent with EFSA's 2022 report on food risks, which indicated high trust in practitioners and specialists (89%), scientists at universities or publicly funded research organisations (82%), and consumer organisations (82%). Similar results from studies in the U.S. and the U.K. show that consumers consider the government as their primary source of information on genetics technology (Moon & Balasubramanian, 2001) and that universities and research organisations are also trusted (Martin *et al.*, 2016). Cummings & Peters (2022) found that institutional trust significantly influences U.S. consumers' choices regarding gene-edited foods. In line with our results, consumers in the EU and elsewhere display lower trust in journalists, food industries, and celebrities or influencers on social media (Martin *et al.*, 2016; EFSA, 2022b).

Humans are naturally conservative regarding new, innovative foods and novel food technologies (Siddiqui *et al.*, 2022). This conservatism is reflected in our findings of food technology neophobia, where over 40% of consumers reject new technologies (Figure 5). Consequently, those more fearful of novel food technologies are less willing to accept CRISPR-edited food. Similar findings results were reported in two studies (Ortega *et al.*, 2022; Baum *et al.*, 2023), indicating that consumers with a greater fear of novel food technologies hold less favourable views on the benefits of CRISPR. Reducing consumer fears about novel food technologies could substantially enhance bioengineered food products' valuation and market acceptance (Ortega *et al.*, 2022).

Regarding the utility and WTP attached to the different tomato attributes, consumers preferred EU-grown tomatoes (€ 2.149 per kg) over non-EU tomatoes, indicating that origin is an essential consideration for EU consumers. This is supported by an EU public consultation where 93% of respondents believed consumers want to know the origin of food products (European Parliament, 2024c). When presented with various tomato products, a majority (73% to 88%) deemed mandatory origin labelling essential (European Parliament, 2024c). Our findings align with EFSA's results (2022b), which ranked product origin as the fourth most influential factor in food-related decisions.

Growing concerns about the environmental impacts of conventional agriculture are key drivers behind the rise in organic farming. The organic production method was Spanish consumers' second most valued attribute, willing to pay € 0.945 for a kg of organic tomatoes. This is consistent with findings by Edenbrandt *et al.* (2017), who reported that organic production was the most preferred among Danish consumers. Regular organic consumers indicated they would continue purchasing such products even if GE and GM pesticide-free alternatives were introduced (Edenbrandt, 2018). Both studies found that Danish consumers preferred organic over pesticide-free food products (Edenbrandt *et al.*, 2017; Edenbrandt, 2018). Regarding pesticide reduction, consumers in our study were willing to pay € 0.02 per kg for each per cent point reduction in pesticides, with an average of € 1.5 for a kg of tomato produced using 75% fewer pesticides. This might be an expected result since pesticide residues were one of the most selected concerns on the food safety aspects of EU consumers (EFSA, 2022b). This result aligns with previous studies that reported preferences for pesticide-free bread in Denmark (Edenbrandt *et al.*, 2017; Edenbrandt, 2018) and tomatoes in Germany (Götz *et al.*, 2022) and the U.S. (Tran *et al.*, 2023).

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 by 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), and CRISPR technology specifically (Shew *et al.*, 2018; Uddin *et al.*, 2022; Orivri *et al.*, 2023; Deng *et al.*, 2024), compared to conventional breeding methods. Muringai *et al.* (2020) observed that the required discount varied depending on the nature of the improvements. For instance, participants required a smaller discount for GE potatoes with health-related improvements (lowering acrylamide) than those related to environmental benefits (pesticide and food waste reduction). Conversely, our study found a positive WTP for CRISPR when pesticide reduction reached 67%. This indicates that consumers' negative valuation of CRISPR could be mitigated by the pesticide reduction benefit that this technology could offer. Deng *et al.* (2024) support this, suggesting that coupling the CRISPR production method with benefits-focused information may reduce the discount consumers place on these food products. Research shows that consumers are generally interested in the advantages of plant breeding methods, with some studies indicating improved attitudes toward GE after receiving such information (Edenbrandt *et al.*, 2017; Edenbrandt, 2018; Shew *et al.*, 2018; Caputo *et al.*, 2020; Borrello *et al.*, 2021; De Marchi *et al.*, 2021; Götz *et al.*, 2022; Kilders & Caputo, 2021; Marette *et al.*, 2021a; 2021b; Lemarié & Marette, 2022; Ortega *et al.*, 2022; Hu *et al.*, 2022; Kato-Nitta *et al.*, 2022; Uddin *et al.*, 2022; Baum *et al.*, 2023; Orivri *et al.*, 2023; Schneider *et al.*, 2023; Paudel *et al.*, 2023; Atimango *et al.*, 2024; Bearth *et al.*, 2024; Hao *et al.*, 2024).

Regarding the profile of consumers less reluctant to CRISPR, our results suggested that WTPs significantly depended on education and income. More precisely, the higher the level of studies attained and the higher the income, the lower the WTP for CRISPR-edited food. This finding aligns with Hwang & Nam (2021), who reported that highly educated individuals with higher earning potential are less inclined to purchase GM food (Hwang & Nam, 2021). Other socio-demographic variables, such as gender and age, showed no significant correlation with WTP for CRISPR (Table 6). Lastly, consumers with a more positive perception of the possible benefits of CRISPR also present a lower discount when accepting this new technology. Those consumers with higher risk perceptions derived from the technology and who are more phobic towards new food technologies are also more reluctant to use CRISPR and less willing to pay.

As noted by De Marchi *et al.* (2021), targeted communications can effectively help consumers recognise the long-term benefits of GE. For these individuals, strategies should emphasise GE's potential to deliver short-term and long-term positive outcomes. Educational campaigns on GE safety could help alleviate consumer concerns, as multiple studies indicate that worries over food safety significantly drive aversion to biotechnology (Uddin *et al.*, 2021). Marketing managers and policymakers could be crucial in promoting GE food adoption. Educating consumers presents an opportunity to reduce information gaps, achievable through clear, concise, and recognisable food labels that enhance transparency, such as product packaging labels. Given the current negative WTP for CRISPR foods, evidence suggests that supply-side strategies must incorporate incentives and educational campaigns to encourage consumer acceptance of CRISPR-edited foods.

Conclusions

This study sheds light on consumer behaviour and willingness to pay (WTP) for CRISPR-edited tomatoes among consumers in Northern Spain. The study was pre-registered before data collection, and here we analysed the pooled data to test the six hypotheses summarised in table 7. Our results show that gene-edited tomatoes would need to be sold at a significant discount in the absence of environmental co-benefits. However, if the gene-edited trait significantly reduces pesticide applications, it could capture a market premium. 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.

{Approximate position of Table 7}

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). 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.

We found that consumer acceptance of CRISPR-edited food increases when positive information about the benefits of this technology is highlighted. 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.

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Tables

Table 1. 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

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

Variable	Indicator	% sample	% population
Gender [a]	Male	48.2	49.4
	Female	51.8	50.6
Age [a]	18-34 years old	20.5	21.0
	35-44 years old	16.9	16.2
	45-54 years old	23.0	19.3
	≥ 55years old	39.5	43.6
Education [b]	Up to compulsory school (primary, secondary)	20.2	32.6
	High school or equivalent	26.5	24.1
	University	53.4	43.3
Net household income (€/month) [c]	≤ € 1500 per month	15.2 [19.0]	28.3
	€ 1501-3000 per month	34.6 [43.3]	43.6
	€ 3001-5000 per month	25.7 [32.2]	21.9
	> € 5000 per month	4.4 [5.5]	6.2
	n.a.	20.1 [0.0]	-
Household size [d]	Average size (std. deviation)	2.6 (1.06)	2.4
Household composition [d]	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: [a] Population figures for gender and age in Aragón in 2023, from INE (2024a); [b] Population figures for education in Aragón in 2022, from EUROSTAT (2023). [c] Population data on income for Spain, from INE (2024b). Figures in brackets are percentages over the sample with reported values of income. [d] Population data on household size for Aragón in 2021 (IAEST, 2023).

1 **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
	Organic	23.8

Purchase of organic tomatoes	Organic & conventional	20.9
	Organic only	1.7

Source: Own elaboration

Table 4. 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)
α	-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 (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).

Table 5. Marginal and Total Willingness to pay (RPL with interactions)

	CRISPR	Organic	Pesticide [b]	EU origin
		Marginal WTP		
Mean [a]	-1.048	+0.945	+0.020	+2.149
Median [a]	-0.830	+0.958	+0.023	+1.947
		Total WTP		
At Pest = 0	-0.856 [b]	-	0	+1.969 [0]
At Pest = 25	-0.532	-	+0.512	+2.664 [0.515]
At Pest = 50	-0.209	-	+1.023	+3.360 [1.031]
At Pest = 75	+0.115	-	+1.535	+4.056 [1.546]
At EU = 1	-	-	+0.025	-
At EU = 0	-	-	+0.018	-

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); standard error uses the Delta method (*nlcom* command in Stata). [a] WTP for an attribute/level evaluated at mean values of the interacted variables. [b] Calculated as $-(\beta_{CRISPR} * CRISPR + \beta_{CRISPR\_PEST} \cdot CRISPR * PESTICIDE + \beta_{PEST} \cdot PESTICIDE)/\beta_{PRICE}$, where $CRISPR$ = 1 and $PESTICIDE$ = 0, 25, 50 and 75.

Table 6. Conditional WTP for CRISPR per subgroup of consumers (€/kg). Model with interactions.

Variable	Indicator	WTP (mean)
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.

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.

Table 7. 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.	Coefficient of CRISPR variable in table 4	Supported
2. Positive valuation of reductions on pesticide use	Coefficient of PESTICIDE variable in table 4	Supported
3. Negative valuation of CRISPR by consumers can be mitigated by reduction in pesticide use	Total WTP calculation in table 5.	Supported
4. EU Local food products are preferred over imports	Coefficient of EU variable in table 4.	Supported
5. Negative valuation of imports versus EU products could benefit from the claim of a reduction in the use of pesticides	Coefficient of EU-PESTICIDE interaction in table 4. Total WTP calculation in table 5.	Not supported
6. Negative valuation of CRISPR by consumers can be mitigated by use in organic farming	Coefficient of CRISPR-ORGANIC interaction in table 4.	Not supported

Source: AsPredicted.org pre-registration.

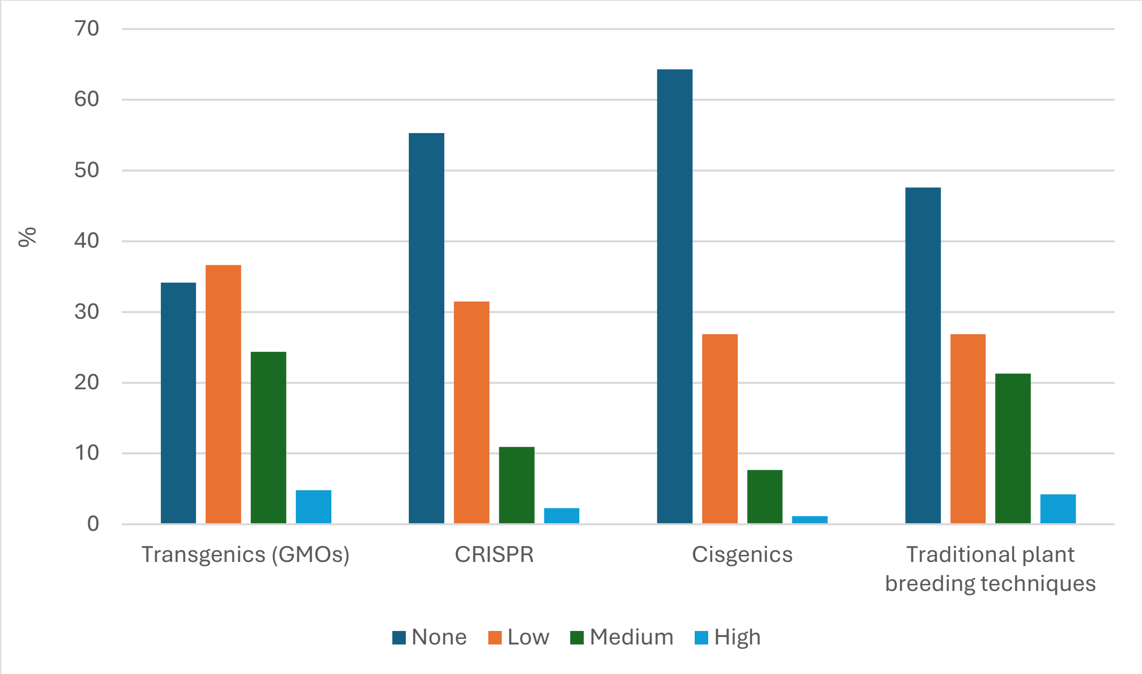
Figures

Figure 1. Example of a choice set.

	Option A	Option B	Option C
Plant breeding method	Traditional	CRISPR	Non-buy
Production method	Conventional	Organic	
Origin of production	European Union	Other countries	
Pesticide reduction	75% Reduction	25% Reduction	
Price	4.5 €/kg	2 €/kg	

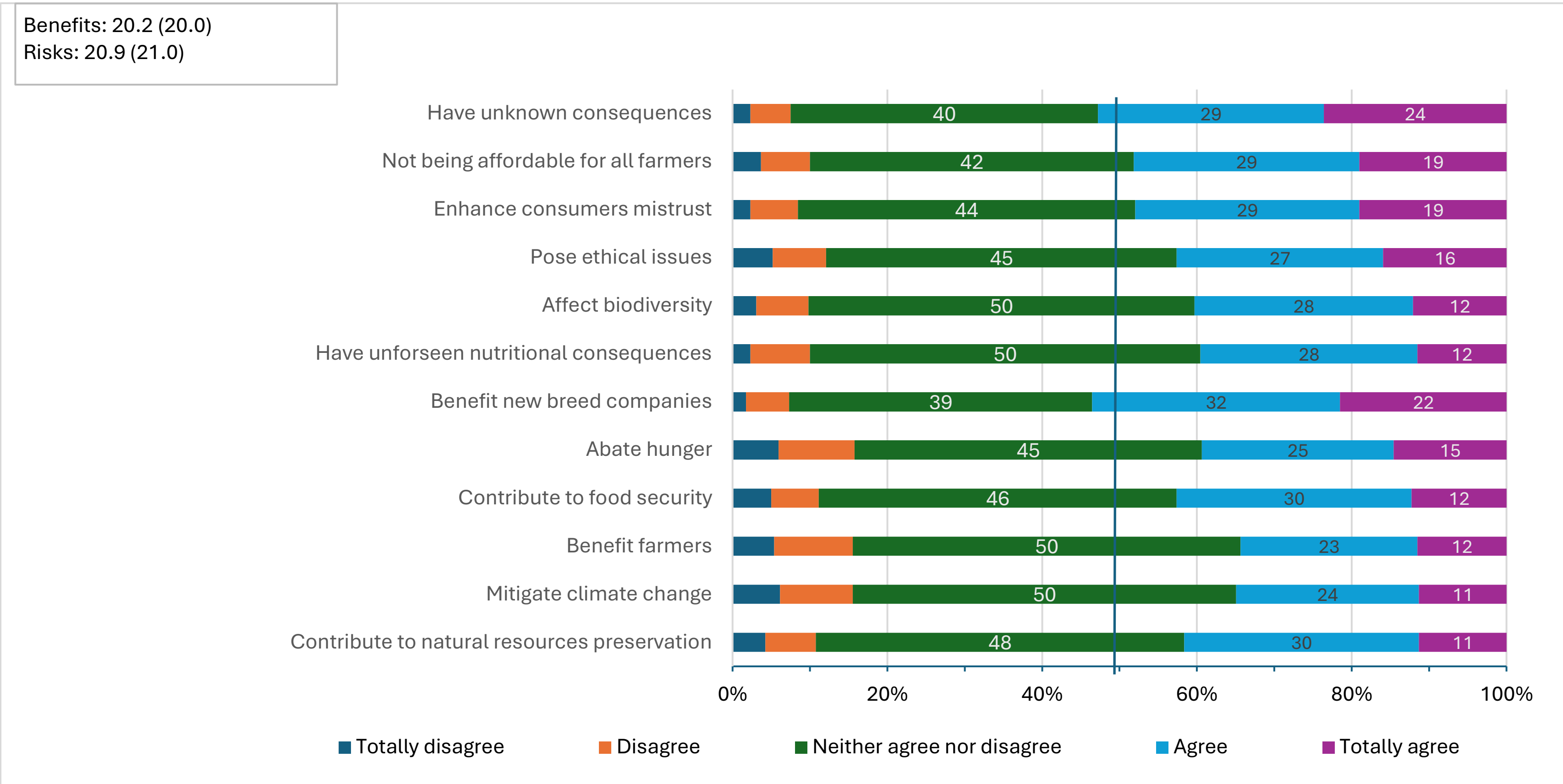
Note: Translated version. Source: Own elaboration

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



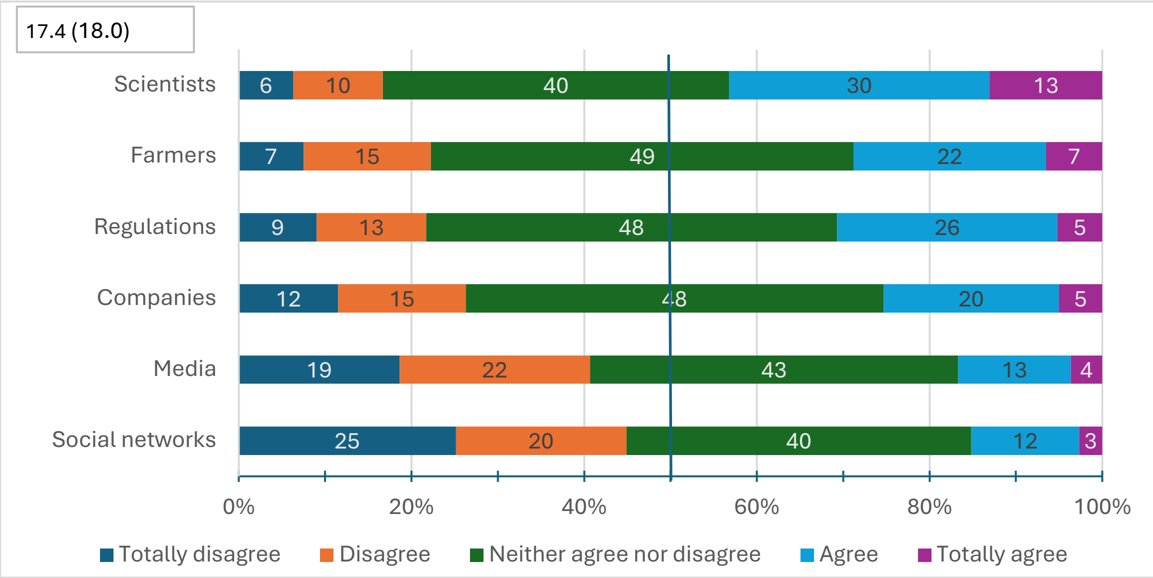
Source: Own elaboration

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



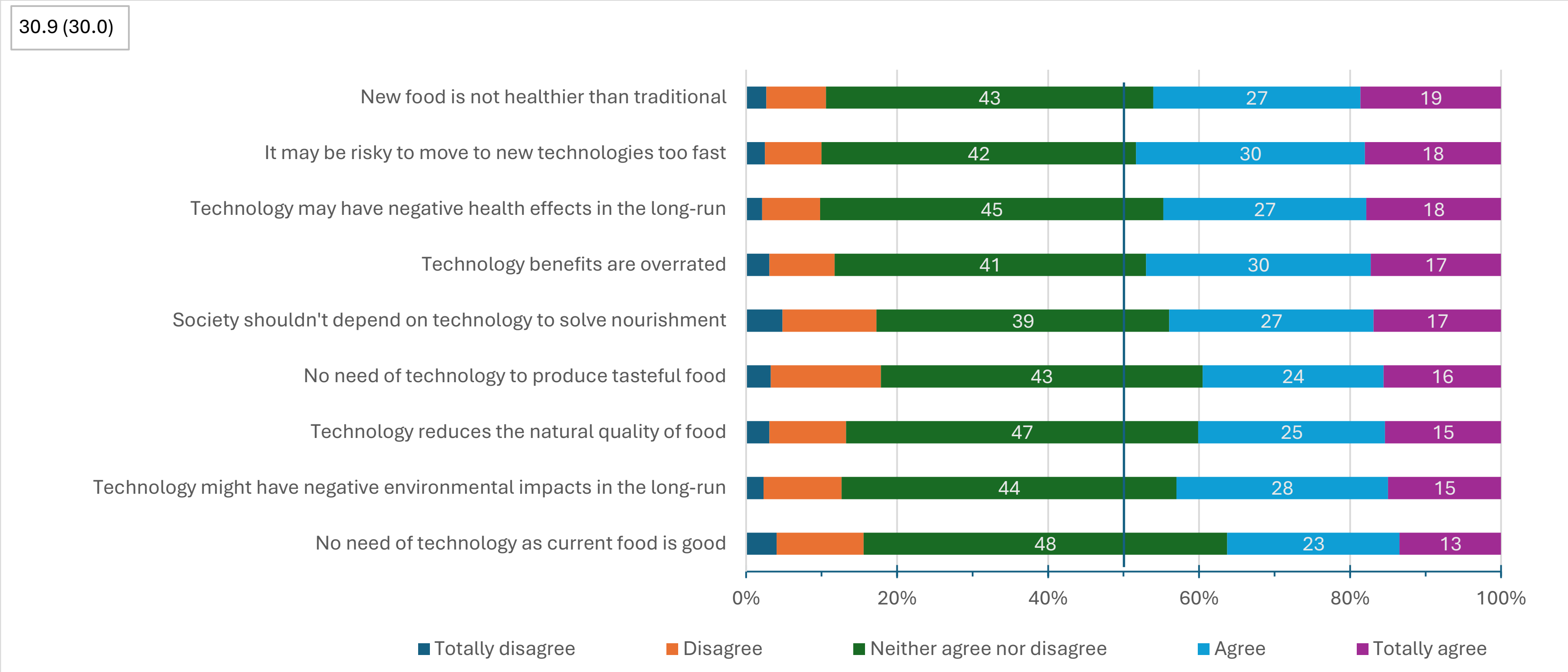
Source: Own elaboration. Notes: In the top left corner, the mean (median) of the aggregate score was obtained by adding up the valuations (between 1 "totally disagree" to 5 "totally agree") of the 6 items related to benefits and 6 to risks, respectively. The range of the aggregated score is 6-30.

Figure 4. Trust in CRISPR-related institutions (% 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.

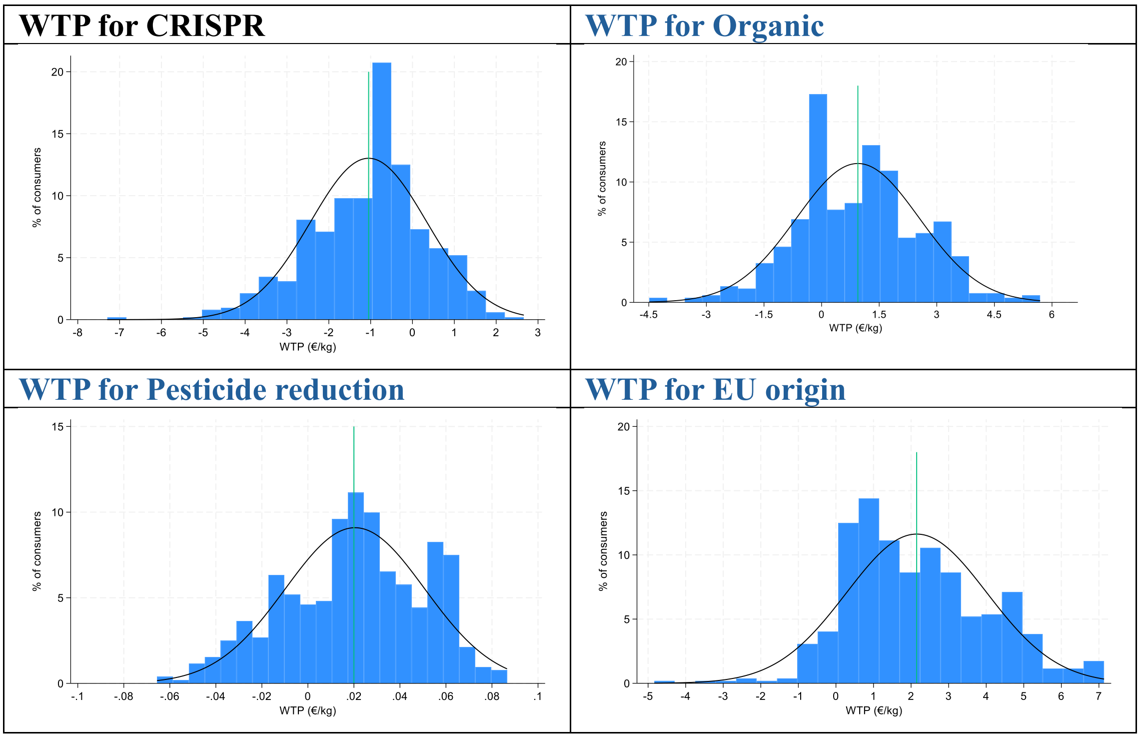
Figure 5. Scale of Phobia to new food technologies.



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.

Figure 6. Distribution of WTP (Conditional WTP with interactions).



Source: Source: Own elaboration.

Notes: The vertical line indicates the mean. Normal distribution superimposed.

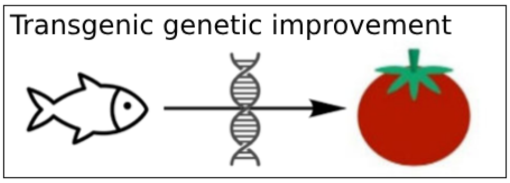
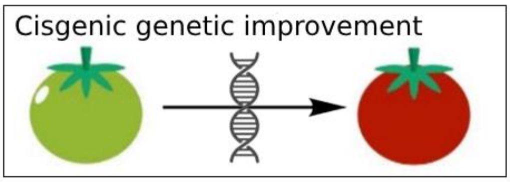
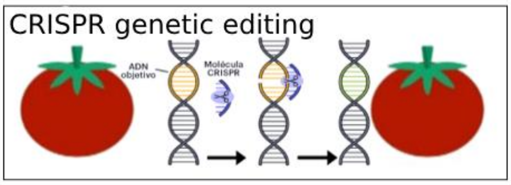
Annexes

Annex I

General information

Human beings have certain traits, such as eye colour, hair colour, skin tone, and height, that differentiate us. Similarly, plants have characteristic traits, such as the fibre content of their fruit, water absorption capacity, fruit size and taste, and yield. Historically, **traditional plant breeding** has relied on varietal crosses. For many years, chemical processes or irradiation have produced improved plant varieties that could have arisen spontaneously. Some of these improvements have resulted in tastier tomatoes, seedless watermelons, and more drought-resistant plants. More recently, new **genetic modification or editing techniques** have been developed, allowing for the acceleration of the plant improvement process and achieving desired varieties in a shorter time than traditional breeding methods.

There are **different types of genetic modification or editing**:

Transgenic genetic improvement involves adding genes from other plants, microorganisms, and/or animals to, for example, the tomato seed being developed. Genetically modified organisms (GMOs) are considered a form of transgenic genetic modification.	
Cisgenic genetic improvement allows for adding genes only from different varieties of the same plant, implying that the improvement could have occurred spontaneously in nature. With this method, genes from a more disease-resistant type of tomato can be inserted into a less resistant variety. Still, genes from, for example, a fish or an apple cannot be added to the tomato, as is done in transgenic modification.	
Genetic editing removes, edits, inserts, or replaces the plant's DNA without introducing external genes. The most commonly used editing method is CRISPR, which is based on a natural defence	

system that bacteria use against viruses. In this case, the improvement could also have occurred spontaneously in nature.	

Under the current regulation of the European Union, none of the three techniques are permitted unless approval is sought through a rigorous process. If approved, foods must carry an informative label. However, a proposed new regulation from the European Commission would allow genetic editing (CRISPR) to be used without prior approval, as it is considered a highly safe technique. Only notification of its use would be required. Plant foods derived from new seeds improved through genetic editing (CRISPR) could be sold in the market as if they had been obtained through traditional plant breeding techniques.

Annex II

Table 1. Description of the sample (N = 29 individuals)

Variable	**Indicator**	**Sample**
Gender	Male	8 (28%)
	Female	21 (72%)
Age	18-34 years old	3 (10%)
	35-44 years old	6 (21%)
	45-54 years old	9 (31%)
	≥ 55years old	11 (38%)
Education	Up to compulsory school (primary, secondary)	10 (35%)
	High school or equivalent	3 (10%)
	University	16 (55%)
Net household income (€/month)	≤ € 1500 per month	8 (28%)
	€ 1501-3000 per month	5 (17%)
	€ 3001-5000 per month	3 (10%)
	> € 5000	2 (7%)
	n.a.	11 (38%)
Household composition	Single	2 (7%)
	With kids (<18 years old)	8 (28%)
	With retired persons (>65 years)	6 (21%)
	Only adults (18-65 years old)	15 (52%)
Tomato purchase frequency	Every day	0 (0%)
	Twice a week	2 (7%)
	Once a week	8 (28%)
	Twice a month	10 (35%)
	Once a month	3 (10%)
	Never	6 (21%)
Knowledge about the traditional plant breeding methods of tomatoes	Yes/No	9 (31%)
Knowledge about the CRISPR technology in plant breeding	Yes/No	6 (21%)