Food Quality and Preference 133 (2025) 105618

Contents lists available at ScienceDirect

Food Quality and Preference

journal homepage: www.elsevier.com/locate/foodqual

Understanding public perceptions of smart farming technologies

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ARTICLE INFO

Keywords:
Precision agriculture
Smart farming
Associations
Public perception
Technology acceptance

ABSTRACT

Whether the public accepts food produced using new technologies can be a decisive factor for their introduction. It is therefore important to understand public perceptions and address concerns at an early stage. We conducted two studies to investigate public perceptions of smart farming technologies. Study 1 involved an online survey of 287 participants in the German-speaking parts of Switzerland in 2021 (using convenience sampling). We took an exploratory approach using qualitative assessments of two plant-related technologies (hoeing robot and spray drone) and two animal-related technologies (milking robot and virtual fence). The participants provided their spontaneous associations for these technologies. Study 2 involved an online survey of 383 participants from the French- and German-speaking parts of Switzerland (a representative sample) in 2023, following a quantitative approach to analyse the general perception of two specific smart farming technologies often used in Switzerland (hoeing and milking robots). We investigated how political orientation and the perceived importance of food naturalness influenced the acceptance of food produced with the investigated technologies. Across the two studies, the public expressed positive associations with digital technologies, especially plant-related ones, but specific concerns were identified for each technology, with animal welfare being the major concern for virtual fences. Further, perceptions of farmers significantly influenced the affective responses towards milking robots, whereas the importance of food naturalness significantly influenced responses towards hoeing robots. These findings are promising for efforts to increase public acceptance of food produced with these technologies. Implications for policy and practise are discussed.

1. Introduction

Digital technologies in agriculture aim to enable more sustainability in the agricultural and food system and respond to the growing challenges in agricultural production (Finger et al., 2019; Walter et al., 2017), so it is not surprising that experts predict a steady increase in the use of digital technologies in coming years (Ammann, Umstätter, & El Benni, 2022). The use of digital technologies such as robots (e.g. for feeding or hoeing), GPS applications (e.g., driver assistance systems or precision farming applications) and sensors (e.g., measuring soil moisture levels or ammonia levels in barns) brings numerous benefits to farmers and the environment such as using resources only as needed (Walter et al., 2017) and increasing farmers' well-being by providing driver relief through driver-assistance systems (Groher, Heitkämper, Walter, et al., 2020; Holpp et al., 2013). Digital technologies also come with risks, however, such as concerns regarding data ownership and security (Wiseman et al., 2019). A meta-analysis of public acceptance of innovative food technologies has identified risk and benefit perceptions as important drivers of technology acceptance (Bearth & Siegrist, 2016). As with all innovative technologies, public resistance can be a major barrier to technology adoption, so care must be taken to timely address possible public concerns. Furthermore, individuals' technology perceptions differ depending on their background. For instance, farmers' perceptions of animal welfare in livestock breeding are consistently positive, whereas consumers' perceptions tend to be negative (Te Velde et al., 2002).

Given the importance of public acceptance in technology adoption, the present study assessed public perceptions of digital technologies in agriculture to explore the driving factors, because a deep understanding of public acceptance of digital technologies is crucial for the long-term success of the technologies. The study was conducted in Switzerland, where only a few digital technologies have been implemented in

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https://doi.org/10.1016/j.foodqual.2025.105618
Received 19 February 2025; Received in revised form 13 June 2025; Accepted 13 June 2025
Available online 14 June 2025

agriculture to date (Groher, Heitkämper, & Umstätter, 2020; Groher, Heitkämper, Walter, et al., 2020).

One of the few studies assessing consumers' perceptions of digital technologies in agriculture was recently conducted in Germany by Pfeiffer et al. (2020), who asked consumers about their spontaneous associations regarding milking and feeding robots, an autonomous tractor and a swarm of small sowing robots. The technologies were shown to participants as pictures, and no further description was provided. The participants considered digital technologies innovative and relevant but expressed numerous negative associations for animal farming. Overall, they agreed that digital technologies could contribute to animal welfare and environmental protection, and they supported subsidies for farmers using digital technologies. Pfeiffer et al. (2020) illustrated and briefly explained four specific technologies—spot spraying, digital hoeing, near-infrared (NIR) spectroscopy sensor technology and sensors for animal husbandry—and asked participants to rate each technology in terms of their consent to its use. The highest consent was found for digital hoeing technology, followed by sensors for livestock farming, NIR sensors and spot spraying. Overall, consent was quite high.

Still, digital technologies are not a homogeneous construct. For instance, technologies in plant production are perceived differently than those in livestock farming. Furthermore, views tend to be more critical when robotics is used in the handling of live animals (Pfeiffer et al., 2020). To explore consumer perceptions of precision livestock technologies in the pork and dairy value chains, Krampe et al. (2021) conducted a total of six focus group discussions in Finland, the Netherlands and Spain, finding that consumers' perceptions differ depending on the technology. For instance, consumers assumed that precision livestock farming technologies could reduce stress in the rearing of pigs. By contrast, they indicated that the use of precision livestock farming technologies for cows would increase stress levels, as they would reduce cows' interactions with farmers (Krampe et al., 2021). Pfeiffer et al. (2020) found that, for dairy farms, the milking robot was associated with more negative terms than the feeding robot. Again, the milking robot would reduce interactions with farmers. Overall, the authors contend that consumers' critical perceptions of these technologies may be due to their perceiving the technologies as being more beneficial to farmers than to cows.

Automatic milking systems and the milking robot were among the first autonomous machines used in dairy farming (Holloway & Bear, 2017). As a result, they have been investigated in a number of studies (Henchion et al., 2022; Pfeiffer et al., 2020). For instance, data from an older postal survey in the UK reveal that around 30 % of the participants rated the technology positively and 41 % negatively, with over 30 % undecided (Millar et al., 2002). Consumer concerns focused mostly on animal welfare (Millar et al., 2002), although it has been shown that the introduction of a robot affects both cows and farmers (Driessen & Heutinck, 2014). In terms of benefits, 60 % of the consumers in Millar et al.'s sample believed that the technology would benefit farmers, whereas only 25 % believed that it would benefit cows. Furthermore, 50 % expected that cow welfare would suffer (Millar et al., 2002). Although the study investigated the effect of demographic and household information as well as technology awareness, it provides very little information on additional factors that may influence technology acceptance such as psychological factors and technology perceptions.

In the case of virtual fences, consumers are likewise deeply concerned about animal welfare (Stampa et al., 2020), although research has found that the welfare and behaviour of cattle in grazing systems that use virtual fencing are very similar to those in systems that use electric fencing (Campbell et al., 2019) and that pasture grazing itself positively affects cattle welfare (Crump et al., 2019). Furthermore, virtual fences can optimise pasture grazing to contribute to biodiversity conservation, for example, by protecting sensitive areas (Stampa et al., 2020). However, the focus in communication should be on the benefits instead of on the technology.

For technologies in plant production, diverse concerns play important roles. Drones, for instance, can reduce carbon emissions but contribute to noise pollution in the environment (Khan et al., 2018). Heavy machinery on agricultural fields can cause soil compaction, and robots and technologies in general can contribute to environmental pollution or industrialisation (Pfeiffer et al., 2020). Technologies in the plant protection domain such as spot spraying, tend to be perceived negatively, as they are associated with chemicals, poison or environmental pollution (Pfeiffer et al., 2020). Further concerns include data security and—in the case of autonomous machines, for example—the safety of humans and animals.

As mentioned, numerous studies have focused on milking robots, whereas only a few have investigated other technologies. Furthermore, most studies investigate the farmers' side of technology acceptance (Afful-Dadzie et al., 2022; Giua et al., 2022; Guo et al., 2022), and little is known about how factors beyond sociodemographics influence the public's technology perception.

Our study contributes to the literature first by conducting a qualitative analysis of Swiss public perception of four smart farming technologies (i.e. hoeing robot, spray drone, milking robot and virtual fence). Second, our study is the first to analyse how sociodemographic factors, political orientation, perceptions of farmers and the importance ascribed to food naturalness influence technology perception in a representative Swiss sample. In view of the currently low adoption rates of smart farming technologies in Switzerland, these findings are crucial for researchers to identify the main predictors of technology adoption and for practitioners to improve technology communication.

2. Materials and methods

We conducted two studies to investigate public perceptions of smart farming technologies. Study 1 took an exploratory approach, using qualitative assessments of four smart farming technologies: hoeing robot, spray drone, milking robot and virtual fence. As technologies in the plant domain are perceived differently from those in livestock farming (Pfeiffer et al., 2020), the experimental design was balanced for these two conditions. Further, one technology was more established and one less established in each domain (i.e. plant and animal). Specifically, Swiss experts have identified hoeing robots as promising technologies in plant production, whereas spray drones are perceived as less important (Ammann, 2022; Groher, Heitkämper, Walter, et al., 2020). Similarly, milking robots are a more established technology compared to the rather novel virtual fence (Groher, Heitkämper, & Umstätter, 2020; Umstätter, 2011). We asked the participants to provide their spontaneous associations with these four technologies (Fig. 1).

Study 2 followed a quantitative approach to analyse the general perception of the two smart farming technologies that are most often used in Switzerland (i.e. hoeing and milking robots) (Groher, Heitkämper, & Umstätter, 2020; Groher, Heitkämper, Walter, et al., 2020). To better understand the determinants of technology perceptions, we collected data on demographic and personal characteristics that have been found to be important predictors of technology perceptions in the existing literature. Various sociodemographic predictors have been identified as important in technology perception. Among sociodemographic variables, age has been identified as an influential factor, with older participants (>65 years) being more satisfied with contemporary dairy farming and expressing less desire than younger participants for traditional and natural dairy farms (Boogaard et al., 2010). Furthermore, men adopt digital technologies more readily than women do (Ammann, Walter, & El Benni, 2022; Wachenheim et al., 2021), which can also indicate that men have more positive attitudes towards digital technologies than women. This applies to both the agricultural sector and beyond. Indeed, women have been found to show more concern than men about the risks associated with technologies (Greenberg & Schneider, 1995; Siegrist, 1998; Sparks et al., 1995). We controlled for education level, as individual knowledge can affect

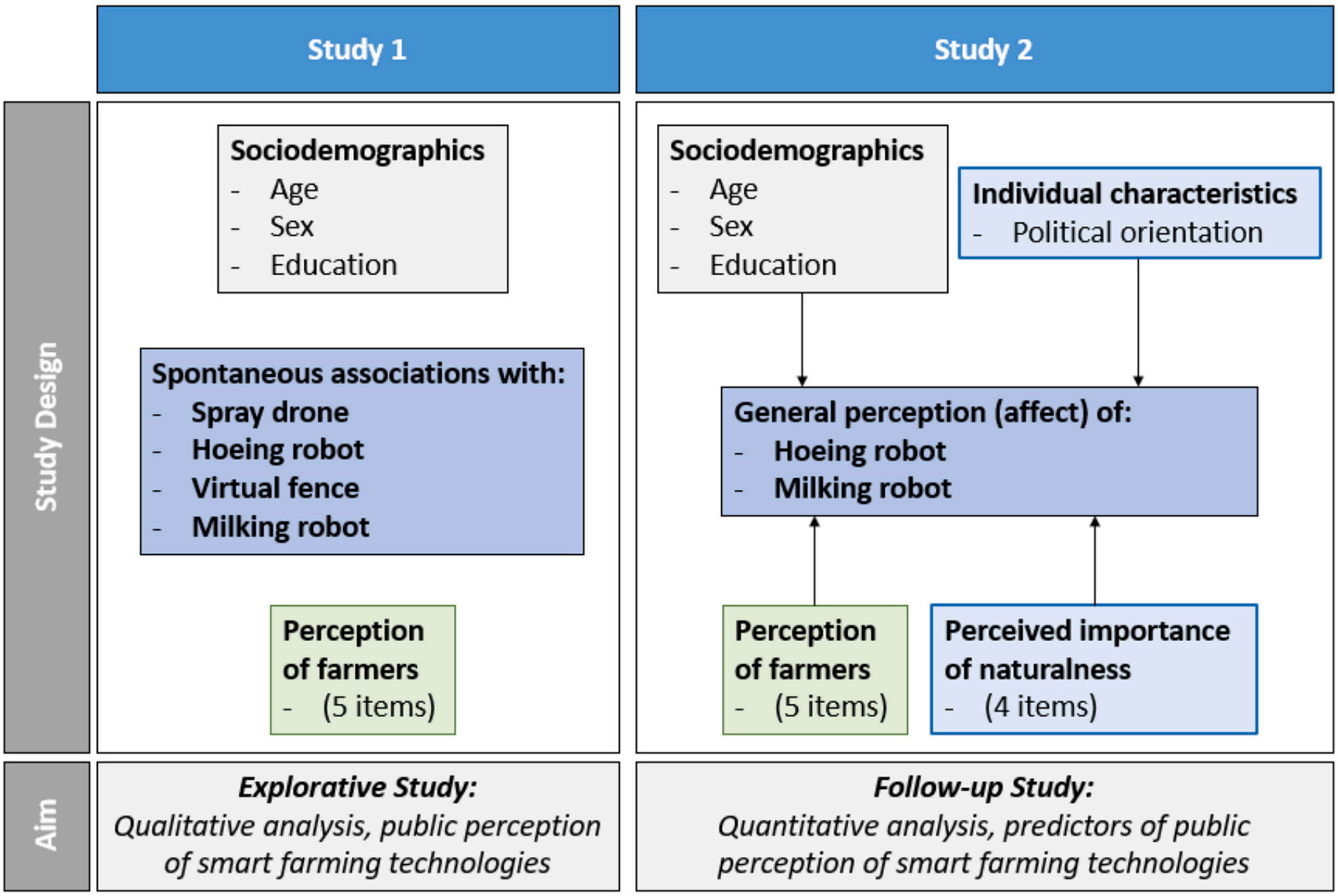

Fig. 1. Conceptual framework of the two studies.

technology perception. For instance, it has been found that, for milking robots, consumers' awareness of the technology was associated with more positive attitudes towards it (Millar et al., 2002). Similarly, farmers' technological awareness is related to their willingness to adopt technology (Jamil et al., 2021; Michels et al., 2019).

In terms of personal attitudes and values, we used statements assessing the participants' perceptions of farmers to investigate whether those perceptions impact technology acceptance. Previous research has found that trust in farmers can influence attitudes towards smart farming technologies (Pfeiffer et al., 2020). Additionally, we investigated how political orientation and preference for food naturalness impact perceptions of smart farming technologies. Political orientation has been shown to be related to individuals' views on science and technology (Drummond & Fischhoff, 2017; Gauchat, 2012), and we included the perceived importance of food naturalness because it has been shown to play an important role for consumers (Román et al., 2017). Moreover, in a Swiss study investigating how chemophobia affects public acceptance of pesticide use and biotechnology in agriculture, it was found that importance of naturalness influenced consumer acceptance of these technologies (Saleh et al., 2021). The conceptual framework of the two studies is shown in Fig. 1.

2.1. Participants

The data for Study 1 were collected using the online survey tool Unipark (Management Questback GmbH, Germany) in the German-speaking parts of Switzerland in autumn 2021. The participants were recruited through diverse channels, including direct invitations and social media, and through an online panel of ETH Zurich comprising individuals who participated in previous studies and agreed to being contacted for further studies. As an incentive for taking part, the participants were offered a short summary of the study results upon completion of data analysis. In total, 287 participants (43 % female) completed the survey, of whom a significant proportion (30 %) indicated that they held a university degree. Table 1 summarises the sample characteristics.

The data for Study 2 were also collected through an online survey in the German- and French-speaking parts of Switzerland in February 2023. The participants were recruited through an internet panel from a certified commercial panel provider (Bilendi AG). Quotas were established for gender (50 % women), age (33 % each of ages 18–35, 36–54 and 55–75,) and language region (50 % German, 50 % French). Participants who took less time than half the median time of all the participants to complete the survey were excluded (for example Ammann et al., 2019) on the assumption that they did not answer the questions reliably. This procedure resulted in a sample size of 485 participants.

2.2. Questionnaires

Before starting the questionnaire for Study 1, the participants provided their written consent. The questionnaire comprised three main parts. The first collected participant information, such as age, sex, education and whether they currently lived in a city, suburb or the countryside. Next, we provided the participants with a short definition of smart farming to ensure that they all had the same level of understanding before moving on to specific questions on smart farming. The definition was phrased as follows:

Smart farming describes the use of new digital technologies in agriculture. All areas of production are affected, such as soil, water and crop management, plant protection, livestock management, animal

Table 1
Sample characteristics for both studies.

	Study 1 (n = 287)			Study 2 (*n* = 383)			Swiss average	
	M	SD	%	M	SD	%	Median	%
Age	49.0	20.3		46.1	15.1		46.0[1]	
Gender (women)			42.9			48.0		50.3[2]
Language (German)			100			49.3		61.4[3]
Place of residence								
City (big and small cities)			30.7			35.3		63.0[4]
Suburbs			41.5			21.4		21.9
Countryside (countryside, village)			27.5			43.4		15.1
No response			0.3			0		
Education level								
low			2.6			4.4		13.7[5]
medium			36.2			45.1		40.2
high			61.0			50.4		46.0

Note. Place of residence is based on participants' self-assessment. Study 1 used 3 categories, Study 2 used 5 categories (see parentheses). Education levels: low = compulsory school; medium = apprenticeship, vocational training, secondary school / vocational secondary school; high = higher technical or vocational training, university (of applied sciences) / university of education.

[1] https://www.bfs.admin.ch/bfs/de/home/statistiken/bevoelkerung/stand-entwicklung/alter.html.
[2] https://www.bfs.admin.ch/bfs/de/home/statistiken/bevoelkerung/stand-entwicklung/geschlecht.html.
[3] https://www.bfs.admin.ch/bfs/de/home/statistiken/bevoelkerung/sprachen-religionen/sprachen.html.
[4] https://www.bfs.admin.ch/bfs/de/home/statistiken/bevoelkerung/stand-entwicklung/raeumliche-verteilung.html.
[5] https://www.bfs.admin.ch/bfs/de/home/statistiken/bildung-wissenschaft.html.

health and automation. The aim of the new technologies is to increase efficiency, reduce environmental impact and obtain higher yields.

Since the legal status of autonomously driving machines has not yet been completely clarified and small farmers in particular may experience a competitive disadvantage due to the high acquisition costs, the technologies have not yet been able to establish themselves on a broad scale.

In part two of the survey, we asked the participants about their spontaneous associations for four specific smart farming technologies: spray drone, hoeing robot, virtual fence and milking robot. Care was taken to include two technologies from plant production and two technologies from animal production to ensure a balanced representation of technologies. For each technology, the participants were shown a picture and a short description to ensure that they all had the same level of knowledge when assessing the technologies (the pictures and descriptions used are shown in the Appendix). The questions regarding spontaneous associations were followed by questions soliciting a hedonic rating. Each spontaneous association was rated on an interactive slider from 0 (very negative) to 100 (very positive).

In part three, the participants rated five statements on their general *perceptions of farmers* on a 7-point Likert scale from 1 (completely disagree) to 7 (completely agree). The items to measure perceptions of farmers were inspired by or adapted from Pfeiffer et al. (2020). We summarised the five items as an averaged scale, which demonstrated good reliability (α = 0.81, M = 5.5, SD = 0.9). Finally, the participants were invited to leave additional comments in a commentary field if they wished to do so. They were asked to provide their email address if they wished to receive a short report on the results. The average time required to complete the survey was around 20 min.

For Study 2, the participants provided their written consent before starting the survey. The questionnaire comprised two parts, the first of which was not related to the results of this study and is the subject of a separate publication (Saleh et al., 2024). In the second part, the participants were randomly assigned to one of five information groups, resulting in around 100 participants per group. The groups then received a short description of a hoeing robot and a milking robot, but the descriptions were framed differently for the five information groups (i.e. female farmer, female scientist, male farmer, male scientist and control). For instance, in the female farmer group, the technology was described as being used by a female farmer, whereas, in the control group, the technology's use was described without any reference to a person. These conditions were used to test and control for possible framing effects, as previous research showed that the information source can impact the credibility of information (Flanagin et al., 2018). We chose two types of experts (i.e. farmers and scientists), who approach the technologies from a more practical or theoretical side, respectively. Further, we balanced for possible gender effects. Testing for differences between the information groups (see Appendix), however, revealed that only one information condition (i.e. male scientists) appeared to have an impact. As this finding was largely unexpected and difficult to explain based on the available literature, we decided to focus our analyses instead on consumers' perceptions of technologies. Consequently, we excluded the male scientist condition and worked with the rest of the sample. This resulted in a final sample size of 383 (see Table 1).

After reading the technology description, the participants were asked to rate each technology by their *willingness to eat* the products produced with them and by *affect* (general feelings towards the technology). All the questions were answered on an interactive slider, ranging from 0 (not at all) to 100 (completely) for willingness to eat and 0 (very negative) to 100 (very positive) for affect. Verbal anchors were provided for both ends and the middle of the scale, and the participants provided their responses by clicking on the interactive slider.

Next, the participants indicated their self-perceived political identity on a scale from 0 (far left) to 100 (far right). We further measured their perceptions of farmers. For this, we used five items similar to those in Study 1, which were rated on a scale from 1 (do not agree at all) to 7 (totally agree). In our sample, farmers were perceived positively (M = 5.8, SD = 0.9), and the scale's reliability was good (α = 0.83) (see Table 2).

The importance of naturalness was measured using three items on a scale from 1 (not important at all) to 4 (very important) (Steptoe et al., 1995). The scale by (Steptoe et al., 1995) was chosen based on the recommendations of previous studies, which found that it is a short, valid measure of the importance of naturalness (Michel & Siegrist, 2019; Román et al., 2017). Our sample indicated a high importance of naturalness (M = 3.3, SD = 0.7), and the scale's reliability was good (α = 0.83).

Table 2
Items used in the survey to assess participants' perceptions of farmers and farming in Study 1 (n = 287) and Study 2 (n = 383).

		Study 1		Study 2	
		M	SD	M	SD
Perceptions of farmers (Cronbach's α = 0.81 and 0.83, respectively)		5.5	0.9	5.8	0.9
1	I have a generally positive attitude towards farmers.[a]	5.6	1.3	5.9	1.2
2	Farmers' work is important and valuable for society.	6.4	1.0	6.4	1.0
3	Farmers are committed to animal welfare.[a]	5.0	1.3	5.2	1.4
4	Farmers have a great environmental awareness.[a]	4.3	1.4	5.0	1.4
5	Family farms are important and should be preserved.[a]	6.1	1.3	6.3	1.0

Note: Items were measured on a 7-point Likert scale from 1 (completely disagree) to 7 (completely agree); [a] item developed in accordance with (Pfeiffer et al., 2020).

2.3. Data processing and statistical analysis

For the spontaneous associations (part two of the survey in Study 1), the participants were instructed to write only one word, but some participants wrote more than one word or even whole sentences. In those cases, we used only the first meaningful word, as we were interested in the first thing was that came to their mind. The qualitative data analysis followed a structured process. First, all responses were reviewed to gain an overview. Next, the main categories were derived through the first author grouping similar responses. The final coding then applied the category system to the entire dataset. The results were then analysed based on category frequency. Associations that were mentioned only once were summarised in the category 'other'.

For Study 2, we conducted a correlation analysis. Further, linear regression analysis was used to identify the influential predictors of technology perception. All statistical analyses were performed using IBM SPSS Statistics version 26 (IBM, Armonk, NY, USA). Following the open science policy, our questionnaire, data and the Study 2 code can be freely accessed through Zenodo (Ammann, 2024).

3. Results

3.1. Spontaneous associations with plant- and animal-related technologies

Study 1 aimed to assess public perceptions of specific examples of smart farming technologies. In the domain of plant production, we used spray drones and hoeing robots. The participants' most frequently mentioned spontaneous associations with those technologies are listed in Table 3. On average, the participants gave similar, positive hedonic ratings to spray drones (M = 65.2, SD = 34.0) and hoeing robots (M = 65.7, SD = 30.8). (see Table 3)

Both of the plant-related technologies mostly inspired positive associations. These included positive adjectives or mentions related to progress, such as 'innovation' or 'future'. For spray drones, the participants worried most about noise. For the hoeing robot, the major negative points were the costs and the effect the robot might have on the soil, such as soil compaction. We further found that social impacts (i.e. labour facilitation) were mentioned for the hoeing robot but not for the spray drone.

As specific technologies in the domain of animal production, we used virtual fences and milking robots. The participants' most frequently mentioned spontaneous associations for virtual fences and milking robots are listed in Table 4Table *3*. For virtual fences, the hedonic ratings were on average negative (M = 34.2, SD = 30.4). The most frequently mentioned associations were related to animal welfare and various negative adjectives or words. A group of 23 participants gave positive adjectives or terms, expressing their interest in and support of this technology. Clearly, a major issue, aside from concerns regarding animal welfare, was that the participants did not see the benefit of this technology. The category *useless* was among the most popular associations for virtual fences, summarising responses that indicated that the technology did not make sense or had no use or that the participants did not see its benefit.

Table 3
Spontaneous associations for plant-related technologies (spray drone and hoeing robot), number of mentions and hedonic ratings (Study 1).

		Hedonic ratings		
Category (examples)	Mentions	Direction	M (SD)	SD
Spray drone			65.2	34.0
Positive (meaningful, clever, super)	60	+	85.4	17.9
Efficient (effective)	33	+	82.8	19.9
Progress (innovation, modernisation, modern, future, futuristic)	41	+	83.3	15.6
Ecological (less poison, ecological, less soil damage)	13	+	87.6	20.6
Noise (noise, volume)	13	−	19.9	20.1
Precision (exact application)	13	+	73.3	26.8
Other	12	=	48.6	35.5
Negative (fear, danger, unsafe)	12	−	18.3	18.3
Plant protection (reduction of pesticides, elimination of pesticides)	11	=	45.2	31.8
Hoeing Robot			65.7	30.8
Positive (good, ingenious, cool)	57	+	85.6	16.3
Progress (futuristic, future, progress, optimisation)	26	+	73.5	24.1
Costs (expensive, high costs)	19	−	40.6	27.4
Environment (sustainable, biodiversity)	19	+	87.6	20.5
Other	18	=	46.3	25.7
Efficient (efficient)	16	+	84.5	13.5
Labour facilitation (relief)	15	+	83.3	22.3
Soil (heavy machines, effects on soil, compaction)	12	−	25.0	20.8
Meaningful (meaningful application, good use of technology)	10	+	86.8	13.9

Note: Only categories with 10 or more mentions are presented. Specific mentions per category are given in parentheses. Hedonic ratings were provided on a scale from 0 (very negative) to 100 (very positive). The category 'other' summarises various single mentions.

On average, the participants' hedonic ratings for milking robots were positive (M = 60.7, SD = 32.5, see Table 4). It seems that this technology is not completely new to consumers, as 10 participants indicated that they already knew about it or that it is an established technology. The most frequently mentioned point of criticism regarding this technology was the decreased relationship between animals and humans.

3.2. Consumers' affect towards hoeing and milking robots

In Study 2, the hoeing robot was perceived significantly more positively than the milking robot in terms of affect (M = 73.0, SD = 21.0 and M = 65.9, SD = 27.3, respectively, $t[382] = 5.7$, $p < .001$) and willingness to eat the products produced (M = 81.9, SD = 18.7 and M = 76.8, SD = 25.7, respectively, t[382] = 4.3, $p < .001$). The importance of naturalness in food is positively correlated with the perception of the hoeing robot (Table 5). Additionally, the more positively farmers are perceived, the higher is the affect and the willingness to eat products produced with a milking or hoeing robot. Further, the participants' perceptions of farmers are positively correlated with political orientation, indicating that more right-leaning individuals have more positive perceptions of farmers than older and more left-leaning individuals (Table 5). Also, women tend to perceive farmers more positively than men do.

Using linear regression analysis, we analysed consumers' affect

Table 4
Spontaneous associations for animal-related technologies (virtual fence and milking robot), number of mentions and hedonic ratings (Study 1).

Category (examples)	Mentions	Hedonic ratings Direction	M	SD
Virtual fence			34.2	30.4
Animal welfare (animal cruelty)	53	−	17.7	21.1
Negative (terrible, horror, hard, no way)	39	−	14.5	13.1
Useless (does not make sense)	21	−	27.8	27.3
Positive (interesting, clever)	19	+	66.3	22.5
Other	16	−	42.1	33.7
Learning ability (conditioning, does cow understand)	13	−	35.1	32.4
Pain (brutal, suffering)	13	−	12.9	14.7
Progress (innovative)	12	+	75.2	24.8
Danger (children, hiker)	12	−	28.9	32.9
Milking robot			60.7	32.5
Positive (intelligent, ingenious, interesting, cool)	43	+	85.5	12.6
Animal welfare (brutal, cow as machine)	39	=	49.4	38.5
Missing relation to humans (impersonal)	19	−	30.6	28.5
Labour facilitation (more free time)	18	+	81.3	16.3
Self-determination (voluntary)	16	+	75.8	20.8
Scepticism (impossible, danger, doubt)	15	−	44.2	27.8
Negative (cold, questionable, terrible)	15	−	33.8	27.9
Efficient (exact)	12	+	84.8	18.4
Progress (modern, innovation)	11	+	83.2	16.0
Known (nothing special, standard)	10	+	77.3	29.5
Other	10	=	53.0	33.6

Note: Only categories with 10 or more mentions are presented. Specific mentions per category are given in parentheses. Hedonic ratings were provided on a scale from 0 (very negative) to 100 (very positive). The category 'other' summarises various single mentions.

towards the described hoeing and milking robots (Table 6). The results of the correlation analysis are confirmed. Both the hoeing and milking models are statistically significant, explaining 9 % and 14 % of the variance, respectively. The perceptions of farmers and the importance of naturalness emerged as the most influential predictors of affect towards hoeing robots (B_{hoeing} = 4.36 and 4.26, respectively), whereas, for the milking robot, perceptions of farmers was most influential ($B_{milking}$ = 9.15).

4. Discussion

The overarching aim of the present work was to investigate public perceptions of plant-related and animal-related technologies and determine the factors that influence perceptions of them. Study 1 found that, overall, participants gave higher hedonic ratings to the two technologies in the domain of plant production (i.e., spray drones and hoeing robots) than to the technologies in the domain of animal production (i.e., virtual fences and milking robots). This is in line with the results of a study by Pfeiffer et al. (2020), who found that the commonly mentioned categories for animal-related technologies were more negatively associated than those for plant-related technologies. However, those researchers found that three of the five most frequently mentioned associations for the milking robot—animal cruelty, rejection and industrial agriculture—were negative, whereas we found only one negative association (i.e., the missing relation to humans) and one neutral category (i.e., animal welfare) among the most frequent five. Three positive associations were also among the five most mentioned associations in our study, including labour facilitation for farmers and cows' self-determination. Therefore, consumers seem more sceptical about animal-related technologies due to animal welfare concerns, whereas, in regard to plant production technologies, they are concerned with environmental matters.

In Study 1, the frequently mentioned, positively associated aspects of all four technologies (i.e. hoeing robot, spray drone, milking robot and virtual fence) can be summarised by the terms *future* and *progress*, which is in line with the findings of Pfeiffer et al. (2020). Attributes such as *innovative*, *ingenious*, *futuristic* and *modern* were important for all four technologies. We see this as an indication of the public's general interest in or fascination with these technologies, but their perceptions of the technologies differed depending on the domain in which the technologies are used (animal or plant production). Overall, we found positive perceptions of smart farming technologies among the participants. This

Table 6
Linear regression analysis predicting affect towards the two technologies (Study 2, n = 383).

	Hoeing Robot B	SE	β	Milking Robot B	SE	β
Constant	22.98**	8.72		0.68	11.03	
Age	0.22**	0.07	0.15	0.25**	0.89	0.14
Gender	4.28*	2.10	0.10	7.45**	2.65	0.14
Political orientation	−0.02	0.05	−0.02	0.08	0.06	0.06
Perceptions of farmers	4.36***	1.16	0.19	9.15***	1.46	0.31
Naturalness	4.26**	1.59	0.14	−1.98	2.02	−0.05
Model	F(5, 377) = 7.71***			F(5, 377) = 12.35***		
R^2	0.09			0.14		

Note: Gender: 0 = woman, 1 = man; political orientation from 0 (very left) to 50 (middle) to 100 (very right); perceptions of farmers = 5 items as used in Study 1 and measured on a 7-point Likert scale from 1 (do not agree at all) to 7 (completely agree); naturalness = 3 items in accordance with (Steptoe et al., 1995) and rated for importance on a scale from 1 (not important at all) to 4 (very important); * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 5
Pearson's correlations (Study 2, n = 383).

		1. Age	2. Gender	3. Political orientation	4. Perceptions of farmers	5. Naturalness	6. Affect	7. Willingness to eat
1.	Age	1						
2.	Gender	0.068	1					
3.	Political orientation	0.035	0.050	1				
4.	Perceptions of farmers	−0.015	−0.130*	0.253**	1			
5.	Naturalness	0.226***	−0.087	−0.090	0.015	1		
Hoeing Robot								
6.	Affect	0.188***	0.075	0.030	0.175***	0.167**	1	
7.	Willingness to eat	0.140**	0.015	−0.006	0.212***	0.089	0.666***	1
Milking Robot								
6.	Affect	0.132**	0.113*	0.157**	0.307***	−0.030	1	
7.	Willingness to eat	0.129*	0.120*	0.138**	0.364***	−0.109*	0.759***	1

Note: Gender: 0 = woman, 1 = man; political orientation from 0 (very left) to 50 (middle) to 100 (very right); perceptions of farmers = 5 items as used in Study 1 and measured on a 7-point Likert scale from 1 (do not agree at all) to 7 (completely agree); naturalness = 3 items in accordance with (Steptoe et al., 1995) and rated for importance on a scale from 1 (not important at all) to 4 (very important); * $p < .05$, ** $p < .01$, *** $p < .001$.

is well aligned with the findings of Spykman et al. (2021) in Germany, who found that the general tendency towards specific technologies in Germany (i.e. weed management and sensors in dairy production) is positive.

For plant-related technologies specifically, the associations and ratings were mostly positive, whether in terms of efficiency, the environment or labour facilitation. The positive perception of plant-related technologies in our study might be due to the fact that both technologies aim to reduce the use of pesticides, which was found to be an important attribute in previous studies (Garnitz et al., 2025). Given that individuals supporting the Green Party in Germany were found to be more supportive of crop robots (Zeddies & Busch, 2025), it seems possible that this could be due to more environmental awareness among this group of consumers, together with the fact that crop robots can be used to reach environmental goals, such as the reduction of pesticides.

However, the public perceives soil compaction as a negative side effect of hoeing robots in our study, even though experts believe that they can reduce soil compaction as compared to traditional farming methods (Gerhards et al., 2022), so there seems to be a mismatch between experts and lay people regarding the perceived risk of soil compaction. This merits further examining consumers' perceived risks of such technologies to better understand their concerns and positions.

The most important associations and ratings for the animal-related technologies related to animal welfare. It was the most frequently mentioned aspect for virtual fences and had a negative hedonic rating; for milking robots, it was the second most frequently mentioned and had on average, a neutral hedonic rating. Overall, the milking robot was perceived more positively than the virtual fence. Although a comparably small share (about 6 %) of dairy farms in Switzerland currently use milking robots (Bach et al., 2022; Groher, Heitkämper, & Umstätter, 2020), their adoption by farmers is rapid due to increased flexibility in daily work and great relief from the physically heavy work of milking (Cockburn et al., 2019). Furthermore, the technology was among the first autonomous machines used in dairy farming and is therefore quite well known by farmers and consumers. The introduction of a robot affects the welfare of both cow and farmer, so it is interesting to note that the associations found in our study suggest that the public primarily focusses on the cow (Driessen & Heutinck, 2014). This may indicate the great importance that the public assign to animal welfare (Ammann, Mack, et al., 2023).

Research on virtual fences has found that animals learn the concept of a virtual fence and remain in the virtually fenced area (Langworthy et al., 2021) and that the welfare of cows is not negatively affected as compared to when electric fencing is used (Verdon et al., 2021). Still, the scepticism of the general population is reflected in legislation. For example, legislation in Switzerland does not currently allow the use of virtual fences for practical purposes because the animal has no visual orientation as in the case of common fencing systems. Accordingly, based on public demand, research trials are underway to investigate the technology's viability for Swiss agriculture and its impact on animal welfare. The finding that numerous individuals did not see the benefit of virtual fences may be partly due to the description we provided, yet it strongly indicates that clear communication focused on benefits is needed if this technology is to be used more widely. Similar effects have been reported for gene technology, with the absence of consumer benefits leading to more perceived risks and moral concerns, calling the technology into question (Gaskell, 2000). Therefore, as suggested elsewhere (Stampa et al., 2020), communication with the general public should focus not on the technology but on its benefits that are relevant and important to consumers.

As in Study 1, the results of Study 2 showed higher acceptance of plant- than animal-related technologies. Further, it revealed that women were more sceptical than men towards the milking robot, which is in accordance with previous research reporting that men adopt digital technologies more readily than women do (Ammann, Walter, & El Benni, 2022; Wachenheim et al., 2021). Women also tend to be more critical than men towards farmers, which could be related to the fact that the perceptions of farmers included items regarding animal welfare and caring for the environment, two topics about which women seem to be more sensitive than men (Ammann, Arbenz, et al., 2023; Ammann, Mack, et al., 2023; Grunert et al., 2014; Pomarici & Vecchio, 2014).

Interestingly, we found no significant influence of political orientation on peoples' perceptions of technologies. Zeddies and Busch (2025) found that individuals in Germany with Green Party preferences tended to be supporters of or enthusiasts for of robotics and autonomous systems, whereas more sceptical tendencies were identified for individuals with preferences for the right-wing party, which might indicate a positive correlation between technology acceptance and left-wing party preferences. The absence of this effect in our sample could be due to the fact that we did not ask about political parties but rather about political orientation (left-wing vs. right-wing tendencies) and that the political environment in Switzerland is somewhat different.

Study 2 revealed that food naturalness is an important factor influencing consumers' perceptions of plant-related technologies. The more important naturalness in food was to consumers, the likelier they were to perceive hoeing robots positively. We assume this is because hoeing robots fight weeds manually instead of chemically through the use of herbicides, which would be perceived as less natural. Robots evidently satisfy consumers' desire for food grown naturally without the controversial use of pesticides or herbicides, which they perceive as harmful to health and the environment (Saleh et al., 2024). This accords well with previous research conducted in Germany, where consumers expressed a general wish for natural and traditional farming (Zander et al., 2013) and considered the reduction of pesticides through the use of spot-spraying as an important improvement compared to conventional spraying (Spykman et al., 2022). It is important to keep in mind that in other studies, the general public did not see the use of technology as generally beneficial (Wilmes et al., 2022). Still, they also found that the relationship can turn positive when environmental arguments are included. Therefore, it is crucial to investigate further and identify aspects, such as perceived naturalness, that may help support positive technology perception.

For both the milking and hoeing robots, perceptions of farmers seem to be the most important determinant. The more the participants perceived that farmers care for animal welfare and the environment, the more positive their perceptions of the robots. The result suggests that both environmental and social aspects, such as the minimal use of pesticides and farmers' working conditions, are important factors in evaluating new technologies and the products produced with them. This is in line with previous research reporting that descriptions of animal welfare and environmental protection encourage public acceptance (Pfeiffer et al., 2020). Similarly, Spykman et al. (2022) concluded that communication about crop robots should focus on the environmental benefits rather than economic gains. Overall, our findings indicate a divergence in the relevance of the factors influencing consumer perceptions depending on the type of technology investigated.

In line with Rose et al. (2022), we conclude that the narratives surrounding smart farming technologies are not linear. Public perception differs not only in regard to the technology under consideration but also within technologies, with some individuals perceiving the technology as positive and others perceiving it as negative. The use of a technology affects both farmers (e.g. through physical relief or more flexibility) and their farms (e.g. through more efficient use of resources) and farm animals (e.g. through better monitoring of health data). Individuals weigh these aspects differently, resulting in individual perceptions that may differ from the general narrative. It is important to shed light on these individual perceptions to strengthen our understanding of technology perception and, ultimately, technology acceptance. Communication efforts should focus on highlighting the relevant beneficial aspects of the technologies for animals, farmers and the environment.

4.1. Limitations and outlook

A few limitations of the present study must be acknowledged. First, Study 1 employed a convenience sample with relatively high levels of education, so conclusions about the general population should be drawn with caution. Furthermore, our data for both studies relied on self-reporting, so the results may be influenced by social desirability bias. This means that it is possible that the participants provided answers they thought would appear favourable to others instead of revealing their true preferences. Further, it is unclear whether the recorded perceptions would translate to behaviours and decisions in real situations. Consumers might be in favour of a technology, but in a purchase setting, many factors, such as price or taste, strongly influence consumer decisions. A similar phenomenon is described by the consumer-citizen gap. Citizens might be accepting of a technology (e.g. vote for it), but when faced with actual products in the store, as consumers, they may still choose different products. Still, we believe that our exploratory approach to investigating consumer perceptions may help develop beneficial communication strategies. Building on these insights, future studies should specifically investigate and identify potential public resistance. A final limitation to address is the selection of technologies. Our study focused on some of the more frequently used and discussed technologies in Swiss agriculture, mainly the use of robotics in plant and livestock production. Importantly, we found that these technologies are perceived differently, with animal-related technologies tending to be perceived more negatively than plant-based technologies. To complete the picture, future research should study different motivations behind technology perceptions to allow for tailored communication to consumers. Our studies address an important area of research that has not gained a great deal of scientific attention to date. However, with experts predicting steady increases in the use of digital technologies in agriculture (Ammann, Umstätter, & El Benni, 2022), future studies should follow the evolution of consumers' acceptance of these technologies.

5. Conclusion

The present study took both qualitative and quantitative approaches to investigate public perceptions of smart farming technologies. We found that consumers generally express positive associations towards digital technologies in agriculture. Importantly, we found that the importance of food naturalness may play a role in the perception of plant-related technologies, whereas, for animal-related technologies, perceptions of farmers and animal welfare seem more important. As a result, communication regarding plant-related technologies should focus on the naturalness of the food produced, whereas communication regarding animal-related technologies should highlight the well-being of animals. Based on our results, we conclude that the focus in communication should be on the benefits instead of on the technology. Our findings offer an interesting starting point for efforts to increase public acceptance of specific technologies.

CRediT authorship contribution statement

Jeanine Ammann: Writing – original draft, Visualization, Project administration, Methodology, Data curation, Conceptualization. **Gabriele Mack:** Writing – review & editing, Resources, Conceptualization. **Nadja El Benni:** Writing – review & editing, Conceptualization. **Rita Saleh:** Writing – review & editing, Methodology, Conceptualization.

Ethical statement

Study 1:

The study was explained to consumers in the online questionnaire. They were informed that they would participate in the survey using their personal smartphone or computer, that all data will be deidentified and only reported in the aggregate. All participants acknowledged an informed consent statement in order to participate in the study. To thank them for their participation, participants received a short summary of the results of the study.

Study 2:

The study was explained to consumers in the online questionnaire. They were informed that they would participate in the survey using their personal smartphone or computer, that all data will be deidentified and only reported in the aggregate. All participants acknowledged an informed consent statement in order to participate in the study. They were financially compensated for their participation by the panel provider (Bilendi AG).

Author statement

Jeanine Ammann: Conceptualization, Methodology, Data Curation, Project administration, Visualisation, Writing – Original Draft **Gabriele Mack.**: Conceptualization, Resources, Writing - Reviewing and Editing **Nadja El Benni**: Conceptualization, Writing - Reviewing and Editing. **Rita Saleh:** Conceptualization, Methodology, Writing- Reviewing and Editing.

Funding

This research did not receive any third-party funding.

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.

Acknowledgements

The authors thank Professor Dr. Michael Siegrist for his valuable feedback on the survey of Study 1. The authors also thank Sacha Hunter for his assistance in data collection for Study 1.

Appendix A. Appendix

Table A1
Descriptions of the smart farming technologies used in Study 1.

	Original German description [English translation]
1	Auf dem Bild sehen Sie eine **Spritzdrohne** beim Einsatz am Rebberg. Sie soll körperliche Belastung bei der Bewirtschaftung von Steillagen mindern. Ausserdem kann sie Pflanzenschutzmittel sehr zielgenau ausbringen, was dazu führt, dass weniger Pflanzenschutzmittel eingesetzt werden können.

(continued on next page)

Table A1 (*continued*)

	Original German description [English translation]
	[The picture shows a **spraying drone** in use at the vineyard. It is intended to reduce physical strain when cultivating steep slopes. It can also apply pesticides very precisely, which means that fewer pesticides can be used.]
2	Auf dem Bild sehen Sie einen **autonomen Hackroboter**. Er beseitigt mechanisch, also ganz ohne Pflanzenschutzmittel, allfällige Unkräuter im Feld. Er kann bspw. per Smartphone gesteuert werden und soll an Zeit und Aufwand einsparen. [The picture shows an **autonomous hoeing robot**. It removes any weeds in the field mechanically, i.e. without any pesticides. It can be controlled by a smartphone, for example, and is intended to save time and effort.]
3	Auf dem Bild sehen Sie **virtuelle Zäune**. Diese sollen eine nachhaltigere Weidenutzung zulassen und somit die biologische Vielfalt fördern. Das Tier erhält einen Stromschlag beim Verlassen des Gebietes, nach drei Stromschlägen schaltet es automatisch ab, um keine Gefährdung der Tiere zu riskieren. [In the picture, you can see **virtual fences**. These are intended to allow more sustainable pasture use and thus promote biodiversity. The animal receives an electric shock when leaving the area; after three electric shocks, it switches off automatically so as not to risk endangering the animals.]
4	Auf dem Bild sehen Sie einen **Melkroboter**. Die Kühe können selbstbestimmt während des Tages den Melkroboter aufsuchen, um sich melken zu lassen. Für den Bauern oder die Bäuerin bedeutet das flexiblere Arbeitszeiten und eine Arbeitserleichterung. [In the picture, you can see a **milking robot**. The cows can visit the milking robot during the day to be milked. For the farmer, this means more flexible working hours and less work.]

Table A2
Original German items used in the survey of Study 1 (N = 287).

	Item	M	SD
Perceptions of farmers (5 items, α = 0.81)		5.5	0.9
1 (completely disagree) to 7 (completely agree)			
1	Ich bin Bauern gegenüber generell positiv eingestellt [a]	5.6	1.3
2	Die Arbeit der Bauern ist wichtig und wertvoll für die Gesellschaft.	6.4	1.0
3	Bauern setzen sich für das Tierwohl ein. [a]	5.0	1.3
4	Bauern haben ein grosses Umweltbewusstsein. [a]	4.3	1.4
5	Bäuerliche Familienbetriebe sind wichtig und sollten erhalten [a] bleiben.	6.1	1.3

[a] Item developed in accordance with (Pfeiffer et al., 2020).

Table A3
ANOVA testing for the effect of information condition on the perception of (affect towards) smart farming technologies (Study 2, $N = 485$).

Milking Robot
Complete sample (N = 485)
Levene's test for heterogeneity of variances: (F [4, 480] = 2.20, $p = .07$)
The model is significant, indicating that information condition has a significant influence on technology perception (F [4, 480] = 2.92, $p < .05$, $\eta_p^2 = 0.02$).
Post hoc analysis with Bonferroni correction shows that the 'male scientist' condition significantly differs from the 'neutral' condition (i.e. higher ratings for affect).
After removal of the 'male scientist' condition (n = 383)
Levene's test for heterogeneity of variances: (F [3, 379] = 2.20, $p = .33$)
The model is not significant, indicating that information condition no longer has a significant influence on technology perception (F [3, 379] = 0.52, $p = .57$, $\eta_p^2 = 0.04$).
Hoeing Robot
Complete sample (N = 485)
Levene's test for heterogeneity of variances: (F [3, 379] = 0.78, $p = .54$)
The model is not significant, indicating that information condition does not have a significant influence on technology perception (F [3, 379] = 1.41, $p < .05$, $\eta_p^2 = 0.01$).
After removal of the 'male scientist' condition (n = 383)
Levene's test for heterogeneity of variances: (F [3, 379] = 1.03, $p = .38$)
The model is not significant, indicating that information condition still does not have a significant influence on technology perception (F [3, 379] = 1.36, $p = .25$, $\eta_p^2 = 0.01$).

Data availability

data is available and has been cited in the manuscript

References

Afful-Dadzie, E., Lartey, S. O., & Clottey, D. N. K. (2022). Agricultural information systems acceptance and continuance in rural communities: A consumption values perspective. *Technology in Society, 68*. https://doi.org/10.1016/j.techsoc.2022.101934

Ammann, J. (2022). *2-round Delphi study on digital technologies in vegetable farming in Switzerland Zenodo*. https://doi.org/10.5281/zenodo.6901096

Ammann, J. (2024). *Swiss public's acceptance and sustainability perceptions of food produced with chemical, digital and mechanical weed control measures and the influence of information source on technology perception in agriculture Zenodo*. https://doi.org/10.5281/zenodo.10817295

Ammann, J., Arbenz, A., Mack, G., Nemecek, T., & El Benni, N. (2023). A review on policy instruments for sustainable food consumption. *Sustainable Production and Consumption*. https://doi.org/10.1016/j.spc.2023.01.012

Ammann, J., Mack, G., Irek, J., Finger, R., & El Benni, N. (2023). *Consumers' meat commitment and the importance of animal welfare as agricultural policy goal Appetite*, 112(105010). https://doi.org/10.1016/j.foodqual.2023.105010.

Ammann, J., Siegrist, M., & Hartmann, C. (2019). The influence of disgust sensitivity on self-reported food hygiene behaviour. *Food Control, 102*, 131–138. https://doi.org/10.1016/j.foodcont.2019.03.023

Ammann, J., Umstätter, C., & El Benni, N. (2022). The adoption of precision agriculture enabling technologies in Swiss outdoor vegetable production - a Delphi study. *Precision Agriculture*. https://doi.org/10.1007/s11119-022-09889-0

Ammann, J., Walter, A., & El Benni, N. (2022). Adoption and perception of farm management information systems by future Swiss farm managers – An online study. *Journal of Rural Studies, 89*, 298–305. https://doi.org/10.1016/j.jrurstud.2021.12.008

Bach, L., Ammann, J., Bruckmaier, R., Müller, U., & Umstätter, C. (2022). Drying-off practices on Swiss dairy farms: Status quo and adoption potential of integrating incomplete milking. *Journal of Dairy Science, 105*(10), 8342–8353. https://doi.org/10.3168/jds.2021-21735

Bearth, A., & Siegrist, M. (2016). Are risk or benefit perceptions more important for public acceptance of innovative food technologies: A meta-analysis. *Trends in Food Science & Technology, 49*, 14–23. https://doi.org/10.1016/j.tifs.2016.01.003

Boogaard, B. K., Bock, B. B., Oosting, S. J., Wiskerke, J. S. C., & van der Zijpp, A. J. (2010). Social acceptance of dairy farming: The ambivalence between the two faces of modernity. *Journal of Agricultural and Environmental Ethics, 24*(3), 259–282. https://doi.org/10.1007/s10806-010-9256-4

Campbell, D. L. M., Lea, J. M., Keshavarzi, H., & Lee, C. (2019). Virtual fencing is comparable to electric tape fencing for cattle behavior and welfare. *Frontiers in Veterinary Science, 6*. https://doi.org/10.3389/fvets.2019.00445

Cockburn, M., Gomez, Y., Schick, M., Maffiuletti, N. A., Gygax, L., Savary, P., & Umstatter, C. (2019). Effect of milking stall dimensions on upper limb and shoulder muscle activity in milkers. *Journal of Dairy Science, 102*(5), 4563–4576. https://doi.org/10.3168/jds.2018-15316

Crump, A., Jenkins, K., Bethell, E. J., Ferris, C. P., & Arnott, G. (2019). Pasture access affects behavioral indicators of wellbeing in dairy cows. *Animals (Basel), 9*(11). https://doi.org/10.3390/ani9110902

Driessen, C., & Heutinck, L. F. M. (2014). Cows desiring to be milked? Milking robots and the co-evolution of ethics and technology on Dutch dairy farms. *Agriculture and Human Values, 32*(1), 3–20. https://doi.org/10.1007/s10460-014-9515-5

Drummond, C., & Fischhoff, B. (2017). Individuals with greater science literacy and education have more polarized beliefs on controversial science topics. *Proceedings of the National Academy of Sciences, 114*(36), 9587–9592. https://doi.org/10.1073/pnas.1704882114

Finger, R., Swinton, S. M., El Benni, N., & Walter, A. (2019). Precision farming at the Nexus of agricultural production and the environment. *Annual Review of Resource Economics, 11*(1), 313–335. https://doi.org/10.1146/annurev-resource-100518-093929

Flanagin, A. J., Winter, S., & Metzger, M. J. (2018). Making sense of credibility in complex information environments: The role of message sidedness, information source, and thinking styles in credibility evaluation online. *Information, Communication & Society, 23*(7), 1038–1056. https://doi.org/10.1080/1369118x.2018.1547411

Garnitz, J., Gabriel, A., & Emberger-Klein, A. (2025). Public preference for alternative farming systems: Balancing environmental protection, automated technologies, and price settings. In *45*. Austria: GIL, Wieselburg.

Gaskell, G. (2000). Agricultural biotechnology and public attitudes in the European Union. *AgBioForum, 3*, 87–96.

Gauchat, G. (2012). Politicization of science in the public sphere: A study of public Trust in the United States, 1974 to 2010. *American Sociological Review, 77*(2), 167–187. https://doi.org/10.1177/0003122412438225

Gerhards, R., Andújar Sanchez, D., Hamouz, P., Peteinatos, G. G., Christensen, S., & Fernandez-Quintanilla, C. (2022). Advances in site-specific weed management in agriculture—A review. *Weed Research, 62*(2), 123–133. https://doi.org/10.1111/wre.12526

Giua, C., Materia, V. C., & Camanzi, L. (2022). Smart farming technologies adoption: Which factors play a role in the digital transition? *Technology in Society, 68*. https://doi.org/10.1016/j.techsoc.2022.101869

Greenberg, M. R., & Schneider, D. F. (1995). Gender differences in risk perception: Effects differ in stressed vs. non-stressed environments. *Risk Analysis, 15*(4), 503–511. https://doi.org/10.1111/j.1539-6924.1995.tb00343.x

Groher, T., Heitkämper, K., & Umstätter, C. (2020). Digital technology adoption in livestock production with a special focus on ruminant farming. *Animal, 14*(11), 2404–2413. https://doi.org/10.1017/S1751731120001391

Groher, T., Heitkämper, K., Walter, A., Liebisch, F., & Umstätter, C. (2020). Status quo of adoption of precision agriculture enabling technologies in Swiss plant production. *Precision Agriculture, 21*(6), 1327–1350. https://doi.org/10.1007/s11119-020-09723-5

Grunert, K. G., Hieke, S., & Wills, J. (2014). Sustainability labels on food products: Consumer motivation, understanding and use. *Food Policy, 44*, 177–189. https://doi.org/10.1016/j.foodpol.2013.12.001

Guo, Z., Chen, X., & Zhang, Y. (2022). Impact of environmental regulation perception on farmers' agricultural green production technology adoption: A new perspective of social capital. *Technology in Society, 71*. https://doi.org/10.1016/j.techsoc.2022.102085

Henchion, M. M., Regan, A., Beecher, M., & MackenWalsh, A. (2022). Developing "smart" dairy farming responsive to farmers and consumer-citizens: A review. *Animals (Basel), 12*(3). https://doi.org/10.3390/ani12030360

Holloway, L., & Bear, C. (2017). Bovine and human becomings in histories of dairy technologies: Robotic milking systems and remaking animal and human subjectivity. *BJHS Themes, 2*, 215–234. https://doi.org/10.1017/bjt.2017.2

Holpp, M., Kroulik, M., Kviz, Z., Anken, T., Sauter, M., & Hensel, O. (2013). Large-scale field evaluation of driving performance and ergonomic effects of satellite-based guidance systems. *Biosystems Engineering, 116*(2), 190–197. https://doi.org/10.1016/j.biosystemseng.2013.07.018

Jamil, I., Jun, W., Mughal, B., Raza, M. H., Imran, M. A., & Waheed, A. (2021). Does the adaptation of climate-smart agricultural practices increase farmers' resilience to climate change? *Environmental Science and Pollution Research International*. https://doi.org/10.1007/s11356-021-12425-8

Khan, R., Tausif, S., & Javed Malik, A. (2018). Consumer acceptance of delivery drones in urban areas. *International Journal of Consumer Studies, 43*(1), 87–101. https://doi.org/10.1111/ijcs.12487

Krampe, C., Serratosa, J., Niemi, J. K., & Ingenbleek, P. T. M. (2021). Consumer perceptions of precision livestock farming-a qualitative study in three European countries. *Animals (Basel), 11*(5). https://doi.org/10.3390/ani11051221

Langworthy, A. D., Verdon, M., Freeman, M. J., Corkrey, R., Hills, J. L., & Rawnsley, R. P. (2021). Virtual fencing technology to intensively graze lactating dairy cattle. I: Technology efficacy and pasture utilization. *Journal of Dairy Science, 104*(6), 7071–7083. https://doi.org/10.3168/jds.2020-19796

Michel, F., & Siegrist, M. (2019). How should importance of naturalness be measured? A comparison of different scales. *Appetite, 140*, 298–304. https://doi.org/10.1016/j.appet.2019.05.019

Michels, M., Fecke, W., Feil, J.-H., Musshoff, O., Pigisch, J., & Krone, S. (2019). Smartphone adoption and use in agriculture: Empirical evidence from Germany. *Precision Agriculture, 21*(2), 403–425. https://doi.org/10.1007/s11119-019-09675-5

Millar, K. M., Tomkins, S. M., White, R. P., & Mepham, T. B. (2002). Consumer attitudes to the use of two dairy technologies. *British Food Journal, 104*(1), 31–44. https://doi.org/10.1108/00070700210418721

Pfeiffer, J., Gabriel, A., & Gandorfer, M. (2020). Understanding the public attitudinal acceptance of digital farming technologies: A nationwide survey in Germany. *Agriculture and Human Values, 107-128*. https://doi.org/10.1007/s10460-020-10145-2

Pomarici, E., & Vecchio, R. (2014). Millennial generation attitudes to sustainable wine: An exploratory study on Italian consumers. *Journal of Cleaner Production, 66*, 537–545. https://doi.org/10.1016/j.jclepro.2013.10.058

Román, S., Sánchez-Siles, L. M., & Siegrist, M. (2017). The importance of food naturalness for consumers: Results of a systematic review. *Trends in Food Science & Technology, 67*, 44–57. https://doi.org/10.1016/j.tifs.2017.06.010

Rose, D. C., Barkemeyer, A., de Boon, A., Price, C., & Roche, D. (2022). The old, the new, or the old made new? Everyday counter-narratives of the so-called fourth agricultural revolution. *Agriculture and Human Values, 1-17*. https://doi.org/10.1007/s10460-022-10374-7

Saleh, R., Bearth, A., & Siegrist, M. (2021). How chemophobia affects public acceptance of pesticide use and biotechnology in agriculture. *Food Quality and Preference, 91*. https://doi.org/10.1016/j.foodqual.2021.104197

Saleh, R., El Benni, N., Masson, S., & Ammann, J. (2024). Public acceptance and sustainability perceptions of food produced with chemical, digital and mechanical weed control measures. *Food Quality and Preference, 113*. https://doi.org/10.1016/j.foodqual.2023.105079

Siegrist, M. (1998). Belief in gene technology: The influence of environmental attitudes and gender. *Personality and Individual Differences, 24*(6), 861–866.

Sparks, P., Shepherd, R., & Frewer, L. J. (1995). Assessing and structuring attitudes toward the use of Gene Technology in food production: The role of perceived ethical obligation. *Basic and Applied Social Psychology, 16*(3), 267–285. https://doi.org/10.1207/s15324834basp1603_1

Spykman, O., Emberger-Klein, A., Gabriel, A., & Gandorfer, M. (2021). *Society's perspective on automation in crop and dairy production Agricultural & Applied Economics Association Annual Meeting.* Texas: Austin.

Spykman, O., Emberger-Klein, A., Gabriel, A., & Gandorfer, M. (2022). Autonomous agriculture in public perception - German consumer segments' view of crop robots. *Computers and Electronics in Agriculture, 202*. https://doi.org/10.1016/j.compag.2022.107385

Stampa, E., Zander, K., & Hamm, U. (2020). Insights into German consumers' perceptions of virtual fencing in grassland-based beef and dairy systems: Recommendations for communication. *Animals (Basel), 10*(12). https://doi.org/10.3390/ani10122267

Steptoe, A., Pollard, T. M., & Wardle, J. (1995). Development of a measure of the motives underlying the selection of food: The food choice questionnaire. *Appetite, 25*(3), 267–284.

Te Velde, H., Aarts, N., & Van Woerkum, C. (2002). Dealing with ambivalence: Farmers' and consumers' perceptions of animal welfare in livestock breeding. *Journal of Agricultural and Environmental Ethics, 15*, 203–219.

Umstätter, C. (2011). The evolution of virtual fences: A review. *Computers and Electronics in Agriculture, 75*(1), 10–22. https://doi.org/10.1016/j.compag.2010.10.005

Verdon, M., Horton, B., & Rawnsley, R. (2021). A case study on the use of virtual fencing to intensively graze Angus heifers using moving front and Back-fences [original research]. *Frontiers in Animal Science, 2*. https://www.frontiersin.org/article/10.3389/fanim.2021.663963.

Wachenheim, C., Fan, L., & Zheng, S. (2021). Adoption of unmanned aerial vehicles for pesticide application: Role of social network, resource endowment, and perceptions. *Technology in Society, 64*. https://doi.org/10.1016/j.techsoc.2020.101470

Walter, A., Finger, R., Huber, R., & Buchmann, N. (2017). Opinion: Smart farming is key to developing sustainable agriculture. *Proceedings of the National Academy of Sciences*

of the United States of America, 114(24), 6148–6150. https://doi.org/10.1073/pnas.1707462114
Wilmes, R., Waldhof, G., & Breunig, P. (2022). Can digital farming technologies enhance the willingness to buy products from current farming systems? *PLoS One, 17*(11), Article e0277731. https://doi.org/10.1371/journal.pone.0277731
Wiseman, L., Sanderson, J., Zhang, A., & Jakku, E. (2019). Farmers and their data: An examination of farmers' reluctance to share their data through the lens of the laws impacting smart farming. *NJAS - Wageningen Journal of Life Sciences, 90-91*. https://doi.org/10.1016/j.njas.2019.04.007
Zander, K., Isermeyer, F., Bürgelt, D., Christoph-Schulz, I., Salamon, P., & Weible, D. (2013). *Erwartungen der Gesellschaft an die Landwirtschaft*.
Zeddies, H. H., & Busch, G. (2025). Public acceptance of robots and autonomous crop farming – A cluster analysis of German citizens' attitudes and concerns. *German Journal of Agricultural Economics, 74*, 1–28. https://doi.org/10.52825/gjae.v74i.2283