sustainability

Review

Consumer valuation of and attitudes towards novel foods produced with New Plant Engineering Techniques: A review

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Abstract: We follow the PRISMA extension for scoping reviews to review the emerging international body of empirical evidence on consumers' 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 review sorts out findings to identify conditioning factors that 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 a key determinant of acceptance and WTP. Acceptance and WTP tend to increase when socially beneficial attributes—as opposed to producer-oriented cost-saving attributes—are generated by NPETs. NPET-improved foods are systematically less discounted than transgenic foods. Most of the valuation estimates 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); genome editing; gene editing; cisgenic; willingness to pay (WTP)

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1. Introduction

New Plant Engineering Techniques (NPETs) include genome/gene editing, cisgenesis, intragenesis, non-transgenic RNA interference, and others (see Table 1 for definitions of biotech terms based on [1], and of economic terms). The empirical evidence has reached a critical mass, lending itself to a systematic review. Using the PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation [2] to conduct the review, we examine the emerging and fast-growing international body of empirical evidence on consumers' attitudes and limited willingness to pay (WTP) for and consume novel foods produced with inputs generated using NPETs. 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 using NPETs. When applied to animals, these techniques can also improve animal welfare and disease resistance [3–5]. Improving disease resistance in plants and animals may mitigate antimicrobial resistance [6], which can arise with the overuse of antimicrobials.

Table 1. Definitions of biotechnological and economic terms.

.Term	Abbreviation	Definition
New Plant Engineering Techniques	NPETs	Recent biotechnological techniques used to do targeted insertion, deletion and gene replacement, or stable silencing of a gene, in the DNA of a plant. These techniques include RNA interference (RNAi), cisgenesis/intragenesis, and gene editing techniques including zinc finger nucleases (ZFNs), clustered regularly interspaced short palindromic repeats/CRISPR-associated protein 9 (CRISPR/Cas9), and Transcription Activator-Like Effector Nucleases (TALEN) to introduce new traits into a host plant genome.
New Plant Breeding Techniques	NPBTs	See definition of *New Plant Engineering Techniques*.
Genome or Gene Editing	GE	A technique that adds, deletes, or modifies precisely and site-specifically genes from the genome of a plant or animal. The additions are from plants or animals with which the original subject can reproduce. The resulting organism could be obtained via conventional breeding, which uses natural hybrids.
GE Scissors		Methods to edit genes including CRISPR/Cas9, TALEN, and ZFN
Cisgenic		Introduction of a gene that belongs to the same species or a crossable species. Cisgenic introduction includes the gene cassette with its regulatory sequences integrated in the host organism and is indistinguishable from mutation obtained with conventional breeding.
Ingenic		See definition of *Cisgenic*.
Intragenic		Similar to cisgenic, but the gene coding sequence is regulated by promoters and terminators of different genes from the same or crossable gene pool. Intragenic organisms cannot be obtained by conventional breeding techniques although they do not contain transgenic material.
RNA Interference	RNAi	A technique used to regulate or silence the transcription of a specific native gene in the host organism. Here we restrict RNAi to non-transgenic modifications. Organisms obtained through RNAi cannot be obtained by conventional breeding.
Genetically modified organism	GMO	Plants/crops with DNA modified using genetic material from an unrelated species to confer some benefits (increased resistance to pests, or nutrition).
Transgenic		Introduction of genetic material from an unrelated (non-crossable) species.
Willingness to pay	WTP	The maximum amount of money a consumer is willing to pay to acquire a product or product attribute.
Discount		The difference in valuation (WTP) for a lower-valued good relative to a more highly valued good resulting from differences in consumers’ preferences for attributes of the products; in these studies discounts are frequently found for foods generated using biotechnology relative to a close substitute obtained through conventional breeding.
Premium		The difference in valuation (WTP) for a more highly valued good relative to a lower-valued good resulting from differences in consumers’ preferences for attributes of the products.
Willingness to eat or consume		An attitudinal dichotomous variable (yes/no) expressing the willingness to consume or eat a given food item. This willingness to eat can be conditioned

		on a reference price or range of prices. It measures the (un)favorable attitude of a consumer toward a food.
Hypothetical bias		A phenomenon in which consumers' WTP for a product differs depending on whether the consumers are making a real—that is, binding—or hypothetical choice. This bias can be mitigated in experiments by providing a "cheap talk" script asking subjects to think as if they were in a shopping environment as well as through other methods.

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 [7]. NPETs have had little commercial prevalence so far for two main reasons [8–10]. NPETs are new and unfamiliar to consumers relative to other breeding techniques and the regulatory process is ill-defined and shifting in many countries [11]. Particularly relevant in the context of our review, existing studies suggest that consumers discount these novel foods relative to conventional foods on average [12]. Our objective is to parse the findings in the extant literature on NPETs 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 [13,14]. Issues related to distrust—including labelling, scientific knowledge, risk perception, and perception of naturalness—are present with NPETs, just as they were with GMOs [15,16]. Our investigation points out the key differences in perceptions and 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 [17], 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 the sustainability of food supply chains and foster better health outcomes for consumers and the environment.

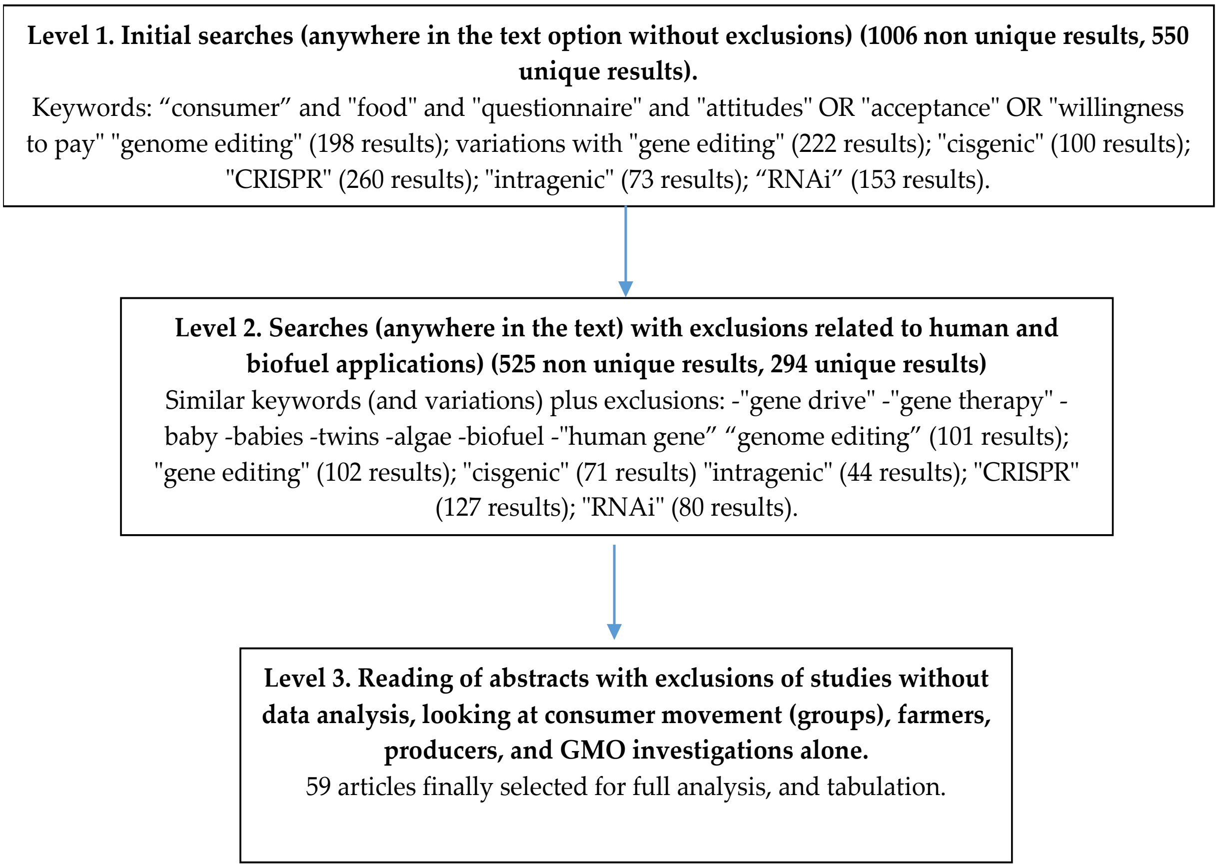
In most studies reviewed, the average consumer discounts these NPET-based novel foods relative to conventional ones, although the discount is not as pronounced as for transgenic (GMO) foods, when comparative results are available [18,19] (see section 3.3 for further references). The limited familiarity with NPETs, questions about their naturalness, and attitudes toward food innovations are also major reasons why consumers discount NPET-based products relative to conventional versions [19–22]. 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 [23]—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 such as color or shape changes are discounted [16].

Most of the valuation elicitations are based on hypothetical experiments and surveys in standard research setups (e.g., lab experiments, online surveys), in large part because few NPET-based novel foods have been commercialized due to regulatory approval processes and difficulty penetrating markets. The few exceptions are GE soy oil with high oleic acid, which has been commercialized since 2019, GE herbicide resistant canola grown in Montana, and RNAi apples [24]. Additionally, GE enhanced tomatoes were commercialized in Japan in 2021 [25]. The hypothetical valuations reported in the research studies await validation through revealed preferences in actual purchases in the food retailing environments when these novel foods become widely available.

2. Materials and Methods

The article relies on a systematic review of the emerging literature on NPETs, specifically focusing on consumers' attitudes and willingness to pay for NPET-based food. We followed principles for conducting scoping reviews documented in the PRISMA-ScR [2] and guidance for Cochrane reviews [26]. We first defined the objective of the review—to review the literature on consumers' attitudes and willingness to pay for NPET-based foods and their conditioning factors. Defining the review objective guided the choice of search terms to be used to identify candidate articles. We undertook a systemic search for available articles written in the English language, published or not, using Google Scholar searches with the following keywords as shown in Figure 1.

Figure 1. Literature search sequence with keywords used in Google Scholar (September 26, 2021)



Note: Additional searches with "new plant breeding technique" and "new plant engineering technique" were overly restrictive and so were searches within titles ("allinttle" option).

NPET terms included gene/genome editing, cisgenic, intragenic, ingenic, RNAi, and CRISPR. We searched for articles that included these terms and at least one of the following terms: consumer acceptance (or attitudes), or consumers' willingness to pay, to purchase, to eat, or to consume the product. This search yielded 550 unique candidates which was narrowed down to 294 unique results, using exclusion of terms related to human therapy and biofuel applications (see level 2 in Figure 1). We then read the article abstracts and further excluded articles with no data analysis, and those not examining consumers, and those only covering GMOs (see Level 3 in Figure 1). This yielded 59 useable studies. During the reading of these articles, we double-checked their references to see if we missed any relevant articles in our searches. In the 59 useable studies, one was a meta-analysis (not generating any new data but formalizing the data process) and 58 provided analysis using original data collected for their respective investigations. Several investigations 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. Among the 59 publications, 44 (75%) had gone through a formal journal refereeing process in a journal.

We tabulated the 59 studies in searchable spreadsheet format (see supplemental excel folder) 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 organisms or products; 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; additional remarks; addressing heterogeneity of consumers; and refereed article status. A subset of key attributes is presented in Appendix Table 1. Then, we used descriptive statistics (counts and frequencies) to characterize the key attributes of these studies. We evaluated the estimated results and findings in a qualitative way to obtain stylized facts (common patterns across studies) on discounts and premia in WTP, and treatment effects influencing the acceptance of and attitudes toward NPETs. We could not undertake a formal meta-analysis of WTP estimates because of the limited number of estimates and the difficulty of normalizing them for comparability (marginal utility for some additional attribute, WTP for the complete bundle of attributes, premium or discount in percent and some in monetary units). Hence, formal comparability using a common metric (relative discount or premium) and its distribution among subjects was not possible. While falling short of undertaking a formal meta-analysis, we follow the PRISMA-ScR format.

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, 4 between 2014 and 2016, 28 between 2017 and 2019, and 19 from 2020 through September 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 59 identified studies investigating consumer attitudes/behavior with respect to NPETs, 37 focused on genome/gene editing, while 24 examined other NPETs (17 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 [18,27–29]. The more recent papers focus on GE, RNAi, and other newly developed NPETs. Among these 59 studies, 43 address consumer attitudes and acceptance and willingness to eat or consume; 31 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 (32 studies) and North America (USA and Canada) (22 studies) have received the most attention, while the number of studies examining consumer attitudes/valuation in Asia (11), 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, 45 investigations involve comparative analysis of technologies—a combination of conventional, GMO, and/or organic versus NPETs. Among these comparative studies, 34 cover conventional technologies/hybrids, 38 involve GMO, and 12 deal with organic goods. Organic foods are not NPETs but are often compared to NPETs in surveys, because of their sustainable and nutritious attributes (e.g., reduced pesticide use and residues).

Most investigations and experiments involve hypothetical or fictitious choices, since very few NPET-based goods have been commercialized with the exceptions of GE soybean and GE canola oil, and RNAi apples [24]. 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 [7]. Two articles that used real—rather than hypothetical—choices elicited data on WTP through an experimental auction with real food products [18,29]. However, even though real transactions occurred, the goods sold 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) [30,31].

3.2. Methods to elicit attitudes and WTP

Many of the articles—33 out of 59—estimate valuation of NPETs. 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) [18], 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 [32]. 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 the respondents are about their decision, and honesty priming tasks, as well as valuation calibration techniques, among others [32–34]. 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 [35,36].

The three main approaches used to elicit data for WTP estimation in these studies are choice experiments, multiple price lists (MPLs), and experimental auctions. 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. Research suggests that these three methods provide comparable estimates of valuation in non-hypothetical settings, though the experimental auction approach may yield more conservative estimates of WTP than choice experiments and MPLs [37].

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. Researchers vary prices and product attribute levels to estimate valuation of 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. Choice experiments are well suited for situations in which the researchers wish to vary and evaluate multiple attributes of the products. The choice experiment is the most widely used WTP elicitation technique in studies of NPET valuation [12,19–21,24,30,31,38–50].

MPL-based studies present a list of prices for two products (at a time) to respondents. One of the products' prices incrementally changes in each row of the list. In each row, the respondent makes a choice between each product. The approach documents 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 elicitation techniques. The MPL is the second most commonly used experimental approach to elicit data on valuation for NPETs [51–56].

Third, 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 values elicited under two conditions significantly differ) 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 are also most appropriate for use when participants can make real purchases of products due to greater threat of hypothetical biases [32]. 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 [18,29].

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 [16] and face-to-face interviews [16,57], as well as eliciting open-ended responses to questions from large numbers of participants in online surveys [58,59]. 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) [16,57–59].

Finally, a couple of studies use Twitter data and machine learning to assess (un)favorable opinions about genome editing [60,61]. These data are generated in a noisy and spontaneous environment and it may be difficult to account for key factors influencing the tweets and their intensity. It is however a novel way to study the attitudes of the general public—and potential consumers—towards NPETs.

3.3. Findings on consumer behavior

The first key—and robust—finding is that consumers on average discount food goods generated using NPETs relative to foods produced using traditional breeding techniques [12,19–21,30,31,40–42,45,46,48–56]. All studies that compare valuation of conventionally bred food products with NPET-produced food products reflect this discounting of NPET-based goods relative to conventional goods (or NPET-based attributes relative to similar attributes generated from conventional breeding techniques), when averaging over all subjects participating in the research. However, the use of NPETs to provide novel, beneficial attributes that are absent in the conventionally produced item can lead to higher valuation of NPET-derived products than conventional products [18,29]. A second finding is that NPET-based innovations and goods tend to be valued more highly than their GMO counterparts [19,20,30,31,38,41,45–47,51,52,54,56,62]. This is particularly true when NPETs embody improvements beneficial to the environment or human and animal health. While the majority of studies that compare consumer valuation of NPETs to GMOs find higher WTP for NPETs, there are, however, a few particular situations in which consumers do not differentiate WTP between NPETs and GMOs [24] or even require lower discounts for GMOs than for NPETs [20] because of limited knowledge of NPETs.

Another important result common to many investigations is that there exists multidimensional 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 naturalness of NPET-based foods, and have varying concerns about the risk presented by the use of NPETs 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 [19,43,49].

An important source of heterogeneity seems to arise from consumers' country of residence, which may reflect varying regulatory approaches or cultural values [11]. For instance, trust in the regulatory bodies of one's home country is associated with positive attitudes towards approved technologies [16]. All but one study find marked differences in WTP or willingness to consume among countries. The exception (Ferrari et al. [3]) compares young consumers in Belgium and the Netherlands, neighboring countries with similar cultures, who are "millennials" or members of Generation Z, which may be more accepting of the use of NPET technology than older generations [53]. The range of concerns and attitudes gets amplified with geographic and cultural distance, which reflects findings from the literature on GMO-based agriculture and food [63,64]. 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 [28] on vegetables; Marette et al. [19,43] for apples; Narh et al. [65] on rice; and Shew et al. [51] on acceptance of CRISPR rice). Intriguingly, residents of Quebec hold more negative views of NPETs than residents of other Canadian provinces [66], suggesting that culture is important. 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 foods are much lower than they were for transgenic food but they remain highly heterogeneous across countries [67–71].

The heterogeneity of acceptance and valuation of NPET-derived foods extends to the type of food item and the level of processing [72], which is reminiscent of findings for GMO-based food [63,64]. The lowest levels of acceptance are for meat and milk [73,74]. 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 [20].

WTP for NPET-derived foods increases with tangible improvements such as tastier grapes [41,49], improved health benefits [29,38,75], environmental benefits (reduced pesticides, water use) [31,55,76], or improved animal welfare [42,77]. 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 [16]. 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 [3,16,66,74,78]. Greater knowledge about the product being modified—specifically, in this case, wines—also promotes greater WTP for NPET-based products [53]. Interestingly, basic familiarity with products that contain modified ingredients may also promote positive 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 [79].

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 [23]. 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. Even simply highlighting similarities between conventional breeding and NPETs can significantly increase support for products derived from NPETs [44].

A recent finding on knowledge and support for GMOs highlights the importance of objective (i.e., measurable)—as opposed to subjective (self-reported)—knowledge [80]. 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 [80]. 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. [21], Marette et al. [19], Edenbrandt et al. [42]). However, consumers can get confused by conflicting messages and these cancel out any additional support for NPETs [18,29].

General familiarity—beyond formal knowledge—may also be important. For GMOs, EU consumers were much more worried in 2010 than they were in 2019 about GMOs 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 [54,56,57]. Neophobia—the fear of the unknown—is well-established as influencing attitudes about foods [81], and is related to other important individual characteristics, such as education and age [12,46]. Neophobia has been found to decrease with repeated exposure to the novel item [82]. Attitudes—particularly with respect to perceived risks and benefits of the use of NPETs—are significantly related to acceptance/valuation [3,5,11,15,16,53,66,68,77,78].

In experiments addressing labeling of NPET-derived foods, labeling is preferred, especially in European countries [3,8,16,18,29,30,71]. 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 [4]. 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 because they are new.

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.

Labeling 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 [18,29]. 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 [79].

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 [83]. These technologies, initially driven by non-profit research institutions, have led to an unusual number of patents globally, and many startups [9,84]. 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 [7,85,86].

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 folder detailing the studies' characteristics is available online.

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Appendix A Table 1: Articles on NPETs Included in the Review (see supplemental table for more details)

Authors	Organism/ product	WTP	Attitude acceptance	GMO	GE	Non-GE NPETs	Conventional	Organic	Country
An et al. (2019) [38]	canola oil	x	na	x	x	na	na	na	Canada
Arias-Salazar et al. (2019) [87]	food, crops, rice, beans	na	x	na	x	na	na	na	Costa Rica
Basinskiene and Seinauskiene (2021) [88]	generic food	na	x	x	x	na	na	na	Lithuania
Borrello et al. (2021) [53]	wine	x	x	0	x	na	x	0	Italy
Britton and Tonsor (2019) [39]	beef	x	na	na	na	RNAi	na	na	usa
Britton and Tonsor (2020) [5]	beef	na	x	na	na	RNAi	na	na	usa
Busch et al. (2021) [73]	wheat, humans, milk, beef, pork	na	x	na	x	na	na	na	Canada, Austria, Germany, Italy, USA
Caputo et al. (2020) [20]	pork, tomato, spinach	x	x	x	x	na	x	x	USA
Colson and Huffman (2011) [18]	vegetables	x	na	x	na	intragenic	x	na	USA
Colson et al. (2011) [29]	tomato, broccoli, potato	x	na	x	na	intragenic	x	na	USA
De Marchi et al. (2020a) [12]	apples	x	x	na	x	na	x	na	Italy
De Marchi et al. (2020b) [21]	apples	x	x	na	na	cisgenic	x	na	Italy
De Marchi et al. (2019) [40]	apples	x	na	na	na	cisgenic	x	na	Italy
De Steur et al. (2016) [89]	tomato, broccoli, potato, vegetables	x	x	x	na	intragenic	x	na	USA, China, France, NZ,
Delwaide et al. (2015) [54]	rice	x	x	x	na	cisgenic	x	0	EU countries: Belgium, France, The Netherlands,

Authors	**Organism/ product**	**WTP**	**Attitude acceptance**	**GMO**	**GE**	**Non-GE NPETs**	**Conventional**	**Organic**	**Country**
									Spain, The UK.
Edenbrandt (2018) [30]	rye bread	x	na	x	na	cisgenic	x	x	Denmark
Edenbrandt et al. (2018a) [31]	rye bread	x	na	x	na	cisgenic	x	x	Denmark
Edenbrandt et al. (2018b) [41]	grapes	x	na	x	na	cisgenic	x	na	USA
EFSA (2010) [67]	food, drink	na	x	x	na	na	x	na	EU-27
EFSA (2019) [69]	food, drink	na	x	x	x	na	x	na	EU-27
Farid et al. (2020) [15]	food, crops	x	x	na	x	na	na	na	Japan
Ferrari et al. (2020) [3]	food	na	x	x	x	na	na	na	Belgium, Netherlands
Gaskell et al. (2011) [70]	food	na	x	x	na	cisgenic	x	na	EU-27
Gatica-Arias et al. (2019) [90]	food, crops, rice, beans	na	x	na	x	na	na	na	Costa Rica
Kato-Nitta et al. (2021) [74]	tomato, pork	na	x	x	x	na	x	na	Japan
Kato-Nitta et al. (2019) [78]	crops	na	x	x	x	na	x	na	Japan
Kato-Nitta et al. (2021) [11]	livestock, vegetables	na	x	0	x	na	x	0	Germany, Japan, US
Kilders and Caputo (2021) [42]	milk	x	na	na	x	na	x	na	USA
Kronberger et al. (2014) [71]	animals, human, plants, apples	na	x	x	0	cisgenic	x	0	Austria, Japan, EU 27
Lusk and Rozan (2006) [28]	vegetables	na	x	x	na	ingenic	na	0	France USA
Lusk et al. (2018) [62]	food	x	x	x	x	cisgenic	x	na	USA
Marette et al. (2021a) [43]	apples	x	na	x	x	na	x	na	France, USA
Marette et al. (2021b) [19]	apples	x	na	x	x	na	x	na	France, USA

Authors	**Organism/ product**	**WTP**	**Attitude acceptance**	**GMO**	**GE**	**Non-GE NPETs**	**Conventional**	**Organic**	**Country**
McFadden et al. (2021) [44]	oranges	x	na	na	x	na	na	na	USA
Mielby et al. (2013) [22]	crops	na	x	x	na	cisgenic	na	na	Denmark
Müller et al. (2019) [60]	plants, animal, bacteria, humans	na	x	na	x	na	na	na	Switzerland
Muringai et al. (2020) [45]	potato	x	x	x	x	na	x	na	Canada
Narh et al. (2019) [65]	rice	na	x	x	x	RNAi	na	0	Australia, Belgium, Canada, France, USA
Nkott and Temple (2021) [91]	rice	na	x	na	x	na	na	na	Madagascar
Norwegian Biotechnology Advisory Board (NBAB). 2020 [16]	fruits, vegetables, wheat, crops, beef, pork, salmon, potato	x	x	x	x	na	na	x	Norway
Ortega et al. (2021) [46]	rice, pork	x	x	x	x	na	x	na	China
Paudel (2021) [24]	apples, soy oil	x	x	x	x	na	x	na	USA
Pruitt et al. (2021) [47]	potato	x	na	x	x	na	na	na	USA
Rousselière and Rousselière (2017) [68]	apples	na	x	x	na	cisgenic	na	na	EU-27, Norway, Iceland, Turkey
Saleh et al. (2021) [76]	potato	na	x	na	x	cisgenic	x	x	Switzerland
Schaart (2004) [27]	strawberries	x	x	x	na	cisgenic	na	na	Norway, Denmark, UK
Schenk et al. (2011) [75]	apples	na	x	x	na	cisgenic	x	na	Netherlands
Shew et al. (2016) [55]	rice	x	x	x	na	cisgenic	x	na	India

Authors	Organism/ product	WTP	Attitude acceptance	GMO	GE	Non-GE NPETs	Conventional	Organic	Country
Shew et al. (2017) [51]	rice	x	x	x	na	RNAi	x	na	Australia, Belgium, Canada, France, USA
Shew et al. (2018) [52]	rice	x	x	x	x	na	x	na	Australia, Belgium, Canada, France, USA
Son and Lim (2021) [48]	soybean oil, cotton	x	na	x	x	na	na	na	South Korea
Tabei et al. (2020) [61]	food generic	na	x	na	x	na	na	na	Japan
Tsiboe et al. (2017) [56]	rice	x	na	x	na	cisgenic	x	na	Ghana
Uddin et al. (2021) [49]	grapes	x	x	na	x	na	x	na	USA
Vasquez Arreaga (2020) [72]	potato, apples, milk, salmon, papaya, sweet corn	na	x	x	x	na	na	x	Canada
Yang and Hobbs (2020a) [66]	food	na	x	0	x	na	na	na	Canada
Yang and Hobbs (2020b) [50]	apples	x	na	x	x	na	x	na	Canada
Yunes et al. (2019) [77]	pork	na	x	na	x	na	na	na	Brazil
Yunes et al. (2021) [57]	beef	na	x	na	x	na	na	na	Brazil

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