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Beyond plastic – Consumers prefer food packaging derived from genetically modified plants☆

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ABSTRACT

The technology of genetically modified organisms (GMO) and especially genetically modified plants (GMP) applied in agriculture is a key element in a bioeconomy-based sustainability transition. However, consumers in many European countries allegedly disapprove of 'green biotechnology'. Drawing on innovation adoption and risk perception literature, we explore the acceptance of GMP-based food packaging. Fossil-fuel-based production and plastic waste have become a major concern in many societies, and GMP-based technologies might offer solutions. Taking fully degradable material based on GMP as an example to replace conventional plastic in many applications, we present new insights into the GMP debate using a choice-based conjoint analysis in four European countries. Our results show that GMP-based packaging material is preferred to conventional plastic packaging in all countries. We present implications for research policies.

1. Introduction

> Greenpeace and other environmental groups' opposition to green biotechnology is an own goal, because green biotechnology could provide rather useful tools to their cause.
>
> John Macleod (1998)

Genetically modified plants (GMP) have been subject to many protest campaigns over the years. More recently however, young members of Germany's Green party proposed: 'Genetic engineering can be an important building block for sustainable, holistic agriculture in the future' (Noé and Kopton, 2019). Technologies and contexts evolve and so do discussions about modern plant breeding and possibly also consumer acceptance (FAO, 2022).

The urgency of sustainability problems might increase readiness to consider GMP technology as a way of contributing to their solutions. Yet, in its current practice, genetic engineering in agriculture, on the one hand, and agroecology, on the other, follow two different technological paradigms (Vanloqueren and Baret, 2009; Purnhagen et al., 2021). Also, regulatory and economic factors put small-scale farmers at a disadvantage regarding the application of GMP (Fischer, 2016; FAO, 2022), and the majority of consumers in Europe and the USA seems to be opposed to GMP (Gaskell et al., 2010; Castellari et al., 2018). This opposition might be rooted in moral values rather than in fear of negative (health) consequences, as Scott et al. (2016) show in their study of GM food in the United States.

Over decades, and most recently in 2010, Eurobarometer results on biotechnology (Gaskell et al., 2003, 2006, 2010) have documented the

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low and decreasing public acceptance in Europe of GMP regarding agriculture in general and food in particular. By contrast, in the medical field genetic engineering applications receive more support (Bonfadelli et al., 2007; Gaskell et al., 2010).

Thus, in the application field of medicine ('red biotechnology'), genetic engineering has been broadly welcomed, but in the field of GM food it has been viewed with skepticism. Regarding nonfood GMP, some environmental groups are opposed to any application of genetic engineering to plants (Aerni et al., 2016). Yet, we know less about consumer attitudes regarding products based on nonfood GMP. Here regulation in most parts of the world does not require mandatory labeling and thus, despite widespread implementation of, for example, Bt cotton,[1] consumers might not be aware of the underlying technology.

Reasons for consumer skepticism towards genetic engineering in agriculture are explored especially in the innovation adoption and risk perception literature (e.g. Klerck and Sweeney, 2007; Rumble et al., 2016; Frewer, 2017). Many scientists have high expectations regarding plant biotechnology's potential to address climate change and associated problems through, for example, reduction of fossil fuel use, development of flood, drought, and heat-tolerant plants, or coproduction of different materials (Aerni et al., 2016; Wesseler and von Braun, 2017; Leopoldina, 2019; Tylecote, 2019; Horton et al., 2021).

We explore this notion of a possible rift between scientists' expectations and public skepticism (e.g. Zilberman et al., 2018; Kim et al., 2022) by asking whether, in the context of the growing urgency of sustainable development, the use of GMP-based materials are in fact acceptable to the public. Findings would have important implications for policy makers, practitioners, and researchers.

To this end, this paper provides key arguments in the debate and explores the preferences for GMP-based packaging materials in four different European countries. Conventional packaging involves the use of plastic, which in turn is the largest application of (nonbiodegradable) synthetic organic polymers (Geyer et al., 2017), thereby posing a significant environmental problem. A host of measures is needed to mitigate plastic pollution, from developing innovative technologies (e.g. Heinrich, 2019) to adapting business strategies (e.g. Brockhaus et al., 2016) and changing consumer behavior (e.g. Jia et al., 2019). Here, we focus on consumer responses to a technological innovation. While application of genetic modification in the field of food and agriculture tends to have a bad reputation in Europe, at the same time a majority of European citizens consider themselves as environmentally friendly and are willing to buy more sustainable products (Eurobarometer, 2020).

Can consumers perceive GMP-based materials as part of sustainable development? In our study we address this—from the perspectives of many consumers—and investigate the acceptance of GMP-based packaging material compared to conventional plastic (and other alternatives) through choice experiments. The attribute of interest is a biodegradable packaging material based on the natural biopolymer cyanophycin (CGP) derived from a transgenic tobacco plant (hereafter GMP bioplastic). Thus, our research question is:

> What are consumer preferences for GMP bioplastic compared to conventional plastic as packaging material?

We combine phenomenon-driven research (Lynch Jr et al., 2012) with insights from research on technology and innovation management. We investigate European consumer attitudes towards GM bioplastic and discuss our results in light of insights from the innovation adoption and risk perception literature.

In Section 2 we provide the context by recapturing core arguments in the divergent evaluations of green biotechnology. In Section 3 we present our study and in Section 4 report its findings. In Section 5 we discuss our findings and then conclude in Section 6.

2. Recapturing core arguments: the evaluation of 'green biotechnology'

2.1. Progress in science

Over the last 70 years, research on genetic modification has been marked by important milestones in its discovery and invention journey. The proposition of the double-stranded helix structure of DNA (Franklin and Gosling, 1953; Watson and Crick, 1953) and the development of recombinant DNA technology in the early 1970s gave rise to the field of modern biotechnology (Tramper and Zhu, 2011), but also to concern amongst scientists (Berg, 2011). Following the conference held in 1975 at the Asilomar Conference Center, safety guidelines were set up to govern respective research fields (Barinaga, 2000). The Asilomar Conference has been called the 'Woodstock of molecular biology' and 'a landmark of social responsibility and self-governance by scientists' (Barinaga, 2000: 1584), but also a successful attempt to avoid 'excessive regulation of the search for new knowledge' (Grobstein, 1976: 1133). Since then, genetic modification has been applied as gene transfer within (cisgenic) and across (transgenic) species and more recently as gene editing to improve breeding precision (Qaim, 2020; Ricroch et al., 2022; FAO, 2022). Compared to conventional crops, the use of genetically modified crops can reduce the amounts of pesticides and carbon emissions (Brookes and Barfoot, 2018), reduce land use and provide more space for nature conservation (Barrows et al., 2014), improve crop yield and resilience (Bailey-Serres et al., 2019), and provide important contributions to food security (FAO, 2022). The genetic modification technologies used in the field of agriculture do not bear *inherently* higher environmental or health risks (Qaim, 2020), a position held by a majority of the scientific community (e.g. Leopoldina, 2019), as given the limits of our current knowledge, uncertainties exist in both conventional breeding and genetic modification (van den Daele, 2007; Turnbull et al., 2021). These technologies could play a key role in a more sustainable development, yet unfolding its potential requires institutional reforms (Tylecote, 2019) and public acceptance (Qaim, 2020). One promising application is the production of biopolymers (bio-based plastics) in plants. Biopolymers can be produced by biological systems (microorganisms, animals, and plants) or can be chemically synthesized from biological starting materials such as sugar and starch (Börnke and Broer, 2010; Niaounakis, 2014). Biopolymers produced in plants could replace the use of some chemicals in industry, supply proteins in agriculture and food production, and provide an alternative to petroleum-based plastic in divergent fields. As plant coproducts, they reduce the use of land, water, and pesticides.

2.2. Reception by the public in Europe

In Europe, GMP technologies and especially genetically modified food products (GM food) are, broadly speaking, perceived negatively. In many European countries, according to Eurobarometer surveys, many consumers disapprove of GM technologies being applied to the agricultural sector (Gaskell et al., 2010). The many protests against the use of GMP have been reported in the mass media, which has strengthened negative perceptions (van den Daele, 2007; Lucht, 2015). Debates include health concerns about GM foods, but the rejection of GMP technologies goes well beyond health issues, with key reasons for disapproval being 'tampering with nature' and 'moral inappropriateness' (Dragojlovic and Einsiedel, 2013; Battacchi et al., 2020). Furthermore, GMP are often associated with negative social consequences (such as increased power of multinational companies) and the exacerbation of unsustainable practices (such as increased pesticide use). Qaim (2020) points out that campaigns by environmental groups discredit the technology itself rather than its inappropriate use. However, if conventional products were considered harmful compared to

[1] For example, in 2022, 95 % of cotton grown in the USA was genetically modified: https://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-u-s/.

GMP products, consumer acceptance of GMP might be higher, as Muringai et al. (2020) discovered using a choice experiment involving GM food with health benefits.

GMP innovations are often associated with risks. To explore reasons for disapproval, we draw on insights from literature on (a) innovation adoption and (b) risk perception. Furthermore, we briefly discuss our (c) empirical study to explain the advantages of choice experiments compared to opinion surveys when conducting studies of this kind.

(a) Innovation characteristics

What drives consumer adoption or rejection of innovations arising from research and technological development in general and regarding GMP in particular? Rogers (2003) proposes that understanding the adoption side of innovation requires investigating how an innovation is perceived with respect to relative advantage, compatibility with values, low complexity of use, trialability, and observability. In a literature review Weick and Walchli (2002) conclude that these five adoption factors are not fulfilled for GMP products. Research points to the lack of perceived advantages by consumers (Gaskell et al., 2004; Frewer, 2017). A study with US undergraduate students in the field of agriculture and life sciences identifies 'compatibility' as the factor influencing the consumption likelihood of GMP citrus fruit (Rumble et al., 2016). Scott et al. (2016) find evidence of moral opposition to GMP in the United States, and Hingston and Noseworthy (2018) find that advertising GMP as human-made (as opposed to natural) decreases that opposition. In the European Union, only one crop, Bt maize, is cultivated (mainly in Spain), although >50 transgenic events are authorized for import and the use in feed and food (EC, 2015). With hardly any identifiable GMP products on the EU market, consumers are largely unable to observe its benefits or try them out. Furthermore, many producers and retailers use labels to inform consumers that their products are 'GMO-free', implying that the absence of a product characteristic is a benefit. 'GMO-free' indicates the absence of human intervention (André et al., 2019), which, as 'naturalness', is important for consumer acceptance (Battacchi et al., 2020). Consumers tend to perceive the complexity of the technology as high (Bredahl, 1999), with assessments of consumer knowledge revealing that some consumers believe that conventionally grown plants do not contain genes (e.g. Eurobarometer, 1997). There is a lack of understanding of the scientific and biotechnological background of GMP products, especially in comparison to conventional breeding techniques and production processes (Weick and Walchli, 2002). In conclusion, Rogers' innovation characteristics associated with the adoption of new technology are not favorable for consumer adoption of GMP products.

(b) Risk perception

Attitudes towards a technology or a product play a crucial role for their successful adoption or commercialization (Zhang et al., 2019). The other side of perceived advantages is perceived disadvantages, and here risk perception is a key factor for evaluation. New technologies and the innovations they give rise to always entail uncertainty. And if technologies in particular are seen as risky, they are less likely to be accepted (Van Kleef et al., 2007; Costa-Font and Gil, 2009; Frewer et al., 2011; Gupta et al., 2012). Risk perception is subjective and is influenced by 'a wide array of psychological, social, institutional, and cultural factors' (Slovic, 2000: xxiii). Insights from studies on risk perception stem from interhazard, intergroup, and interindividual analyses (Weisenfeld and Ott, 2011).

The interhazard approach provides a taxonomy of hazards based on perceptions of their various properties (Slovic, 1987). In Slovic's (1987) example, a factor analysis produces a cognitive map of hazards along the dimensions 'dread risk' and 'unknown risk', with GMO ('DNA technology') positioned as both dreadful and unknown. Sjöberg (2004) identifies a third dimension of 'interfering with nature', which is important in the perception of genetic engineering. While in principle, differences between (groups of) people could be analyzed, psychometric studies focus on the aggregated differences between hazards (Siegrist and Árvai, 2020).

The intergroup approach analyses average risk perception between groups of people. Research comparing experts and laypeople identifies significant differences between these groups: with regard to GMP, experts perceive, on average, lower risks than laypeople (Sjöberg, 1998; Siegrist et al., 2018). According to the cultural theory of risk perception (Douglas and Wildavsky, 1982), rather than evaluating a technology 'bottom up' on the basis of its characteristics, people categorize risks of technologies depending on their cultural worldview. In this perspective, the concept of 'cultural cognition' relates people's risk perception to their cultural outlooks, with people holding egalitarian or communitarian worldviews being more concerned about environmental risks, while people with individualistic or hierarchical worldviews are more dismissive about these risks (Kahan et al., 2009). These positions tend to be reinforced through biased information processing (Kahan, 2010). Regarding GMP, the egalitarian-communitarian worldview is associated with a preference for mandatory labeling and the tendency to avoid GM food (Kemper et al., 2018).

Interindividual analyses use a range of individual characteristics such as knowledge, personal experience with the technology, moral beliefs, and media reception to explain risk perception (e.g. Sjöberg, 2004; Frewer, 2017). Attitude formation towards technologies and their risks is associated with some kind of 'knowledge'. While findings regarding the interplay of knowledge and attitudes about GMP are mixed, extreme opposition to GM (food) is associated with a low level of objective knowledge in science and genetics but a high level of self-assessed knowledge: 'Extreme opponents know the least, but think they know the most' (Fernbach et al., 2019: 251).

In addition to these factors, a number of social and interactional contexts are considered to shape opinions and intentions (e.g. Feindt and Poortvliet, 2020). The literature shows then that research on risk perception identifies GMP as a dreadful and unknown hazard, with experts' perceived risks considerably lower than laypeople's, and worldviews being related to technologies' reception. However, while risk perception plays an important role for attitudes towards technology and related products, the presentation of these risks (Tversky and Kahneman, 1981), assessment of benefits (Frewer, 2017), and relative advantages are also key for their evaluation.

(c) Type of empirical study

The method for collecting responses ('how you ask') has a significant influence on results (Dannenberg, 2009). Surveys that assess opinions via isolated judgements of statements (such as degree of agreement) provide limited information on actual decision making. There is a substantial difference between opinion surveys and experimental studies when evaluating consumer response to GMP (Marks et al., 2003). European studies of attitudes towards (amongst others) technology, biotechnology, and GM food provide useful insights into relations between science and society. Nevertheless, these studies do not require respondents to make choices involving a trade-off between different characteristics. Choice experiments seek to address this lack by presenting respondents with situations that put a characteristic such as 'genetically modified' into a context of other attributes, thus presenting participants with tasks that mimic the trade-offs they make in their daily lives.

We used the choice-based conjoint technique as a suitable approach for assessing such trade-offs, with respondents selecting a product from a set of options or using a no-choice option if none of the choice alternatives are attractive. The no-choice option serves to ensure that respondents are not forced to choose a product they would not actually buy. Preference for attributes and attribute levels of these choice options can then be derived from the observed choices.

2.3. Context and hypotheses

Research has enabled the production of cyanophycin (CGP), a cyanobacterial polymer in transgenic plants (Neumann et al., 2005; Nausch et al., 2016), which could not have been achieved by traditional breeding methods. CGP can be converted into useful biomaterials such as polyaspartic acid and diaminobutane polymers, and substitute a wide range of currently fossil-fuel based products (Huckauf et al., 2022), but it can also serve as an ingredient source in food and feed (Nausch et al., 2016). Feasibility tests on potato and tobacco plants demonstrate the potential of the plant-based production of this biopolymer for industrial requirements (Hühns et al., 2009; Schmidt et al., 2017).

Tobacco can be used as a production platform of CGP as a coproduct to oil and protein. Such GMO-based material would be able to replace, for example, some fossil fuel-based materials with biodegradable products and preserve land for food production (Huckauf et al., 2022).

Sustainable packaging material competes with conventional plastic and paper-based material, as well as with package-free options. The biomass materials approach (Herbes et al., 2018; Brockhaus et al., 2016) is seen as a promising sustainability-oriented approach, as biopolymers are renewable and compostable (though not always biodegradable) and less toxic than petroleum-based materials. Thus, biopolymers 'display tremendous versatility, making them the focus of researchers and practitioners' (Herbes et al., 2018: 204).

Our consumer choice study concerns the acceptance of CGP-based products in Europe that explicitly states GMP technology is involved. While the stimuli used in our hypothetical choice experiments involve nonfood, nonfeed products and are thus not subjected to labeling requirements, we chose scenarios that confront consumers with GMP, namely, food packaging derived from genetically modified transgenic plants.

Before the experiment, we presented half of the sample with additional information about the sustainability impact of the materials (see Appendix A.1). We emphasized (a) that petroleum has detrimental effects as a material source, (b) that plants as a renewable source often compete with food and feed production, and (c) that the GMP in question produces a biopolymer as a coproduct without additional land use (thus *not* competing with food and feed production).

We assume a positive impact of that information on preferences for environmentally more conducive alternatives (Klein et al., 2019; Rumm et al., 2013; Schleenbecker and Hamm, 2013; McDonald et al., 2009).

Based on past empirical studies showing GMP skepticism and on insights from risk perception and adoption literature (Section 2), our first hypothesis is:

H1. Preferences for GMP bioplastic packaging will be lower than for conventional packaging.

With regard to the additional information provided in the experiment, we propose a second hypothesis:

H2. Providing additional information about the sustainability effects of GMP bio-based products will increase consumer acceptance of GMP bioplastic packaging.

3. Empirical study

Our survey consists of a questionnaire including the consumer choice experiment. We begin by asking questions related to general purchase behavior and consumer characteristics, followed by specific purchase behavior and preferences for bread and food packaging. Thereafter, we include our choice-based conjoint (CBC) experiment (with or without receiving additional information). After the choice experiment, we collected further information related to background knowledge regarding our topic and respondents' general risk perceptions and acceptance of GMP products as consumers. Finally, we asked questions concerning demographic characteristics. We begin by describing the CBC experiment and then introduce further explanatory variables in our statistical model. The complete questionnaire is available as supporting material.

3.1. Choice-based conjoint analysis

We used a CBC experiment to answer our research questions. Based on predefined attributes and attribute levels, respondents were asked to choose one out of J fictional alternatives in repeated hypothetical choice situations (see, e.g. Fischer and Henkel, 2013; Hoenig and Henkel, 2015). From these choices, we estimated preferences (so-called utility parameters) for each attribute and attribute level (Louviere and Woodworth, 1983), which were randomly varied within and across the hypothetical choice situations to form choice alternatives. Observing choices being made in the CBC experiment allows inferences about what drives choice behavior (preferences).

In our study, we decided to analyze preferences for GMP in the context of food packaging for bread. We used four attributes to describe the hypothetical choice alternatives of food packaging, namely, packaging material, antibacterial effect, environmental certificate, and price in euros. Respondents had the opportunity to inform themselves as part of our study about the specifics of these attributes (and attribute levels). Attribute levels of packaging material were defined as plastic (non-compostable), GMP bioplastic (completely compostable), paper (partly compostable), natural plant material (completely compostable), and no packaging. The attribute antibacterial effect defined whether the packaging has antibacterial coating (attribute levels: yes/no). Next, we included typical environmental certificates as an attribute with the respective attribute levels CSE (certified sustainable economics), NCP (natural care product), and no certificate. To increase the external validity of our results, we also included price for the food packaging as an attribute in our CBC experiment using the following attribute levels (in euros): 0.01, 0.05, 0.10, 0.30, 0.50.

Since our CBC is a main effects model, all attribute level combinations have to be considered independently from each other. Consequently, we excluded several combinations when creating the experimental design (e.g. a price point or a certificate cannot be shown together with no packaging).

The predefined attributes and attribute levels create the attribute space with potential experimental stimuli. The number of hypothetical choice situations each respondent faced was set to 12 and the choice-set size for each choice situation was set to $J = 5$, namely four alternatives plus a no-choice option (Sawtooth, 2017). This specific CBC experimental setting was chosen based on the number of attributes and attribute levels defined in our study to maximize the number of stimuli combinations to be evaluated. Using a no-choice option in each choice set was chosen to avoid forced choices (which could lead to biased preferences). After data collection, the subject's choice of alternative i from the alternatives J (with $j = 1, \ldots, J$ and $J = 5$) becomes the multinomial dependent variable and the attribute levels represent the explanatory variables X. Linking choice to the attribute levels as explanatory variables allows identification of the utility parameters, which then describe preferences for attributes and attribute levels (Louviere and Woodworth, 1983).

Based on random-utility theory (McFadden, 1973), respondents are assumed to choose the alternative i out of J based on utility maximization. The utility of subject n for alternative j becomes $U_{nj} = X_{nj}\, b + e_{nj}$. Here, $X_{nj}\, b$ is the deterministic part of utility and connects the attribute levels X_{nj} and the utility U_{nj} via the utility parameters b. For parameter identification, a stochastic part of utility e_{nj} is defined as a random variable using an independent and identically distributed Type I Extreme Value distribution leading to the well-known multinomial logit model (Train, 2009). Finally, the choice probability P of alternative i by subject n then becomes the ratio of the utility of alternative i to the sum of utilities of all alternatives j* in the choice set (taken to the power of e denoted as exp, see Train, 2009: 14): $P_{ni} = \exp(U_{ni})/\Sigma_{j^*} \exp(U_{nj^*})$.

Typically, the utility parameters are estimated using a maximum likelihood approach. Preferences for attributes and attribute levels are evaluated by the sign and magnitude of the utility parameter b (Louviere and Woodworth, 1983).

Advances in Bayesian Markov Chain Monte Carlo (MCMC) methods allow estimating individual-level utility parameters for each subject instead of one common utility parameter for all respondents (for further elaboration, see Train, 2009, ch. 12). This variation in utility parameters is interpreted as preference heterogeneity for the attributes and attribute levels. To arrive at individual-level utility parameters (b_n), we used a Hierarchical Bayesian (HB) approach for our multinomial logit model and specified the prior for the individual-level utility parameters as a multivariate normal distribution with mean b and a full covariance matrix W. Following common practice in Bayesian MCMC, we further specified diffuse prior settings and employed 60,000 draws using the hybrid Gibbs sampler proposed by Rossi et al. (2005, ch. 5). After 60,000 draws, we discarded the first 40,000 draws as burn-in and kept the remaining 20,000 draws to summarize our posterior distribution.[2] We summarized the marginal posterior distributions of b by the mean as our parameter estimates (Post. b) and evaluated the uncertainty using the 95 % credibility interval (CI). Of particular interest are the individual-level utility parameters for GMP bioplastic. Taken together, our CBC experiment in combination with the approach to estimate individual-level utility parameters is considered a more reliable approach to measure preferences for GMP-based products for each respondent compared with directly asking about these aspects.

Our HB approach further allows a simultaneous estimation of a multivariate regression model with the individual-level utility parameters for each attribute level as a dependent variable and further subject-specific explanatory variables to explain the variation in preference heterogeneity (in our case for GMP bioplastic with linear parameters Post. d). Our choice of subject-specific explanatory variables in form of behavioral and attitudinal drivers is described in the next section.

3.2. Heterogeneity in GMP bioplastic preference

Consumers differ in their preferences for food packaging. Some of these differences will be attributable to international, institutional, and technological settings, which is why country-specific analyses are appropriate. Within (and across) countries, users will differ regarding their expectations and uses of packaging (which functions does packaging fulfill and what are its key requirements?). Thus, to explain preference heterogeneity for GMP bioplastic, we first assessed the importance of various properties of the object of interest (packaging characteristics other than the type of material). Here we wanted to identify which factors of packaging are important to consumers. Second, as explained in Section 2.2, innovations such as GMP bioplastic packaging need to be seen as offering some advantages in order to be adopted, but might also be associated with risks. Therefore, we asked questions regarding advantages that would promote adoption (motives for buying GMP), and we collected data regarding risk perception and acceptance of GMP, background knowledge, and environment-related issues (partly adapted from the Eurobarometer survey). Finally, we asked whether respondents would pay a surcharge for ecologically friendly packaging.

3.2.1. Packaging characteristics

Our first set of questions relates to the importance of several characteristics for food packaging. We asked eleven questions each starting with ‘When I buy packaged food it is important to me that the packaging is’ and followed by typical characteristics related to sustainability (e.g. ‘eco-labeled’ or ‘made from natural ingredients’) and functionality (e.g. ‘tear-resistant’ or ‘low price’). All questions were answered on a 5-point scale with 1 = not at all to 5 = most important (see the first column of Table A.2 in the appendix). We conducted a factor analysis (separately for each country, with Promax rotation to allow for correlated factors) to assess how the subjects' importance ratings resulted in the two latent dimensions of *importance sustainability* and *importance functionality*. We then used the resulting factor scores as our first potential drivers of GMP bioplastic preference (see full results of our factor analyses in Table A.2 in the appendix).

3.2.2. Potential benefits of buying GMP bioplastic

We explored possible benefits for using GMP bioplastic. We asked ten questions each starting with ‘Would you buy a GMP-based product if it’ and then proposed advantages (see for example Eurobarometer, 1997; Hallman et al., 2003) such as ‘is verifiably good for your health’, ‘tastes better than regular food’, or ‘serves as a substitute for chemicals’ (for all benefits, see Table A.4 in the appendix). We used Cronbach's alpha to evaluate internal consistency ($\alpha > 0.95$), and then calculated the mean of all benefits for each respondent as multi-item operationalization of our explanatory variable *buy GMP for benefits*.

3.2.3. Risk-related issues

A major concern for consumers regarding innovations based on plant biotechnology is their safety (Bailey-Serres et al., 2019). Many Europeans are also not prepared to accept technologies for the sake of economic growth, as the Eurobarometer 2010 showed (Gaskell et al., 2010). Finally, the debate on GM food (e.g. Hingston and Noseworthy, 2018) indicates the importance of transparency for consumer choices.

Accordingly, we differentiated between three different aspects of risk: the product perception level ‘Products that have genetically modified ingredients are safe’, (agreement with *GM safe*), the technology acceptance level ‘We should accept some degree of risk from modern biotechnology if it enhances economic competitiveness in Europe’ (agreement with *accept risk*), and the use condition level ‘It is not worth putting special labels on genetically modified foods’ (agreement with *no label*). Respondents could state their agreement to these statements on a 5-point scale with 1 = strongly disagree to 5 = strongly agree.

3.2.4. Background knowledge about topic

Research does not provide a clear picture of the relationship between knowledge and acceptance of GMP products (House et al., 2004). We assessed respondent knowledge related to our topic by asking a set of questions such as ‘By eating a genetically modified fruit, a person's genes could also become modified’ where respondents could state true, false, or I don't know (see Table A.3 in the appendix). In addition, *background knowledge* was calculated as the sum of correct answers with values ranging between 0 and 7 (for results summarized by each question and each country, see Table A.3 in the appendix).

3.2.5. Price premium

Finally, we asked respondents the following question: ‘Would you be willing to pay more for food packaging certified as ecologically friendly?’ (yes or no).

3.3. Sample

We recruited respondents from four European countries—Germany, the Netherlands, Finland, and Italy—to provide meaningful cross-country insights into preference for GMP bioplastic and its drivers. We employed commercial online panel providers to ensure high data quality and to obtain representative samples with respect to the four countries (following age and gender). Initial sample sizes were $N = 1086$ for Germany, $N = 551$ for the Netherlands, $N = 544$ for Finland, and $N = 1078$ for Italy. We excluded respondents from our data in two cases. First, respondents were excluded if they did not complete the CBC experiment and the questions related to the behavioral and attitudinal

[2] Visual inspection of the MCMC chains provides evidence for convergence after 40,000 burn-in draws.

drivers or if response times were exceedingly short. Second, we also excluded respondents if they showed so-called 'straight-lining' in the CBC experiment (see, e.g. Allenby et al., 2014), meaning that they always chose the response in the same position of the choice set (e.g. always left-most alternative). This is not a plausible response pattern, because the attributes and attribute levels randomly vary across the choice sets and choice situations. After data exclusion, the following sample sizes remained for our analysis: $N = 878$ for Germany, $N = 457$ for the Netherlands, $N = 436$ for Finland, and $N = 910$ for Italy.

4. Results

We conducted our analysis for each country separately. Table 1 provides results of the CBC analysis and the utility parameters b. For parameter identification, we set one utility parameter in each attribute to zero (with the remaining utility parameters in each attribute interpreted against this baseline attribute level). Following common practice, we tested our utility parameters against zero using the 95 % credibility interval (CI) of the marginal posterior distribution. To assess our model fit, we calculated McFadden R^2 for each model using the posterior log-likelihood draws (with the null model holding only the utility parameter for 'no choice'). In terms of typical McFadden R^2 evaluation (Louviere et al., 2000), we observed high model fit for all our country-specific models (Germany: 0.65, the Netherlands: 0.66, Finland: 0.53, Italy: 0.56).

Of utmost interest is the utility parameter for GMP bioplastic (vs. baseline: conventional plastic). Here, we observed a positive and significant utility parameter in each of the four country-specific models (Germany: b = 2.29, 95 % CI = [1.79, 2.84]; the Netherlands: b = 3.36, 95 % CI = [2.92, 3.81]; Finland: b = 2.19, 95 % CI = [1.86, 2.52]; Italy: b = 2.81, 95 % CI = [2.54, 3.08]). From this, we conclude that respondents in all four countries had a higher utility (and choice probability) for food packaging made out of GMP bioplastic in comparison to conventional plastic. As a result, for all four countries our first hypothesis is not confirmed. For each country, we found that the utility parameter for GMP bioplastic was the highest amongst all food packaging alternatives (see Table 1, attribute: packaging material), with respondents from Germany having the highest preference for no packaging material (b = 3.58, 95 % CI = [2.95, 4.15]) and respondents from the Netherlands and Finland preferring conventional plastic over no packaging (The Netherlands (b = −1.92, 95 % CI = [−2.92, −1.02]); Finland (b = −1.38, 95 % CI = [−2.15, −0.71])).

The utility parameters for the remaining attributes and attribute levels are summarized as follows (see utility parameters and 95 % CI in Table 1): The preference for antibacterial packaging was positive and significant across all four country-specific models (compared to none). Preference for environmental certificate for the food packaging (CSE and NCP), was negative for Germany, but positive for respondents from Finland and Italy. For price, we observed within each country-specific model a typical pattern following the law of demand: lower preference for increasing price (for utility parameters and 95 % CI, see Table 1).

Next, we summarize our results with respect to the behavioral and attitudinal drivers of individual-level GMP bioplastic preference (b_n). We also included the demographics age and gender as variables in the multivariate regression model of the CBC analysis (see Section 3). We first provide summary statistics of each of these variables for each country in Table 2.

For the set of questions about background knowledge, the highest share of right answers in all four countries was achieved for the statement 'Microplastic causes sea pollution' (70–84 %), followed by 'Yeast for brewing beer contains living organisms' (53–68 %). By contrast, the shares of right answers for the statements related to GMP technology were lower, for example, for the statement 'Ordinary tomatoes do not contain genes, whereas genetically engineered tomatoes do' (34–53 %), and for the statement 'Genetically modified animals are always larger than ordinary animals' (32–46 %). Such low percentages of correct answers were also reported in the Eurobarometer 1996 (N = ca. 15,900), where the statement about tomatoes was identified correctly as false by 35 % and the statement 'Genetically modified animals are always larger than ordinary animals' was identified correctly as false by 36 %.

The linear parameters (as the mean of the marginal posterior distribution Post. d) describing the relationship between the behavioral and attitudinal drivers to the individual-level GMP bioplastic preference (vs. conventional plastic) are summarized in Table 3.[3] Again, we used the 95 % CI of the posterior distribution to test these linear parameters against zero. To assess our model fit, we calculated R^2 for each regression model, and we observed good model fit across our four country-specific models (Germany: 0.52, the Netherlands: 0.51, Finland: 0.34, Italy: 0.48).

We found no significant differences in preferences for types of packaging between the experimental group given additional information and the one without additional information, as described in our second hypothesis (see Table 3; for the explanatory variable experiment 50 % of respondents received additional information on the detrimental effects of petroleum and on the GMP grown in coproduction, see Appendix A.1). Furthermore, additional information did not significantly impact choice of packaging material by respondents who placed higher value on *importance sustainability* (no interaction effect). Our second hypothesis is therefore also not confirmed.

4.1. Packaging characteristics

For the factor of *importance sustainability*, we observed a higher preference for GMP bioplastic as food packaging (compared to conventional plastic) when respondents had higher values of *importance sustainability* in food packaging. Whereas for the factor of *importance functionality*, we did not observe any significant differences for the individual-level utility parameters for GMP bioplastic.

4.2. Background knowledge

Regarding background knowledge, we found only a few significant effects and a mixed pattern across the four country-specific models: to an extent results show a positive relationship between knowledge and preference for GMP bioplastic.

4.3. Potential benefits

Buying GMP products based on benefits increased individual-level preference for GMP bioplastic (vs. conventional plastic) in Germany, the Netherlands, and Finland, but not in Italy.

4.4. Risk-related issues

There was no significant relationship between risk perception ('Products that have genetically modified ingredients are safe' (agreement with *GM safe*)) and preference for GMP bioplastic. Respondents with higher agreement with 'Accept some degree of risk from modern biotechnology if it enhances economic competitiveness in Europe' (agreement with *accept risk*) showed a significantly lower preference for GMP bioplastic (vs. conventional plastic) in the case of Italy and Germany. Similarly, higher agreement with the statement 'It is not worth putting special labels on genetically modified foods' (agreement with *no label*) is associated with lower preferences for GMP bioplastic (vs. conventional plastic) in the case of Italy and Germany.

[3] This regression model and the respective results are also available for all other utility parameters, but we will focus only on the results relevant for our research question.

Table 1
CBC analysis: utility parameters (summary of posterior distribution).

	Country	Germany		Netherlands		Finland		Italy	
	Sample size	N = 878		*N* = 457		*N* = 436		*N* = 910	
Attribute	Attribute-level	Post *b*	95 % CI	Post *b*	95 % CI	Post *b*	95 % CI	Post *b*	95 % CI
	No choice	0.40	[−0.22, 0.99]	−0.14	[−0.57, 0.35]	**−1.49**	[−2.05, −0.99]	0.00	[−0.36, 0.35]
Packaging material	Plastic	0		0		0		0	
	GMO bio-plastic	**2.29**	[1.79, 2.84]	**3.36**	[2.92, 3.81]	**2.19**	[1.86, 2.52]	**2.81**	[2.54, 3.08]
	Paper	**2.10**	[1.70, 2.58]	**2.79**	[2.33, 3.32]	**0.90**	[0.63, 1.17]	**2.17**	[1.92, 2.42]
	Natural	**1.63**	[1.00, 2.17]	**2.05**	[1.47, 2.62]	**1.77**	[1.43, 2.10]	**2.49**	[2.23, 2.76]
	No wrapping	**3.58**	[2.95, 4.15]	**−1.92**	[−2.92, −1.02]	**−1.38**	[−2.15, −0.71]	0.36	[−0.05, 0.86]
Antibacterial packaging	No	0		0		0		0	
	Yes	**0.41**	[0.18, 0.60]	**0.46**	[0.25, 0.66]	**0.31**	[0.16, 0.47]	**0.86**	[0.73, 0.99]
Environmental certificate	None	0		0		0		0	
	CSE	**−0.58**	[−0.83, −0.29]	−0.23	[−0.56, 0.11]	**0.49**	[0.24, 0.77]	**0.41**	[0.22, 0.58]
	NCP	**−0.44**	[−0.69, −0.14]	−0.31	[−0.66, 0.02]	**0.56**	[0.34, 0.82]	**0.42**	[0.25, 0.61]
Price	0.01 EUR	0		0		0		0	
	0.05 EUR	**−0.84**	[−1.10, −0.56]	**−1.14**	[−1.54, −0.77]	**−0.77**	[−1.08, −0.47]	**−0.47**	[−0.65, −0.29]
	0.10 EUR	**−1.25**	[−1.63, −0.91]	**−2.66**	[−3.09, −2.23]	**−1.38**	[−1.72, −1.07]	**−1.04**	[−1.26, −0.82]
	0.30 EUR	**−3.12**	[−3.60, −2.64]	**−5.52**	[−6.28, −4.84]	**−2.60**	[−3.04, −2.19]	**−2.57**	[−2.91, −2.25]
	0.50 EUR	**−3.77**	[−4.28, −3.30]	**−6.94**	[−7.73, −6.18]	**−3.35**	[−3.81, −2.84]	**−3.58**	[−3.98, −3.22]
	Model fit: McFadden R^2	0.65		0.66		0.53		0.56	

Notes: Post *b* = posterior mean; 95 % CI = posterior 95 % credibility interval.
Utility parameters in bold indicate a 95 % CI that does not contain zero (i.e. "significant").

Table 2
Summary of survey measures.

Country	Germany		Netherlands		Finland		Italy	
Sample size	N = 878		N = 457		N = 436		N = 910	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Importance sustainability	0.00	0.99	0.00	1.01	0.00	1.02	0.00	0.97
Importance functionality	0.00	0.86	0.00	0.83	0.00	0.90	0.00	0.80
Tomatoes knowledge	0.44	0.50	0.34	0.47	0.53	0.50	0.35	0.48
Yeast in beer knowledge	0.67	0.47	0.53	0.50	0.68	0.47	0.58	0.49
Microplastic knowledge	0.78	0.41	0.70	0.46	0.83	0.37	0.76	0.43
Gm fruits eating knowledge	0.27	0.44	0.34	0.47	0.42	0.49	0.44	0.50
Organic no genes knowledge	0.52	0.50	0.46	0.50	0.62	0.48	0.42	0.49
Paper bags harm knowledge	0.25	0.44	0.44	0.50	0.38	0.49	0.34	0.47
Gm animals knowledge	0.41	0.49	0.39	0.49	0.46	0.50	0.32	0.47
Buy GMO for benefits	3.07	0.90	3.30	0.86	3.28	0.95	3.14	1.05
Agreement GMO safe	2.44	1.00	2.77	0.83	2.80	0.99	2.61	0.95
Agreement accept risk	2.49	1.09	2.74	1.06	2.67	1.04	2.37	1.01
Agreement no label	2.41	1.17	2.54	1.07	2.50	1.08	2.10	1.09
Price premium eco-label (0/1)	0.53	0.50	0.39	0.49	0.48	0.50	0.65	0.48
Demographics: age (in years)	47.47	15.21	51.82	16.66	41.39	16.69	46.54	16.74
Demographics: female (0/1)	0.51	0.50	0.48	0.50	0.50	0.50	0.50	0.50

Notes: Mean for binary measures of knowledge (0/1) represents share of 1 = correct (vs. 0 = wrong or don't know).
The EUROBAROMETER 1996 posed- amongst others - the following statements:
Ordinary tomatoes do not contain genes, whereas genetically engineered tomatoes do (FALSE) – share of correct answers: 0.35.
If people eat genetically modified fruit, their genes could also become modified (FALSE) – share of correct answers: 0.48.
Yeast for brewing beer contains living organisms (TRUE) – share of correct answers: 0.68.
Genetically modified animals are always larger than ordinary animals (FALSE) – share of correct answers: 0.36.

4.5. Demographic variables

Regarding demographic characteristics, higher age is associated with higher preference for GMP bioplastic in Germany, Finland, and Italy (but not in the Netherlands). For female respondents, we did not observe any significant differences in individual-level preference for GMP bioplastic (vs. conventional plastic).

5. Discussion

The main finding of our study in four European countries is that food packaging based on genetically modified plants is on average preferred over conventional food packaging. This holds regardless of whether respondents received additional information on environmental properties of the different materials or not.

Over decades, opinion surveys have shown negative attitudes towards GMP in food production. More generally, studies on risk perception and acceptance suggest that green biotechnology has come to be associated across the globe with negative effects regarding environmental and social outcomes. Furthermore, the institutional environment in Europe supports negative attitudes towards GMP, a finding that can partly be explained by the political economy of GMP (Van den Daele, 2007; Smart et al., 2017).

Out of all packaging options, with the exception of Germany, GMP bioplastic achieved on average the highest utility. In Germany, only the option of no packaging was preferred over GMP bioplastic - here we observe a trend of increasing acceptance of unpackaged goods (Marken and Wagenfeld, 2020). Respondents who place more importance on

Table 3
Observed heterogeneity of utility parameters (for GMO bio-plastic).

Dependent variable: individual-level utility parameter for GMO bio-plastic								
Country	Germany		Netherlands		Finland		Italy	
Sample size	N = 878		N = 457		N = 436		N = 910	
Explanatory variable:	Post *d*	95 % CI	Post *d*	95 % CI	Post *d*	95 % CI	Post *d*	95 % CI
Experiment (information)	0.15	[−0.37, 0.71]	−0.51	[−1.38, 0.36]	0.34	[−0.25, 0.93]	0.08	[−0.34, 0.48]
Importance sustainability	**0.68**	[0.35, 0.98]	**1.51**	[1.06, 1.98]	**0.49**	[0.15, 0.85]	**0.50**	[0.26, 0.74]
Importance functionality	−0.15	[−0.49, 0.21]	0.01	[−0.52, 0.57]	−0.13	[−0.50, 0.24]	−0.05	[−0.33, 0.23]
Tomatoes knowledge	**0.87**	[0.14, 1.57]	0.58	[−0.58, 1.73]	−0.45	[−1.22, 0.26]	−0.49	[−1.05, 0.09]
Yeast in beer knowledge	−0.32	[−1.02, 0.42]	−0.76	[−1.74, 0.17]	0.26	[−0.50, 1.03]	0.08	[−0.38, 0.56]
Microplastic knowledge	**1.14**	[0.42, 1.88]	**1.77**	[0.73, 2.82]	0.85	[−0.02, 1.70]	0.32	[−0.21, 0.84]
Gm fruits eating knowledge	0.25	[−0.41, 0.92]	−0.39	[−1.36, 0.62]	−0.18	[−0.84, 0.47]	**0.50**	[0.03, 1.00]
Organic no genes knowledge	−0.50	[−1.28, 0.23]	−0.05	[−1.15, 1.09]	0.23	[−0.54, 0.98]	0.18	[−0.31, 0.72]
Paper bags harm knowledge	0.28	[−0.32, 0.88]	0.17	[−0.72, 1.03]	−0.20	[−0.85, 0.47]	**0.86**	[0.41, 1.31]
Gm animals knowledge	−0.13	[−0.77, 0.49]	−0.08	[−1.15, 1.00]	0.25	[−0.42, 0.92]	0.19	[−0.31, 0.68]
Buy GMO for benefits	**0.55**	[0.17, 0.93]	**0.86**	[0.30, 1.41]	**0.61**	[0.21, 1.03]	0.06	[−0.18, 0.29]
Agreement GMO safe	−0.14	[−0.49, 0.20]	−0.12	[−0.75, 0.57]	−0.36	[−0.75, 0.01]	0.07	[−0.18, 0.33]
Agreement accept risk	**−0.40**	[−0.75, −0.07]	−0.06	[−0.52, 0.44]	−0.11	[−0.45, 0.23]	**−0.32**	[−0.55, −0.08]
Agreement no label	**−0.27**	[−0.53, −0.02]	−0.43	[−0.86, 0.01]	−0.14	[−0.45, 0.18]	**−0.44**	[−0.67, −0.21]
Price premium eco-label (0/1)	**0.79**	[0.07, 1.44]	0.57	[−0.42, 1.51]	0.45	[−0.23, 1.11]	**0.51**	[0.01, 1.01]
Demographics: age (in years)	**0.02**	[0.00, 0.04]	0.00	[−0.03, 0.02]	**0.02**	[0.00, 0.04]	**0.02**	[0.01, 0.04]
Demographics: female (0/1)	0.53	[−0.03, 1.11]	0.71	[−0.22, 1.53]	0.45	[−0.19, 1.07]	0.13	[−0.27, 0.51]
Model fit: R^2	0.52		0.51		0.34		0.48	

Notes: Post *d* = posterior mean; 95 % CI = posterior 95 % credibility interval.
Linear parameters in bold indicate a 95 % CI that does not contain zero (i.e. "significant").
Interpretation, e.g.,
Germany:
People who know that tomatoes contain genes have on average higher utility for GMO bio-plastic.

sustainability characteristics (*importance sustainability*) have an even higher preference for GMP bioplastic, which may be due to people concerned about environmental problems being more solution oriented.

In the context of interhazard risk perception, one possible explanation for GMP bioplastic being preferred over other packaging materials is that GMP might be recognized as less of a hazard. With pollution and climate change in particular becoming more and more dreadful, it could be that GMP material is perceived as part of an urgent solution to deal with these wicked problems. It would then be seen as necessary in Europe to apply GMP technology to agriculture. These problems especially concern people with an egalitarian-communitarian worldview (intergroup perspective), as they tend to care more about environmental pollution and its social effects, and would welcome technologies that promote sustainability. While individual risk perception (agreement with *GM safe*) does not seem to influence the preference for GMP bioplastic, in Italy and Germany lower preference for GMP bioplastic is associated with higher agreement to 'Accept some degree of risk from modern biotechnology if it enhances economic competitiveness in Europe'. This seems counter-intuitive, yet here acceptance of risk is not motivated by sustainability issues but might be motivated rather by the prospect of economic gains.

Another important result is that additional information about sustainability effects has no significant influence on the decision for GMP bioplastic (for details on information as an explanatory variable, see Table 3).

From an innovation adoption perspective, the perceived lack of benefit for consumers (Gaskell et al., 2004; Frewer, 2017) is addressed by contributing to a solution for the plastic pollution problem. Thus, for consumers who might have rejected GMP-based products, the characteristic of GMP addressing plastic pollution is attractive. While tampering with nature was seen as a key factor for rejecting GMP-based products (Sjöberg, 2004), recent studies of plastic pollution reported in the media have made abundantly clear how plastic itself impacts nature.

With regard to the design of our study, we suggest that as asking for opinions (e.g. in the Eurobarometer studies) does not involve a trade-off, feelings of uncertainty may be expressed without reservation. However, if placed in the context of benefit trade-offs, consumer responses to green biotechnologies are more nuanced (see also Frewer, 2017; Huffman and McCluskey, 2020).

6. Conclusion

While the occasional difference between countries point to some institutional (as well as cultural) heterogeneity regarding behavioral and attitudinal drivers, the overall result for the four European countries is that food packaging based on GMP is on average preferred over conventional food packaging.

For decades, genetic modification applied in agriculture has been less supported than genetic modification in the field of medicine, or even rejected, by the European public. At the same time, European citizens are said to be sustainability-oriented (Eurobarometer, 2014), place high importance on environmental protection, and a majority considers themselves as consumers of environmentally-friendly products (Eurobarometer, 2015).

We propose that GMP-based technology that could contribute to solutions for pressing environmental problems may have become more acceptable amongst the public than generally thought. Insights from the field of risk perception and of innovation adoption support this proposition. GMP-based technology might be seen as a less dreadful hazard when perceived as a tool to address more dreadful environmental problems. This may especially hold for people with a communitarian or egalitarian worldview who are particularly concerned about environmental problems and who see its advantages in the context of combating pollution.

Given the enormous amounts of packaging waste and its use of water, energy, and material that generate high emissions and drive global warming (Herbes et al., 2018; Fitzpatrick et al., 2012; Nordin and Selke, 2010), the reduction of packaging waste and the use of more sustainable material are key objectives towards more sustainable production and consumption.

While consumer studies have primarily focused on one attribute or one type of sustainable packaging (Herbes et al., 2018), we explored the choice between different packaging options including a package-free option and the interplay with individual characteristics such as knowledge, sustainability orientation, and risk-related issues.

Our research provides important implications for policy makers, practitioners, and researchers. For policy makers, higher social acceptance of GMP-based materials enlarges the toolbox by adding GMP technologies. However, using these tools requires changes in regulatory and financial frameworks. Technological tools must also be implemented in a context-sensitive way through consideration of national and local circumstances as well as other context specificities.

For practitioners, implications relate to the communication of benefits and risks to the public. Showing trade-offs between the use of technological tools and outcomes relates messages to consumers' different concerns and promotes informed choices.

For researchers, we point to the limitations of our research and draw lessons for further research. Our study explored respondent trade-offs between different attributes, which provides more nuanced results compared to asking for respondent opinions. Nevertheless, if respondents reject a specific product in a choice experiment, this does not mean they will necessarily reject respective consumer products. Future studies could address a potential gap between stated preferences and actual behavioral decision making concerning GMP-based technologies as part of solutions in sustainability contexts. Linking responses with socio-economic characteristics would help identify similarities and differences between respondents. Hence, the results provide novel insights for further research as well as policy implementation (Bennett and Birol, 2010). Especially with regard to current European innovation and research policy in the field of GMP, our study delivers reasons for supporting bioeconomic and green biotechnology research.

CRediT authorship contribution statement

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A

A.1. Additional information about the sustainability impacts of the materials

The main difference in the products presented here lies in the technique of growing and processing of the materials used for these products.

Petroleum, also known as crude oil is a limited resource used in manufacturing for a wide variety of materials such as fuels, plastics, pharmaceuticals, and cosmetics. Using petroleum is said to cause global warming, air pollution and ocean acidification at every stage - from mining and recovery to refining, transporting, and using it as fuel, asphalt or other chemicals.

Bio-material based products are made of natural renewable resources derived from living organisms such as plants. Regarding pollution, they can be perceived as better than petroleum-based products, only if they are grown sustainable and are biodegradable. Paper, Bioplastics, Plant oils and other bio-materials also require high amount of water, energy or other resources to be produced as well as certain conditions such as heat, water, and chemicals for composting of biodegradable bio-based materials. Growing bio-based material requires land, thus it often competes with feed and food production. Using genetically-modified (GM) plants for producing bio-based material aims at overcoming this disadvantage as they increase the yield per unit of land: GM-Bio products contain an additional biopolymer gene which produce bio-oil as a by-product. That means the plants are primarily sowed and used for the production of feed, food, bio-fuel or other purposes and provide in addition the bio-oil for biomaterials without supplementary land usage.

Table A.2
Factor analysis (importance for food packaging).

Country	Germany			Netherlands		
Sample size	N = 878			N = 457		
When I buy a packaged food, it is important to me that the wrapping…	Mean (SD)	Factor1	Factor2	Mean (SD)	Factor1	Factor2
…is tear-resistant	3.79 (1.04)	−0.01	<u>0.62</u>	3.52 (0.93)	−0.08	<u>0.64</u>
…is lightweight	3.50 (1.11)	−0.02	<u>0.68</u>	2.99 (1.09)	0.10	<u>0.49</u>
…is biodegradable	4.04 (0.97)	<u>0.78</u>	−0.01	3.71 (1.11)	<u>0.84</u>	0.00
…is eco-labeled	3.23 (1.17)	<u>0.61</u>	−0.01	3.02 (1.11)	<u>0.76</u>	−0.05
…is reusable	3.73 (1.04)	<u>0.33</u>	0.24	3.61 (1.04)	<u>0.68</u>	−0.01
…is environmentally-friendly produced	3.98 (0.95)	<u>0.92</u>	−0.02	3.57 (1.03)	<u>0.90</u>	0.00
…is made from natural ingredients	3.88 (1.01)	<u>0.87</u>	−0.05	3.45 (1.07)	<u>0.84</u>	−0.01
…is easy to recycle	4.21 (0.88)	<u>0.73</u>	0.02	3.93 (0.98)	<u>0.71</u>	0.11
…has a nice design	2.29 (1.20)	−0.06	<u>0.38</u>	2.10 (1.08)	−0.01	<u>0.35</u>
…has a low price	3.77 (1.02)	−0.22	<u>0.54</u>	3.60 (1.05)	−0.17	<u>0.44</u>
…contains the goods hygienically flawless	4.19 (0.89)	0.18	<u>0.46</u>	3.86 (0.99)	0.17	<u>0.46</u>
Eigenvalue		3.31	1.56		3.83	1.19
Factor correlation		0.28			−0.41	

Country	Finland	Italy
Sample size	N = 436	N = 910

(*continued on next page*)

Table A.2 (*continued*)

Country	Finland			Italy		
Sample size	N = 436			N = 910		
When I buy a packaged food, it is important to me that the wrapping…	Mean (SD)	Factor1	Factor2	Mean (SD)	Factor1	Factor2
When I buy a packaged food, it is important to me that the wrapping…	Mean (SD)	Factor1	Factor2	Mean (SD)	Factor1	Factor2
…is tear-resistant	3.42 (1.05)	−0.10	0.69	3.55 (1.09)	0.01	0.53
…is lightweight	3.16 (1.08)	−0.02	0.68	3.30 (1.13)	0.05	0.62
…is biodegradable	3.67 (1.04)	0.73	0.09	4.22 (0.85)	0.79	0.04
…is eco-labeled	3.46 (1.07)	0.78	0.07	3.79 (1.00)	0.66	0.01
…is reusable	3.52 (1.12)	0.63	0.02	4.06 (0.96)	0.58	0.03
…is environmentally-friendly produced	3.62 (1.02)	0.91	−0.09	4.16 (0.85)	0.84	−0.05
…is made from natural ingredients	3.64 (1.00)	0.87	−0.11	3.90 (0.97)	0.72	0.03
…is easy to recycle	4.08 (0.93)	0.66	0.02	4.32 (0.77)	0.78	−0.01
…has a nice design	2.95 (1.16)	0.05	0.45	2.30 (1.17)	−0.13	0.45
…has a low price	3.93 (0.90)	−0.10	0.40	3.55 (1.09)	−0.08	0.39
…contains the goods hygienically flawless	4.17 (0.89)	0.16	0.29	4.56 (0.66)	0.49	0.10
Eigenvalue		3.60	1.42		3.48	1.03
Factor correlation		−0.44			−0.31	

Notes: Mean (with standard deviation in parenthesis). Number of factors determined via Parallel Analysis (Hoyle and Duvall, 2004); Factor loadings from Promax rotation (correlated factors). Factor loading > 0.40 are underlined. Factor1 denoted as Importance Sustainability, Factor2 denoted as Importance Functionality.

Table A.3
Questions to assess knowledge in food technology.

Country	Germany	Netherlands	Finland	Italy
Sample size	N = 878	N = 457	N = 436	N = 910
Statements	%Correct	%Correct	%Correct	%Correct
Ordinary tomatoes do not contain genes, whereas genetically engineered tomatoes do. (False)	43.7	33.7	53.4	35.5
Yeast for brewing beer contains living organisms. (True)	67.3	53.0	67.7	57.9
Micro plastic causes sea pollution. (True)	78.1	69.8	83.5	75.9
By eating a genetically modified fruit, a person's genes could also become modified. (False)	26.8	33.7	42.2	44.2
Organic products don't contain any genes. (False)	51.9	46.4	62.4	41.6
Manufacturing and disposing paper bags harms the environment. (True)	25.4	43.8	38.3	33.5
Genetically modified animals are always bigger than ordinary ones. (False)	40.9	39.2	46.1	32.1
Average sum of correct answers (0–7)	3.34	3.19	3.94	3.21

Notes: %Correct represents the percentage of individuals with correct answer within each country.

Table A.4
Motives to buy GMO-based products.

Would you buy a GMO-based product if it…
…is scientifically tested and classified as safe.
…is verifiably good for your health.
…is verifiably good for the environment.
…is certificated as an environmentally friendly product.
…has natural antibacterial effects.
…serves as a substitute for chemicals.
…tastes better than regular food.
…provides an alternative to fossil resources.
…would be cheaper than regular food
…contributes to solving the problem of worldwide hunger.

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