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Uncomfortable trade-offs in plant protection – public perceptions of chemical and biotechnology options

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Abstract

Improvements to the agricultural system and tackling challenges emerging from societal, geo-political or climate change requires decision makers to consider trade-offs between technological solutions and consumer preferences. Such a challenge is the breeding of resilient crops through traditional techniques (i.e. crossbreeding, mutagenesis) and new breeding techniques (i.e. transgenesis, cisgenic genetic modification, intragenesis, genome editing), and the protection from pests and diseases using plant protection products. This article presents nuanced insights into consumers views of plant protection products and new breeding techniques regarding the specific case study focused on potato blight. Two online studies were conducted in the German-speaking part of Switzerland. In the first study ($N=965$), synthetic and natural fungicides, cisgenic genetic modification and genome editing were rated similarly by the participants in terms of acceptance and perceived naturalness. The second study ($N=1061$) extended these insights and showed that different types of fungicides (i.e. natural vs. synthetic, named vs. unnamed) elicited different spontaneous associations, levels of acceptance and perceived naturalness. Interestingly, the ubiquitous mutagenesis was rated similarly as breeding techniques currently restricted by EU regulations.

Keywords Agriculture · Trade-offs · Public perceptions · Plant protection products · New breeding techniques

Introduction

Background

Improvements to the agricultural system and tackling challenges emerging from societal, geo-political or climate change requires decision makers, such as regulatory agencies, industry professionals or politicians, to consider trade-offs (Campbell et al. 2018). The translation of innovations from basic to applied research and practice frequently involves weighing future benefits against citizens' and consumer preferences for familiarity and naturalness (Etale & Siegrist, 2021; Román et al. 2017). A particular challenge in this regard is the breeding of resilient crops and the protection from pests and diseases using plant protection products (Jauhar, 2006; Jorasch, 2020). Prior research suggested that breeding or production process (e.g., genetic modification) reduces perceived naturalness more than content and quantity of substances (e.g., potential residues from plant protection products) (Rozin 2006). The lower perceived naturalness and associated risk perceptions have been cited as one of the reasons for the societal reluctance towards genetically-modified crops and foods as developed in the 1990's and 2000's (Bearth and Siegrist 2016; Scott, et al. 2018; Siegrist, 2000).

However, the breeding processes have evolved over the years, extensive risk assessments have been conducted and a new generation of citizens and consumers have reached adulthood who might be more open to technological tools to combat agricultural challenges (Farid et al. 2020; De Steur, 2019). The New Breeding Techniques (NBTs), such as genome editing, which change or silence specific genes, are argued to represent processes that have more in common

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with traditional breeding approaches, such as cross-breeding used since the dawn of agriculture or mutagenesis used since the 1930's, than with transgenic genetic modification where alien DNA is inserted into host organisms (German National Academy of Sciences Leopoldina 2019; Ricroch et al. 2022). This has been manifested in calls in Europe to revise the current regulation of NBTs and facilitate field trials and the implementation of beneficial applications (European Commission 2023; German National Academy of Sciences Leopoldina 2019; Purnhagen et al. 2021). A frequent matter of debate, sparked by these calls to revise regulation, is the role of citizen and consumer acceptance of NBTs and products bred with NBTs (German National Academy of Sciences Leopoldina 2019). This article aims at contributing to this debate by providing insights into consumers' views of traditional and innovative food technologies for the beneficial application of combatting potato blight. Specifically, we aim to pry apart different cognitive mechanisms at play when people are presented with a complex problem and potential solutions in agriculture and utilise this nuanced assessment to provide insights into consumers preferences for labelling when presented with complex trade-offs.

Theoretical framing

Public acceptance of food technologies is a broad concept, which refers to the extent to which citizens actively or passively accept or reject innovation in the food system (e.g., through voting behaviour, protesting, petitioning), as well as market success through consumers' willingness to eat novel food product as part of their diets (Fischer and Reinders 2022). Predicting it is challenging due to the underlying complexity of the concept of acceptance, and public preferences for naturalness in foods. Prior research suggests that consumers favour foods that are perceived as natural, which means to them that foods are minimally processed, free from subjectively unwanted ingredients and residues, and closely resembling their original state with minimal human intervention (Michel and Siegrist 2019; Rozin 2005). This means that consumers and lay citizens generally evaluate food technologies, such as chemical agents or genetic modification, with a somewhat critical outlook based in their broader societal concerns about the naturalness of the food system. For example, consumers and lay citizens have been found to be generally critical about the widespread use of plant protection products, particularly in organic agriculture (Koch et al. 2017; Lehberger & Becker 2020; Saba & Messina 2003). This is very different from experts, who mostly stress the technological potential of NBTs for agricultural innovation, food security and resilience of the food system (Blok et al. 2008; Fischer & Rock 2023; Henderson et al. 2023), and the beneficial contribution of plant protection methods to achieve that. This study focuses the two concepts overall *acceptance* and the role of *preferences for naturalness* therein due to their inherent importance for the sustained success of innovations in the food system.

One factor that might impact public acceptance of plant protection measures is the contextual information about the agricultural system and the technology or innovation that is provided or available to people (Fernbach et al. 2019; Kato-Nitta et al. 2019; Rose et al. 2019). On the one hand, due to the inherent complexity of agricultural challenges and the tools to address these challenges (i.e., plant protection products, NBTs) in combination with limited public knowledge about these technologies, survey and experimental research into public acceptance of NBTs generally relies on providing participants with at least some degree of information. This bears its own set of challenges; among them, the question whether it is possible to describe these issues neutrally or if a specific framing might (unduly) influence people's responses (Doxzen and Henderson 2020; Durfee 2006; Yang & Hobbs 2020a). Prior research has suggested that peripheral factors, such as the wording used for the technology might serve mental shortcuts to determine acceptance, particularly in the absence of knowledge about the matter at hand (Bryant and Barnett 2019; Zahry and Besley 2019). The effect of specific wording can be explained under the umbrella of the affect heuristic (Finucane et al. 2000; Slovic et al. 2007), which states that emotions can serve as mental shortcuts in decision making. The exact terms and or images used to describe a technology activate spontaneous associations (related images, words, and emotions) and these positive or negative emotions in turn efficiently determine acceptance.

Knowledge gap and research questions

Despite the rich theoretical conceptualisation associated with the public acceptance of innovations, research that pries apart the cognitive mechanisms at play when citizens and consumers make sense of an agricultural challenge and potential solutions is lacking (Bearth and Siegrist 2016; Wirz et al. 2020; Yang and Hobbs 2020a). Of the few studies that focused on cognitive mechanisms when judging applications of NBTs, a recent study by Saleh et al. (2021) investigated evaluations of different options to protect potatoes from potato blight. Given the damage potato blight does to the agricultural system, protection from this fungus could be considered as a beneficial application of crop protection, either chemical or through breeding resistance into potato crops. Saleh et al. (2021) found among other things that higher importance of naturalness in foods (defined as consumers' preferences for foods that are perceived as natural) were negatively related with the acceptance of chemical and biotechnological options (defined as expressing acceptance towards the use of the technology and as willingness to eat foods derived from these options). They also found that the participants expressed higher acceptance of cisgenic genetic modification than of chemical treatments (i.e., natural or synthetic fungicides) or genome editing, and perceived the prior as more natural than the latter. An alternative explanation why people preferred the cisgenic genetic modification provided by Saleh et al. (2021) was that participants may have misunderstood cisgenesis as conventional crossbreeding, as it was not explicitly labelled as gene technology but the term "*gene transfer*" was used. Prior research, showing a negative effect of negatively-connotated wording on acceptance, supports this interpretation (Bryant and Barnett 2019; Zahry and Besley 2019). Our study uses the same case study as Saleh et al. (2021) (i.e., treatment options for late blight fungus in in potatoes) to, in a first step, rule out this alternative explanation and to add insights on how people evaluate agri-technological solutions of agricultural challenges. Thus, study 1 aimed at testing the alternative explanation that people understood cisgenesis as crossbreeding and the effect of different wording (i.e., with negative or neutral connotations) on people's evaluations of biotechnological and chemical interventions in agriculture. The following research questions were tested in study 1:

- How do people evaluate different options to protect potatoes from late blight fungus in terms of perceived naturalness, and acceptance in terms of voiced opinion as well as, willingness to eat the resulting potatoes?
- To what extent do people's evaluations of biotechnological options differ based on whether a negatively-connotated term is given (i.e., gene technology), a neutral term is given (i.e., genome editing) or no specific term is given for the technology in use?

In answering these research questions, we expand on the study by Saleh et al. (2021) by investigating an alternative explanation (i.e., wording) to their findings. However, the study by Saleh et al. (2021) and our study 1 solely featured a between-subjects design and closed-format questions. This only allowed for limited investigation of alternative explanations for the results or observation of cognitive mechanisms. Therefore, study 2 goes a few steps further. In addition to the closed-format questions, we collected qualitative insights on associations and elicited affect in line with assumptions of the affect heuristic (i.e., in the absence of time, motivation or knowledge, people base their judgments on spontaneous associations and elicited affect) (Finucane et al. 2000; Slovic et al. 2007). In addition, study 2 aimed at observing trade-offs that address consumer response when first, 'learning about an issue', second, 'hearing about different solutions' and third 'deciding about a range of options.' To investigate the decision-making elicited when 'learning about an issue,' and the role of wording therein, different groups of people were informed about potato blight and the use of different fungicides in potato farming, either named generically (i.e., natural or synthetic fungicides) or by their specific names (i.e., Azoxystrobin, Copper). For the second aim to investigate decision-making elicited when 'hearing about different solutions,' people were asked about their views of three different breeding options that can generate blight resistance in potatoes (i.e., mutagenesis, cisgenic genetic modification, genome editing) when compared to previous chemical options. Mutagenesis refers to the process of inducing more or less random changes in genes of plants through radiation or chemical agents aiming to find more productive or resilient mutants (Krishna et al. 2023; Oladosu et al. 2016). Cisgenic genetic modification refers to the process of transferring specifically selected genes between organisms of the same or closely related species and lastly, genome editing refers to changes made by inserting, silencing or removing genes from a plant's genetic material (Chen et al. 2019; Krishna et al. 2023; Swiss Academies of Arts and Sciences 2018). Finally, the third aim of 'deciding about a range of options' was to see which solution was favoured, either chemical protection of potatoes, blight resistance breeding in potatoes or no intervention leading to substantial losses in potato harvest. Although this choice is somewhat artificial, as any approach for the future will involve several strategies to protect plants form pests and diseases, it nonetheless, offers insights into what people would decide if pressed for a choice. The following research questions were tested in study 2:

- How do people evaluate different biotechnological and chemical options to protect potatoes from late blight fungus in terms of acceptance and perceived naturalness?
- Do people's evaluations of the chemical options differ based on the name of the fungicide used?
- Which option is favoured, either the chemical, resistance breeding or no solution with substantial losses in potato harvest?

Study 1: Evaluation of different options to protect potatoes from blight

Methodology

Recruiting and sample description

This experiment was part of and positioned to the end of a larger study about toxicological risk assessment published elsewhere (Bearth et al. 2024). Target participants were people from the German-speaking part of Switzerland above the age of 18. Participants accessed the anonymous online survey via a link that was shared with them through a professional market research company (Bilendi & respondi). This link took participants to an information page, where they were asked to provide informed consent. The study's sample was determined through an a priori power analysis (power = . 80; critical p-value (α) = 0.05), assuming a small to medium effect and featured quota sampling to ensure heterogeneity in gender and age of the participants. The survey was screened and accepted by the ethical committee of the Federal Institute of Technology (EK-2023-N-53). A sample of $N=965$ participants was recruited ($n=463$ male, $n=499$ female, $n=3$ non-binary/diverse; $M_{age}=45$, $SD_{age}=15$, range: 18–70). The detailed educational levels were recoded into low ($n=536$, 56%; comprising mandatory schooling, apprenticeships, high school) and high ($n=424$, 44%; comprising higher professional education, applied universities, university).

Table 1 Descriptions of options to protect potatoes from blight

Option	Description
1. and 2. Synthetic and natural fungicides	*In [conventional/organic] agriculture, a [synthetic/natural] fungicide is sprayed until harvest time to protect potatoes from potato blight. The fungicide is sprayed onto the leaves of the potato while the spuds are underground. This means that there is no direct contact between the fungicide and the potatoes.*
3., 4. and 5. Cisgenic genetic modification	*To protect potatoes from potato blight, part of the genetic material of a wild potato that is resistant to potato blight is transferred into the potato's genetic material [using gene technology/using genome editing/-]. This can result in desired changes in the potato's genetic material so that it can protect itself against potato blight.*
6., 7. and 8. Genome editing	*To protect potatoes from potato blight, certain parts of the potato's genome are edited, e.g. added, changed or removed [using gene technology/using genome editing/-]. This can result in desired changes to the potato's genetic material through genome editing so that it can protect itself against potato blight.*

Study design and material

At the start of the questionnaire socio-demographics were assessed (i.e., gender, age, highest level of education). The participants were then shown a picture of several potato plants in a field and were asked about perceived naturalness of this plant on a slider from 0 'not natural at all' to 100 'completely natural' ("How natural do you think this potato plant is"). This served as the *baseline perceived naturalness.* Then, participants were introduced to the problem of late blight fungus by showing them a picture of a blight infested potato and potato plant (cf. Supplemental Material) accompanied by the text providing some information:

> *Potatoes are an important crop in Switzerland. One of the biggest challenges in potato cultivation is potato blight (also known as late blight). This is a fungal disease that attacks the leaves of the potato and can spread very quickly throughout the potato, destroying it. Among other issues, potato blight was responsible for the great famine in Ireland in the 19th century and still leads to major losses in the potato harvest in Switzerland and worldwide.*

The subsequent experiment comprised a between-subjects design with eight conditions. The independent variable was the option presented to the participants to tackle potato blight: either chemical (i.e., synthetic fungicides in conventional agriculture, natural fungicides in organic agriculture – condition 1&2) or biotechnological resistance breeding (i.e., cisgenic genetic modification communicated as genetic material being transferred – conditions 3, 4, 5, genome editing conditions 6, 7, 8). For the biotechnological options the descriptive term of the technique was systematically varied (i.e., unspecified, gene technology, gene editing) (cf. Table 1). The participants were randomly assigned to one of these eight conditions.

After this, the participants were asked to rate how acceptable they thought the use of this fungus control approach was on a slider from 0 'not acceptable at all' to 100 'completely acceptable' (*acceptance,* "How acceptable do you think the use of this method in potato cultivation is?"), whether they would be willing to eat this potato on a slider from 0 'definitely not' to 100 'certainly' (*willingness-to-eat,* "Would you eat these potatoes?") and how natural they thought the potato is on a slider from 0 'not natural at all' to 100 'completely natural' (*perceived naturalness,* "How natural do you find these potatoes?").

Data analysis

The data was analysed in SPSS 29 (IBM Corp. 2023). A one-way ANOVA, followed up with Sidak-corrected pairwise comparisons, tested for differences in *acceptance and willingness-to-eat*. Additionally, a mixed ANOVA was used to test for differences in *perceived naturalness* across options and in comparison, to the *baseline perceived naturalness*. Pearson correlations were used to test for relationships between acceptance, willingness-to-eat and perceived naturalness. Effect sizes for ANOVA are reported (η^2) using the suggestion of Cohen (1992, 2013) to interpret effect sizes in social sciences as < 0.01 negligible, 01. to 0.09 small, 01. to 0.25 medium and larger than 0.25 as large effect.

Results

Table 2 shows the mean responses for acceptance, willingness-to-eat and (baseline) perceived naturalness for the eight options for potato blight introduced. There was no significant effect of type of solution on acceptance ($F(7, 957)=1.2$, $p=0.321$, $\eta^2=0.01$) or willingness-to-eat ($F(7, 957)=1.5$, $p=0.157$, $\eta^2=0.01$). There was no significant effect of type of solution on perceived naturalness ($F(7, 957)=1.6$, $p=0.122$, $\eta^2=0.01$) and no interaction effect between timepoint (baseline perceived naturalness compared to perceived naturalness after hearing of the type of solution; $F(7, 957)=1.5$, $p=0.177$, $\eta^2=0.01$). There was, however, a significant and large effect of timepoint ($F(1, 957)=361.1$, $p<0.001$, $\eta^2=0.27$). The introduction of any type of option for potato blight treatment reduced perceived naturalness significantly over all eight options (baseline perceived naturalness: $M=75.3$, $SD=20.3$; perceived naturalness: $M=57.7$, $SD=28.3$). The correlations among variables were very high: Acceptance and willingness-to-eat correlated with $r=0.85$, $p<0.001$, acceptance and perceived naturalness with $r=0.74$, $p<0.001$, and willingness-to-eat and perceived naturalness with $r=0.73$, $p<0.001$.

Discussion of study 1

Study 1 only partially replicated the findings of Saleh et al. (2021) – synthetic and natural fungicides, cisgenic genetic modification and genome editing were rated similarly in terms of acceptance and willingness-to-eat. Different wording did not impact people's evaluations either, which stands in contrast to prior studies that found that using terms, such as genetic engineering or genetic modification can impact people's evaluations (Zahry and Besley 2019). Study 1 offered some additional insights for the design of study 2. Specifically, acceptance and willingness-to-eat were highly correlated, which is why willingness-to-eat was dropped in study 2. Moreover, the phrasing of the perceived naturalness question was adjusted in study 2. In study 1 there was an erroneous mismatch between the baseline naturalness perception and the perceived naturalness after the information. At baseline, perceived naturalness of the potato plant was assessed, whereas after the information perceived naturalness of the potato was assessed. This is a likely alternative explanation for the pre- and post-intervention difference in naturalness perceptions.

Study 2: Evaluations of chemical and biotechnology options to protect potatoes from blight

Methodology

Recruiting and sample description

The same target participants (people from the German-speaking part of Switzerland over the age of 18) and

Table 2 Acceptance, willingness-to-eat and (baseline) perceived naturalness for different options to protect potato from blight ($n=965$)

	Conventional potato		Cisgenic genetic modification			Genome editing			Total
	Synthetic fungicide (n = 119)	Natural fungicide (n = 120)	Un-specified (n = 123)	named "gene technology" (n = 120)	named "genome editing" (n = 117)	Un-specified (n = 120)	named "gene technology" (n = 125)	named "genome editing" (n = 121)	(N = 965)
	1	2	3	4	5	6	7	8	M (SD)
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	
Acceptance	63.8 (26.5)	61.6 (25.5)	66.4 (27.7)	60.1 (30.1)	65.5 (27.3)	65.8 (25.1)	59.4 (30.4)	61.8 (28.3)	63.1 (27.7)
Willingness-to-eat	68.3 (29.0)	64.4 (30.2)	67.1 (31.1)	60.3 (33.1)	66.3 (30.7)	67.3 (27.9)	58.8 (33.2)	63.1 (32.3)	64.4 (31.1)
Baseline perceived naturalness	76.5 (19.2)	75.5 (18.8)	76.8 (20.7)	73.1 (22.2)	75.1 (19.9)	74.8 (19.3)	74.3 (21.5)	76.1 (20.5)	75.3 (20.3)
Perceived naturalness	61.8 (27.4)	62.1 (26.2)	61.5 (27.4)	55.1 (30.2)	56.1 (28.1)	58.1 (28.0)	52.1 (30.8)	54.9 (27.0)	57.7 (28.3)

Note. m: mean, sd: standard deviation

recruitment procedure was applied as study 1 (link shared through Bilendi & respondi). The study's sample was determined through an a priori power analysis (power = 0.80, $\alpha = 0.05$), assuming a small to medium effect and featured again a quota design to ensure heterogeneity in gender and age of the participants. The survey was screened and accepted by the ethical committee of the Federal Institute of Technology (EK-2024-N-36). A sample of $N = 1061$ participants ($n = 521$ male, $n = 533$ female, $n = 7$ non-binary/diverse; $M_{age} = 45$, $SD_{age} = 15$, range: 18–80) was recruited. As in study 1 educational levels were recoded into two: low ($n = 591$, 56%; comprising mandatory schooling, apprenticeships, high school) and high ($n = 470$, 44%; comprising higher professional education, applied universities, university). Around a fifth of the participants ($n = 230$, 22%) indicated to have personal or familial ties to agriculture.

Study design and material

At the start of the questionnaire, socio-demographics (i.e., gender, age, highest level of education) and contextual variables (i.e., personal or familial ties to agriculture, subjective knowledge about agriculture) were collected. The participants were again shown the picture of potato plants in a field (cf. Supplemental Material) to measure their *baseline perceived naturalness* (slider from 0 'not natural at all' to 100 'completely natural'; "How natural do you think this potato plant is"). This was followed by the statement about the late blight fungus and the two pictures of an infested potato and potato plant (cf. Supplemental Material).

The subsequent experiment covered different research questions in different sections. In the first section (between-subjects design), participants were randomly assigned to one of four conditions: generically named 'synthetic fungicide, 'natural fungicide' or specifically named 'Azoxystrobin' and 'copper.' The following text, adapted to the corresponding condition introduced the participants to a potential chemical option to protect the potato from blight:

> *In [conventional/organic agriculture], a [synthetic fungicide/Azoxystrobin/natural fungicide/copper] is sprayed until harvest time to protect potatoes from potato blight. [The fungicide/Azoxystrobin/copper] is sprayed onto the leaves of the potato while the spuds are underground. This means that there is no direct contact between the [fungicide/Azoxystrobin/copper] and the potatoes.*

After this, the participants were again asked to indicate the first word or picture that spontaneously came to their minds after reading this text (*association;* "After reading the text, what is the first word or image that comes to your mind spontaneously?"), in accordance with previous studies in a similar setting (Connor & Siegrist 2011; Saleh et al. 2019). On the next page, the participants were shown their own word again and were asked to indicate the *affect* elicited by this word on a drag-and-drop slider ("You have indicated that the following word or image spontaneously came to mind in relation to the text: [association]. Is this word more associated with negative or positive feelings?"). Next, they were asked to rate how acceptable they thought the use of this fungicide was on a slider from 0 'not acceptable at all' to 100 'completely acceptable' (*acceptance,* "How acceptable do you think the use of [synthetic fungicides / Azoxystrobin / natural fungicide / copper] in potato cultivation is?") and how natural they thought a potato plant would be after being treated with this fungicide on a slider from 0 'not natural at all' to 100 'completely natural' (*perceived naturalness,* "How natural do you think a potato plant is that has been treated with [a synthetic fungicide / Azoxystrobin / natural fungicide / copper]?). To rule out the alternative explanation for the pre-post information naturalness perception in study 1, the wording of this question assessed the perceived naturalness of the potato *plant* at both baseline and after the information and we clarified what the participants were asked to rate (i.e., "… a potato plant that has been treated with …"). Lastly, they were asked whether they thought that consumers should be informed about the use of this fungicide on the packaging of the potatoes (*informational need,* "Should consumers be made aware of the use of [synthetic fungicides / Azoxystrobin / natural fungicide / copper] in potato cultivation by means of a label on the potato packaging?" 1: yes, 2: no, 3: do not know).

In the subsequent within-subjects section, the participants were told that there are other options to protect potatoes from blight, followed by short descriptions of five different options, featuring chemical, as well as biotechnology options (cf. Table 3). Subsequently, each option was presented to them again on individual pages, followed by two sliders to indicate their acceptance (0: 'not acceptable at all' to 100 'completely acceptable') (*acceptance*) and perceived naturalness of a potato plant treated in this way (0 'not natural at all' to 100 'completely natural') (*perceived naturalness)*.

In the forced choice section, the participants were asked the following: If you could decide: "Which of the following options would you favour for the cultivation of potatoes in Switzerland?" (*forced choice)*. Then, they were shown the following six response options:

- "Protecting the potato by spraying copper (natural fungicide)"
- "Protecting the potato by spraying Azoxystrobin (synthetic fungicide)"

Table 3 Descriptions of options to protect potatoes from blight

Option	Description
1. and 2. Synthetic and natural fungicides	To protect the potatoes from potato blight, *a fungicide is sprayed until harvest time. The fungicide is sprayed onto the leaves of the potato while the potato spuds are underground. This means that there is no direct contact between the fungicide and the potatoes, and it can be either a synthetic or a natural fungicide.* • *A commonly used synthetic fungicide is azoxystrobin.* • *A commonly used natural fungicide is copper.*
3. Mutagenesis	To protect the potatoes from potato blight, *random mutations are induced in the potato's genetic material by irradiation or treatment with chemicals. Randomly, this can result in desired changes in the potato's genetic material so that it can protect itself against potato blight.*
4. Cisgenic genetic modification	To protect potatoes from potato blight, *part of the genetic material of a wild potato that is resistant to potato blight is transferred into the potato's genetic material using gene technology. This can result in desired changes in the potato's genetic material so that it can protect itself against potato blight.*
5. Genome editing	To protect potatoes from potato blight, *certain parts of the potato's genome are edited, e.g. added, changed or removed. This can result in desired changes to the potato's genetic material through genome editing so that it can protect itself against potato blight.*

- "Breeding resistant potatoes through random mutations in the potato's genetic material (triggered by irradiation or treatment with chemicals, mutation breeding)"
- "Breeding resistant potatoes by transferring the genetic material of a wild potato (gene technology)"
- "Breeding resistant potatoes by editing certain parts of the potato genome (genome editing)"
- "Neither, i.e. the potatoes are not protected or made resistant and crop losses occur"

Data analysis

The data was analysed in SPSS 29 (IBM Corp. 2023). The open responses regarding the associations were sorted and thematically analysed. For the associations, a flexible coding scheme was created based on prior literature (Bearth et al. 2024; Saleh et al., 2019) and extended and adjusted during the process of coding by two coders. The two coders had an interrater reliability of $\kappa = 0.96$. Inconsistencies in the coding were discussed among the two coders and resolved by one of the coders. Several tests were undertaken for the between-subjects design. For the dependent variable *associations* and *informational need*, χ^2-tests were used to test for differences in associations across the four conditions. A one-way ANOVA, followed up with Sidak-corrected pairwise comparisons, tested for differences in *affect* and *acceptance*. Additionally, a mixed ANOVA was used to test for differences in *perceived naturalness* across options and in comparison, to the *baseline perceived naturalness*. For the subsequent within-subjects design, a repeated ANOVA tested for differences in *acceptance* and *perceived naturalness* (the latter also in comparison to the *baseline perceived naturalness)*. The forced choice design was analysed descriptively, as well as linked to the sociodemographic (i.e., gender, age, level of education) and the contextual factors (i.e., personal or familial ties to agriculture, subjective knowledge about agriculture) using χ^2-tests and Pearson correlations. Standardised residuals (sample size independent differences between the observed and expected values for a cell) were used to determine the cells that contributed most to the results of the statistical test (outside the −2,2 range). Effect sizes for ANOVA (η^2) and χ^2-tests (Cramer's V) are reported using suggestions from Cohen (1992, 2013) for interpretation with $\eta^2 < 0.01$ negligible, 01. to 0.09 small, 01. to 0.25 medium, > 0.25 large and Cramer's V, > 0.10 for a relevant effect.

Results

Individual evaluation of different types of fungicides

Table 4 shows the categorised spontaneous associations that the participants had regarding the agricultural challenge for each of the four types of fungicides. There was a significant and relevant effect of type of fungicide, $\chi^2(36) = 119.6$, $p < 0.001$, Cramer's V = 0.20. Overall, the image of the disease (e.g., blight, mouldy potato) stuck with a majority of participants and was raised most frequently. The generically named natural fungicides, but not the synthetic, or specifically named azoxystrobin or copper, elicited neutral or positive response regarding the plant of food (e.g., tasty potatoes, crisps; Std. Res. = 2.3). Azoxystrobin elicited more frequently (Std. Res. = 2.3) and natural fungicides less frequently health risk associations (e.g., poison, deadly; St. Res. = −2.9). Some participants, particularly in the copper group (Std. Res. = 4.2) repeated terms or phrases from the texts presented previously; which happened less frequently in the azoxystrobin group (St. Res. = −2.9). Azoxystrobin elicited more frequently (Std. Res. = 3.6) and natural fungicides less frequently Chemistry/Chemical associations (e.g., chemical terms; St. Res. = −2.2). Azoxystrobin less frequently (Std. Res. = −2.2) and natural fungicides more frequently elicited Organic/Natural associations (e.g., natural, organic agriculture; Std. Res. = 4.2) compared to the other two types of fungicides. Lastly, synthetic fungicides more frequently elicited Synthetic associations (e.g., unnatural, not organic; Std. Res. = 2.4). Associations regarding

Table 4 Spontaneous associations regarding the four types of fungicides

	Synthetic fungicide (n=270)	Azoxy-strobin (n=267)	Natural fungicide (n=262)	Copper (n=262)	Total
	n(%) Std. Res.	*n*(%) Std. Res.	*n*(%) Std. Res.	*n*(%) Std. Res.	*n*(%)
Disease	54 (20%) −0.1	61 (23%) 0.9	51 (20%) −0.2	48 (19%) −0.6	214 (21%)
Food/Plant: neutral or positive	42 (16%) −0.8	46 (18%) −0.2	61 (24%) 2.3	37 (15%) −1.2	186 (18%)
Health risk	28 (11%) 0.2	39 (15%) 2.3	11 (4%) −2.9	28 (11%) 0.4	106 (10%)
Repetition of text	26 (10%) −0.2	12 (5%) −2.9	20 (8%) −1.1	47 (19%) 4.2	105 (10%)
Benefit/Necessity	28 (11%) 1.8	17 (6%) −0.7	19 (8%) 0.0	14 (6%) −1.2	78 (8%)
Chemistry/Chemical	13 (5%) −1.2	33 (12%) 3.6	8 (3%) −2.2	16 (6%) −0.3	70 (7%)
Food/Plant: negative	16 (6%) 0.4	15 (6%) 0.2	12 (5%) −0.5	13 (5%) −0.2	56 (6%)
Agriculture	15 (6%) 0.6	10 (4%) −0.8	17 (7%) 1.4	8 (3%) −1.2	50 (5%)
Organic/Natural	7 (3%) −1.6	5 (2%) −2.2	27 (11%) 4.2	11 (4%) −0.3	50 (5%)
Other	8 (3%) −0.5	8 (3%) −0.5	11 (4%) 0.6	11 (4%) 0.6	38 (4%)
Unbelievable	12 (5%) 1.0	9 (3%) 0.0	5 (2%) −1.2	9 (4%) 0.2	35 (3%)
Environmental risk	1 (<1%) −1.3	5 (2%) 0.9	3 (1%) −0.1	4 (2%) 0.5	13 (1%)
Synthetic	12 (4%) 2.4	2 (1%) −1.7	6 (3%) 0.1	4 (2%) −0.8	24 (2%)
Total	262	262	251	250	1025
Missing/Do now know	7	5	11	12	35

*Note. Cells show the frequency (n), column-percentages (%) and standardised residuals (*Std. Res.*). Cells with Std. Res. outside the −2.0 and 2.0 range are highlighted*

Table 5 Affect, acceptance and (baseline) perceived naturalness in the between-subjects design

	Synthetic fungicide (n=270)	Azoxy-strobin (n=267)	Natural fungicide (n=262)	Copper (n=262)	Total (N=1061)
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Affect	45.0[a] (32.2)	42.4[a] (33.9)	53.2[b] (33.3)	43.3[a] (30.6)	46.0 (32.7)
Acceptance	55.7[a] (27.9)	53.4[a] (26.8)	71.9[b] (24.9)	50.4[a] (25.9)	57.8 (27.7)
Baseline perceived naturalness	79.6[a] (19.6)	81.0[a] (20.0)	81.1[a] (18.7)	80.0[a] (20.0)	80.4 (20.0)
Perceived naturalness	49.4[a] (28.7)	44.9[a] (28.0)	67.5[b] (26.5)	44.3[a] (28.3)	51.5 (29.4)

Note. Different letters stand for significant difference after Sidak-corrected pairwise comparisons of main effects (p < 0.001). M: mean, SD: standard deviation

Disease, Benefit/Necessity (e.g., needed to keep potatoes healthy, advantageous), Food/Plant: negative (e.g., disgusting, inedible), Agriculture (e.g., farmer, field, spraying), Environmental risk (e.g., harmful to nature, polluting), Unbelievable (e.g., lying, incorrect) and Other (e.g., "I did not know this," green Irish fields) did not exhibit substantial differences in response patterns (Std. Res. = −1.3 to 1.8).

Table 5 shows the mean responses for affect, acceptance and (baseline) perceived naturalness for the four types of fungicides. There was a significant but small effect of type of fungicide on affect ($F(3, 1057) = 6.0$, $p < 0.001$, $\eta^2 = 0.02$). The participants in the group with the generically named natural fungicide reported associations that elicited more positive affect than azoxystrobin ($p < 0.001$), copper ($p = 0.003$) and synthetic fungicides ($p. = 022$). No significant differences in affect were found among the other three types of fungicides ($p > 0.935$).

There was a significant small to medium effect of type of fungicide on acceptance ($F(3, 1057) = 34.6$, $p < 0.001$, $\eta^2 = 0.09$). The generically named natural fungicide was rated as more acceptable than the generically named synthetic fungicide ($p < 0.001$), azoxystrobin ($p < 0.001$) and copper ($p < 0.001$). No significant differences in acceptance were found among the other three types of fungicides ($p > 0.113$).

There was a significant but small interaction effect of type of fungicide and time on (baseline) perceived

Table 6 Informational need in the between-subjects design

	Synthetic fungicide *n* (%) Std. Res.	Azoxy-strobin *n* (%) Std. Res.	Natural fungicide *n* (%) Std. Res.	Copper *n* (%) Std. Res.	Total ($n=1061$)
Should be labelled	201 (75%) 0.4	191 (72%) −0.1	176 (67%) −1.0	198 (76%) 0.6	766
Should not be labelled	41 (15%) −0.3	36 (13%) −1.0	59 (23%) 2.7	32 (12%) −1.5	168
I do not know	28 (10%) −0.8	40 (15%) 1.4	27 (10%) −0.8	32 (12%) 0.1	127
Total	270 (100%)	267 (100%)	262 (100%)	262 (100%)	1061

*Note. Cells show the frequency (n), column-percentages (%) and standardised residuals (*Std. Res.*). Cells with Std. Res. above 2.0 are highlighted*

naturalness ($F(3, 1057)=31.2$, $p<0.001$, $\eta^2=0.08$), and a small main effect of type of fungicide ($F(3, 1057)=24.0$, $p<0.001$, $\eta^2=0.06$) and, as in study 1 a large effect of time ($F(1, 1057)=947.6$, $p<0.001$, $\eta^2=0.47$). There were no significant differences in baseline perceived naturalness across the four types of fungicides ($p>0.945$). Specifically there was a substantial drop in perceived naturalness ($M=51.5$, $SD=29.4$) compared to the baseline perceived naturalness ($M=80.4$, $SD=19.6$) for all fungicides. The drop was smallest for the generically named natural fungicide compared to the generically named synthetic fungicide ($p<0.001$), azoxystrobin ($p<0.001$) and copper ($p<0.001$). No significant differences in perceived naturalness was found for the other three types of fungicides ($p>0.209$).

Table 6 shows the responses regarding the informational need. Overall, for all four types of fungicides, most participants would like them to be labelled. There was a significant effect of type of fungicide ($\chi^2(6)=15.3$, $p=0.018$, Cramer's $V=0.09$). For the natural fungicide, the participants expressed more frequently that they do not need to be labelled on the potato packaging (Std. Res. = 2.7) compared to the other types of fungicides. The other cells did not exhibit substantial differences in response patterns (Std. Res. −1.5 to 1.4).

Comparative evaluations of different types of options against potato blight

Figure 1 shows the mean acceptance of the participants regarding the five different measures against potato blights after being able to compare all of them. There was a significant small to medium effect of the type of solution against potato blight ($F(3, 4240)=105.8$, $p<0.001$, $\eta^2=0.09$). Natural fungicides (e.g., copper) were rated as most acceptable ($p<0.001$), followed by synthetic fungicides (e.g., azoxystrobin) ($p<0.001$), followed by mutagenesis, cisgenic genetic modification and genome editing that were all rated similarly ($p>0.087$).

Figure 2 shows the perceived naturalness of the potato plant treated with different options and the initial evaluation of the potato plant before the information (baseline). There was a significant and large effect of the type of solution on the perceived naturalness of the potato plant ($F(5, 5300)=596.1$, $p<0.001$, $\eta^2=0.36$). For all options, there was a substantial drop in perceived naturalness compared to the baseline perceived naturalness ($p<0.001$). The potato plant treated with natural fungicides (e.g., copper) was rated as most natural ($p<0.001$), followed by the potato plant treated with synthetic fungicides (e.g., azoxystrobin) ($p<0.001$), followed by mutagenesis, cisgenic genetic modification and genome editing that were all rated similarly ($p>0.609$).

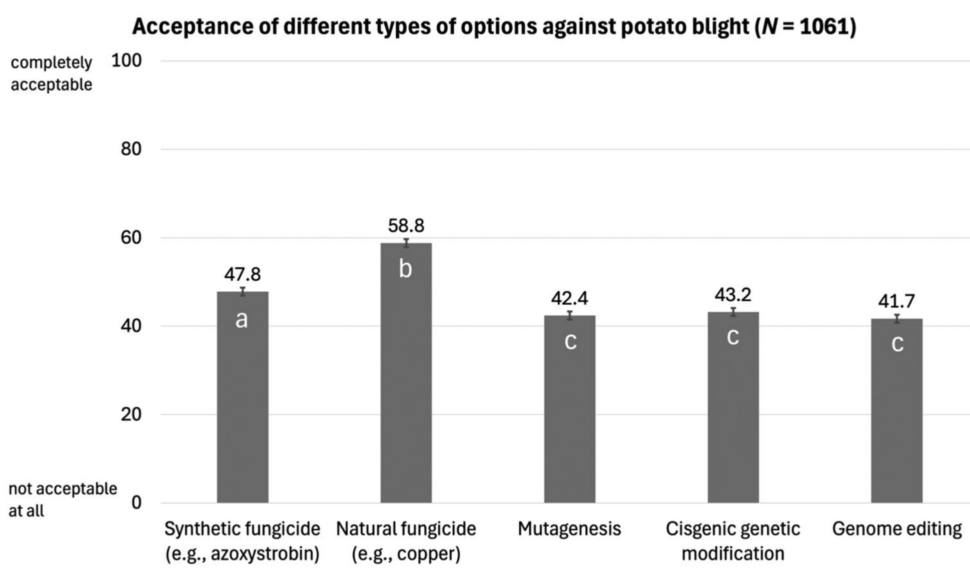

Fig. 1 Acceptance of the five options against potato blight measured consecutively (means and standard errors, $N=1061$). Bars sharing the same letter are not significantly different based on Sidak-corrected pairwise comparisons

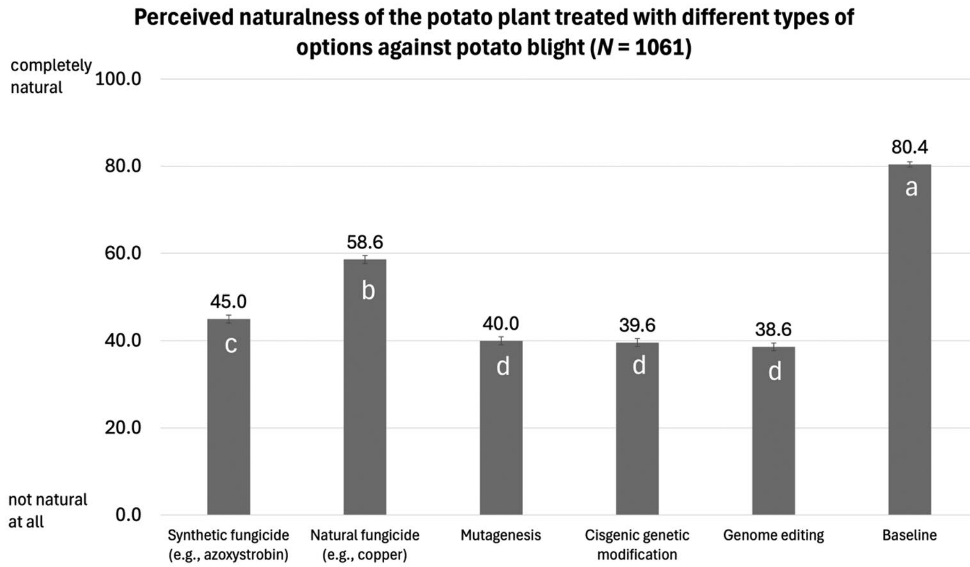

Fig. 2 Perceived naturalness of a potato plant at baseline and treated with five options against potato blight measured consecutively (means and standard errors, $N = 1061$). Bars sharing the same letter are not significantly different based on Sidak-corrected pairwise comparisons

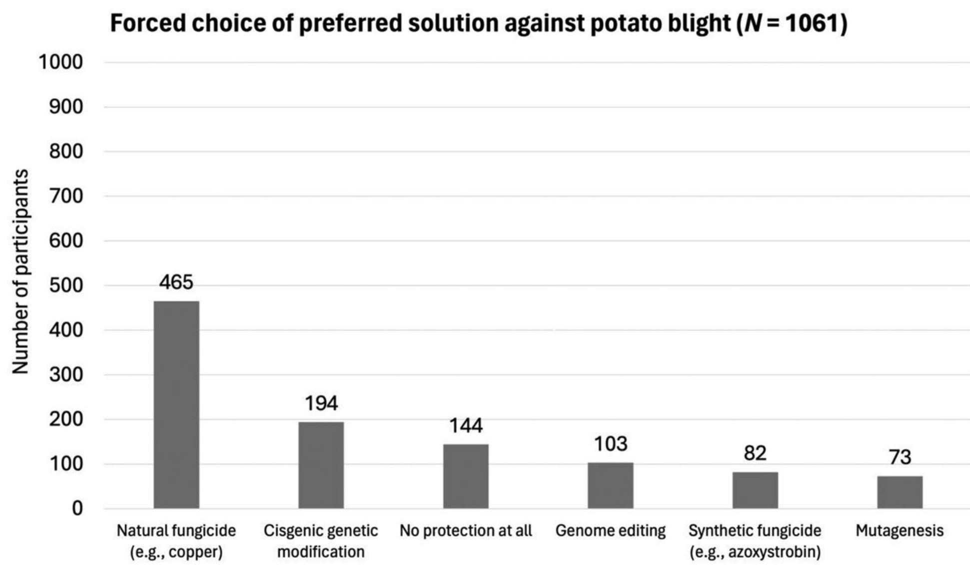

Fig. 3 Preferred solution against potato blight (forced choice, $N = 1061$)

Forced choice of preferred solution against potato blight and links to sociodemographics and contextual factors

Figure 3 shows the participants' preferred solution against potato blight. A clear majority of participants chose the protection of potatoes through the spraying of copper or another natural fungicide ($n = 465$, 44%), followed by the breeding of resistant potatoes through cisgenic genetic modification ($n = 194$, 18%). Some participants also favoured that potatoes are not protected at all ($n = 144$, 13%) despite risk of blight infection. The less favoured options were the breeding of resistant potatoes through genome editing ($n = 103$, 10%), by spraying azoxystrobin or a similar synthetic fungicide ($n = 82$, 8%), although this reversed their preference compared to acceptance and naturalness ratings. The breeding of resistant potatoes through mutagenesis was least favoured of all options ($n = 73$, 7%).

Significantly different response distributions were found for gender ($\chi^2(5) = 38.8$, $p < 0.001$, Cramer's V = 0.19), in that women more frequently chose the spraying of copper or another natural pesticide ($n = 275$, 52% women chose this over other options; Std. Res. = 2.7); men chose this less frequently ($n = 187$, 36% men chose this over other options; Std. Res. = −2.7). Oppositely, male participants more frequently chose mutagenesis ($n = 52$, 10% men chose this over other options; Std. Res. = 2.8), while women chose this less frequently ($n = 20$, 7% women chose mutagenesis over other options; Std. Res. = −2.7). The other cells did not exhibit substantial gender differences (standardised residual −1.6 to 1.6). No significant differences in choices were observed for participants with different educational levels ($\chi^2(5) = 3.0$,

$p = 0.699$, Cramer's V = 0.05) and personal or familial ties to agriculture ($\chi^2(5) = 8.1$, $p = 0.151$, Cramer's V = 0.09). Table A in the Appendix presents the detailed results of these analyses.

Discussion of study 2

The first part in study 2 investigated consumer responses when 'learning about an issue.' It showed that the introduction of blight, as an agricultural challenge, elicits strong associations in many participants. Different associations were raised based on the type of fungicide introduced. Interestingly, the generically named natural fungicide more frequently elicited neutral or positive associations than its named counterpart copper. The same deviation in elicited associations were found for the generically named synthetic fungicide and its named counterpart azoxystrobin, with the latter generating mostly negative associations of Chemistry/Chemical and Health risk. Importantly as in study 1, a substantial drop in acceptance before and after the information was observed ruling out the alternative explanation that findings of study 1 were merely due to the difference between potato plant and potato (product). Among all four types of fungicides, the generically named natural fungicide exhibited the highest level of acceptance and lowest drop in perceived naturalness compared to copper, azoxystrobin and synthetic fungicides. Accordingly, the participants to a lesser degree felt that natural fungicides needed to be labelled, opposed to copper, azoxystrobin and synthetic fungicides. It is, however, important to note that a majority of participants agreed that all four types of fungicides should be labelled.

The second part of study 2 investigated consumer responses when 'hearing about different solutions.' The results showed that the participants expressed higher acceptance for chemical options over mutagenesis, cisgenic genetic modification and genome editing. Interestingly, the ubiquitous mutagenesis was rated similarly as the techniques restricted by EU regulations: cisgenic genetic modification and genome editing. These patterns in acceptance were matched with the patterns in perceived naturalness with a substantial drop in perceived naturalness for all solutions. The results also showed that the chemical options elicited a lower drop in perceived naturalness than all three biotechnological options.

The last part of study 2 investigated consumer responses when 'deciding about a range of options.' In this part, the participants were asked to imagine if it was up to them, which of the solutions would they favour for the cultivation of potatoes in Switzerland. While this is obviously a somewhat artificial choice, it forces people to think about their preferences, particularly in the comparison between chemical and biotechnological solutions, and in comparison, to not protecting potatoes at all. The most favoured solution was spraying the potatoes with copper or another natural fungicide, followed by breeding of resistant potatoes through cisgenic genetic modification. In terms of trade-offs, several participants favoured not protecting the potatoes at all and accepting crop losses. Less favoured options were genome editing and spraying azoxystrobin or similar synthetic fungicides. Interestingly, the relatively positive ratings of azoxystrobin were not reflected in a choice for that option and again, the currently generally applied mutagenesis was least favoured.

General discussion

This study contributes to nuanced insights into public perception of agricultural challenges, specifically the management of plant diseases, and their preferences for specific chemical and biotechnological solutions. Particularly, the study generated several thematic insights that might inform current debates on public perceptions and acceptance of NBTs, and several methodological insights into the measurement of public perceptions and preferences regarding agri-technological innovations. Particularly, it fills a gap in the current literature looking into trade-offs and associated cognitive mechanisms used to make decisions regarding these trade-offs without expert knowledge about risks and benefits.

Thematic insights on public perceptions and acceptance of NBTs

A prior study (Saleh et al. 2021) focused on individual-level factors (i.e., chemophobia, tampering with nature, importance of naturalness) that explain people's views of chemical and biotechnological solutions to address plant diseases, and compared unnamed synthetic and natural fungicides with cisgenic genetic modification and genome editing. That previous study showed that, when only presented with one these solutions, participants preferred the biotechnological solution cisgenic genetic modification over the chemical solution (unnamed fungicide), although it is not clear whether participants misunderstood the phrasing "gene transfer" as natural cross-breeding. It also showed that fungicides and genome editing elicited similar spontaneous responses. These findings were partially replicated in study 1, as participants, similar to the study by Saleh et al. (2021), did not differentiate between chemical and biotechnological solutions in terms of acceptance, willingness-to-eat or changes in perceived naturalness. The addition of the descriptors "gene technology" and "genome editing" to the biotechnological solutions did not influence people's evaluations and resulted that the "gene transfer" solution no longer received more positive evaluation. This suggests that the description of cisgenic genetic modification may indeed have been misunderstood as cross breeding in the previous study. However, the finding that biotechnological solutions, explicitly named "gene technology" score comparable to chemical crop protection contradicts previous findings on the stigmatising effect of certain wording and phrasing (e.g., gene technology, genetic modification) (Yang and Hobbs 2020b; Zahry and Besley 2019). Cultural and regulatory contexts might play a role in explaining these differences, as these prior studies were conducted in North America (Yang and Hobbs 2020b; Zahry and Besley 2019), as has been suggested in two earlier meta-analyses (Bearth and Siegrist 2016; Frewer et al. 2013).

In study 2, this followed-up by a three-step process, to differentiate how people evaluate current solutions to an issue (i.e., the use of different fungicides to counter the effects of blight), how they react to other solutions to this issue (i.e., existing and novel resistance breeding options) and lastly, which solution, overall, they favoured. The spontaneous associations elicited by the four types of fungicides revealed expected thought patterns, specifically that natural fungicides elicit mostly neutral or positive associations, whereas a synthetic fungicide with a complicated, chemically-sounding term (i.e., Azoxystrobin) elicit mostly negative, risk-based associations. A matching pattern could be observed for affect (i.e., most positive for natural fungicide), acceptance (i.e., highest acceptance for natural fungicide) and perceived naturalness (i.e., smallest drop for natural fungicides) which shows using chemical names compared to their colloquial synonym leads to reduced naturalness perception (Asioli et al. 2017; Evans et al. 2010; Román et al. 2017). Accordingly, the participants were more prone to disagree that natural fungicides need to be labelled on potato packaging, compared to synthetic fungicides. Thus, people may perceive untreated plants, as well as plants sprayed with natural fungicides, as a baseline, and any other treatment as requiring a label. These findings suggest that people apply the natural-is-better heuristic to make judgments about natural vs. synthetic fungicides, as suggested in prior research (Siegrist and Hartmann 2020). The results also suggest a lack of awareness among the public of the distinction in risk assessment between synthetic and natural fungicides, as copper, used as natural fungicide in organic agriculture (Katsoulas et al. 2020; Kuhne et al. 2017), was rated more similarly to synthetic fungicides and Azoxystrobin. Consumers are aware of the hazardousness of certain chemicals of natural origin, such as mercury in fish or arsenic used as a deadly poison in crime fiction (Ferreira-Rodríguez et al. 2021; Mondal et al. 2019; Murakami et al. 2017); similarly, they might be aware of the neurotoxic properties of copper (Grasmuck and Scholz 2005). The findings suggest that people think of something else than copper, when confronted with the term "natural fungicide," From our results we speculate that the use of fungicides in general is already considered with substantial hesitation regardless of the specific substance used.

In the next step, the widely used mutagenesis (Oladosu et al. 2016) and the two options currently ruled under the gene technology moratorium (Parliament 2021), cisgenic genetic modification and genome editing, were introduced as resistance breeding alternatives to the use of synthetic and natural fungicides. The participants expressed the highest levels of acceptance for natural fungicides over synthetic fungicides, followed by all three resistance breeding options. It appears that the *process* of human intervention in form of plant breeding is accepted less and leads to higher drops in perceived naturalness, than spraying fungicides, which may or may not leave traces of the *content* of the fungicide on the potato, as stressed by some participants in their spontaneous associations (i.e., health risk, unbelievable). This explanation is in line from the finding from Rozin (2006) that process dominates content in people's preferences. When forced to choose, participants preferred spraying natural fungicides over cisgenic breeding approaches, with no protection at all being even favoured over genome editing, the use of azoxystrobin and specifically mutagenesis.

The forced choice shows an interesting distinction compared to acceptance of naturalness ratings, where more than half participants still preferred fungicide uses over NBTs, most preferred natural fungicide, and they placed the chemical fungicide next to lowest on the priority list. The artificiality of the choice (in reality, no single person would decide which is applied, and likely a combination of solutions would be most effective) may favour the use of a single criterions heuristics (e.g., natural-is-better heuristic) (Siegrist 2008; Slovic et al. 2004). This may explain the preference for more natural or natural-sounding solutions. It may also suggest that consumers make a two-step evaluation impacted by the context and choice set (Otto et al. 2022), where they decide to prefer fungicide over NBTs first and then pick their preferred choice in the fungicide category, contrasting that with the alternative, followed by a preference within the new breeding category. It is also interesting to note that the only legally allowed and broadly applied breeding technique (mutagenesis) is chosen less than techniques that are currently not allowed. These findings can be explained by a lack of awareness for current practices in plant breeding (i.e., the use of mutagenesis), and the specific semantic make-up of the word "mutagenesis" possibly referring to mutation or mutant associations. A recent qualitative study (Nales and Fischer 2023) highlighted that spontaneous associations heavily influence consumer acceptance of different breeding techniques, particularly in the absence of more informative information or knowledge. It is nevertheless of interest that the description of the process of mutagenesis elicited similar responses as the description of the other NBTs, cisgenesis and genome editing. This finding is somewhat in line with the findings from an Australian study (Batalha et al. 2021), which found that mutagenesis was perceived most negatively compared to cross-breeding, genetic modification and genome editing.

Methodological insights into the measurement of public perceptions and preferences regarding agri-technological innovations

As highlighted in the introduction, measuring public perceptions or even predicting citizens' and consumers' preferences regarding agri-technological innovations is tricky. Among other aspects, wording and framing used in the descriptions and the other options presented alongside of these innovations can influence their evaluations (Batalha et al. 2021; Zahry and Besley 2019). One methodological consideration is the use of single items. Single items were selected as they often provide the same conclusions as multi-item scales (Bergkvist and Rossiter 2007), and we wanted to keep the questionnaire as short as possible to avoid selective participation from highly interested participants (Gardner and Markley 2021; Li et al. 2022). Nevertheless, the constructs "acceptance" and "perceived naturalness" are potentially complex. Consumer acceptance of food innovations may for example take on different forms (e.g., active vs. passive acceptance, naturalness perception of technology vs. product) (Bearth and Siegrist 2016; Frewer et al. 2011; Segrè Cohen et al. 2025). Future studies may want to diversify the measurement of these constructs by including multiple items, measuring different facets of the concept. Further, prior knowledge, either objective or subjective and awareness of challenges in agriculture may impact people's evaluations (Connor and Siegrist 2010; Farid et al. 2020; Fernbach et al. 2019). Nevertheless, alongside the regulatory debates on how to regulate NBTs, calls have been made to generate knowledge about consumer acceptance and citizens' preferences regarding different regulatory options (i.e., labelling, bans) to inform policy development (European Commission 2023; German National Academy of Sciences Leopoldina 2019). Our study places some question marks with overly relying on public surveys to inform the policy debate. In the current case, this is particularly salient as the legally allowed, and generally applied, mutagenesis was disliked as much and seen as unnatural as the two more modern gene-technologies (cisgenesis, genome editing). In line with other research (Nales and Fischer 2023), this suggests the semantics of including "gene" raised negative associations in itself regardless of the technology it is associated with. Negative associations with biotechnology extend beyond agriculture, and could have been one of the reasons for hesitation of the public surrounding mRNA vaccines compared to traditional vaccines, even when mRNA vaccines were instrumental in suppressing the SARS-CoV-2 pandemic (Xu et al. 2024). Many participants in our study expressed strong negative associations regarding blight, highlighting that this case study is likely to elicit a strong awareness of the problem, which could increase a thoughtful and potentially positive response among the people towards options for controlling blight. Prior research shows that the type of benefit tied to the application of new breeding techniques likely impacts acceptance (Bearth and Siegrist 2016; Boccia and Punzo 2021; Busch et al. 2021). Thus, it is possible that different patterns will be found in acceptance of plant breeding technologies for other purposes, in line with findings that consumer response to NBTs are least in favour of application for yield increase followed by nutritional benefits with sustainability and climate resilience being most acceptable (Stetkiewicz et al. 2023) although prior research differences across three applications of NBTs to be small (Bearth et al. 2024; Segrè Cohen et al. 2025). The effect of the perceived benefit of the interventions may have been further enhanced by including pictures of potatoes affected by blight and by mentioning "famine" and "major losses" in the description. Initially, the description of potato blight was more neutral. However, pilot testing showed that people required better understanding of the magnitude of the problem that blight causes in agriculture to make sense of the issue, which is why we included this. Nevertheless, future studies may want to replicate our findings with more neutral descriptions or using a different use case. These findings highlight the challenges associated with the prediction of democratic votes and market success of NBT plants and products.

Conclusion

Both, study 1 and study 2 suggest that consumers prefer untreated potatoes and consider this the baseline of production. This is in line with the natural-is-better heuristic (Siegrist and Bearth 2019; Siegrist and Hartmann 2020). It does point at possible divergence between what the public expects in terms of labelling and application of crop protection in agricultural reality, suggesting a rift between public opinion and policies that warrant further investigation in the light of trust in government and food production. For complex problems, such as agricultural challenges and potential novel solutions, public opinions are rooted in individual's

Table A Gender, educational level and ties to agriculture in the between-subjects design

	Natural fungicide	Synthetic fungicide	Mutagenesis	Cisgenic genetic modification	Genome editing	Neither	Total ($n=1061$)
Gender							
Male	187 (41%) −2.7	44 (54%) 0.6	52 (72%) 2.8	111 (58%) 1.6	59 (58%) 1.2	68 (47%) −0.4	521
Female	275 (59%) 2.7	37 (46%) −0.6	20 (28%) −2.7	82 (42%) −1.6	43 (42%) −1.2	76 (53%) 0.4	533
Educational level							
Low	267 (57%) 0.5	49 (60%) 0.5	39 (53%) −0.3	100 (52%) −0.8	59 (57%) 0.2	77 (54%) −0.4	591
High	198 (43%) −0.6	33 (40%) −0.6	34 (47%) 0.3	94 (48%) 0.9	44 (43%) −0.2	67 (46%) 0.4	470
Ties to agriculture							
Yes	101 (22%) 0.0	27 (33%) 2.2	17 (23%) 0.3	35 (18%) −1.1	20 (19%) −0.5	30 (21%) −0.2	230
No	364 (78%) 0.0	55 (67%) −1.2	56 (77%) −0.2	159 (82%) 0.6	83 (81%) 0.3	114 (79%) 0.1	831

Note. Cells show the frequency, column-percentages and standardised residuals

preferences and attitudes, but might shift based on media framing, naming of approaches, statements made or decisions taken by stakeholder groups or changes in jurisdiction (Bearth and Siegrist 2016; Doxzen and Henderson 2020; Siegrist and Hartmann 2020). Our study shows that measuring people's acceptance of agri-technological innovations in surveys and experiments depends on the information provided, making it challenging to compare outcomes at a superficial level. Thus, there is a need for a nuanced approach, a clear awareness for limitations and the impact of contextualisation in the prediction of democratic votes and market success of NBT plants and products. Despite focusing on lay citizens and consumers, our study also extends to some of the inconsistencies in the regulation of different solutions. In light of current debates on the regulation of NBTs, it is not always clear based on what information, be it scientific or context-based (e.g., perceived societal acceptance, pressures from politics and/or industry), technologies are accepted, allowed or banned. Future studies may want to focus not just on the decision making of the general public, but specific influential groups (e.g., regulators, farmers, journalists).

Appendix

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10460-025-10818-w.

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

Declarations

Conflict of interest The authors declare no conflict of interests.

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