



# Genome-edited *versus* genetically-modified tomatoes: an experiment on people's perceptions and acceptance of food biotechnology in the UK and Switzerland

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## Abstract

Biotechnology might contribute to solving food safety and security challenges. However, gene technology has been under public scrutiny, linked to the framing of the media and public discourse. The study aims to investigate people's perceptions and acceptance of food biotechnology with focus on transgenic genetic modification versus genome editing. An online experiment was conducted with participants from the United Kingdom ( $n=490$ ) and Switzerland ( $n=505$ ). The participants were presented with the topic of food biotechnology and more specifically with experimentally varied vignettes on transgenic and genetic modification and genome editing (scientific uncertainty: high vs. low, media format: journalistic vs. user-generated blog). The results suggest that participants from both countries express higher levels of acceptance for genome editing compared to transgenic genetic modification. The general and personal acceptance of these technologies depend largely on whether the participants believe the application is beneficial, how they perceive scientific uncertainty, and the country they reside in. Our findings suggest that future communication about gene technology should focus more on discussing trade-offs between using an agricultural technologies and tangible and relevant benefits, instead of a unidimensional focus on risk and safety.

**Keywords** Risk perception · Uncertainty communication · Gene technology · Genome editing · Genetic modification

## Abbreviations

ANOVA Analysis of Variance.

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CH Switzerland.  
EU European Union.  
GMOs Genetically-Modified Organisms.  
NGO Non-Governmental Organisation.  
PCA Principal Component Analysis.  
TV Television.  
UK United Kingdom.  
WTB Willingness-To-Buy.  
WTE Willingness-To-Eat.

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## Introduction

Producing safe and high-quality food, while simultaneously handling consumer aversion towards novel food technologies are among the challenges the food industry faces today (Augustin et al. 2016; Asioli et al. 2017). Food biotechnology, more specifically, gene technology, is under a

significant amount of scrutiny and scepticism from the public (Connor and Siegrist 2010; Runge et al. 2017; Rose et al. 2019; Siegrist and Hartmann 2020). However, the variety of applications summarised under the term “gene technology” (or sometimes genetic engineering) vary in terms of targeted produce (e.g., plant vs. animal), novelty or regulation, and unsurprisingly, different applications are perceived in different ways by the public (Kronberger et al. 2013; Siegrist and Hartmann 2020; Busch et al. 2021). The possible technologies used in plant breeding range from traditional breeding and mutagenesis (i.e., mutation may occur spontaneously, through targeted cross-breeding or as a result of exposure to chemical or radiation) to cis- or transgenic gene modification (i.e., insertion of (foreign) gene material) and finally, genome editing (i.e., insertion, deletion, modification or replacing of gene material). In this article, we will use the term “genetic modification” for older technologies and the term “genome editing” for new plant breeding techniques (for an overview of technologies and terminology see Beghin and Gustafson 2021).

The limited existing data (Weisberg et al. 2017; Shew et al. 2018) suggests that the editing of genes to achieve desirable changes of a plant’s attributes seems (as yet) to be under less public scrutiny than breeding technologies summarised under the term of genetic modification (e.g., transgenics). Due to their political situation of taking regulatory decisions somewhat independently from the European Union (EU), Switzerland, and the United Kingdom (UK) are faced with the decision to either adhere to the EU’s existing precautionary regulatory framework or change the current regulation based on the new technologies. In Switzerland, an adjustment versus prolongation of the current restrictive regulation regarding gene technology was recently discussed, which led to a controversial prolongation of the moratorium in autumn 2021 (The Federal Council of Switzerland 2020; Swiss Parliament 2021a). However, a recent decision by the Swiss Council of States suggests that gene technology, which does not involve the insertion of foreign gene material, might eventually be exempt from this moratorium (Swiss Parliament 2021b). Post Brexit, the UK government exhibited a more open strategy towards genome editing by proposing that genome-edited crops are exempted from GMO regulations, provided the genetic changes could occur naturally or via existing conventional breeding techniques (Parliamentary Office of Science and Technology, 2022). To support production of abundant and healthy food with less negative impact on the environment, the UK Department for Environmental Food and Rural Affairs recently conducted a public consultation about the regulation of genetic technologies, with a particular focus on genome editing (Department for Environment, Food & Rural Affairs Press Office 2020; Department for Environment, Food & Rural Affairs 2021).

Following this, a new legislation is on the way to enable scientists across England to undertake plant-based research and development using genome editing (Department for Environment, Food & Rural Affairs, 2022; Ledford, 2021). For all these decisions, it is vital to take into account the public’s view of associated uncertainties and benefits, as well as regulatory decisions (Helliwell et al. 2019). Thus, the present study aims to investigate people’s perceptions and acceptance of gene technology in these two countries with a particular focus on genome editing compared to genetic modification. For this, an interdisciplinary focus was chosen, combining psychology (public perception and acceptance) and communication science (communicating scientific uncertainty, role of information source).

## Theoretical background and study aim

The public perception and acceptance of genetic modification and genome editing.

For decisions regarding the regulation of emerging applications of gene technology, it is vital to understand the public’s view, and learn from previous challenges that have for example led to the 1998 de facto moratorium that suspended approvals of new genetically modified organisms in the EU including UK (Frewer et al. 2011), and a moratorium in Switzerland, in place since 2005, that prohibits the use of genetically modified organisms in agriculture (Hansen et al. 2003; Wohlfender-Bühler et al. 2016). Food biotechnology denotes the use of gene technology in agriculture, namely its use in crops and livestock. For example it can be applied for reducing food waste, pest and disease control or improving nutritional profile of a particular crop (Acatech 2017). From a scientific standpoint, decisions leading to the development and implementation of a technology are accompanied by weighing of benefits, costs, and uncertainties. However, for the implementation, sustenance and finally the success of a technology, public perceptions and acceptance need to be properly managed as well (Winkler et al. 2019).

Due to limited capacity processing, the public makes use of a variety of analytical (e.g., available knowledge) and heuristic strategies (e.g., trust heuristic, affect heuristic, prior experience, and representativeness heuristic), to form an opinion regarding a new and potentially complex technology (Connor and Siegrist 2010; Runge et al. 2017; Rose et al. 2019). Predicting the public reaction to a specific technology is therefore not straightforward, but rather requires a good understanding of the mechanisms at play. For example, the spontaneous associations that the technology raises for people, might determine what affect is associated with the technology (Finucane et al. 2000; Slovic et al. 2004). This in turn might determine, whether a technology

is accepted or not, and whether people would buy food produced with this technology (Connor and Siegrist 2011).

Recent studies suggest that people are more positively inclined towards genome editing than (transgenic) genetic modification (Weisberg et al. 2017; Shew et al. 2018; McCaughey et al. 2019; Brossard 2019; European Food Safety Authority 2019; Beghin and Gustafson 2021). A recently published study by Busch et al. (2021) showed that genome editing is met with higher public acceptance for medical and food protection applications compared to applications in animals. Kronberger et al. (2013) found that public concerns are higher when the boundaries of species are crossed in breeding (transgenics) than if the boundaries are not crossed and genes from similar or the same species are inserted (cisgenics). Moreover, editing of genes within a host leads to less negative associations than the insertion of foreign genes to the host, as this is associated with contamination and “Frankenstein food” (Delwaide et al. 2015; Edenbrandt et al. 2018). Another important factor is that genome editing is a more precise technology than traditional breeding, mutagenesis, and cis- or transgenic gene modification, and thus, it is associated with less (perceived) uncertainty (Shew et al. 2018; Brossard 2019). Lastly, the conceptualisation of genome editing in the media is more positive than the conceptualisation of genetic modification, and thus far, oppositional non-governmental organisations (NGOs) have not been particularly active against the technology (Zhang et al. 2018; Brossard 2019; McCaughey et al. 2019). The latter point might be particularly relevant, as in the digital information environment journalistic and user-generated media might act as an important communicator of uncertainties, risks, and benefits of a new technology.

### The communication of scientific uncertainty

Generally, technological innovations such as gene technology, involve a degree of (scientific) uncertainty regarding opportunities, risks, and outcomes (Acatech 2017; Lang et al. 2019). A recent report by the European Food Safety Authority et al. (2019) recommended communicating scientific uncertainty<sup>1</sup> to the public to increase perceived transparency and social trust in regulators. Social trust refers to the perception that institutions (e.g., regulation) are honest, credible, capable of managing a particular technology and share similar values (Siegrist 2008; Siegrist et al. 2000; Siegrist 2021). However, science communication, particularly communicating scientific uncertainty to lay-people is not a trivial task, and the literature has thus far not substantiated the claims that communicating uncertainty generally

increases trust (Peters and Dunwoody 2016; Retzbach et al. 2016; Guenther et al. 2019). For example, it was suggested that the admission of uncertainty by experts (e.g., scientists, regulators) might also lead to a decrease in perceived competence, and thus, reduce the social trust needed for the acceptance of a technology (Siegrist 2019). However, Hendriks et al. (2016) found that if researchers as blog authors mentioned uncertainties themselves, epistemic trust remained stable.

Additionally, people differ in their awareness for scientific evidence and uncertainty, and even in their tolerance for (scientific) uncertainty (Kessler 2016; Retzbach et al. 2016; Lilleholt 2019). This will likely have an additional impact on the effect of uncertainty communication on their beliefs and acceptance (Kessler 2016). For example, people usually contextualise chemical substances as either safe or dangerous (Bearth et al. 2019; Saleh et al. 2019). This is rooted in people's unfamiliarity with risk assessments, which rely on scientific methodology that introduce some degree of uncertainty (e.g., dose-response mechanisms, reliance on animal testing) (Kraus et al. 1992; Saleh et al. 2019). Therefore, people might not be willing to accept gene technology unless it is described as certainly safe for health and the environment. It is important to note though that, while the perception of the absence of a significant risk is certainly a precondition for acceptance, prior research clearly shows that it is not a guarantee for acceptance (Marris 2001; Stirling 2007).

The influence of journalistic media vs. user-generated media in public's perception of communication about gene technology.

The public perception of and scepticism towards gene technology applied to food production has, among other sources, been linked to the media (Augoustinos et al. 2010; Bearth and Siegrist 2016; Runge et al. 2017). For example, a study about UK newspaper articles on genetically modified crops and food (Augoustinos et al. 2000) showed that the topical focus was first, on genetic modification as risky, uncontrollable, and as an unnatural “Frankenstein” technology, and second, on the roles of different stakeholders (e.g., the opposed public, the government determined to introduce genetic modification despite opposition, inconclusive science, lobbying companies). Walker and Malson (2020) suggest that the public views genome editing in a slightly more positive light than genetic modification. The topics that dominated public discussions on Facebook regarding news posts on genome editing in agriculture are as follows: messing with nature or the natural order, pro-science arguments and focus on beneficial aspects, the conflation with genetic modification and referencing science fiction.

As shown by Walker and Malson (2020), digitalisation has contributed to a landscape of bi-directional public

<sup>1</sup> In this study, we focused on epistemic uncertainty of scientific claims, that is, claims based on scientific evidence or theories and/or claims communicated by scientists.

discourse, which means that people are no longer passive receivers of information but might even actively communicate via online blogs (Kwak et al. 2010). With at least 150 million professional and amateur blogs on the Internet, blogging offers a potentially powerful tool for engaging large and diverse audiences with science (Ranger and Bultitude 2014). In general, blogs have emerged as increasingly important news sources that might even influence the public discourse and societal decision making. The essential qualities of credibility and capturing public trust in the news sphere, however, often depends upon the established reputation of journalistic news (Gunter et al. 2000; Lofgren 2013). Bloggers are occasionally criticized by journalists and the public for not being able to master the professional rules and standards of message delivery as there is no clear or legitimate gatekeeping process, for having a highly personal and opinionated nature, for the fact that anyone can create a blog and publish their thoughts on any subject they like, regardless of whether they are qualified, and sometimes for spreading misinformation based on personal interests (Gunter et al. 2009).

Previous research showed ambivalent findings on the question of whether people trust in online newspapers more than blogs. For example, Gunter et al. (2009) point out that only a few blogs can reach the trust placed in traditional (online) news. However, the experimental study by Mackay and Lowrey (2007) shows that, information on blogs was judged to be more credible than the same information in an online newspaper. In addition, among experienced internet users, blogs are perceived as more credible or at least as credible as journalistic media such as newspapers or television (TV; Banning and Sweetser 2007; Johnson and Kayne 2009). Overall, it is largely unclear, how user-generated media (e.g., blogs) versus journalistic media (e.g., online newspaper articles) affect people's perceptions of information on gene technology and their trust in these two sources.

### Study aims and objectives

This study aimed to investigate people's perceptions and acceptance of food biotechnology with a particular focus on transgenic genetic modification versus genome editing. It was conducted in the UK and Switzerland because the findings may help UK Government Agencies with their recent plans on post-Brexit regulation of plant breeding techniques including genome editing, as well as the Swiss government's open questions regarding the regulation of genome editing (Department for Environment, Food & Rural Affairs Press Office 2020; Federal Office for the Environment 2020; The Federal Council of Switzerland 2020). Thus, the research questions of this study were as follows:

- (1) What kind of associations (e.g., words, images, thoughts) and affect do Swiss and UK citizens have regarding the term "food biotechnology"?
- (2) Is the acceptance of genome editing higher than the acceptance of transgenic genetic modification? Does the acceptance relate to the level of communicated uncertainty (high versus low) and the media format (journalistic versus user-generated)?
- (3) What role do individual factors play in people's acceptance of transgenic genetic modification and genome editing in agriculture?

## Methodology

### Study design

Our online study comprised three parts: (1) people's associations and affect towards food biotechnology, (2) an experiment on people's views of the agricultural application of transgenic genetic modification<sup>2</sup> and genome editing, and (3) individual variables (e.g., perceived uncertainty of scientific evidence, trust). As this study was part of a larger project, not all variables included in the questionnaire will be presented in this article (e.g., genetic literacy, objective and subjective knowledge about genetic modification versus genome editing)<sup>3</sup>. The experimental part was a 2 (*technology: genetically-modified food vs. genome-edited food*) by 2 (*uncertainty: high certainty vs. high uncertainty*) by 2 (*media: journalistic vs. user-generated blog*) mixed design. *Technology* was a within-person variable, while *uncertainty*, *media* and *country* were between-person variables.

### Study procedure

The questionnaire was originally developed in English and translated to German by a bilingual translator. The stimulus material and questionnaire in both languages were pretested and revised accordingly, prior to data collection. The samples were recruited and incentivised in collaboration with a market research company (respondi AG; Koeln, Germany). Quota sampling was applied based on gender, age, and education. Participants with a very short completion time were excluded (UK:  $n = 43$ ; Switzerland:  $n = 25$ ). For this, the cut-off point was a duration of the median divided by two (UK: 358.5 s; Switzerland: 404.0 s) as recommended in the literature (Greszki et al. 2014)<sup>4</sup>.

<sup>2</sup> Subsequently called 'genetic modification' for reader friendliness.

<sup>3</sup> Full questionnaire available upon request from the corresponding author.

<sup>4</sup> Additionally, it was controlled how much time the participants spent on the sites with the texts on genetically-modified food (Median:



## Materials

### First part: Associations and affect towards biotechnology

After providing informed consent, participants' *gender*, *age*, and *education* were assessed. Participants were next asked to provide the words, images, and thoughts that come to their minds when hearing the term "food biotechnology" (*associations of food biotechnology*). The participants were asked to provide at least one association and were free to provide up to a total of three associations. Subsequently, they were presented with a slider (1 'very negative feelings,' 5 'neutral feelings,' to 11 'very positive feelings') for each mentioned association (*affect to associations of biotechnology*). Next, the following introduction to 'food biotechnology' and its role in securing our food supply was provided, followed by another slider inquiring what kind of feelings were evoked by this description to measure their *affect to*

3.2 min) and genome-edited food (Median: 4.1 min), but no participants were excluded based on this.

## Genetically-modified tomato introduced to battle food waste

Science News > Genetically-modified tomato introduced to battle food waste



With the use of genetic modification, a gene from yeast was transferred to the tomato to increase its shelf-life at home by one week and thus, reduce food waste in consumer households.

Before these new genetically-modified tomatoes hit the stores, scientific risk assessments were conducted. These risk assessments have the goal to assess whether eating this tomato might have any negative impact on health. Scientists conclude with high certainty that it is safe to consume the genetically-modified tomato.

Sarah Braun, October 15<sup>th</sup> 2019

Genetically-modified food  
Group: "certain newspaper"

*biotechnology* (1 'very negative feelings,' to 6 'neutral feelings,' to 11 'very positive feelings'):

In order to secure our food supply, the prolongation of shelf life and thus, the reduction of food waste, is an important goal that could be tackled by food biotechnology. Some developments in food biotechnology, such as the use of plastic wraps, may seem like simple advances in the world of food production and consumption. Others appear to be a lot more technological, such as the modification or editing of the genes of our food sources (e.g., maize, soya or tomatoes). These new species have desired properties to reduce food waste, such as pest resistance or longer shelf life.

**Sarah Braun**  
Just now · 🌐

⋮

Gene-edited tomato introduced to battle food waste:

With the use of gene editing, the tomato gene that slows the softening of the tomato was edited to increase its shelf-life at home by one week, and thus, reduce food waste in consumer households. Compared to genetic modification, gene editing is more precise. It allows targeting highly specific genome sequences, without necessarily introducing genes from other organisms, such as yeast.

Before these new gene-edited tomatoes hit the stores, scientific risk assessments were conducted. These risk assessments have the goal to assess whether eating this tomato might have any negative impact on health. Scientists conclude with high uncertainty that it is safe to consume this tomato.

👍 Like
💬 Comment
➦ Share

Genome edited food  
Group: "uncertain blog"

Fig. 1 Examples of experimental material presented to the participants

## Second part: Experimental section on a specific application in agriculture

For the experimental part, participants from each country were randomly split into four groups (*uncertainty* x *media*). Participants in each group were presented first a text on a genetically-modified tomato with prolonged shelf life followed by a text on a genome-edited tomato with prolonged shelf life. The texts differed between-person in the sentence regarding scientific *uncertainty*: ‘Scientists conclude with high certainty...’ for groups 1 and 3 and ‘Scientists conclude with high uncertainty...’ for groups 2 and 4. Additionally, the texts differed between-person in the presented *media*: Groups 1 and 2 were asked to imagine that the two texts originate from an online newspaper, while groups 3 and 4 were asked to imagine that the texts originate from an online food blog that they regularly follow. Figure 1 presents two example texts for genetically-modified and genome-edited food.

*Acceptance* was measured directly after presenting each text with three items comprising general acceptance (‘Based on the text, do you think genetic modification/genome editing should be used in the production of fruits and vegetables?’ on a slider from 1 ‘should not be used under any circumstances’ to 11 ‘should definitely be used.’) and personal acceptance in form of willingness to buy (WTB) and willingness to eat (WTE). WTB was measured as ‘How willing would you be to buy a genetically modified tomato/genome-edited tomato with extended shelf life?’ and WTE as ‘How willing would you be to eat a genetically modified tomato/genome-edited tomato with extended shelf life?’ on a slider from 1 ‘not willing at all’ to 11 ‘very willing.’ The three items resulted in a one-factor solution according to a Principal Component Analysis (PCA; for genetic modification: KMO=0.7, Eigenvalue: 2.7, % of variance: 90.9%; for genome editing: KMO=0.8, Eigenvalue: 2.8, % of variance: 93.9%) and exhibited an excellent internal consistency (for genetic modification:  $\alpha = .95$ ; for genome editing:  $\alpha = .97$ ).

Manipulation checks were implemented for the two between-person independent variables *uncertainty* and *media*. As a manipulation check for the variable *uncertainty*, the perceived uncertainty regarding the safety of genetically-modified and genome-edited food was measured directly after the experimental part with the following item: ‘Based on the text, how certain or uncertain are you that the risk assessments ensure the safety of the genetically modified tomato/genome-edited tomato?’ on a slider from 1 ‘certain that the safety is NOT ensured’ to 6 ‘uncertain’ to 11 ‘certain that the safety is ensured.’ For ease of interpretation, the scale was recoded into three categories (1 to 5 ‘certain that safety is NOT ensured,’ 6 ‘uncertain’ and 7 to 11 ‘certain that the safety is ensured’). As a manipulation check

for the variable *media*, participants were asked to indicate what online newspaper or food blog they were imagining when reading the experimental text.

## Third part: Individual variables related to the acceptance

All subsequently presented multi-item scales were subjected to a PCA (oblique rotation in case of multi-dimensionality) and reliability analysis (Cronbach’s Alpha). The scales were built by taking the mean over all respective items.

First, participants were asked to indicate their trust in different information sources. This item was based on prior literature and adapted to the current context (Costa-Font et al. 2008). A PCA with oblique rotation resulted in two subscales (cf. Table 1): *Trust in institutions* with government agencies, farmers, scientists, and the food industry ( $\alpha = 0.72$ ) and *trust in the media* with online blogs, journalistic, and social media ( $\alpha = 0.82$ ).

Second, a scale measuring the *perceived certainty of scientific evidence* (Marschall et al. 2011; Retzbach et al. 2016) was included (cf. Table 1). Compared to the original scale (Retzbach et al. 2016), solely the objective subscale was used in this article, where higher scores indicate higher perceived certainty of scientific evidence. The five items resulted in a one-factor solution according to a PCA with an excellent internal consistency (cf. Table 1,  $\alpha = 0.91$ ).

Third, *relevance of prolonged shelf life* was measured with the following self-developed item: ‘In general, how desirable do you find it that tomatoes have a longer shelf life?’ slider from 1 ‘not desirable at all’ to 11 ‘very desirable’).

Fourth, overall text content and source credibility were assessed for the two experimental texts (Roberts 2010). The scale comprises 10 bipolar items ranging for instance from 1 to 5 (the source...: can/cannot be trusted, is inaccurate/accurate, is unfair/fair, does not tell the complete story/tells the complete story, is biased/is not biased; the text...: is unbelievable/believable, is inaccurate/accurate, is not trustworthy/is trustworthy, is biased/not biased, reflects part of the story/the whole story). The 10 items were combined into one scale by taking the mean over all items, measuring the *credibility of the messenger and message* (KMO=0.9, Eigenvalue: 6.0, % of variance: 59.8%;  $\alpha = 0.92$ ).

Lastly, participants’ *general risk aversion* was measured with one self-developed item: ‘How do you describe yourself: How willing are you in general to take risks?’ (1: ‘not willing to take risks at all’ – 7: ‘very much willing to take risks.’).

## Data analysis

For the associations regarding the term “food biotechnology,” a manual standardised content analysis was conducted, which resulted in 15 categories. The analysis was performed by three trained and independent coders with good intercoder reliability (Krippendorff's Alpha=0.81; Cohens Kappa=0.81). For the final version, the first author reviewed and resolved all irregularities. Subsequently, correspondence analysis was applied for analysing the relationship between categorical data (in this case associations and country) and other variables (in this case affect). The descriptive and multivariate data analyses were conducted in SPSS 25 (IBM Corp. 2017). All included variables and scales were subjected to descriptive and an exploratory data analysis prior to the multivariate analyses. The experimental effects on people's perceptions were assessed with a mixed Analysis of Variance (ANOVA) with three independent variables (*technology, uncertainty, media*) and the dependent variable *acceptance*. The mixed ANOVA were conducted separately for Switzerland and the UK. Lastly, the impact of individual variables on people's acceptance of genetically-modified and genome-edited food was analysed in two separate linear regression analyses.

## Results

### Sample description

There were  $n=505$  participants (50.8%) from Switzerland and  $n=490$  participants (49.2%) from the UK. Table 2 presents an overview of the socio-demographics of the sample in total and separated by country. Education was recoded to approximate comparability with educational systems in Switzerland and the UK into low ( $n=430$ , 43.2%) and high ( $n=560$ , 56.3%). Based on the quota design, gender, age, and education distributions were representative for the respective populations in Switzerland and the UK above 18 years of age (United Nations 2019).

### Food biotechnology: associations and affect

In total, participants provided 2415 usable associations, whereof 857 first associations, 806 s associations and 752 third associations were provided. Table 3 shows an overview of the 15 categories identified in the content analysis. The following three categories were most prevalent: “Science and research” (21.4%), “Specific food, eating and nutrition” (12.7%) and “Genes and genetic modification” (9.7%). Other prevalent associations were regarding industry, innovation, unnaturalness and chemicals. Moreover, a

**Table 1** Mean values (M), standard deviations (SD) and corrected item-total correlation ( $r_i$ ) for the items in the two trust scales and certainty of scientific evidence scales

	M	SD	$r_i$
<b>Trust ...<sup>1</sup></b>			
1: do not trust at all to 7: trust very much			
<b>... in institutions</b>			
Government agencies	3.9	1.7	0.5
Farmers	4.3	1.5	0.4
Scientists	4.5	1.4	0.6
Food industry	3.3	1.6	0.6
<b>... in the media</b>			
Journalistic media (e.g., newspaper, TV)	3.1	1.5	0.5
Social media (e.g., Facebook, Twitter)	2.4	1.4	0.8
Blogs (e.g., food blogs, bloggers on social media)	2.6	1.4	0.7
<b>Perceived certainty of scientific evidence<sup>2</sup></b>			
1: do not agree at all to 7: strongly agree			
Scientific facts, if carefully examined, are valid for all times.	3.3	1.8	0.7
What has been published in a prestigious scientific journal can be seen as proven.	3.5	1.7	0.8
Scientific predictions are certain when they are well-founded.	3.6	1.6	0.8
Results from an experiment can be seen as proof.	3.7	1.6	0.8
If scientists have worked carefully, their results can be seen as certain.	3.9	1.6	0.8

Note: <sup>1</sup>PCA: KMO=0.8, factor 1 (...in institutions): Eigenvalue: 3.3, % of variance: 47.8%, factor 2 (...in the media): Eigenvalue: 1.2, % of variance: 16.8%; <sup>2</sup>PCA: KMO=0.9, Eigenvalue: 3.8, % of variance: 75.0%

substantial number of participants reported generic positive and negative associations. The affective rating of the most prevalent associations (i.e., first association, mentioned more than 100 times) was positive for “Science and research” ( $M=7.0$ ,  $SD=2.3$ ) and for “Specific food, eating and nutrition” ( $M=8.0$ ,  $SD=2.7$ ), while “Genes and genetic modification” was associated with negative affect ( $M=3.8$ ,  $SD=2.7$ ). The overall affect reported for the mentioned associations was near the midpoint of the scale (Switzerland:  $M=6.3$ ,  $SD=2.4$ , UK:  $M=6.1$ ,  $SD=2.6$ ) and did not differ significantly between countries,  $t(993)=1.1$ ,  $p=.249$ ,

**Table 2** Socio-demographics of two samples from Switzerland ( $n=505$ ) and the United Kingdom ( $n=490$ )

	Switzerland	United Kingdom
<b>Gender<math>n</math>(%)</b>		
Female	267 (52.9%)	246 (50.2%)
Male	236 (46.7%)	241 (49.2%)
Other	2 (0.4%)	3 (0.6%)
<b>Age<math>M</math>(SD)</b>		
	45.5 (14.3)	47.9 (13.3)
<b>Education<math>n</math>(%)</b>		
Low education	248 (49.1%)	182 (37.1%)
High education	257 (50.9%)	303 (61.8%)
Not identified	-	5 (1.0%)

**Table 3** Frequencies and percentages of the associations regarding the term “food biotechnology”

	Total		1st association		2nd association		3rd association	
Science and research (e.g., laboratory, experiment)	516	21.4%	221	25.8%	173	21.5%	122	16.2%
Specific food, eating and nutrition	307	12.7%	116	13.5%	97	12.0%	94	12.5%
Genes and genetic modification (e.g., GMO, genes)	234	9.7%	137	16.0%	56	6.9%	41	5.5%
Industry (e.g., profit, marketability, company)	176	7.3%	40	4.7%	64	7.9%	72	9.6%
Generic negative (e.g., bad, danger, not acceptable)	171	7.1%	32	3.7%	55	6.8%	84	11.2%
Innovation (e.g., advancement, the future, new)	155	6.4%	45	5.3%	57	7.1%	53	7.0%
Health, safety, and security (e.g., risk, allergies)	140	5.8%	30	3.5%	60	7.4%	50	6.6%
Unnatural (e.g., artificial, against nature, man-made, fake)	139	5.8%	50	5.8%	45	5.6%	44	5.9%
Chemical (e.g., additive, toxin, ingredient)	135	5.6%	43	5.0%	49	6.1%	43	5.7%
Generic positive (e.g., interesting, clever, necessary)	103	4.3%	20	2.3%	27	3.3%	56	7.4%
Eco products	87	3.6%	35	4.1%	31	3.8%	21	2.8%
Natural and sustainable	77	3.2%	20	2.3%	28	3.5%	29	3.9%
Specific innovation (e.g., algae, artificial meat)	76	3.1%	33	3.9%	31	3.8%	12	1.6%
Transformation (e.g., altering, changing)	65	2.7%	26	3.0%	21	2.6%	18	2.4%
Control and responsibility	34	1.4%	9	1.1%	12	1.5%	13	1.7%
Total	2415	100%	857	100%	806	100%	752	100%
Unclear/missing			30		20		212	
Don't know			87		20		21	
Other (e.g., molecular cuisine, Monsanto)			21		-		10	



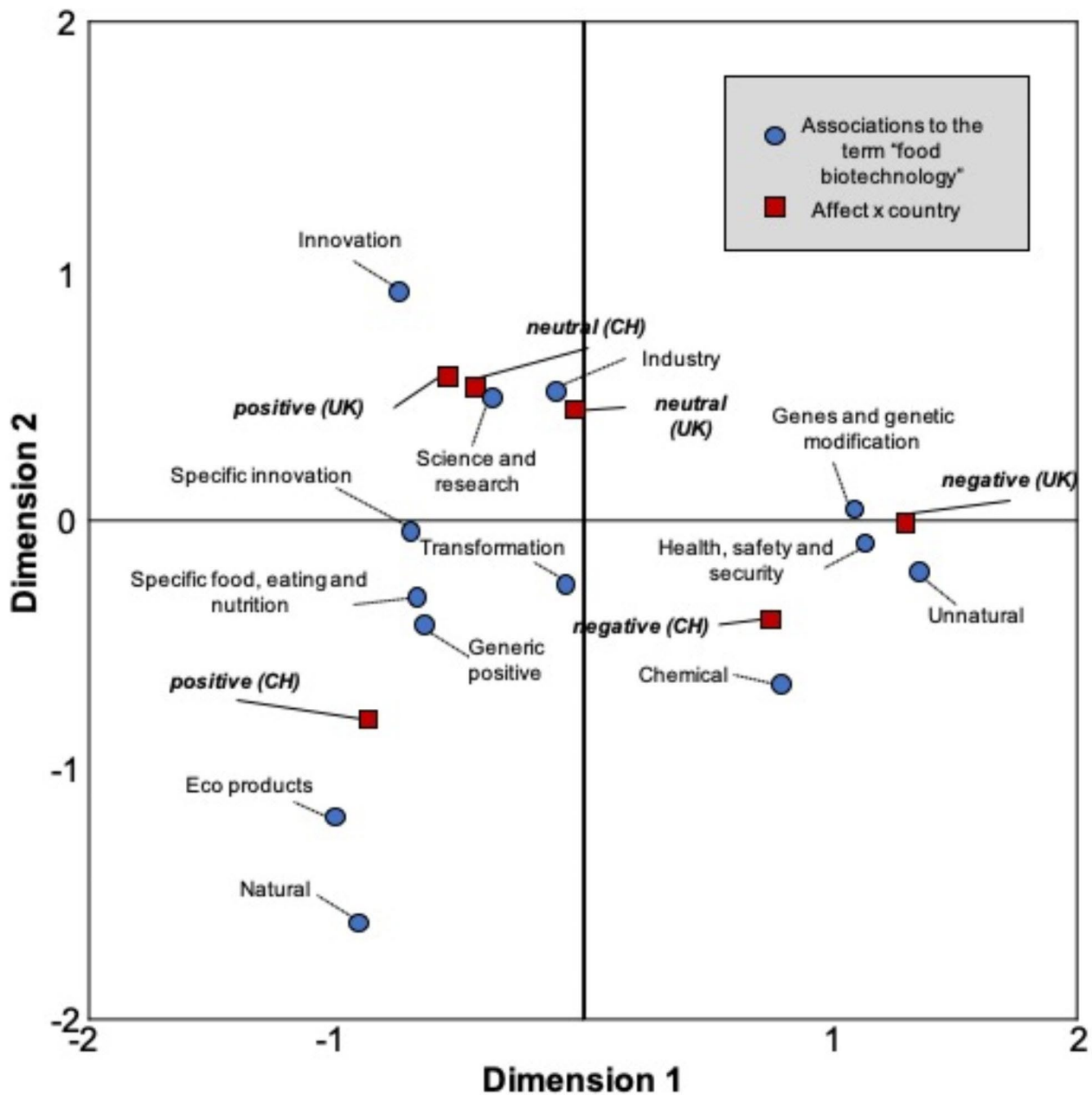


Fig. 2 Correspondence analysis with people's associations to the term "food biotechnology" (N = 848) in relation to their affect and country

$d=0.1$ . However, after reading the introductory text, participants from the UK ( $M=6.5$ ,  $SD=2.8$ ) reported more positive affect than participants from Switzerland ( $M=6.0$ ,  $SD=2.6$ ),  $t(985) = -2.7$ ,  $p = .006$ ,  $d=0.2$ .

A correspondence analysis was conducted with the first associations that were mentioned at least 20 times, the valence of the affect related to the association (negative, neutral, or positive), and the country of the respondent. Correspondence analysis is a way to visualise large cross-tables. In this case, the cross-table was made up of 13

columns (the 13 associations) and 6 rows (negative, neutral, and positive affect in the two countries) that displays the observed frequency in the cells. The cross-table, which is the basis of this correspondence analysis, can be found in the Supplementary material (Table B). For the correspondence analysis, the following values were uncovered:  $\chi^2(60)=413.5$ ,  $p < .001$ , with an inertia of  $\lambda G=0.49$ . The first dimension explained 73% of variance and the second dimension explained 17%, which is why a two-factor solution was used in Fig. 2. Associations that are further from

**Table 4** Overview of main and interaction effects on acceptance per country

Country	Main and interaction effect	Results
Switzerland	Technology	$F(1, 501) = 15.5, p < .001, \eta^2 = 0.03$
	Uncertainty	$F(1, 501) = 3.5, p = .062, \eta^2 = 0.01$
	Media	$F(1, 501) = 1.2, p = .265, \eta^2 = 0.00$
	Technology x uncertainty	$F(1, 501) = 7.1, p = .008, \eta^2 = 0.01$
	Technology x media	$F(1, 501) = 0.0, p = .827, \eta^2 = 0.00$
	Uncertainty x media	$F(1, 501) = 0.3, p = .572, \eta^2 = 0.00$
	Technology x uncertainty x media	$F(1, 501) = 0.4, p = .552, \eta^2 = 0.00$
UK	Technology	$F(1, 486) = 9.9, p = .002, \eta^2 = 0.02$
	Uncertainty	$F(1, 486) = 9.1, p = .003, \eta^2 = 0.02$
	Media	$F(1, 486) = 0.1, p = .731, \eta^2 = 0.00$
	Technology x uncertainty	$F(1, 486) = 5.7, p = .018, \eta^2 = 0.01$
	Technology x media	$F(1, 486) = 5.1, p = .024, \eta^2 = 0.01$
	Uncertainty x media	$F(1, 486) = 0.1, p = .773, \eta^2 = 0.00$
	Technology x uncertainty x media	$F(1, 486) = 0.0, p = .903, \eta^2 = 0.00$

the centre (i.e., innovation, eco products, natural) are more discriminating than associations closer to the centre (i.e., transformation, industry, science, and research). This allows to draw conclusions on the relationship between association, affect, and country of respondent. “Eco products” (in down/left quadrant, far from centre) and “natural” (in down/left quadrant, far from centre) were mostly mentioned by Swiss

participants and were associated with positive affect. As both associations are far from the centre, they discriminate well between Swiss and UK participants and the valence of the associated affect. “Chemical” (in bottom/right quadrant, rather close to the centre) was more frequently mentioned by Swiss than UK participants, and it was mostly associated with negative affect in both countries. “Genes and genetic modification” (in top/right quadrant, close to the axis of dimension 2) was mostly mentioned by UK participants, yet with varying affect. In another example, “innovation” (in top/left quadrant, far from the centre) was mostly associated with positive affect in the UK, while in Switzerland, it was mostly associated with neutral affect.

### Acceptance of genetically-modified and genome-edited tomato

In this section, the results of the experimental section on acceptance of a specific application in agriculture are presented. Prior to the experimental effects, the manipulation checks regarding the independent variables *uncertainty* and *media* are presented. Regarding *uncertainty*, the expected effect was achieved: Significantly more participants in the ‘high uncertainty’ condition were certain that the safety is not ensured for genetically-modified tomato (61.7%,  $\chi^2(2) = 43.5, p < .001$ ) and for genome-edited food (62.2%,  $\chi^2(2) = 62.1, p < .001$ ) than participants in the ‘high certainty’ condition (38.3% and 37.8%). The manipulation check regarding *media* demonstrated that it was easier for participants to imagine an online newspaper than an online food blog, as 227 participants (46.3%) indicated not reading an online newspaper compared to 435 participants (86.1%) that indicated not reading food blogs. Participants named a

**Table 5** Linear regression analyses: Acceptance of genetically-modified and genome-edited food

	Acceptance of genetic modification			Acceptance of genome editing		
	B [95% CI]	$\beta$	<i>p</i>	B [95% CI]	$\beta$	<i>p</i>
Constant	-0.66 [-1.85, 0.54]		0.281	-0.43 [-1.63, -0.77]		0.481
Gender (0: female)	0.35 [0.10, 0.60]	0.06	0.006	0.10 [-0.15, 0.35]	0.02	0.439
Age	-0.01 [-0.01, 0.01]	-0.02	0.433	-0.01 [-0.01, 0.01]	-0.01	0.808
Education (0: low)	-0.05 [-0.30, 0.20]	-0.01	0.717	0.18 [-0.07, 0.43]	0.03	0.159
Country (0: Switzerland)	0.40 [0.13, 0.66]	0.07	0.004	0.25 [-0.02, 0.52]	0.04	0.065
Uncertainty (0: high certainty)	-0.31 [-0.55, -0.06]	-0.05	0.014	-0.57 [-0.82, -0.32]	-0.09	<0.000
Media (0: journalistic)	0.24 [-0.01, 0.48]	0.04	0.055	0.13 [-0.12, 0.37]	0.02	0.308
Affect regarding biotechnology	0.22 [0.16, 0.27]	0.19	<0.000	0.18 [0.13, 0.23]	0.15	<0.000
Relevance of prolonged shelf life	0.45 [0.40, 0.49]	0.49	<0.000	0.50 [0.45, 0.54]	0.53	<0.000
Credibility of messenger/message	0.35 [0.15, 0.54]	0.09	0.001	0.57 [0.37, 0.77]	0.14	<0.000
Perceived certainty of scientific evidence	0.15 [0.03, 0.28]	0.07	0.013	0.20 [0.08, 0.33]	0.09	0.001
Trust in institutions	0.19 [0.04, 0.33]	0.07	0.012	0.04 [-0.10, 0.19]	0.02	0.556
Trust in the media	-0.09 [-0.22, 0.03]	-0.04	0.130	-0.04 [-0.17, 0.08]	-0.02	0.485
General risk aversion	-0.22 [-0.30, -0.13]	-0.10	<0.000	-0.21 [-0.29, -0.12]	-0.09	<0.000

Note. Acceptance of genetically-modified food ( $R^2 = 0.60$ ;  $F(13, 971) = 113.60, p < .001$ ); Acceptance of genome editing ( $R^2 = 0.63$ ;  $F(16, 970) = 128.13, p < .001$ )

variety of online newspapers in Switzerland (e.g., Tagesanzeiger, 20 Minuten, Neue Zürcher Zeitung) and the UK (e.g., The Telegraph, The Guardian, Daily Mail). However, for the blogs, many participants did not mention any food blog at all, but rather mentioned Facebook, companies, or recipe blogs (e.g., Nigella Lawson, Betty Bossy).

For *acceptance*, solely small effects of the experimental manipulation were observed (cf. Table 4). The mean values and 95% Confidence Intervals (CI) for each cell are presented in Table A of the Supplemental Material. Regarding *acceptance*, the significant main effect of technology exhibited the largest effect size. Participants from both countries exhibited slightly higher levels of acceptance for the genome-edited food (CH:  $M=4.4$ , 95%CI[4.1, 4.7]; UK:  $M=5.6$ , 95%CI[5.3, 5.9]) than for genetically-modified food (CH:  $M=4.2$ , 95%CI[3.9, 4.4]; UK:  $M=5.4$ , 95%CI[5.1, 5.6]). Smaller effects for an interaction between *technology* and *uncertainty* were found in both countries. Participants exhibited similarly low acceptance for the genetically-modified and genome-edited food in the 'high uncertainty' condition, but higher acceptance for the genome-edited food than the genetically-modified food in the 'high certainty' condition. In the UK, a main effect of uncertainty was uncovered, while this main effect was only marginally significant in Switzerland. Participants exhibited higher acceptance of the genetically-modified and genome-edited food in the 'low uncertainty' condition. In the UK, a significant interaction effect of *technology* and *media* suggests that acceptance was higher for genetically-modified food in the 'user-generated condition,' but not in the 'journalistic condition.' All other main and interaction effects were not significant.

### The role of individual factors in the acceptance of genetically-modified vs. genome-edited food

To investigate participants' acceptance of genetically-modified vs. genome-edited food further, two linear regression analyses were conducted but experimental manipulations were controlled. Table 5 presents the results of these two linear regression analyses. Similar amounts of variance in acceptance of genetically-modified vs. genome-edited food respectively could be explained by the suggested independent variables (roughly 60% for the acceptance of genetically-modified and genome-edited tomatoes). Similarly, almost the same variables were important for the acceptance of the two technologies, with three exceptions: Gender, country, and trust in institutions was only relevant for the acceptance of genetically-modified food. For these variables, acceptance of genetically-modified food was higher if participants were male, from the UK, and had higher trust in institutions. The most important variable was whether participants deemed it important that the shelf life of a tomato

is prolonged. The more important participants thought this was, the higher their acceptance was for both genetically-modified and genome-edited food. The acceptance of both genetically-modified and genome-edited tomato was higher if (1) participants initially expressed more positive affect towards biotechnology, (2) they perceived the message and messenger to be more credible, and (3) they perceived more scientific certainty. Acceptance of genetically-modified and genome-edited food was lower if (1) participants expressed higher general risk aversion, and (2) participants were in the high uncertainty condition.

### Discussion and implications for practice and future research

This study sheds light on Swiss and UK citizens' perceptions of food biotechnology and their acceptance of the application of genetic modification and genome editing in agriculture.

It replicates previous findings (e.g., Gaskell et al. 2011; European Food Safety Authority 2019) that people in the UK are more supportive of biotechnology than people in Switzerland or other European countries. The continuously prolonged moratorium in Switzerland prohibiting the use of genetically-modified organisms (GMOs) in agriculture likely impacts people's perceptions of biotechnology. The debate about this moratorium has been present in the public discourse and thus, shapes the public perception of biotechnology in Switzerland (Connor and Siegrist 2011). The differences in concern about biotechnology in Switzerland, compared to the UK, are also documented in the Eurobarometer survey from 2010, where participants from the UK exhibited the highest support for GMOs (44% compared to solely 20% in Switzerland) (Gaskell et al. 2011). This finding is also reflected in the most recent Eurobarometer survey, where the UK participants did not express particularly high concern regarding genetically modified food (European Food Safety Authority 2019). Aside from these cross-country and regulatory differences between the UK and Switzerland, our findings also explain some of the differences in acceptance of these technologies suggesting interesting starting points for future research.

First, it is possible that large interpersonal differences exist in people's understanding of food biotechnology including both genetic modification and genome editing. Many participants in our study did not provide a single association, but rather three different associations suggesting a multi-dimensional conceptualisation of food biotechnology. Future research should be aware of the different aspects that people associate with food biotechnology. Swiss participants exhibited some misconceptions regarding what food

biotechnology (“Lebensmittelbiotechnologie” in German) comprises because organic farming (“Biologische Landwirtschaft” in German) and eco products (“Bioprodukte” in German) were frequently mentioned. This might purely be based on the associations raised by the similarity in the wording. Moreover, Swiss people’s affective response towards biotechnology became more negative compared to UK participants after reading the definition. For UK participants, the term “food biotechnology” was more strongly associated with innovation. The findings of a previous Swiss study (Connor and Siegrist 2011) show some overlap (e.g., mention of science, manipulation, nutrition), as well as deviations that are likely be explained by changes in the public discourse over time and by the specific sample of the previous study (i.e., people living near protected sites in Switzerland).

Second, genome editing was more positively perceived and highly accepted than genetic modification in both samples (particularly, under conditions of low uncertainty). This might be explained partly by the fact that the former has been described as *more precise* compared to the latter in our vignette. The increased precision, compared to mutagenesis and genetic modification, is indeed one of the most relevant novelties of genome editing. Science communicators should discuss differences in technologies in terms of precision (e.g., mutagenesis, transgenic genetic modification) (cf. for a discussion of precision and genomic irregularities: Rosenbaum 2019; Kawall et al. 2020). A study on people’s acceptance of cisgenic and transgenic rice found that acceptance was higher for inserting genes from the plant’s own gene pool than for inserting genes from another plant (Delwaide et al. 2015). Therefore, it may be concluded that introducing “foreign” genes in a plant triggers the notion of contamination and thus, sparks rejection in consumers (Egolf et al. 2019; Siegrist and Hartmann 2020). This should potentially explain the higher acceptance of genome editing applications that do not require mixing of genes from different species. Improved precision and the notion of contamination are just two of the underlying factors that might explain differences in the perception of genetic modification and genome editing. Other factors may range from trust in science to ethical considerations to familiarity and terminology (Siegrist and Hartmann 2020; Beghin and Gustafson 2021).

Third, our results revealed that having tomatoes with longer shelf life is the most important predictor of UK and Swiss participants’ acceptance of genome-edited tomatoes. This suggests the importance of perceiving relevant personal or societal benefits on the acceptance of gene-edited foods. Prior research has also suggested that offering clear and tangible benefits positively impacts consumer acceptance of food innovations and technology (Frewer et al. 2011; Bearth and Siegrist 2016; Zahry and Besley 2019).

Therefore, more personal benefits from genome-edited foods, such as the nutrient-enhanced golden rice or the non-browning artichoke might have even stronger impacts on people’s acceptance. Thus, further research is needed to examine the role of benefit perceptions in consumer acceptance of genome-edited foods.

Fourth, the experimental results for both genetic modification and genome editing suggest that people differentiate between levels of uncertainty regarding safety, and if high levels of uncertainty are communicated people are less willing to accept the technology. The effect of uncertainty perception on acceptance was small, whereas other factors, such as perceived benefit and the associations raised by the technology (i.e., increasing shelf life), were higher. Generally, research into people’s acceptance could benefit from focusing more strongly on benefit perception rather than perceived uncertainty regarding safety or risk perception. For example, genome editing can be suggested as a more sustainable alternative to conventional agriculture (e.g., the use of fungicides) to combat late blight in potato (Swiss Academies of Arts and Sciences 2018). Moreover, in this article, we focused on perceived uncertainty of safety, whereas uncertainty also relates to financial or social outcomes (Marris 2001). To conclude, showing the usefulness of gene technology might be a more successful strategy to improve people’s perceptions and acceptance than affirming that the risks are negligible (Kaptan et al. 2018).

Lastly, in this study, the source of this information (*media*) did not have a significant impact on Swiss and UK participants’ acceptance. This finding, however, should be interpreted with caution as the manipulation check suggested that journalistic sources were more easily available to the participants than user-generated blogs and that the provided scenario was hypothetical and the sources of information fictitious. Furthermore, people might have trusted in the information, regardless of the indicated source as the experiment was conducted on behalf of two universities. Future studies should attempt to deepen the understanding of the role that the new digital information landscape plays in the perception and acceptance of gene technology.

## Limitations

This study has several limitations that should be considered when interpreting the results and designing future studies. First, the participants were recruited via a professional market research company. Its participants are likely composed of people that regularly fill out questionnaires. Despite data cleaning, it is possible that not all participants read the texts carefully. Second, it is challenging to measure education levels comparably, as Switzerland and the UK have different educational systems. Therefore, more UK participants were

categorised into the high education group than Swiss participants, although this might not necessarily reflect different educational levels. However, it cannot entirely be ruled out that the participants from the two countries had different levels of scientific knowledge, which might explain some of the uncovered differences. Third, we measured self-reported acceptance for a hypothetical newspaper / blog story and are thus, not able to make predictions regarding actual decision making when confronted with a real article or blog, as well as real genetically-modified or genome-edited tomato sold in the shops. Fourth, the uncertainty manipulation and corresponding manipulation check focused rather simplistically on safety, while uncertainty might also relate to other aspects, such as economic or social outcomes of implementing genetic modification and genome editing in agriculture. These additional aspects that might relate to uncertainty should be covered in future experiments. Lastly, the results regarding genetic modification and genome editing might have turned out differently if we had not utilised a within-subjects design (i.e., shown the text of genome editing after genetic modification) or counterbalanced the order of presentation. Therefore, future studies should investigate the differences in the perception of older and newer breeder technologies in more depth.

## Conclusions

To sum up, the following three main conclusions can be drawn from the findings. (1) genome editing might be met with more favourable perceptions than genetic modification in agriculture, (2) to improve people's acceptance of gene technology, it is necessary to present tangible and relevant benefits (i.e., a higher perceived need for a tomato with a prolonged shelf-life implied higher acceptance), and (3) how scientific uncertainty is communicated has an impact on people's perceptions and acceptance. Frequently, risk communication efforts are recommended to transparently broach the topic of uncertainty, despite the lack of broad knowledge about the effects of the communication of uncertainty, particularly in the field of innovative food technologies. Future research should attempt to clarify what types of uncertainty need to be communicated, and how these should be communicated regarding gene technology.

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