

Review

Consumer valuation of and attitudes towards novel foods produced with NPETs: A review

John C. Beghin ^{1,*} and Christopher R. Gustafson ²

¹ Department of Agricultural Economics, Institute of Agriculture and Natural Resources, and Clayton Yeutter Institute of International Trade & Finance, University of Nebraska-Lincoln; beghin@unl.edu

² Department of Agricultural Economics, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln; cgustafson6@unl.edu

* Correspondence: beghin@unl.edu; Tel.: +1 (402) 472-2749

Abstract: We review the emerging international body of evidence on attitudes and willingness to pay (WTP) for novel foods produced with New Plant Engineering Techniques (NPETs). NPETs include genome/gene editing, cisgenesis, intragenesis, RNA interference and others. These novel foods are often beneficial for the environment and human health and more sustainable under increasingly prevalent climate extremes. These techniques can also improve animal welfare and disease resistance when applied to animals. Despite these promising attributes, evidence suggests that many, but not all consumers, discount these novel foods relative to conventional ones. Our systematic review sorts out findings to identify conditioning factors which can increase the acceptance of and WTP for these novel foods in a significant segment of consumers. International patterns of acceptance are identified. We also analyze how information and knowledge interact with consumer acceptance of these novel foods and technologies. Heterogeneity of consumers across cultures and borders, and in attitudes towards science and innovation emerges as key determinants of acceptance and WTP. Acceptance and WTP tend to increase when beneficial attributes—as opposed to producer-oriented cost-saving attributes—are generated by NPETs. NPETs improved foods are systematically less discounted than transgenic foods. Most of the valuation elicitation are based on hypothetical experiments and surveys and await validation through revealed preferences in actual purchases in food retailing environments.

Keywords: new plant engineering techniques (NPETs); new breeding techniques (NBTs); GMO; transgenic; genome editing; gene editing; cisgenic; CRISPR; RNAi; willingness to pay (WTP)

1. Introduction

We review the emerging and fast-growing international body of empirical evidence on consumers' attitudes and limited willingness to pay for/consume novel foods produced with inputs generated using New Plant Engineering Techniques, or NPETs. NPETs include genome/gene editing, cisgenesis, intragenesis, non-transgenic RNA interference, and others.¹ These novel foods often feature traits introduced via NPETs to benefit the environment and human health and to increase sustainability in the face of climate extremes. Water savings, reduced pesticide applications, reduced food waste, resistance to pests and diseases, and more nutritious food are among the benefits created

¹ We closely follow Sticklen [1] to define NPETs. Genome or gene editing (GE) refers to a technique that adds, deletes or modifies precisely and site-specifically genes from the genome of a plant or animal. GE “genetic scissor” methods include CRISPRcas9, TALEN, and zinc finger nuclease (ZFN). When introducing a gene belonging to the same or cross breedable species, the resulting crop is called “cisgenic” or sometime ingenic. Cisgenic introduction includes the gene cassette with its regulatory sequences integrated in the host plant. Intragenic inserts are close to cisgenic, but the gene coding sequence is regulated by promoters and terminators of different genes from the same cross-breedable gene pool. RNA interference (RNAi) is a technique used to regulate or silence the transcription of a specific native gene in the host plant. Here we restrict RNAi to non-transgenic modifications.

using NPETs. When applied to animals, these techniques can also improve animal welfare and disease resistance. Improving disease resistance in plants and animals may mitigate antimicrobial resistance [2], which can arise with the (over)use of antimicrobials.

Despite the benefits that NPETs confer, public (e.g., governmental) and private (individual) opposition to these technologies may limit their development by disincentivizing researchers and firms from investing in them [3]. Particularly relevant in the context of our review, existing studies suggest that consumers discount these novel foods relative to conventional foods on average. Our systematic review sorts out findings to identify conditioning factors that can influence and increase the acceptance of these novel foods in a significant segment of consumers. We also examine international patterns of acceptance. NPETs, like genetically modified organisms (GMOs) twenty years ago, offer the potential to efficiently introduce desirable traits into organisms but also appear to face issues of consumer distrust, leading to decreased valuation of the new technology despite its potential to improve sustainable agricultural practices [4,5]. Issues related to distrust—including labelling, scientific knowledge, risk perception, and perception of naturalness—are present with NPETs, just as they were with GMOs. Our investigation points out the key differences in perceptions and willingness to pay (WTP) for NPET-based foods relative to GMO-based foods and conventional and/or organic substitutes. We also identify conditioning determinants of WTP, namely, the tangible benefits consumers are interested in and those they discount.

As private firms and associated supply chains are increasingly focused on improving their sustainability and social engagement with environment, sustainability and governance (so-called “ESG”) criteria [6], it is critically important to understand consumer behavior towards biotechnology and new foods relying on NPETs. These new foods could be misperceived and rejected even though these new biotechnologies hold much promise to improve sustainable food supply chains and foster better health outcomes for consumers and the environment.

In most studies reviewed, the average consumer discounts these NPET-based novel foods relative to conventional ones, although the discount is not as pronounced as for transgenic (GMO) foods, when comparative results are available. However, consumers are heterogeneous in their preferences and valuations, as documented by many studies. Heterogeneity of consumers within and across cultures and borders, heterogeneity in attitudes towards science and innovation and in risk perceptions—which are related to objective knowledge about biotechnology [7]—emerge as key determinants of acceptance and WTP. Acceptance and WTP are higher when consumers perceive the attributes generated by NPETs as beneficial. Tangible benefits include improvements in nutritional value or taste and more sustainable processes such as reduced pesticide or water use. Superficial improvements are discounted.

Most of the valuation elicitation are based on hypothetical experiments and surveys in standard research setups (e.g., lab experiment, online survey), in part because few NPET-based novel foods have been commercialized. These hypothetical valuations await validation through revealed preferences in actual purchases in the food retailing environments when these novel foods will become widely available.

2. Materials and Methods

The article relies on a systematic review of the emerging literature on NPETs, consumers’ attitudes and willingness to pay for NPET-based food. We first undertook a systematic search for available articles written in the English language, published or not, using Google Scholar searches with the following keywords: gene/genome editing, CRISPR, Talen, cisgenic, intragenic, ingenic in addition to consumer acceptance (or attitudes), or consumer willingness to pay (purchase, eat, consume). This process yielded more than 50

references. Next, during the reading process we collected additional references to articles that we did not identify in our initial literature searches. We complemented our list of search-based candidate studies with these additional articles. Finally, the reading process also revealed that some studies did not cover NPETs or had been erroneously cited as addressing consumer behavior towards NPETs. The final process yielded 53 useable studies, two of which were review articles (not generating any new data) and 51 of which were based on original data collected for their respective investigation. Several studies on consumer behavior and NPETs yielded more than a single article. Additionally, a number of investigations were international in nature and yielded WTP estimates for multiple populations.

We tabulated the 53 studies in searchable spreadsheet format to catalogue the following characteristics: the name of the authors, year of appearance; the full reference; the topic (attitude/acceptance, WTP, framing effects, etc.); the commodity(ies) or food items; what was estimated (WTP, attitude or acceptance); comparative study of more than one technology; traits covered by the innovations; methodology/approach (choice experiment, auction, survey, statistical methods, qualitative, etc.); the sample size; estimated values/key results; technologies covered (GMO, GE gene/genome editing, other NPETs/NBTs (cisgenic, intragenic, ingenic), conventional/hybrids, and organic); country(ies); population sampled; and additional remarks. These key attributes are presented in Appendix Table 1. Then, we used descriptive statistics (counts and frequencies) to characterize the key attributes of these studies. We then evaluated the estimated results and findings in a more qualitative way to obtain stylized facts on discounts and premia in WTP, and treatment effects influencing the acceptance of and attitudes toward NPETs. While falling short of undertaking a full-blown meta-analysis, we go much beyond the typical literature survey. The tabulated folder is posted online and searchable by NPET type, country/region, and commodity. Appendix Table 1 presents the studies with key attributes.

3. Key Findings and Results

3.1. The studies

Studies examining attitudes and WTP for NPET-based foods have increased markedly in recent years. Through 2010, 3 studies were identified, while we found 5 between 2011 and 2013, 5 between 2014 and 2016, 18 between 2017 and 2019, and 22 in the 1.5 years from 2020 through July 2021. Most of the studies have been published in refereed journals or are book chapters; a few are publications by official agencies such as the European Food Safety Authority, and the Norwegian Biotechnology Advisory Board, or graduate theses.

Among the 53 identified studies investigating consumer attitudes/behavior with respect to NPETs, 30 focused on genome/gene editing, while 23 examined other NPETs (16 cisgenic/ingenic; three intragenic; four RNAi) covering the period 2004-2021. The earliest investigations predominantly focused on goods generated with cisgenic or intragenic modifications relative to standard (transgenic) GMO substitutes [8–11]. The more recent papers focus on GE, RNAi, and other newly developed NPETs. Among these 53 studies, 36 address consumer attitudes and acceptance and willingness to eat or consume; 29 studies provide WTP or willingness to purchase information. These two sets of studies include a number of comparative, multiple-country studies, and all WTP studies include some version of variables that capture attitudinal information of participants in their surveys

The studies cover a wide range of countries, though coverage is predominantly focused on two regions. European countries (24 studies) and North America (USA and Canada) (20 studies) have received the most attention, while the number of studies examining consumer attitudes/valuation in Asia (5), Latin America and the Caribbean (4), and Africa

(2) are limited. Information about the specific country or region for which data were collected in the studies we survey is included in Appendix Table 1. Although the majority of the investigations use experiments and questionnaires that involve participants making choices, several of the studies are framed in terms of consumers' perceptions and attitudes regarding NPETs, and associated perceived risks and benefits, without asking participants to make explicit choices. Further, 39 investigations involve comparative analysis of technologies—a combination of conventional, GMO, and/or organic versus NPETs. Among these comparative studies, 31 cover conventional technologies/hybrids, 36 involve GMO, and ten deal with organic goods.

Most investigations and experiments involve hypothetical or fictitious choices, since very few NPET-based goods have been commercialized with the exceptions of soybean and canola oil, and apples. Even those products that have been commercialized are not widely available and, due to regulatory issues, have not been approved for production/commercialization in many countries or regions, such as the EU [3]. Two articles that used real—rather than hypothetical—choices elicited data on WTP through an experimental auction with real food products [10,11]. However, even though real transactions occurred, the goods in the auction were not actually produced using NPETs; rather, purchasers were given a conventional version of the product. Another set of studies attempts to incorporate non-hypothetical data by combining store scanner data and NPET survey data for the same subjects in an effort to condition the responses to the survey with scanner data (the revealed preferences of shoppers through their purchases of organic milk and rye bread) [12,13].

3.2. Methods to elicit attitudes and WTP

Many of the articles—29 out of 55—estimate valuation of NPETs. The three main approaches used to elicit data for WTP estimation in these studies are choice experiments, experimental auctions, and multiple price lists (MPLs). While each of these techniques is designed to estimate valuation of products or product attributes, the approach used by each method—as well as situations in which each method is most beneficial—differs. In choice experiments, respondents view choice sets that contain a few product alternatives (typically two) along with an option to indicate they would not purchase either option, yielding binary data on choices, which are associated with variations in prices and attributes. Choice experiment investigations of WTP rely on a Random Utility Model (RUM) and some form of binary (logit or probit) regression model with various degrees of sophistication to address latent variables and estimate preference heterogeneity, or deal with other statistical challenges like zero willingness-to-pay for boycott/protest consumers and data censoring. Some investigations directly estimate WTP whereas other derive it by using ratios of estimated marginal utility of attributes divided by the negative of the price response. Both are standard ways to derive WTP. Choice experiments are well-suited for situations in which the researchers wish to evaluate multiple attributes of the products.

Experimental auction approaches directly elicit WTP measures by having participants bid directly on food products with varying attributes. These WTP measures can then be used in simple statistical tests (such as t-tests to evaluate whether, say, WTP elicited under two conditions significantly differs) or in linear regression models, depending on the design of the research. Experimental auction studies are typically used when there is a single focal attribute (or condition) that researchers wish to estimate WTP for. Auctions also require real purchases due to greater threat of hypothetical biases [14]. In the context of NPETs, these studies evaluate differences in WTP between conventional and modified product variants. As noted previously, the lack of commercialized NPET-based products limits the use of methods that rely on non-hypothetical choices; few studies on consumer valuation of NPETs have used experimental auctions [10,11].

MPL-based studies present respondents a list of prices for two products (at a time). One of the products' prices incrementally changes in each row of the list. The respondent makes a choice between each product in each row. The approach captures when the respondent switches from one product to the other or to none. These studies frequently use interval regression to analyze the data derived from MPL studies [15,16].

The novelty of NPETs means that, unless researchers trade out NPET-based products for conventional products at the end of the experiment (after presenting choices as real) [10], most studies are by necessity hypothetical. While there are widespread concerns about biased valuation estimates resulting from hypothetical decisions, hypothetical choices—and consequences of hypothetical studies, such as hypothetical bias—have been widely studied [14]. Researchers have developed methods to reduce overestimates of valuation stemming from the hypothetical nature of these choices, including the use of cheap talk scripts—which remind participants to think about budget constraints or other demands on their money, certainty follow-ups that ask how sure they are about their decision, and honesty priming tasks, as well as valuation calibration techniques, among others [14,17,18]. While hypothetical bias has been widely documented, multiple studies in consumer choice settings have noted that the bias affects the WTP level—that is, the total amount the consumer is willing to pay for the good—but not marginal WTP for attributes [19,20].

A few studies complemented quantitative methods to understanding consumer perceptions with qualitative approaches. Qualitative studies (or components of studies) included interacting with small numbers of participants in focus groups [21] and face-to-face interviews [21,22], as well as eliciting open-ended responses to questions from large numbers of participants in online surveys [23]. This qualitative research identified themes related to consumer attitudes towards NPETs, including concerns about risks of the use of these novel technologies for human and environmental health, perceptions of unnaturalness of the NPET-derived organisms, distrust in firms' use of NPETs to modify organisms, and misperceptions about the food production system (e.g., concerns that modifying dairy cattle to eliminate horns would prevent them from fighting off predators) [21–23].

3.3. Findings on consumer behavior

The first key—and quite robust—finding is that consumers on average discount food goods generated using NPETs relative to foods produced using traditional breeding techniques. All studies reflect this discounting of NPET-based goods relative to conventional goods (or NPET-based improvements relative to similar improvements generated from conventional breeding techniques), when averaging over all consumers surveyed or subjects in experiments. However, when compared to WTP for (transgenic) GMOs, NPET-based innovations and goods tend to be valued more highly than their GMO counterparts, provided they embody improvements beneficial to the environment or human and animal health. This finding is also robust.

Another important result common to many investigations is that there exists multi-dimensional heterogeneity among consumers with respect to their acceptance of and WTP for NPETs. Forty-three investigations find some form of heterogeneity, either by identifying a segment of consumers who heavily discount the novel foods or are not willing to consume or purchase them at any price; or through statistically significant standard deviations of estimated parameters capturing the range of WTPs in the sampled population. Consumers show heterogeneous levels of knowledge about NPETs, have various attitudes towards food innovations and technology, have variable ethical concerns about unnaturalness of NPET-based foods, and have varying concerns about the risk the use of NPETs presents for health and the environment. These multiple aspects influence the willingness

to consume and WTP for NPET-based novel foods, including products that feature improved attributes with clear, tangible benefits to the consumer or society. This also means that there is a market segment for these novel foods when they offer additional health, taste or environmental benefits, appealing to consumers who are open to food innovations [24–26].

An important source of heterogeneity seems to arise from consumers' country of residence, which may reflect varying regulatory approaches or cultural values; for instance, trust in the regulatory bodies of one's home country is associated with attitudes towards approved technologies [21]. All but one study find marked differences in WTP or willingness to consume among countries. The exception (Ferrari et al. [27]) compares young consumers in Belgium and the Netherlands, neighboring countries with a common culture, who are "millennials" or members of Generation Z, who may be more accepting of the use of NPET technology than older generations [28]. The range of attitudes, concerns and attitudes gets amplified with geographic and cultural distance, which reflects findings from the literature on GMO-based agriculture and food [29,30]. In particular, the divide between the European continent and North America is as striking as it was for GMO-based foods. For example, French consumers have lower acceptance and/or WTP for NPET-based foods than U.S. and Canadian consumers do (see, for instance, Lusk and Rozan [9] on vegetables; Marette et al. [24,25] for apples; Narh et al. [31] on rice; and Shew et al. [15] on acceptance of CRISPR rice). In addition, in many WTP studies based on discrete choices, the standard deviations of most relevant parameters are significant, indicating that the valuation of attributes is heterogeneous. Within Europe, perceived risks and concerns about NPET-derived food are much lower than they were for transgenic food but they remain highly heterogeneous across countries [32–36].

The heterogeneity of acceptance and valuation of NPET-derived foods extends to the type of food item and the process level, which is reminiscent of findings for GMO-based food [29,30]. The lowest levels of acceptance are for meat and milk [37]. The relative WTP for NPET-derived fresh tomato and spinach is higher than the WTP in processed form (pasta sauce, frozen spinach). The opposite is true for bacon and pork produced using NPETs. WTP for NPET-derived bacon—a more highly processed product—is higher than the WTP for pork [38].

WTP for NPET-derived foods increases with tangible improvements such as tastier grapes, improved nutritional value, or environmental benefits (reduced pesticides, water use) or improve animal welfare. Marginal improvements such as color of grapes or benefits accruing to farmers (more muscle mass on animals) tend to be discounted in NPET valuation experiments. However, the premium over conventional substitutes lacking the tangible improvements is limited in all these experiments. Unless some superlative attribute is added, the improvements brought about by NPETs are likely to result in incremental increases in WTP rather than drastic changes yielding higher valuations for NPET-derived products.

Knowledge—in various forms—also appears to be an important factor in consumer response to NPETs. Higher levels of knowledge about science and technology promote acceptance/WTP for the use of NPETs and NPET-derived products [21,27]. Greater knowledge about the product being modified—specifically, in this case, wines—also promotes greater WTP for NPET-based products [28]. Interestingly, basic familiarity with products that contain modified ingredients may also promote attitudes. A study of attitudes towards GMOs in the US found that residents of Vermont—which implemented the first GMO labeling policy in the US—became more positive towards GMOs after the implementation of the labeling policy relative to residents of other states [39].

An experiment that educated consumers about the function of genetic modification technology in food production via a five-week course suggests a causal role for knowledge [7]. Participants in the course developed more positive attitudes, greater willingness to consume the foods, and decreased perceived risk of the foods during the course in three countries: the US, the UK, and the Netherlands. A recent finding on knowledge and support for GMOs highlights the importance of objective (i.e., measurable)—as opposed to subjective (self-reported)—knowledge [40]. Those individuals who were the most opposed to the use of GMOs had the lowest levels of objective knowledge, but believed that they had high levels of knowledge about GMOs [40]. Several investigations focus on information and communication strategies implications to increase acceptance of these NPETs, building on lessons learned with GMOs (see De Marchi et al. [41], Marette et al. [24], Edenbrandt et al. [42]). However, consumers can get confused by conflicting messages and these cancel out [10,11].

A time aspect: for GMO, EU consumers were much more worried in 2010 than they were in 2019 about GMO in their food supply. The concern for GE is already small relative to GMOs, so NPET-based foods may have an easier transition to acceptance.

In experiments addressing labelling of NPETs derived foods, labelling is preferred, especially in European countries [10–12,21,27,36,43]. To the extent that consumers may feel deceived if not informed about the use of NPETs in the development of ingredients or foods they purchase, there is a legitimate reason to add a label, including on imported goods [44]. However, consumers may pay less attention to attributes—including the use of NPETs—in real buying/retailing environment when information and sensory overload is heightened.

4. Implications and Conclusions

In summary and with the appropriate qualifiers spelled out in the previous sections, the accumulated evidence suggests that large segments of consumers, but not all, are willing to consume and pay for NPET-derived foods, especially if they embody useful traits that the consumers perceive as beneficial for human and animal health and the environment. However, these foods tend to be discounted relative to close substitutes obtained through conventional breeding methods. In most situations when informed about these useful traits, consumers discount NPET-derived foods to a lesser extent than their transgenic (GMO) substitutes. They also find them more “natural” although their knowledge about and familiarity with NPETs are limited.

The major limitation of current knowledge on consumers’ behavior vis a vis NPETs is that most of these elicited WTPs and attitudes are based on hypothetical choices and/or in artificial settings of lab experiments, experimental auctions, or online surveys. The limited commercialization of NPET-based foods precludes study of consumer preferences for these products under more natural, or at least incentivized, conditions. Future validation or falsification of these findings in real retailing situations will be possible once these novel foods become widely available.

Labelling is probably preferable as consumers are concerned by process attributes and want to know the improved characteristics of the novel food and how they have been derived. It remains to be seen how consumers will react in real shopping environments when a deluge of information signals might cancel each other and might not be as instrumental as declared in hypothetical choices. Colson’s work suggests this possibility in an auction setting [10,11]. However, the incorporation of NPET-based ingredients may also promote acceptance of the technology if labeling is present to help consumers make the connection, as apparently occurred with GMO-labeling [39].

We assessed the promising demand side of the market for NPET-derived foods. How will the supply side shape up and how will specialized markets develop for NPET-derived foods? NPETs do not require the scale of transgenic biotechnology as they are much less expensive in the R&D stage, especially for emerging techniques like CRISPR [45]. These technologies, initially driven by non-profit research institutions, have led to an unusual number of patents globally, and many startups [46,47]. Nevertheless, scale is useful for marketing and distribution aspects of food and food retail markets are typically competitive environments. It would be useful to assess commercialization efforts of these novel foods. The current regulatory uncertainty on NPETs may also inhibit the emergence of these markets [3,48,49].

Supplementary Materials: The following Table S1 is available online at www.mdpi.com/xxx/Table S1: details of WTP and attitudes towards NPETs.

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Data Availability Statement: A supplemental excel sheet detailing the studies' characteristics is available online.

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Appendix A Table 1: Articles on NPETs Included in the Review

Authors	Commodity/food item	WTP	Attitude acceptance	GMO	GE	Non GE NPETs	Conventional	Organic	Country
An et al. (2019) [50]	canola oil	x		x	x	na	na	na	Canada
Arias-Salazar et al. (2019) [51]	food, crops, rice, beans		x	na	x	na	na	na	Costa Rica
Britton & Tonsor (2019) [52]	beef	x		na	na	RNAi	na	na	USA
Britton & Tonsor (2020) [53]	beef		x	na	na	RNAi	na	na	USA
Borrello et al. (2021) [28]	wine	x	x		x	na	x		Italy
Busch et al. (2021) [37]	wheat, humans, milk, beef, pork		x	na	x	na	na	na	Canada, Austria, USA, Germany, Italy
Caputo et al. (2020) [38]	pork, tomato, spinach	x	x	x	x	na	x	x	USA
Colson & Huffman (2011) [10]	vegetables	x		x	na	intragenic	x	na	USA
Colson et al. (2011) [11]	tomato, broccoli, potato	x		x	na	intragenic	x	na	USA
De Marchi et al. (2020) [54]	apples		x	na	x	na	x	na	Italy
De Marchi et al. (2020) [41]	apples		x	na	na	cisgenic	x	na	Italy

Authors	Commodity/food item	WTP	Attitude acceptance	GMO	GE	Non GE NPETs	Conventional	Organic	Country
De Marchi et al.(2019)[55]	apples	x		na	na	cisgenic	x	na	Italy
De Steur et al.(2016) [56]	tomato, broccoli, potato, vegetables	x	x	x	na	intragenic	x	na	USA, China, France, NZ
Delwaide et al.(2015) [57]	rice	x	x	x	na	cisgenic	x		Belgium, France, Netherlands, Spain, UK
Edenbrandt (2018) [12]	rye bread	x		x	na	cisgenic	x	x	Denmark
Edenbrandt et al.(2018a) [13]	rye bread	x		x	na	cisgenic	x	x	Denmark
Edenbrandt et al.(2018b) [42]	grapes	x		x	na	cisgenic	x	na	USA
European Food Safety Authority (EFSA) (2010) [32]	food, drink		x	x	na	na	x	na	EU-27
European Food Safety Authority (EFSA) (2019) [34]	food, drink		x	x	x	na	x	na	EU-27
Farid et al.(2020) [58]	food, crops	x	x	na	x	na	na	na	Japan
Ferrari et al.(2020) [27]	food		x	x	x	na	na	na	Belgium, Netherlands
Gaskell et al.(2011) [35]	food		x	x	na	cisgenic	x	na	EU-27
Gatica-Arias et al.(2019) [59]	food, crops, rice, beans		x	na	x	na	na	na	Costa Rica
Ishii & Araki (2016) [43]	food		x	na	na	na	na	na	na
Kato-Nitta et al.(2021) [60]	tomato, pork		x	x	x	na	x	na	Japan
Kato-Nitta et al.(2019) [61]	crops		x	x	x	na	x	na	Japan
Kilders & Caputo (2021) [62]	milk	x		na	x	na	x	na	USA
Kronberger et al.(2014) [36]	animals, human, plants, apples		x	x		cisgenic	x		Austria, Japan, EU-27
Lusk & Rozan (2006) [9]	vegetables		x	x	na	ingenic			France USA
Lusk et al.(2018) [63]	food	x	x	x	x	cisgenic	x	na	USA
Marette et al.(2021a) [24]	apples	x		x	x	na	x	na	France, USA
Marette et al.(2021b) [25]	apples	x		x	x	na	x	na	France, USA
McFadden et al. (2021) [64]	oranges	x		na	x	na	na	na	USA
Mielby et al.(2013) [65]	crops		x	x	na	cisgenic	na	na	Denmark
Muringai et al.(2020) [66]	potato	x	x	x	x	na	x	na	Canada

Authors	Commodity/food item	WTP	Attitude acceptance	GMO	GE	Non GE NPETs	Conventional	Organic	Country
Narh et al (2019) [31]	rice		x	x	x	RNAi	na		Australia, Belgium, Canada, France, USA
Nlend Nkott & Temple (2021) [67]	rice		x	na	x	na	na	na	Madagascar
Norwegian Biotechnology Advisory Board (2020) [21]	fruits, vegetables, wheat, crops, beef, pork, salmon, potato	x	x	x	x	na	na	x	Norway
Pruitt et al (2021) [68]	potato	x		x	x	na	na	na	USA
Rousselière & Rousselière (2017) [33]	apples		x	x		cisgenic	na	na	EU-27, Norway, Iceland, Turkey
Schaart (2004) [8]	strawberries	x	x	x	na	cisgenic	na	na	Norway, Denmark, UK
Schenk et al (2011) [69]	apples		x	x	na	cisgenic	x	na	Netherlands
Shew et al (2016) [70]	rice	x	x	x	na	cisgenic	x	na	India
Shew et al (2017) [15]	rice	x	x	x	na	RNAi	x	na	Australia, Belgium, Canada, France, USA
Shew et al (2018) [16]	rice	x	x	x	x	na	x	na	Australia, Belgium, Canada, France, USA
Son & Lim (2021) [71]	soybean oil, cotton	x		x	x	na	na	na	South Korea
Tsiboe et al (2017) [72]	rice	x		x	na	cisgenic	x	na	Ghana
Uddin et al (2021) [26]	grapes	x	x	na	x	na	x	na	USA
Vasquez Arreaga (2020) [73]	potato, apples, milk, salmon, papaya, sweet corn		x	x	x	na	na	x	Canada
Yang & Hobbs (2020) [74]	food		x		x	na	na	na	Canada
Yang & Hobbs (2020) [75]	apples	x		x	x	na	x	na	Canada
Yunes et al (2019) [76]	pork		x	na	x	na	na	na	Brazil
Yunes et al (2021) [22]	beef		x	na	x	na	na	na	Brazil

References

1. Sticklen, M.; Others Transgenic, cisgenic, intragenic and subgenic crops. *Adv Crop Sci Tech* **2015**, *3*, e123.
2. Gholizadeh, P.; Köse, Ş.; Dao, S.; Ganbarov, K.; Tanomand, A.; Dal, T.; Aghazadeh, M.; Ghotaslou, R.; Ahangarzadeh Rezaee, M.; Yousefi, B.; et al. How CRISPR-Cas System Could Be Used to Combat Antimicrobial Resistance. *Infect. Drug Resist.* **2020**, *13*, 1111–1121.
3. Purnhagen, K.; Wessler, J. EU regulation of new plant breeding technologies and their possible economic implications for the EU and beyond. *Appl. Econ. Perspect. Policy* **2020**, doi:10.1002/aep.13084.
4. Qaim, M. Role of new plant breeding technologies for food security and sustainable agricultural development. *Appl. Econ. Perspect. Policy* **2020**, *42*, 129–150.

5. Beghin, J.C. Sanitary and Phytosanitary Measures. In *Current Issues in Global Agricultural and Trade Policy: Essays in Honour of Timothy E Josling*; books.google.com, 2021; pp. 159–180.
6. Escrig-Olmedo, E.; Munoz-Torres, M.J.; Fernandez-Izquierdo, M.A. Socially responsible investing: sustainability indices, ESG rating and information provider agencies. *International Journal of Sustainable Economy* **2010**, *2*, 442–461.
7. McPhetres, J.; Rutjens, B.T.; Weinstein, N.; Brisson, J.A. Modifying attitudes about modified foods: Increased knowledge leads to more positive attitudes. *J. Environ. Psychol.* **2019**, *64*, 21–29.
8. Schaart, J.G. Towards consumer-friendly cisgenic strawberries which are less susceptible to *Botrytis cinerea*. **2004**.
9. Lusk, J.L.; Rozan, A. Consumer acceptance of ingenic foods. *Biotechnol. J.* **2006**, *1*, 1433–1434.
10. Colson, G.; Huffman, W.E. Consumers' Willingness to Pay for Genetically Modified Foods with Product-Enhancing Nutritional Attributes. *Am. J. Agric. Econ.* **2011**, *93*, 358–363.
11. Colson, G.J.; Huffman, W.E.; Rousu, M.C. Improving the Nutrient Content of Food through Genetic Modification: Evidence from Experimental Auctions on Consumer Acceptance. *J. Agric. Resour. Econ.* **2011**, *36*, 343–364.
12. Edenbrandt, A.K. Demand for pesticide-free, cisgenic food? Exploring differences between consumers of organic and conventional food. *British Food Journal* **2018**.
13. Edenbrandt, A.K.; Gamborg, C.; Thorsen, B.J. Consumers' preferences for bread: Transgenic, cisgenic, organic or pesticide-free? *J. Agric. Econ.* **2018**, *69*, 121–141.
14. Penn, J.M.; Hu, W. Understanding hypothetical bias: An enhanced meta-analysis. *Am. J. Agric. Econ.* **2018**, *100*, 1186–1206.
15. Shew, A.M.; Danforth, D.M.; Nalley, L.L.; Nayga, R.M.; Tsiboe, F.; Dixon, B.L. New innovations in agricultural biotech: Consumer acceptance of topical RNAi in rice production. *Food Control* **2017**, *81*, 189–195.
16. Shew, A.M.; Nalley, L.L.; Snell, H.A.; Nayga, R.M.; Dixon, B.L. CRISPR versus GMOs: Public acceptance and valuation. *Global Food Security* **2018**, *19*, 71–80.
17. Lusk, J.L. Effects of Cheap Talk on Consumer Willingness-to-Pay for Golden Rice. *Am. J. Agric. Econ.* **2003**, *85*, 840–856.
18. de-Magistris, T.; Gracia, A.; Nayga, R.M. On the Use of Honesty Priming Tasks to Mitigate Hypothetical Bias in Choice Experiments. *Am. J. Agric. Econ.* **2013**, *95*, 1136–1154.
19. Alfnes, F.; Atle G. Guttormsen; Gro Steine; Kari Kolstad Consumers' Willingness to Pay for the Color of Salmon: A Choice Experiment with Real Economic Incentives. *Am. J. Agric. Econ.* **2006**, *88*, 1050–1061.
20. Lusk, J.L.; Schroeder, T.C. Are choice experiments incentive compatible? A test with quality differentiated beef steaks. *Am. J. Agric. Econ.* **2004**, *86*, 467–482.
21. Board, N.B.A. Norwegian consumers' attitudes toward gene editing in Norwegian agriculture and aquaculture 2020.
22. Yunes, M.C.; Osório-Santos, Z.; von Keyserlingk, M.A.G.; Hötzel, M.J. Gene Editing for Improved Animal Welfare and Production Traits in Cattle: Will This Technology Be Embraced or Rejected by the Public? *Sustainability* **2021**, *13*, 4966.
23. Ritter, C.; Shriver, A.; McConnachie, E.; Robbins, J.; von Keyserlingk, M.A.G.; Weary, D.M. Public attitudes toward genetic modification in dairy cattle. *PLoS One* **2019**, *14*, e0225372.
24. Marette, S.; Disdier, A.-C.; Beghin, J.C. A comparison of EU and US consumers' willingness to pay for gene-edited food: Evidence from apples. *Appetite* **2021**, *159*, 105064.
25. Marette, S.; Beghin, J.; Disdier, A.-C.; Mojduszka, E. Can foods produced with new plant engineering techniques succeed in the marketplace? A case study of apples. **2021**, 36 p.
26. Uddin, A.; Gallardo, K.; Rickard, B.J.; Alston, J.M.; Sambucci, O. Are Consumers Willing to Accept Gene Edited Fruit? An Application to Quality Traits for Fresh Table Grapes. **2021**.
27. Ferrari, L.; Baum, C.M.; Banterle, A.; Hans, D.S. Attitude and labelling preferences towards gene-edited food: a consumer study amongst millennials and Generation Z. *British Food Journal* **2020**, *123*, 1268–1286.
28. Borrello, M.; Cembalo, L.; Vecchio, R. Role of information in consumers' preferences for eco-sustainable genetic improvements in plant breeding. *PLoS One* **2021**, *16*, e0255130.
29. Lusk, J.L.; Jamal, M.; Kurlander, L.; Roucan, M.; Taulman, L. A Meta-Analysis of Genetically Modified Food Valuation Studies. *J. Agric. Resour. Econ.* **2005**, *30*, 28–44.
30. Lusk, J.L. Chapter 10 Consumer Preferences for Genetically Modified Food. In *Genetically Modified Food and Global Welfare*; Colin, A.C., GianCarlo, M., Ian, S., Eds.; Frontiers of Economics and Globalization; Emerald Group Publishing Limited, 2011; Vol. 10, pp. 243–262 ISBN 9780857247582.
31. Narh, A.B.; Nalley, L.L.; Price, H.; Shew, A.M.; Nayga, R.M. A Multi-Country Study of the Willingness-to-Consume Alternative (RNAi, CRISPR and Cisgenic) Genetically Modified Food. **2019**.
32. Eurobarometer, S. 354, 2010, Food-related risks, Conducted by TNS Opinion & Social at the request of the European Food Safety Authority (EFSA). *TNS Opinion & Social Avenue Herrmann Debroux* **40**, 1160.
33. Rousselière, D.; Rousselière, S. Is biotechnology (more) acceptable when it enables a reduction in phytosanitary treatments? A European comparison of the acceptability of transgenesis and cisgenesis. *PLoS One* **2017**, *12*, e0183213.
34. 2019 Eurobarometer on Food Safety in the EU Available online: <https://www.efsa.europa.eu/en/corporate/pub/eurobarometer19> (accessed on Aug 23, 2021).
35. Gaskell, G.; Allansdottir, A.; Allum, N.; Castro, P.; Esmer, Y.; Fischler, C.; Jackson, J.; Kronberger, N.; Hampel, J.; Mejlgaard, N.; et al. The 2010 Eurobarometer on the life sciences. *Nat. Biotechnol.* **2011**, *29*, 113–114.

36. Kronberger, N.; Wagner, W.; Nagata, M. How Natural Is "More Natural"? The Role of Method, Type of Transfer, and Familiarity for Public Perceptions of Cisgenic and Transgenic Modification. *Sci. Commun.* **2014**, *36*, 106–130.
37. Busch, G.; Ryan, E.; von Keyserlingk, M.A.G.; Weary, D.M. Citizen views on genome editing: effects of species and purpose. *Agric. Human Values* **2021**, doi:10.1007/s10460-021-10235-9.
38. Caputo, V.; Lusk, J.; Kilders, V. Consumer Acceptance of Gene Edited Foods: A nationwide survey on US consumer beliefs, knowledge, understanding, and willingness to pay for gene-edited foods under different treatments. *FMI Foundation report* **2020**.
39. Kolodinsky, J.; Lusk, J.L. Mandatory labels can improve attitudes toward genetically engineered food. *Sci Adv* **2018**, *4*, eaaq1413.
40. Fernbach, P.M.; Light, N.; Scott, S.E.; Inbar, Y.; Rozin, P. Extreme opponents of genetically modified foods know the least but think they know the most. *Nature Human Behaviour* **2019**, *1*.
41. De Marchi, E.; Cavaliere, A.; Banterle, A. Identifying Motivations for Acceptance of Cisgenic Food: Results from a Randomized Controlled Choice Experiment; *Journal of Agricultural and Resource Economics* **2020** Preprints.
42. Edenbrandt, A.K.; House, L.A.; Gao, Z.; Olmstead, M.; Gray, D. Consumer acceptance of cisgenic food and the impact of information and status quo. *Food Qual. Prefer.* **2018**, *69*, 44–52.
43. Ishii, T.; Araki, M. Consumer acceptance of food crops developed by genome editing. *Plant Cell Rep.* **2016**, *35*, 1507–1518.
44. Heumueller, D.; Josling, T.; Others Trade restrictions on genetically engineered foods: The application of the TBT agreement. *The regulation of agricultural biotechnology* **2004**, 79–88.
45. Bullock, D.W.; Wilson, W.W.; Neadeau, J. Gene editing versus genetic modification in the research and development of new crop traits: An economic comparison. *Am. J. Agric. Econ.* **2021**, doi:10.1111/ajae.12201.
46. Brinegar, K.; K Yetisen, A.; Choi, S.; Vallillo, E.; Ruiz-Esparza, G.U.; Prabhakar, A.M.; Khademhosseini, A.; Yun, S.-H. The commercialization of genome-editing technologies. *Crit. Rev. Biotechnol.* **2017**, *37*, 924–932.
47. Ricroch, A.; Clairand, P.; Harwood, W. Use of CRISPR systems in plant genome editing: toward new opportunities in agriculture. *Emerg Top Life Sci* **2017**, *1*, 169–182.
48. Menz, J.; Modrzejewski, D.; Hartung, F.; Wilhelm, R.; Sprink, T. Genome Edited Crops Touch the Market: A View on the Global Development and Regulatory Environment. *Front. Plant Sci.* **2020**, *11*, 586027.
49. Turnbull, C.; Lillemo, M.; Hvoslef-Eide, T.A.K. Global regulation of genetically modified crops amid the gene edited crop boom - A review. *Front. Plant Sci.* **2021**, *12*, 630396.
50. An, H.; Adamowicz, W.; Lloyd-Smith, P. Strategic behavior in stated preferences and the demand for gene-edited canola oil. *Mimeo*, **2020**.
51. Arias-Salazar, A.; Pana, J.M.; Melara, M.V.; Arias, A.G. Attitudes towards genome editing among university students in Costa Rica. *Revista de Ciencia y Tecnología* **2019** 35(2).
52. Britton, L.L.; Tonsor, G.T. Consumers' willingness to pay for beef products derived from RNA interference technology. *Food Quality and Preference* **2019** 75, 187-197.
53. Britton, L.L.; Tonsor, G.T. US consumers' attitudes toward RNA interference technology in the beef sector." *Journal of Agriculture and Food Research* **2020** 2, 100049.
54. De Marchi, E.; Cavaliere, E.; Banterle, A. Consumers' Choice Behavior for Cisgenic Food: Exploring the Role of Time Preferences. *Applied Economic Perspectives and Policy*, **2020** doi:10.1002/aep.13043.
55. De Marchi, E.; Cavaliere, A.; Bacenetti, J.; Milani, F.; Pigliafreddo, S.; Banterle, A. Can consumer food choices contribute to reduce environmental impact? The case of cisgenic apples". *Science of The Total Environment*, **2019** 681, 155-162.
56. De Steur, H.; Blancquaert, D.; Strobbe, S.; Feng, S.; Buysse, J.; Stove, C.; Lambert, W.; Van Der Straeten, D.; Gellynck, X. Consumer acceptance and willingness-to-pay for genetically modified foods with enhanced vitamin levels. *Genetically Modified Organisms in Food: Production, Safety, Regulation and Public Health*; Elsevier Academic Press: Amsterdam, Netherlands, **2016**, 195-206.
57. Delwaide, A.-C.; Nalley, L.L.; Dixon, B.L.; Danforth, D.M.; Nayga Jr, R.M.; Van Loo, E.J.; Verbeke, W. Revisiting GMOs: are there differences in European consumers' acceptance and valuation for cisgenically vs transgenically bred rice?." *PloS one* **2015** 10, no. 5, e0126060.
58. European Food Safety Authority (EFSA). Special Eurobarometer Wave EB91.3. Food Safety in the EU. **2019**.
58. Farid, M.; Cao, J.; Lim, Y.; Arato, T.; Kodama, K. Exploring factors affecting the acceptance of genetically edited food among youth in Japan. *International Journal of Environmental Research and Public Health* **2020** 17, no. 8, 2935.
59. Gatica-Arias, A.; Valdez-Melara, M.; Arrieta-Espinoza, G.; Albertazzi-Castro, F.J.; Madrigal-Pana, J. Consumer attitudes toward food crops developed by CRISPR/Cas9 in Costa Rica. *Plant Cell, Tissue and Organ Culture* **2019** 139, no. 2, 417-427.
60. Kato-Nitta, N.; Inagaki, Y.; Maeda, T.; Tachikawa, M. Effects of information on consumer attitudes towards gene-edited foods: a comparison between livestock and vegetables. *CABI Agriculture and Bioscience* **2021** 2, no.1, 1-12.
61. Kato-Nitta, N.; Inagaki, Y.; Maeda, T.; Tachikawa, M. Expert and public perceptions of gene-edited crops: attitude changes in relation to scientific knowledge. *Palgrave Communications* **2019** 5, no. 1, 1-14.
62. Kilders, V.; Caputo, V. Is Animal Welfare Promoting Hornless Cattle? Assessing Consumer's Valuation for Milk from Gene-edited Cows under Different Information Regimes. *Journal of Agricultural Economics* **2021**, in press.
63. Lusk, J.L.; McFadden, B.R.; Wilson, N. Do consumers care how a genetically engineered food was created or who created it? *Food Policy* **2018** 78, 81-90.

64. McFadden, B.R.; Anderton, B.N.; Davidson, K.A.; Bernard, J.C. The effect of scientific information and narrative on preferences for possible gene-edited solutions for citrus greening. *Applied Economic Perspectives and Policy* **2021** DOI: 10.1002/aepp.13154.
65. Mielby, H.; Sandøe, P.; Lassen, J. Multiple aspects of unnaturalness: are cisgenic crops perceived as being more natural and more acceptable than transgenic crops? *Agric. Hum. Values* **2013** 30, 471–480.
66. Muringai, V.; Fan, X.; Goddard, E. Canadian consumer acceptance of gene-edited versus genetically modified potatoes: A choice experiment approach. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* **2020** 68, no. 1, 47-63.
67. Nlend Nkott, A.L.; Temple, L. Societal acceptability conditions of genome editing for upland rice in Madagascar. *Technological Forecasting and Social Change* **2021** 167, 120720.
68. Pruitt, J.R.; Melton, K.M.; Palma, M.A. Does Physical Activity Influence Consumer Acceptance of Gene-edited Food? *Sustainability* **2021** 13(x).
69. Schenk, M.F.; van der Maas, M.P.; Smulders, M.J.M.; Gilissen, L.J.W.J.; Fischer, A.R.H.; van der Lans, I.A.; Jacobsen, E.; Frewer, L.J. Consumer attitudes towards hypoallergenic apples that alleviate mild apple allergy. *Food Quality and Preference* **2011** 22, no. 1, 83-91.
70. Shew, A.M.; Nalley, L.L.; Danforth, D.M.; Dixon, B.L.; Nayga Jr, R.M.; Delwaide, A-C.; Valent, B. All GMOs the Same? Consumer Acceptance of Cisgenic Rice in India. *Plant Biotechnology Journal* **2016** 14 (1), 4–7.
71. Son, E.; Lim, S.S. Consumer Acceptance of Gene-Edited versus Genetically Modified Foods in Korea. *International Journal of Environmental Research and Public Health* **2021** 18 (7), <https://doi.org/10.3390/ijerph18073805>.
72. Tsiboe, F.; Nalley, L.L.; Dixon, B.L.; Danforth, D.M.; Delwaide, A-C; Nayga, R.M. Ghanaian Consumers' Attitudes toward Cisgenic Rice: Are all Genetically Modified Rice the Same?. *Ghana Journal of Development Studies* **2017** 14, no. 1, 1-18.
73. Vasquez Arreaga, O. Canadian Consumer Perception of Genome-Edited Food Products. MS Thesis. University of Saskatchewan, **2020**.
74. Yang, Y.; Hobbs, J.E. Supporters or opponents: will cultural values shape consumer acceptance of gene editing? *Journal of Food Products Marketing* **2020** 26.1, 17-37.
75. Yang, Y.; Hobbs, J.E. The power of stories: Narratives and information framing effects in science communication. *American Journal of Agricultural Economics* **2020** 102.4, 1271-1296.
76. Yunes, M.C.; Teixeira, D.L.; von Keyserlingk, M.A.G.; Hötzel, M.J. Is gene editing an acceptable alternative to castration in pigs? *PloS one* **2019** 14, no. 6, e0218176.