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Consumers' perceptions and acceptance of genome editing in agriculture: Insights from the United States of America and Switzerland

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ABSTRACT

The terms "New Genomic Techniques" (NGTs) or "Genome Editing" refer to various methods that allow finding, cleaving, and repairing specific sequences in the genome. These techniques could contribute to managing various challenges in plant breeding and agriculture. Aside from regulatory uncertainties, the lack of consumer acceptance has frequently been cited as a significant barrier to the widespread use of NGTs in plant breeding and agriculture across the planet. This study was based on an anonymous online survey (N = 1202). It investigated what consumers from two countries that differ in gene technology regulation, namely the United States of America and Switzerland, thought about three specific applications of NGTs in plant breeding (i.e., blight-resistant potato, gluten-free wheat, cold-resistant soybean). The study highlights the importance of the affect heuristic for acceptance, as half of the participants in both countries expressed positive feelings regarding the three applications, a quarter of the participants expressed negative, and the remaining participants expressed torn or neutral emotions. Some evidence was provided that the regulatory context might have acted as a risk cue, as participants in Switzerland expressed more negative feelings, perceptions, and lower acceptance than participants from the United States of America. Lastly, our findings underscore the importance of a collaboration between the life sciences and social sciences in balancing technological innovations and public perceptions and acceptance, which have been shown in this study to be impacted by affect, values, and context.

1. Introduction and theoretical background

1.1. Background and research goal

There exists a broad consensus among researchers that techniques falling under the terms "New Genomic Techniques" (NGTs) or "Genome Editing" could, among other established and novel approaches, contribute to managing various challenges in plant breeding and agriculture, such as droughts, pests, or extreme temperatures (e.g., Kovak et al., 2022; Lemarie & Marette, 2022). It has also been suggested that NGTs could offer benefits for human nutrition, such as improving the nutritional content of foods or reducing allergenic components (e.g., Lombardo & Grando, 2020; Tuberosa et al., 2017). However, many of the benefits stated above were only investigated in laboratory or field trials and have yet to be tested in large-scale field trials or commercial implementations, which are challenged by the varying and evolving legal situations worldwide, ranging from complete bans (e.g., in Switzerland, EU member states) to similar regulations for conventional and NGT crops (e.g., in the United States of America, Japan, or recently also in the United Kingdom) (Metje-Sprink et al., 2020; Turnbull et al., 2021). The legal situation in Europe might change, as the European Commission suggests exempting certain types of NGTs from the current ban (European Commission, 2023).

Aside from regulatory uncertainties, the lack of consumer acceptance has frequently been cited as a major barrier to the widespread use of NGTs in plant breeding and agriculture (Qaim, 2020). Consumers are concerned about the safety and environmental impacts of genetic modification, and these concerns may extend to NGTs (e.g., Busch et al., 2021; Costa-Font et al., 2008; European Food Safety Authority, 2019; Siegrist, 2008). From a scientific perspective, drawing a clear line between genetic modification and NGTs is challenging. In our article, the term "genetic modification" describes methods that involve introducing one or more genes from the same (cisgenic) or a different species (transgenic) into a crop, whereas "NGTs" refers to new methods that can

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but do not have to involve the transfer of genetic material from other species see Lemarie and Marette (2022 for a similar differentiation).

NGTs may be perceived differently from older techniques, as the former is sometimes described as more precise than the latter and, thus, might be seen as less risky (Bearth et al., 2022; Nguyen et al., 2022). Recent studies highlight that benefit perceptions may be more critical for the acceptance of new food technologies than risk perception (Baum et al., 2023; Bearth & Siegrist, 2016; Guo et al., 2020). Technologies that offer a relevant benefit are more likely to be accepted than technologies that do not (Bearth et al., 2022; Saleh et al., 2021; Segrè Cohen et al., 2020), and potential risks directly or indirectly related to the technology are rated as more acceptable if a relevant benefit is offered (Finucane et al., 2000). A *meta*-analysis on the acceptance of new food technologies (Bearth & Siegrist, 2016) speculated, based on an analysis of systematics in the heterogeneity in responses, that the regulation in a particular country might also impact public perceptions and acceptance of technology; for example, a complete ban might be taken as a warning sign or risk cue. This study aims to empirically investigate consumers' perceptions and acceptance of specific, beneficial agricultural applications of genome editing for food production in two countries with different regulatory backdrops (i.e., Switzerland and the United States of America).

1.2. Regulation in plant breeding and agriculture in different countries

Humans have optimised crops since the domestication of plants, increasing yield, improving resistance to diseases, or enhancing their nutritional and sensory attributes (Schlegel, 2018). Since the introduction of Mendel's laws of inheritance, plant breeding has undergone several stages of innovation, ranging from crossbreeding to mutagenesis to genetic modification to NGTs or genome editing (Lee et al., 2015; Oladosu et al., 2016; Schlegel, 2018). The overall goal of plant breeding is to breed plants with desirable qualities and to increase variety in the available crops. The term "conventional breeding" is used in most regions worldwide to describe crossbreeding and mutagenesis and distinguish these practices from "genetic modification." However, many scientists argue that some changes made to crops through NGTs are indistinguishable from those produced through conventional breeding and even natural mutation (Pacher & Puchta, 2017; Turnbull et al., 2021). There have been calls from the global scientific community to overhaul the current regulations to focus on the crop and its genetic traits rather than on the process used to breed the crop (Bradford et al., 2005; Turnbull et al., 2021).

Particularly in Europe, the emergence of NGTs has fostered regulatory debate about whether this technology should fall under the genetically modified organisms (GMOs) legislation (Regulation (EC) 1829/2003). This legislation requires a case-by-case risk assessment of specific applications of genetic modification before they can be authorised for commercial use in food or feed. Directive 2001/18/EC enables member states of the European Union to regulate the use and sale of GMOs within their own country. In Switzerland, the regulation is even stricter, with a temporary moratorium in place since 2005 that prohibits the cultivation and processing of GMO crops (Turnbull et al., 2021) aside from research purposes (Romeis et al., 2013). This moratorium has recently been prolonged until the end of 2025 (Swiss Parliament, 2021a). However, debates about exempting NGTs are underway in Europe (European Commission, 2023) and Switzerland (Swiss Parliament, 2021b).

In the United States, the regulation of NGTs is primarily governed by the Coordinated Framework for Regulation of Biotechnology from 1986 (51 Fed. Reg. 23, 302), administered by three federal agencies: the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), and the United States Department of Agriculture (USDA) (Turnbull et al., 2021). Depending on the usage (e.g., food) and characteristics (e.g., does it contain DNA from "plant pests" like viruses or bacteria) of the crop, one or more of these agencies may be involved (National Academies of Sciences, 2016; Waltz, 2016). For example, crops engineered to resist herbicides or browning may be regulated by the USDA's Animal and Plant Health Inspection Service (APHIS) under its authority to protect plant health by preventing plant pests (Turnbull et al., 2021; Wolt & Wolf, 2018). Crops either receive a regulated or a non-regulated status, which allows their cultivation without oversight from APHIS (Turnbull et al., 2021; Waltz, 2016; Wolt & Wolf, 2018). Overall, the Coordinated Framework for Regulation of Biotechnology signalled a shift from process-based regulation to more trait-based regulation (Wolt & Wolf, 2018).

1.3. Public perception and acceptance of genome editing

The literature on consumers' perceptions and acceptance of human intervention in plant breeding (e.g., Costa-Font et al., 2008; Siegrist, 2008; Siegrist & Hartmann, 2020) offers a solid basis for transferring methods, measurement instruments, and insights to the public's perception and acceptance of NGTs or genome editing. Recent articles suggest more positive views of NGTs than GMOs in countries like Switzerland and the United Kingdom (Bearth et al., 2022), Belgium and the Netherlands (Ferrari et al., 2021), Canada (Muringai et al., 2020), and the United States of America, Canada, Belgium, France, and Australia (Shew et al., 2018). However, translating these perceptions and acceptance into actual consumer behaviour depends on the context, particularly in countries with bans (e.g., available products and their attributes, regulatory frame, and media discourse). It is possible that the regulation and labelling of NGTs as GMOs will lower consumer acceptance (Araki & Ishii, 2015; Asioli et al., 2017) and that the availability of specific applications of NGTs and foods with societal or consumer benefits might shift perceptions and acceptance (Bearth & Siegrist, 2016; Hakim et al., 2020; Kanchiswamy et al., 2015).

The affect heuristic has been instrumental in explaining the public's reactions to (food) technologies (Bearth & Siegrist, 2016; Finucane et al., 2000; Fischer & Frewer, 2009; Lerner et al., 2015; Peters & Slovic, 1996; Siegrist, 2021). The affect heuristic postulates that under uncertainty (i.e., complex issue, lack of expert knowledge), the public's risk and benefit perceptions and acceptance of novel technologies might be coloured by the spontaneous associations and affect raised by these associations (Connor & Siegrist, 2011; Lerner et al., 2015; Slovic et al., 2007), leading risk and benefit judgments to be negatively correlated (Connor & Siegrist, 2011; Lerner et al., 2015; Slovic et al., 2007). The following research question (RQ) was formulated for this study:

- RQ1. What spontaneous associations and affective responses are raised by three different applications of genome editing in agriculture in consumers from the United States of America and Switzerland?

Consumer perceptions and acceptance are linked to the specific purpose or benefit of the application of genome editing (Bearth et al., 2022; Busch et al., 2021; Saleh et al., 2021). Specifically, an application would be using genome editing or another NGT to achieve a specific goal or several goals in plant breeding. For example, Saleh et al. (2021) found a higher acceptance of cisgenic genetic modification to make potatoes blight-resistant compared to the acceptance of synthetic or organic fungicides. Similarly, Busch et al. (2021) found that participants preferred applications that improve human health or enhance crop resistance over applications that change yield or product quality. Several authors (Bearth & Siegrist, 2016; Busch et al., 2021; Marette et al., 2021) found differences in the public's evaluation of GMO or NGT applications across countries and, thus, regulatory frames. However, to our knowledge, authors have yet to explicitly investigate awareness of regulation and public perceptions and acceptance. The following research question and hypotheses (H) were formulated to address this in this study:

- RQ2. How do consumers from the United States of America and Switzerland perceive three different applications of genome editing for food production in agriculture?
  - o H2.1: The applications will be evaluated more positively in a country with more relaxed regulation (i.e., United States of America) compared to a country with more strict regulation (i.e., Switzerland) (main effect).
  - o H2.2: Applications with benefits associated with human health or plant resistance will be evaluated more positively than applications with benefits associated with yield (main effect).
  - o H2.3: Evaluation patterns for different applications will differ depending on the country and regulatory frame (interaction effect).

Prior research has also focused on individual differences that may explain why some people actively or passively oppose GMOs and NGTs, whereas others accept them. As stated above, a regulatory ban on new technology, such as NGTs, might act as a risk cue (Bearth & Siegrist, 2016). This would primarily depend on people's awareness or assumptions about the regulation in their own country (e.g., whether NGTs are banned), as not everyone might know the existing regulation. Based on the affect heuristic, the positive affect raised by the described application of NGTs would be associated with higher acceptance of this application. Next, trust is especially salient; higher trust in institutions and stakeholders, such as scientists, regulators, or industry, has been linked to more positive perceptions and acceptance (Connor & Siegrist, 2010; Hakim et al., 2020; Siegrist, 2021; Siegrist & Hartmann, 2020). Values and personal preferences have also been linked to perceptions and acceptance of GMOs and NGTs. Specifically, individuals differ in their views about nature, whether humans are a part of it, and their aversion to tampering with nature (Hoogendoorn et al., 2021; Raimi et al., 2020; Subrahmanyan & Cheng, 2000). The aversion to tampering with nature has previously been linked to lower acceptance of genome editing (Busch et al., 2021). It is assumed that people who perceive humans as part of nature would be more open to human intervention in nature, such as NGTs, but this has not been investigated. Lastly, it has been suggested that consumers who prefer organic foods are less open to GMOs or NGTs (Bain & Selfa, 2017; Mandolesi et al., 2022). The following research questions (RQ) and hypotheses (H) are aimed at investigating and comparing the relationships between individual differences and the acceptance of NGTs:

- RQ3: How do individual characteristics relate to the acceptance of the applications of NGT in agriculture?
  - o H3.1: Assuming that NGT applications are banned will be negatively associated with the acceptance of the NGT applications.
  - o H3.2: More positive affect will be positively associated with the acceptance of the NGT applications.
  - o H3.3: Trust in institutions will be positively associated with the acceptance of the NGT applications.
  - o H3.4: The aversion to tampering with nature will be negatively associated with the acceptance of the NGT applications.
  - o H3.5: Seeing humans as part of nature will be positively associated with the acceptance of the NGT applications.
  - o H3.6: Preference for organic foods will be negatively associated with the acceptance of the NGT applications.

2. Methodology

2.1. Study procedure and sample

The study procedure and questionnaire were submitted to and accepted by two ethical review bodies: the Ethics Commission of the Federal Institute of Technology (ETH Zurich; EK-2022-N-184) and the Arizona State University Institutional Review Board (IRB). The study questionnaire was developed in English and then translated into German. Subsequently, the texts and questions were pretested in three steps. In the first step, the questionnaire was backtranslated to English to check for the accuracy of the translation. The second step applied an in-person, think-aloud technique with approximately $n = 10$ participants per country. After revising the questionnaire (mostly for clarity in language and phrasing of questions), the programmed online questionnaire was pretested again remotely by $n = 13$ participants. Subsequently, data collection started with the support of a market research company (Bilendi & Respondi). Target participants were people from Switzerland (German-speaking) and the United States of America (English-speaking) above the age of 18. No other exclusion criteria were set. The survey ran from November 23rd to 28th, 2022. A quota design ensured heterogeneity in gender and age. Sample size calculations were based on a priori power analyses (small effect in a two-way ANOVA, $\alpha = 0.001$, $\beta = 0.80$) and suggested $N = 600$ per country.

A total of $N = 1202$ responses were collected of which $n = 613$ were collected in the United States of America and $n = 589$ in Switzerland. Table 1 presents the socio-demographics of the two groups of participants. The participants were equally distributed across the three applications, with $n = 392$ who rated the resistant potato application, $n = 408$ who rated the gluten-reduced wheat application, and $n = 402$ who rated the cold-resistant soybean application.

2.2. Questionnaire

The participants received an invitation through an email from the market research company "Bilendi & respondi" (https://www.bilendi.de/) and accessed the questionnaire through a link in the email. All participants were part of the company's panel. After providing informed consent, participants were led to the questionnaire. In the questionnaire, the term "genome editing" was used, as pilot tests showed that participants were more familiar with this term than the term "NGTs." Participants were first asked about their *subjective knowledge* of genome editing for foods ("How much do you know about genome editing in foods and agriculture?") and plant breeding in agriculture ("How much do you know about plant breeding in agriculture?"). The response options ranged from 1, "I do not know what that is," to 6, "a great deal.".

Then, to ensure that participants had the same baseline level of knowledge about genome editing at the beginning of the study, participants were asked to read an introductory text (cf. Fig. 1) explaining genome editing at a non-technical level. This also aimed at reducing noise in participants' responses and aiding participants in constructing thoughtful responses to subsequent questions. The lead author consulted with experts (e.g., in genome editing, molecular biology, plant breeding) to ensure the accuracy of this information.

At the start of the questionnaire, participants were randomly allocated to one of three applications of genome editing in agriculture that the participants were asked to rate. These applications were also introduced with short texts and a picture (cf. Fig. 1). The chosen applications were crops familiar to participants from the United States of America and Switzerland, grown for human consumption, and were based on published applications in research and development (e.g., Altenbach et al., 2020; Kieu et al., 2021; Kuczynski et al., 2022; Sánchez-León et al., 2018).

After reading the application text, the participants were first asked to rate whether the feelings evoked by this application of genome editing were negative or positive on a 7-point scale ranging from −3 'very negative' to + 3 'very positive' (*affect*). Participants were also asked to "list the *specific kind of feelings* that this application of genome editing evoked in you" in an open response field.

Next, participants were asked to rate several different aspects of the application (application-specific dependent variables). First, their *risk and benefit perceptions* were measured (3 items: "How useful [safe for human health; safe for the environment] do you feel it is to grow potatoes that are resistant to blight with genome editing [wheat that has no or very little gluten with genome editing; soybeans that are resistant to

Table 1
Socio-demographics of the three groups. Variables marked with * were restricted with quotas.

		United States of America		Switzerland	
		Sample	Census[1]	Sample	Census[2]
Age*	Mean (Standard Deviation)	46 (16)	39 (median)	46 (16)	46 (median)
Gender*(%)	woman	288 (47 %)	51 %	299 (51 %)	50 %
	man	314 (51 %)	49 %	289 (49 %)	50 %
	non-binary	10 (2 %)	–	0 (0 %)	–
	prefer not to answer	1 (<1%)	–	1 (<1%)	–
Education (%)	low	152 (25 %)	37 %	29 (5 %)	13 %
	medium	208 (34 %)	25 %	344 (58 %)	42 %
	high	252 (41 %)	38 %	207 (35 %)	45 %
	prefer not to answer	1 (<1%)	–	9 (2 %)	–
Living environment	rural	168 (28 %)	20 %	263 (45 %)	15 %
	suburban	282 (46 %)	80 %	168 (28 %)	85 %
	urban	161 (26 %)		151 (26 %)	
	prefer not to answer	2 (<1%)	–	7 (1 %)	–

Note.[1]*age, gender and living environment:* United States Census Bureau (2023a), *education* statistics*:* United States Census Bureau (2023b) [2]Federal Statistical Office (2021). For both countries, median age includes < 18 year-olds.

cold weather with genome editing]?"). The response options ranged from 1 "very useless" to 7 "very useful" for benefit perception and from 1 "very safe" to 7 "very unsafe" for risk perception. A composite *risk perception* score was generated by taking the mean over the risk perception for human health and the environment ($r = 0.81, p < 0.001$). Second, *perceived naturalness* of the genome edited crop was measured ("How natural do you feel genome edited potatoes [wheat; soybeans] are compared to traditionally bred soybeans?") with a response scale ranging from 1, "much less natural" to 7 "much more natural." Third, *acceptance* was measured ("How acceptable do you think this application of genome editing in agriculture is?") on a scale from 1 "very unacceptable" to 7 "very acceptable." Lastly, their willingness-to-eat (WTE) a traditionally bred and a genome edited potato [wheat; soybeans] was assessed on a scale from 1, "very unwilling," to 7, "very willing." A score for *change in WTE* was generated by subtracting their WTE a genome edited crop from their WTE a traditionally bred crop. The larger the difference in this score, the bigger the negative impact of genome editing on their WTE the crop.

The questionnaire further comprised some covariates. Namely, participants' *awareness of regulation* in their country was measured by asking whether they thought it was currently legal to use genome editing in agriculture (0: yes, 1: no). Their *trust in institutions* was measured with three items. The short *tampering with nature* scale (Raimi et al., 2020) was included (cf. Table 2). For all measures in Table 2, an overall score was computed by taking the mean over all items per participant. Additionally, participants were asked about their *preference for organic food* ("When possible, I prefer to eat organic food.") and whether they perceive *humans as part of nature* ("I see us humans as a part of nature") on a 7-point scale from 1 "strongly disagree" to 7 "strongly agree." Lastly, some socio-demographics were collected for the sample description (age, gender, education, living environment).

2.3. Data analysis

For RQ1, the responses given by the participants in the open response field (evoked feelings) were coded into a pre-determined coding scheme by the first author. The coding scheme was based on the first authors' expectations and prior literature (Connor & Siegrist, 2010; Green et al., 2005) and was extended based on some unexpected responses during coding. The participants wrote, on average, 10 words (*SD* = 11, Mode: 1, Median: 10, Range: 0–181). The following codes were given if the participants expressed solely negative feelings: "generic negative feelings" (e.g., bad, uneasy) and "strong negative feelings" (e.g., hate, anger, fear). The following codes were given if the participants expressed solely positive feelings: "generic positive feelings" (e.g., good, beneficial) and "strong positive feelings" (e.g., hope, relief). If participants expressed mixed or torn feelings, it was coded as "torn feelings." Neutral feelings, and if participants expressed that no feelings were associated with the application were coded as "neutral feelings." In addition, some participants did not express feelings but described other ways that they thought about the application, which was coded into the following three codes: "application is unnecessary," "tampering with nature or playing God," "worry about negative consequences." This coding procedure resulted in $n = 84$ missing values for participants who left the field open, expressed that they did not know, or the meaning of their input was unclear. Several 2x3 ANOVAs (2 countries: Switzerland and the United States of America, 3 application: blight-resistant potato, gluten-free wheat, cold-resistant soybean) were conducted to compare the mean perceptions and acceptance of the three applications across the two countries (RQ2). Benefit perceptions, risk perceptions and perceived naturalness, acceptance and change in WTE served as independent variables. All assumptions of ANOVA were checked and fulfilled prior to the data analysis. Two main effects (H2.1 for country, H2.2 for application) and one interaction effect (H2.3 for country*application) were investigated. Lastly, two linear regression analyses with acceptance of all three applications combined as a dependent variable were conducted, one for the data from Switzerland and one for the data from the United States of America (RQ3). The specific application, awareness of regulation (H3.1), affect (H3.2), trust in institutions (H3.3), tampering with nature (H3.4), humans as part of nature (H3.5) and preference of organic food (H3.6) served as independent variables. All assumptions of linear regression analysis were checked and fulfilled prior to the data analysis. All descriptive and multivariate data analyses were conducted in SPSS 28 (IBM Corp., 2021).

3. Results

3.1. RQ1: Spontaneous feelings and affect evoked by the applications

Table 3 presents the detailed coded feelings that were evoked by the description of the three applications. Half of the participants ($n = 559$, 50 %) in both countries expressed positive feelings regarding the three applications, whereas a quarter of the participants expressed negative feelings and associations ($n = 273$, 25 %). The remaining participants expressed torn ($n = 192$, 17 %) or neutral feelings ($n = 92$, 8 %). There was a significant relationship between the type of spontaneous feelings expressed and country ($X^2(3) = 78.2$, $p < 0.001$). Participants from Switzerland were more likely to express negative feelings ($n = 191$, 35 % of all expressed feelings) than participants from the United States of America ($n = 82$, 14 % of all expressed feelings). Similarly, participants from the United States of America were more likely to express positive feelings ($n = 350$, 61 %) than participants from Switzerland ($n = 209$,

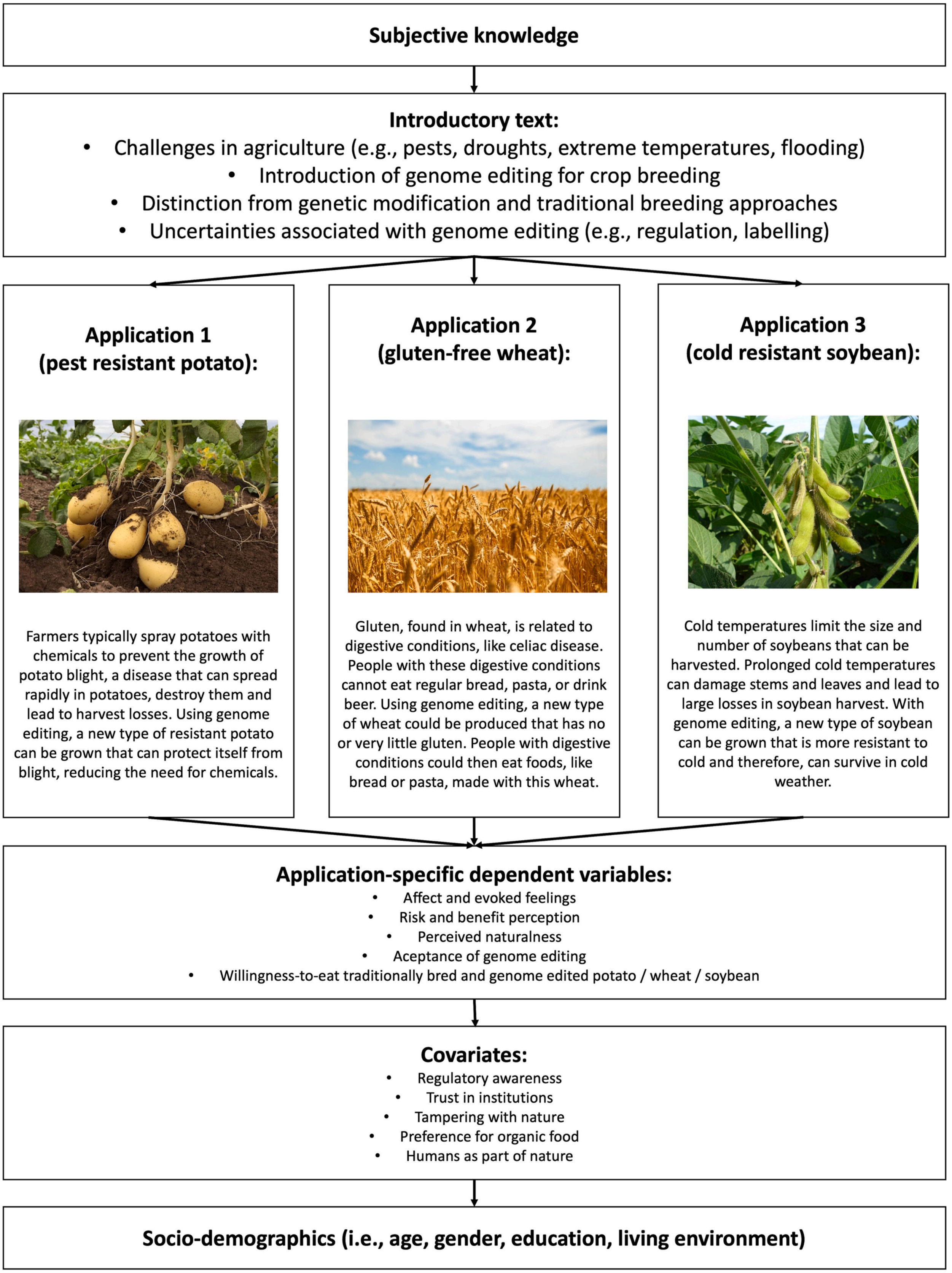

Fig. 1. Survey flow (full introductory text in the Appendix).

Table 2
Means (M), standard deviations (SD), and corrected item-scale correlations for trust in institutions, tampering with nature, and involvement with food (N = 1202).

	United States of America			Switzerland		
	M	*SD*	*r*	*M*	*SD*	*r*
Trust in institutions (response scale: 1–7)	**α = 0.90**			**α = 0.91**		
I trust companies involved in genome editing to be open and transparent about the uncertainties and benefits of foods created using genome editing.	4.2	1.9	0.85	4.1	2.0	0.89
I trust government officials involved in regulating genome edited foods to make decisions that are safe for consumers.	4.1	2.0	0.84	4.5	2.0	0.87
I trust scientific organisations to communicate openly and transparently about new findings on genome editing.	4.7	1.8	0.87	4.5	1.9	0.87
Tampering with nature (response scale: 1–7)	**α = 0.79**			**α = 0.77**		
People who push for technological fixes to environmental problems are underestimating the risks.	4.3	1.6	0.75	4.6	1.6	0.73
People who say we shouldn't tamper with nature are just being naïve. *	4.1	1.7	0.85	4.7	1.8	0.81
Altering nature will be our downfall as a species.	4.0	1.8	0.70	4.2	1.9	0.71
I would prefer to live in a world where humans leave nature alone.	4.5	1.6	0.72	5.1	1.6	0.70
Human beings have no right to meddle with the natural environment.	3.9	1.7	0.71	4.4	1.8	0.70

Note. *: reverse-coded item.

Table 3
Frequency of evoked feelings or associations regarding the three applications in the United States of America (n = 613) and Switzerland (n = 589).

Evoked feelings	United States of America	Switzer-land	Total
Generic positive feelings (e.g., good, beneficial)	231 (40 %)	156 (29 %)	387 (35 %)
Torn feelings	96 (17 %)	96 (18 %)	192 (17 %)
Strong positive feelings (e.g., hope, relief)	119 (21 %)	53 (10 %)	172 (15 %)
Neutral feelings	48 (8 %)	44 (8 %)	92 (8 %)
Tampering with nature or playing God	21 (4 %)	57 (10 %)	78 (7 %)
Worry about explicit consequences	26 (5 %)	47 (9 %)	73 (7 %)
Generic negative feelings (e.g., bad, uneasy)	14 (2 %)	49 (9 %)	63 (6 %)
Strong negative feelings (e.g., hate, anger, fear)	14 (2 %)	22 (4 %)	36 (3 %)
Application is unnecessary	7 (1 %)	16 (3 %)	23 (2 %)
Missing values (i.e., empty field, unclear)	37	49	86
Total	576	540	1202

39 %). There were no substantial differences between torn and neutral feelings across the two countries. No significant relationship was observed for the type of spontaneous feelings expressed and application ($X^2(6) = 10.9$, $p = 0.092$).

These findings are also mirrored in the affect measurement with an overall mean of $M = 0.7$ ($SD = 1.7$), which falls just above the midpoint of the scale. The affect scale ranged from −3 (very negative) to 0 (neutral) and to + 3 (very positive). The evoked affect was more positive in the United States of America ($M = 1.2$, $SD = 1.5$) than in Switzerland ($M = 0.3$, $SD = 1.7$), $F(1, 1196) = 99.7$, $p < 0.001$, $\eta^2 = 0.08$. The differences in evoked affect across the three applications was small and non-significant, $F(2, 1196) = 3.0$, $p = 0.051$, $\eta^2 = 0.01$. The interaction effect of country and application was not significant, $F(2, 1196) = 0.5$, $p = 0.591$.

3.2. RQ2: Differences in perceptions and acceptance based on country and specific application

Table 4 presents the results of the two-way ANOVAs. There were significant differences between the United States of America and Switzerland (small to medium effects) for all dependent variables (H2.1). Participants from the United States of America reported lower risk perception, and higher benefit perception, perceived naturalness, and acceptance than Swiss participants. Moreover, the differences between the WTE traditionally bred crops and genome edited crops was smaller for the participants in the United States of America than in Switzerland. The differences between the three applications (H2.2) were small and mostly non-significant, except for the Change in WTE, which was higher for gluten-free wheat than for cold-resistant soybeans (Sidak, $p < 0.001$). However, the effect size of this main effect was small. No significant interaction effects were observed (H2.3).

3.3. RQ3: 3.3 relationship between individual differences and acceptance of applications

Table 5 shows the bivariate correlations between individual differences and acceptance and Table 6 shows the results of a linear regression analysis with acceptance as dependent variable. The results are presented separately for the United States of America and Switzerland, as the prior analysis showed consistent differences in perception and acceptance for the two countries. The two dummy variables for specific applications were also included to control for the different applications that the participants saw but were not significantly related to acceptance. In both countries, the strongest relationships were observed between affect, trust, aversion to tampering with nature, and acceptance. Participants who expressed more positive affect reported higher acceptance of the applications (H3.2). Participants who expressed higher trust in institutions (i.e., government, industry, science) (H3.3) and lower aversion to tampering with nature expressed higher acceptance of genome editing across applications (H3.4). The other individual differences had no or smaller relationships with acceptance. In Switzerland, higher acceptance was reported by participants who more strongly agreed that humans were part of nature (H3.5). This relationship was not observed for participants from the United States of America. Lower acceptance was associated with thinking that it was not legal to use genome editing in their country (H3.1). This relationship was observed in both countries but was stronger in Switzerland than the United States of America. In both countries, the preference for organic food was not related to acceptance (H3.6). Overall, 66 % and 74 % of the variance in acceptance could be explained by the included variables in the United States of America and Switzerland.

4. Discussion

This study investigated what consumers from the United States of America (i.e., a country where gene technology is legal and in use for food production) and Switzerland (i.e., a country where the commercialisation of gene technology for food production has been banned since 2005) thought about three specific applications of NGTs in plant breeding. Roughly half of the participants expressed positive feelings regarding the three applications in an open response field. This confirmed prior findings (Bearth et al., 2022; Busch et al., 2021; Saleh et al., 2021) that a large share of consumers in both countries are open towards or even excited about NGT applications for food production if they offer relevant benefits (e.g., pest control, health benefits for a specific group of people). However, a quarter of participants also

Table 4
Differences in the dependent variables in the United States of America (n = 613) and Switzerland (n = 589) for the three different applications of genome editing.

	United States of America	Switzerland	
Benefit perception	*M* (*SD*)	*M* (*SD*)	ANOVA
Pest-resistant potato[a]	5.7 (1.5)	5.2 (1.6)	main effect *application*: $F(2, 1196) = 2.4$, $p = 0.088$, $\eta^2 < 0.01$
Gluten-free wheat[a]	5.7 (1.5)	4.9 (1.7)	main effect *country*: $F(1, 1196) = 53.0$, $p < 0.001$, $\eta^2 = 0.04$
Cold-resistant soybean[a]	5.6 (1.6)	4.9 (1.7)	interaction effect: $F(2, 1196) = 1.3$, $p = 0.057$, $\eta^2 < 0.01$
Risk perception			
Pest-resistant potato[a]	3.0 (1.6)	3.9 (1.7)	main effect *application*: $F(2, 1196) = 0.5$, $p = 0.579$, $\eta^2 < 0.01$.
Gluten-free wheat[a]	3.1 (1.6)	4.0 (1.7)	main effect *country*: $F(1, 1196) = 107.5$, $p < 0.001$, $\eta^2 = 0.08$
Cold-resistant soybean[a]	3.0 (1.5)	4.1 (1.7)	interaction effect: $F(2, 1196) = 0.6$, $p = 0.572$, $\eta^2 < 0.01$
Perceived naturalness			
Pest-resistant potato[a]	3.6 (1.6)	3.0 (1.6)	main effect *application*: $F(2, 1196) = 0.1$, $p = 0.975$, $\eta^2 < 0.01$.
Gluten-free wheat[a]	3.6 (1.6)	3.0 (1.5)	main effect *country*: $F(1, 1196) = 52.6$, $p < 0.001$, $\eta^2 = 0.04$
Cold-resistant soybean[a]	3.6 (1.6)	2.9 (1.6)	interaction effect: $F(2, 1196) = 0.1$, $p = 0.895$, $\eta^2 < 0.01$
Acceptance			
Pest-resistant potato[a]	5.2 (1.7)	4.3 (1.9)	main effect *application*: $F(2, 1196) = 1.6$, $p = 0.205$, $\eta^2 < 0.01$.
Gluten-free wheat[a]	5.1 (1.7)	4.2 (1.8)	main effect *country*: $F(1, 1196) = 92.6$, $p < 0.001$, $\eta^2 = 0.07$
Cold-resistant soybean[a]	5.1 (1.7)	4.0 (1.9)	interaction effect: $F(2, 1196) = 0.2$, $p = 0.794$, $\eta^2 < 0.01$
Change in WTE			
Pest-resistant potato[ab]	−0.8 (1.7)	−1.8 (2.3)	main effect *application*: $F(2, 1196) = 8.2$, $p < 0.001$, $\eta^2 = 0.01$.
Gluten-free wheat[a]	−1.0 (1.8)	−2.1 (2.4)	main effect *country*: $F(1, 1196) = 78.4$, $p < 0.001$, $\eta^2 = 0.06$
Cold-resistant soybean[b]	−0.6 (1.4)	−1.4 (1.9)	interaction effect: $F(2, 1196) = 0.7$, $p = 0.497$, $\eta^2 < 0.01$

Note. M: mean, SD: standard deviation. Different superscript letters show significant differences across the three applications (Sidak, $p < 0.001$).

expressed negative feelings, and another quarter expressed torn or neutral feelings towards the applications in the open response field. Swiss participants more frequently reported negative and less frequently positive feelings regarding the three applications than those from the United States of America. Affect was most strongly related to acceptance in both countries, as positive affect was associated with higher acceptance and negative affect with lower acceptance. This reconfirms the affect heuristic's role in the acceptance of novel food technologies (Finucane et al., 2000; Siegrist, 2008, 2021; Siegrist et al., 2000). The results, overall, suggest that the application of NGTs in food production will remain a controversial topic with strong opposition from a minority of consumers, particularly in countries with bans in place.

GM foods have been available to consumers in stores in the United States of America since 1994 with the Flavr Savr tomato (Bruening & Lyons, 2000). This means that there is a history of safe use and consumption of GM foods in the United States of America. Thus, it is hardly surprising that the country of residency was found to be related to consumer perceptions and acceptance, with more positive perceptions and higher acceptance of the NGT applications in the United States of America, where people are already exposed to GM products, than in Switzerland, where they are not. This finding is consistent with prior research suggesting that familiarity is associated with less risk perception and higher acceptance (Fischer & Frewer, 2009; Kronberger et al., 2013). Furthermore, our results support one of the conclusions made in the *meta*-analysis by Bearth and Siegrist (2016): the regulatory background is linked to acceptance, as participants who thought that NGTs were banned in their country expressed lower acceptance than participants who thought that NGTs were not banned in their country. Importantly, we find that this was true independent of the *actual* regulation: specifically, this relationship held for both US and Swiss participants. It is not possible to determine the directionality of this result. It is equally plausible that participants who did not know their country's current regulation responded consistently with their perceptions and acceptance. It might be challenging to untangle these relationships in the future, as experimental designs that vary gene technology regulation for specific participants are difficult, if not impossible (e.g., providing different information about regulation in an experiment interacts and depends on actual knowledge of regulation). However, future research could potentially work with fictitious technologies and vary the information provided about regulation (e.g., type, duration, or history of regulation).

Unlike in prior work (e.g., Busch et al., 2021), we find that the application type was irrelevant for perceptions, and acceptance across both countries, except that for gluten-free wheat, WTE was lower than for cold-resistant soybeans. Based on open responses at the end of the questionnaire, we suspect that this was due to the expected negative impact on wheat quality due to the absence of gluten. It is likely that all three applications were seen as similar and, thus, elicited similar response patterns. In the study by Busch et al. (2021), differences in preferences were found for applications that improve human health or enhance resistance in crops over applications that change yield or product quality. However, in their study, the applications involved

Table 5
Bivariate correlations between independent and dependent variables (United States of America: N = 612, Switzerland: N = 588).

	Accept-ance	Affect	Trust in institutions	Tampering with nature	Humans as part of nature
United States of America					
Acceptance	–				
Affect	0.76***	–			
Trust in institutions	0.61***	0.54***	–		
Tampering with nature	−0.42***	−0.36***	−0.28***	–	
Humans as part of nature	0.13**	0.15***	0.13**	0.06	–
Preference for organic food	0.04	0.08	0.12**	0.20***	0.22***
Switzerland					
Acceptance	–				
Affect	0.81***	–			
Trust in institutions	0.65***	0.56***	–		
Tampering with nature	−0.48***	−0.41***	−0.30***	–	
Humans as part of nature	0.08	0.03	0.13**	0.20***	–
Preference for organic food	−0.01	−0.03	0.04	0.14***	0.22***

Note. **: $p < 0.01$, ***: $p < 0.001$.

Table 6
Linear regression analysis with acceptance as dependent variable (United States of America: N = 612, Switzerland: N = 588).

	B [95 % CI]	β	*t*	*p*
United States of America (R^2 = 0.66, F(8, 604) = 148.0, p < 0.001)				
Constant	4.3 [3.8, 4.9]		15.7	<0.001
Pest-resistant potato[a]	0.1 [−0.1, 0.3]	0.02	0.7	0.459
Gluten-free wheat[a]	−0.1 [−0.3, 0.1]	−0.04	−1.4	0.173
Awareness of regulation[b]	−0.2 [−0.4, −0.1]	−0.06	−2.7	0.007
Affect	0.6 [0.6, 0.7]	0.57	19.2	<0.001
Trust in institutions	0.2 [0.2, 0.3]	0.25	8.8	<0.001
Tampering with nature	−0.2 [−0.3, −0.1]	−0.15	−5.5	<0.001
Humans as part of nature	0.0 [0.0, 0.1]	0.02	0.9	0.347
Preference for organic food	0.0 [−0.1, 0.0]	−0.01	−0.3	0.741
Switzerland (R^2 = 0.74, F(8, 580) = 209.4, p < 0.001)				
Constant	4.4 [3.8, 5.0]		14.7	<0.001
Pest-resistant potato[a]	0.0 [−0.2, 0.2]	0.00	−0.1	0.923
Gluten-free wheat[a]	0.0 [−0.1, 0.3]	0.03	1.2	0.222
Awareness of regulation[b]	−0.4 [−0.7, −0.3]	−0.11	−5.2	<0.001
Affect	0.6 [0.6, 0.7]	0.59	21.9	<0.001
Trust in institutions	0.3 [0.2, 0.3]	0.25	9.6	<0.001
Tampering with nature	−0.2 [−0.3, −0.2]	−0.17	−6.9	<0.001
Humans as part of nature	0.1 [0.0, 0.1]	0.06	2.8	0.005
Preference for organic food	0.0 [0.0, 0.0]	0.00	0.2	0.879

Note. [a]base category (0): cold-resistant soybean. [b]base category (0): legal.

different species (i.e., human, plant, animal), which might have increased the discriminating effect. The variance in preferences in the study by Busch et al. (2021) can partly be explained by the different species, instead of the different applications.

Aside from affect discussed above, acceptance was related to individual differences in trust in government officials, companies, and scientific organisations, and various values and personal preferences. The importance of trust further highlights the role of these stakeholders in both countries in paving the way for new, potentially beneficial technologies. In this study, a total score for trust in companies, government, and scientific organisations was used. However, trust levels and individual reactions to the participation of these three stakeholders in the dialogue about NGTs may differ based on their perceived role, stake, values and competence (Connor & Siegrist, 2010). Whom people place their trust in might be highly dependent on the judgment and decision context. Moreover, in real information and communication environments (e.g., public or media debates, before a public vote) various other stakeholders (e.g., non-governmental organisations, lobby groups, interest groups, and individual citizens) participate in the dialogue as well. This makes recommendations on how to promote trust in stakeholders and who should communicate in what way about NGTs difficult, despite the large evidence base on what promotes and hinders trust in stakeholders (e.g., transparency, the similarity of values, competence), summarised elsewhere (Siegrist, 2021; Siegrist & Hartmann, 2020).

This study also included a scale measuring views on tampering with nature and a question asking whether participants perceive humans as a part of nature or not. The aversion to tampering with nature is a relatively stable preference that differs substantially across individuals (Hoogendoorn et al., 2021; Raimi et al., 2020; Sjöberg, 2000). Interestingly, in this study, the aversion to tampering with nature and seeing humans as part of nature was positively related in both countries. Thus, other than expected, seeing humans as a separate entity from nature does not seem to be a pre-condition for being averse to tampering with nature. However, in Switzerland, people who perceived more strongly that humans were part of nature also reported higher acceptance of the NGT applications. This relationship was not found in the United States of America. Seeing technology as tampering with nature correlates with other stable preferences that have been shown to negatively impact the acceptance of gene technology, namely perceived unnaturalness, uncontrollability of negative consequences, and ideological concerns (Hoogendoorn et al., 2021; Saleh et al., 2021). Thus, due to the relative stability of these constructs within individuals, it will likely not be possible to change this preference with communication efforts. Future research should investigate ways to untangle these relationships, as it might provide further insights into the origins of the strong aversion to gene technology.

Lastly, organic consumers are frequently cited as the primary opponents of gene technology in agriculture, despite the potential benefits of NGTs for organic agriculture (Andersen et al., 2015; Purnhagen et al., 2021). Not least because "GMO-free" is anchored in organic regulations (e.g., in Europe Regulation 848/2018, Art. 5), assurances or commitments. This study could not confirm these suspicions, as no relationship between a preference for organic foods and acceptance in both countries was found. A possible alternative explanation for this finding might be the use of a single item, which might bring along some methodological biases (e.g., socially desirable response patterns). In contrast to our findings, a prior study (Mandolesi et al., 2022) that utilised focus groups concluded that organic consumers hold mostly negative views of NGTs. Focus groups allow for a more open investigation of consumers' views compared to quantitative, closed-format surveys. Utilising these open format results (Mandolesi et al., 2022) suggests that the negative views of organic consumers of NGTs are rooted in the perceived absence of benefits and the misunderstanding that organic farming does not involve human intervention and genetic changes. In line with the goal of enabling citizens and consumers to make informed decisions, future studies might want to investigate this further and use more sophisticated measures, such as actual organic consumer behaviour separated by food type (e.g., meat, vegetables, and fruit). Potentially, this finding raises questions about whether the organic sector's views of the consumers' expectations might be somewhat outdated in light of potentially beneficial technological innovations.

This study was not without its limitations. First, it is a challenge to measure consumer acceptance of a novel technology neutrally, as the complexity and lack of knowledge among the public require providing some information on the technology. For this reason, the provided information in this study featured both potential benefits as well as risks and uncertainties. The responses regarding the feelings evoked by this information suggest that the information allowed for polarised and heterogeneous reactions and that the perceived balance in perspectives may have increased the credibility and trustworthiness of the information. Relatedly, measuring proxy or actual behaviour (i.e., voting for or against a ban, protesting the current regulation, consumer behaviour) might provide more accurate estimates of consumer acceptance rather than a willingness to eat or a theoretical acceptance of NGTs. Future research should investigate more realistic ways of measuring consumer acceptance. Another limitation of this work is that the participants in this study were members of a market research panel. While the sample aimed at being as heterogeneous as possible and representative of the populations in the German-speaking part of Switzerland and the United States of America, it did not feature participants not part of a market research panel. Additionally, comparisons with the national census in the United States of America and Switzerland showed that there were some differences between the population and our samples, specifically in terms of education (higher education in the sample than in the population) and living environment (Switzerland: more rural participants in the sample compared to the population). This reduces the external validity of the results to a certain degree.

5. Conclusion

To conclude, this study suggests that a substantial portion of consumers welcome innovation in agriculture but that the use of NGTs might be substantially complicated by an almost equally large portion of unsure or disapproving consumers. Prior evidence suggests that benefit perception plays a more substantial role in accepting NGT applications than risk perception (Bearth & Siegrist, 2016). To promote NGTs in agriculture, these benefits must first be backed by evidence from laboratory studies and field trials and then discussed in scientific, regulatory, political, and public arenas. However, a citizen or consumer that holds strong values and personal preferences that oppose the use of NGTs will likely not be convinced by benefits and rather focus on potential risks (backed and not backed by scientific evidence), potential economic downsides, inequalities or moral and ethical values that oppose human intervention in nature. This should be kept in mind to avoid falling back into the 'knowledge deficit model,' in which an expert needs to provide sufficient information and education to an unknowing public to raise acceptance (Hansen et al., 2003). Instead, our findings highlight the importance of a collaboration between the life sciences and social sciences in balancing technological innovations and public perceptions and acceptance, which have been shown to be impacted by affect, values and context.

6. Data availability statement

The data that support the findings of this study are available from the corresponding author upon request.

CRediT authorship contribution statement

Angela Bearth: Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Caitlin Drummond Otten:** Writing – review & editing, Resources, Project administration, Methodology, Investigation, Conceptualization. **Alex Segrè Cohen:** Writing – review & editing, Project administration, Methodology, Investigation, Data curation, Conceptualization.

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.

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Appendix – Introductory Text

English

Agriculture faces challenges that make growing crops and maintaining our food supply difficult. These challenges include pests, droughts, extreme temperatures, and flooding.

One of the many possible solutions to these challenges is a technology called "Genome Editing" for crop breeding. Genome editing can insert, adapt, or remove genes from genome sequences to make desired changes in a crop. In other words, genome editing can influence the plants' properties and features. Other terms that you might have heard for genome editing tools are CRISPR/Cas9 or genetic scissors.

Despite the similarities in the names, genome editing is different from genetic modification, as the changes made to the existing genome sequence of a crop are targeted in genome editing.

Genome editing could help tackle some of the challenges faced by agriculture, along with traditional breeding approaches. But there are some uncertainties associated with this new technology, including how this technology would be regulated, and whether foods produced with this technology would be labeled.

We would like to tell you about a specific way in which genome editing could be used in agriculture. We are interested in your honest opinions about this application.

German

Die Landwirtschaft ist mit Herausforderungen konfrontiert, die den Anbau von Nutzpflanzen und die Sicherstellung unserer Lebensmittelversorgung erschweren. Zu diesen Herausforderungen gehören Schädlinge, Dürreperioden, extreme Temperaturen und Überschwemmungen.

Ein möglicher Lösungsansatz für diese Herausforderungen ist eine Technologie namens "Genom Editierung" für die Pflanzenzucht. Durch die Genom Editierung können Gene zielgerichtet eingefügt, verändert oder ausgeschalten werden, um gewünschte Veränderungen an einer Pflanze vorzunehmen. Mit anderen Worten: Genom Editierung kann die Eigenschaften und Merkmale einer Pflanze beeinflussen. Andere Begriffe, die Sie für die Werkzeuge der Genom Editierung gehört haben könnten, sind CRISPR/Cas9 oder Genschere.

Trotz der Ähnlichkeiten im Namen, unterscheidet sich die Genom Editierung von der klassischen Gentechnik dadurch, dass Änderungen an der bestehenden Genomsequenz einer Pflanze bei der Genom Editierung sehr zielgerichtet vorgenommen werden können.

Die Genom Editierung könnte, zusammen mit den traditionellen Züchtungsmethoden, dazu beitragen, die landwirtschaftlichen Herausforderungen anzugehen. Es gibt jedoch einige Unsicherheiten im Zusammenhang mit dieser neuen Technologie, z.B. die Frage, wie diese Technologie gesetzlich geregelt werden soll und ob mit dieser Technologie hergestellte Lebensmittel gekennzeichnet werden sollen.

Wir möchten Ihnen eine konkrete Möglichkeit vorstellen, wie Genom Editierung in der Landwirtschaft eingesetzt werden könnte. Wir sind an Ihrer ehrlichen Meinung zu dieser Anwendung interessiert.

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