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Consumer acceptance of precision fermentation technology: A cross-cultural study

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ABSTRACT

Technological advances in precision fermentation hold great potential for transformative changes in the agri-food system, addressing crucial environmental and food security challenges. However, the successful adoption of this technology hinges on consumer acceptance, which plays a pivotal role in determining its market success. To shed light on consumer acceptance of precision fermentation technology, three studies were conducted. Study 1 found that adopting natural (vs. sustainable) framing positively influenced acceptance ($N = 308$). Study 2 revealed that the information supporting use of representative heuristic can effectively enhance technology acceptance ($N = 300$). Furthermore, Study 3 proposed and tested the technology acceptance model in a cross-cultural setting ($N = 3032$), indicating that when prompting similarity to traditional fermentation positively influenced consumer perceptions. This further fosters higher levels of trust and perceived benefits, significantly impacting consumer acceptance and intention to purchase new products derived from precision fermentation technology. These insights emphasize the critical role of consumer acceptance in driving the adoption and market success of precision fermentation.

1. Introduction

Reducing negative environmental, social, and economic externalities related to the production of foods and beverages are one of the main goals of sustainable development (Capozzi, Fragasso, & Bimbo, 2021; UN, 2022). However, the pursuit of sustainable development goals can face impediments due to a multitude of challenges confronting the modern food supply. These challenges encompass the continued expansion of the global population, the escalating need for more nutrients, and the decreased availability of agricultural land (FAO, 2022). Innovations in food processing technology that could ensure more resilient and efficient food production systems, and enable sufficient production of food with the slightest damage to the environment, are now more urgent than ever (McClements, 2020). Recently, the rapid advances in microbial-based solutions and fermentative processes have resulted in novel food technologies that can be used as mitigating strategies to reduce negative externalities of production associated with sizable environmental footprints (such as pollution in the animal/plant food chains or decrease of water availability and soil fertility), and thus make the food system sustainable and resilient (Capozzi et al., 2021). The enormous potential of precision fermentation for manufacturing of food ingredients, such as microbial production of proteins (e.g., animal-free dairy milk from Perfect Day) that were otherwise traditionally produced from plant or animal sources, as well as creation of new products from non-food biomass (e.g., seaweeds), is predicted to produce significant disruption and transformation of food and agriculture, until 2030 (Tubb & Seba, 2021). Even though disruptive technologies like precision fermentation have the potential to transform the food system, consumers will still have the ultimate word on what food technologies will be successful on the market (Lavilla & Gayan, 2018). How consumers will evaluate these new food technologies has a downstream effect on acceptance of food products (Conroy & Errmann, 2023; Just & Goddard, 2023). Therefore, the efficient use of precision fermentation in production of new foods, and is ability to mitigate existing problems depends on ensuring successful consumers' acceptance of this technology for food production.

Precision fermentation is not new as it has been established biotechnology since the 1970. It uses genetically engineered microorganisms to produce a variety of food ingredients via fermentation that are otherwise conventionally sourced from animals and plants (Teng, Chin, Chai, & Chen, 2021; Zollman Thomas & Bryant, 2021). It is a transition from a traditional fermentation technology (for preservation

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of primary produce) to a more sophisticated precision fermentation technology (for sustainable production of food ingredients at the industry scale) (Barrett, Benton, Cooper, & Al, 2020; Terefe, 2022). A classic example is production of rennet for cheese manufacturing, which since the 1980s has been done using recombinant DNA technology (Terefe, 2022). The main driver behind precision fermentation is that it can be used at any location to create, for example, alternative proteins and deliver a tasty product that is safe, nutritious, and at the same time, can be more favourable for the environment when compared to other food products that are produced conventionally, such as animal-based products (Terefe, 2022). Good examples of such products are animal-free milk protein by Perfect Day (Coyne, 2022), animal-free eggs by Every (Cullen, 2022), and 'designer' sweet proteins by Amai Proteins (Watson, 2022). Precision fermentation can thus effectively curtail the terrestrial and marine footprint of farming, especially in producing higher-value foods for high-quality diets (Barrett et al., 2020). Although precision fermentation shows great potential, it is crucial to take consumers' attitudes into account, as many consumers make negative inferences from technologies (Siegrist & Hartmann, 2020) that they believe are not in line with expectations for natural, healthy, and tasty foods (Frewer et al., 2011).

New applications of precision fermentation are thus driven both by scientific progress (Barrett et al., 2020; Teng et al., 2021) and by consumers' concerns for health, nutrition, and sustainability (Chai, Ng, Samarasiri, & Chen, 2022). Even though precision fermentation is predicted to reduce our dependence on traditional agriculture and enable sustainable food security (Tubb & Seba, 2021), it faces major challenges. These challenges are related to consumers' perception and acceptance of precision fermentation technology. As technology assessment is significantly linked to product acceptance (Conroy & Errmann, 2023), exploring factors that influence consumers' perceptions and attitudes towards new food processing technology should be included in the decision-making process when adopting new technologies (Meijer, Lähteenmäki, Stadler, & Weiss, 2021), and particularly in the early stages of new product development (Grunert, Verbeke, Kugler, Saeed, & Scholderer, 2011). Therefore, in this study we aim to understand consumers' attitudes and acceptance in relation to precision fermentation technology as this is seen as a crucial factor for a successful commercialization and implementation of this technology. The present research comprises three studies that were guided by several objectives. First, we sought to determine how different types of communication and goal framing (e.g., Lee & Pounders, 2019) affect consumer acceptance of precision fermentation technology (Study 1). Second, we sought to investigate whether the effect of goal framing on consumer acceptance would be modified if a new manipulation is introduced to support the use of representative heuristic (Kahneman & Tversky, 1972) (Study 2). Third, we develop and estimate a technology acceptance model for precision fermentation, then replicate and test the robustness of the found effects of goal framing and representative heuristic in the broader context of this technology acceptance model (Study 3). The conceptual development and specific study aims are offered in the subsequent sections.

2. Conceptual development: framing novel food technology and technology acceptance model

2.1. Framing novel food technology

The relative newness of precision fermentation technology implies that the factors influencing consumers' willingness to accept are still not adequately understood. The communication and framing of information, related to how novel technology is described, can have an important effect on consumers' acceptance and attitude (Conroy & Errmann, 2023; Just & Goddard, 2023; Siegrist & Hartmann, 2020). For example, describing a technology as being 'natural' could evoke more positive evaluations (Evans, de Challemaison, & Cox, 2010), as the use of the term 'natural' in relation to food has been shown to induce positive evaluations among consumers (Rozin, Fischler, & Shields-Argeles, 2012). Furthermore, natural foods are also perceived as healthier, tastier, and better for the environment (Banovic et al., 2018; Roman, Sanchez-Siles, & Siegrist, 2017). Alternatively, novel technology can be characterized as beneficial for the environment. Previous research has shown that using messages focused on the environment and sustainability issues impacts consumers' attitude positively (Banovic & Barone, 2021; Lee & Pounders, 2019). Using green claims and messages frames in general enhances consumers' attitudes and influence introduction of green new products (Olsen, Slotegraaf, & Chandukala, 2014).

However, describing new technology as 'natural' or 'sustainable' can also have unintended effects on consumers. Research has shown that when preferences are framed in opposition to consumers' mindset (e.g., if consumers disagree that the technology is natural), it can lead to more negative reactions (Teeny & Petty, 2021). These negative reactions, in turn, can lead to increased punitive behaviour or with the redirection of negativity towards the perceived source (Walten & Wiedmann, 2022). On the other hand, if consumers perceive the source of the message as credible and trustworthy (Lemanski & Villegas, 2015), they are more likely to be persuaded, exhibit behavioural compliance (Hautz, Füller, Hutter, & Thürridl, 2014), and have more positive evaluations of products stemming from innovative food technologies (Walten & Wiedmann, 2022).

Furthermore, framing can be categorized as 'paternalistic,' aiming to improve an individual's own well-being (although potentially violating consumer sovereignty), or 'non-paternalistic,' aiming to enhance social welfare in general (Grüne-Yanoff, 2012; Schubert, 2017; Sunstein, 2014). Most claims or nudges that are implemented can be categorized as paternalistic (Hausman, 2022). For instance, the use of claims like 'natural' (Regulation (EC) No 1924/2006EN and Reg. (EU) No 1047/2012EN) or 'sustainable' (or 'green') (Green Claim Directive, EC, 2023a, 2023b) could be seen as paternalistic nudges (Grüne-Yanoff, 2012), as they direct consumers' food purchasing and consumption behaviour in a certain direction. However, they also incentivize the food industry to improve the quality of their products and empower consumers for the green transition (Reisch & Sunstein, 2016; Schubert, 2017). From this point of view, these claims would be seen as non-paternalistic, 'social nudges,' that aim to address market failures and encourage consumers to voluntarily contribute to public welfare, such as environmental protection (Hausman, 2022; Nagatsu, 2015).

While there has been some important framing research regarding new food technologies (Frewer et al., 2011; Siegrist, 2008; Siegrist & Hartmann, 2020), there has unexpectedly been little research to understand the effect of using 'natural' or 'sustainable' framing. Thus, we sought to explore the effect of the natural vs. sustainable goal framing on the acceptance of precision fermentation technology (Fig. 1).

2.2. Role of heuristics in evaluation of novel technologies

Novel food technologies could be evaluated by using heuristics, such as, similarity heuristics (Li & Chapman, 2012; Read & Grushka-Cockayne, 2011; Siegrist & Hartmann, 2020), affect heuristics (Finucane, Alhakami, Slovic, & Johnson, 2000; Nagaya & Shimizu, 2023; Siegrist & Sütterlin, 2016), and availability heuristics (Bode, Vraga, & Tully, 2021; Siegrist & Árvai, 2020; Wang, 2021). The affect heuristic refers to the tendency to rely on emotional or affective responses when making judgments about technology (Lusk, Roosen, & Bieberstein, 2014; Siegrist & Sütterlin, 2016).

The majority of studies investigating the influence of the affect heuristic on technology acceptance has concentrated on assessing overall affective responses, spanning from negative to positive (Siegrist & Hartmann, 2020; Siegrist & Sütterlin, 2016). It has been shown that individuals' overall emotional response towards technology influences their perception of associated risks and benefits, making affect heuristics more influential than cognitive processing (Finucane et al., 2000;

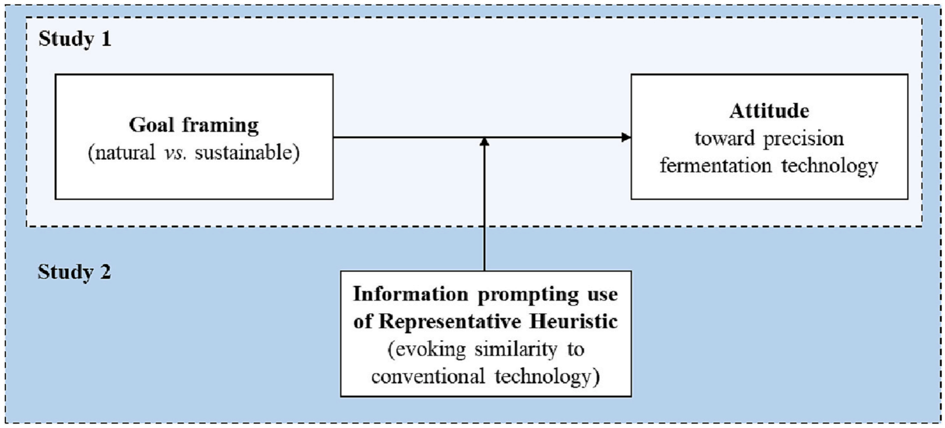

Fig. 1. Conceptual framework (Study 1 and Study 2).

Nagaya & Shimizu, 2023; Slovic, Finucane, Peters, & MacGregor, 2007). This is particularly relevant for laypeople who, because of their limited technical knowledge, rely on their affect-based experience, in contrast to experts who rely more on the analytical systems when evaluating food technology (Sokolowska & Sleboda, 2015). Furthermore, if a technology is perceived as necessary (as in the case of GMO food), it is generally seen as more acceptable and less risky (Tenbült, de Vries, Dreezens, & Martijn, 2005). On the contrary, if a technology is perceived to carry a higher level of risk, it will be less likely to be accepted compared to conventionally produced food (Nagaya & Shimizu, 2023). This halo effect, which refers to the correlation between benefit and risk perception, has been analysed across 40 different technologies (Alhakami & Slovic, 1994). Attitudes and affect were found to play a significant role in explaining the halo effect. Additionally, it was proposed that the affect heuristic provides insights into the workings of the availability heuristic (Slovic, Finucane, Peters, & MacGregor, 2004), as the emotional intensity associated with mental images influences their memorability.

The availability heuristic defined as the ease with which relevant information comes to mind (Kahneman, 2003), are often in the context of novel technologies assed in relation to risk perceptions (Siegrist & Árvai, 2020). The accuracy of the individual's risk perceptions have been found to depend on the availability heuristics, depending partly on the intuitive way they inspire individuals to consult their direct experience to calibrate their concerns about risks (Pachur, Hertwig, & Steinmann, 2012). Further, the availability heuristic may explain why people tend to overestimate technology success, due to the media coverage and image vividness (Lusk et al., 2014). For instance, communication highlighting expert organizations scientific consensus on safety of novel technologies (as GMO) diminishes negative misperceptions among the public and boosts related consumption behaviours (Bode et al., 2021). Similarly, as public perception about novel technologies is often influenced by misinformation, corrective messages supporting use of availability heuristic can influence acceptance of these technologies (Wang, 2021). This salience can also affect the retrieval of information that can be used for targeting the affective dimensions of risk perceptions (Siegrist & Árvai, 2020).

The similarity heuristic, or representative heuristic (Kahneman & Tversky, 1972), is often used to judge the likelihood that, for example, a product is a member of one category rather than another by the degree to which it is similar to others in that category (Read & Grushka-Cockayne, 2011). The representative heuristic relying on correspondence of a novel technology to a conventional one could increase trust in the source of information and consumers acceptance of the technology (Siegrist, 2019). This could further have downstream effects on the subsequent experiential products coming from this technology as they will be evaluated more favourably if the experience matches the inferred representative information (Wilcox, Roggeveen, & Grewal, 2011). Since most everyday decisions are driven by innate similarity standards (Read & Grushka-Cockayne, 2011), evaluating a technology based on its resemblance to a conventional food technology category, particularly in terms of its crucial features, can serve as a natural guide for individuals when accepting that technology, due to enhanced trust (Macready et al., 2020). Similarly, if features of a novel food technology, such as precision fermentation, are associated with representative features of a conventional or familiar technology, like traditional fermentation, individual subsequent judgments may be influenced by the representative heuristic (Read & Grushka-Cockayne, 2011). Based on the above, we sought to investigate whether the effectiveness of goal framing (natural vs. sustainable) on attitudes towards precision fermentation technology would be altered when using alternative phrasing of the technology that supports the use of the representative heuristic (Fig. 1).

2.3. Food technology acceptance model

Previous research into technology acceptance have greatly depended on Davis' technology acceptance model. The model emphasizes the effect of two relevant technology features, namely 'perceived ease of use' and 'perceived usefulness,' on consumers' intention to use a specific technology (Davis, 1989; Venkatesh & Davis, 2000). While consumers do not use a food technology themselves, the perceived usefulness may still impact acceptance. One might expect that an individual's acceptance of a technology would be greater if the individual consumers' goals match the benefits of the technology, for example, in terms of health and environmental benefits the technology offers (Bryant & Dillard, 2019; Conroy & Errmann, 2023). The perceived benefits might include such factors as a perception of naturalness, taste, convenience, nutritional value, safety, and effect on the environment (Frewer et al., 2011; Ronteltap, Van Trijp, Renes, & Frewer, 2007). Even though consumers are increasingly demanding innovation and sustainability in food production, unfamiliar food technologies are often riddled with general public fear and skepticism of the potential risks, especially if they are perceived as something radically novel (Cox & Evans, 2008; Laros & Steenkamp, 2004). As a result, consumers are more likely to reject the technology and refuse to buy innovative products (Demartini, Gaviglio, La Sala, & Mariantonietta, 2019; Eden, Bear, & Walker, 2008). Such skepticism has been labelled food technology neophobia, which can be defined as rejection of new or unfamiliar foods technologies (Cox & Evans, 2008). Further, in situations where there is a lack of knowledge to assess the benefits and risks of a technology, trust plays a crucial role. Consumers rely on beliefs in the competence, care, and openness of food chain actors in the formation of overall trust towards them (Macready et al., 2020) This trust becomes essential in simplifying complex decisions when consumers face limited knowledge (Siegrist, 2008).

Research has shown that trust plays a significant role in shaping perceptions of both the benefits and risks associated with novel technologies, including gene technology, as well as influencing acceptance and willingness to purchase genetically modified (GM) foods (Siegrist, 2000). As new technologies often lead to the development of products with additional benefits that consumers cannot directly experience, producers must effectively communicate these benefits through various labelling schemes and claims (Olsen et al., 2014). When consumers are unable to verify the provided information, they resort to trust as a heuristic, relying on the credibility of the information source (Walten & Wiedmann, 2022). Trust plays a central role in the acceptance of novel foods, particularly functional foods, where health claims are employed to communicate tangible values to consumers that are more relatable than the underlying technology itself (Verbeke, 2006). Furthermore, research has found a positive correlation between the perceived naturalness of food and increased trust, willingness to consume, and acceptance of genetically modified (GM) food (Tenbült et al., 2005). Given the complexity of novel technologies, as precision fermentation, trust is an important factor that drives consumer acceptance of related products and the uptake of information (Lusk et al., 2014).

Based on the above, we expect that the perceived usefulness of precision fermentation will be influenced by consumers' goals related to health and environmental consciousness (Michaelidou & Hassan, 2008; Van der Werff, Steg, & Keizer, 2013), and to their trust in food industry and regulations (Benson, Lavelle, Spence, Elliott, & Dean, 2020; Siegrist, 2008). These are expected to influence perceived benefits (Frewer et al., 2011), fear (Cox & Evans, 2008), skepticism (Eden et al., 2008), and food technology neophobia (Vidigal et al., 2015). Further, we expect that perceived usefulness will lead to more positive attitudes towards novel technology and ultimately to higher intentions to buy innovative products (Siegrist & Hartmann, 2020). The intention to buy innovative products could also be further enhanced by consumers' individual traits such as openness to innovations (i.e., 'need for change') (Wood & Swait, 2002). Fig. 2 shows the proposed food technology acceptance model.

2.4. Research questions

Based on the above, we will present a series of three studies addressing three research questions.

RQ1: Does the framing of precision fermentation technology as 'natural' or 'sustainable' lead to differences in the attitude towards technology, and if so, how?

In other words, does it make a difference whether the framing refers to information about the technology providing naturally produced food, or whether it prompts individuals to think about the environment (Fig. 1)? There is evidence suggesting that, both natural and sustainable framing can enhance positive attitudes towards technology, particularly when focusing on the non-paternalistic perspective (Evans et al., 2010; Olsen et al., 2014; Schubert, 2017). On the other hand, other evidence indicates that if the paternalistic view is emphasized (Grüne-Yanoff, 2012), these frames can lead to negative effects, including disagreement about whether the technology is truly natural or sustainable, resulting in punitive attitudes (Teeny & Petty, 2021; Walten & Wiedmann, 2022).

RQ2: Will information supporting the use of a representative heuristic when presenting precision fermentation technology affect the role of framing in influencing the attitude towards the technology?

We argue that when information prompts individuals to perceive similarity between a novel technology and a conventional one, the relatively unknown novel technology will be associated to a conventional technology that is highly accessible, and the subsequent attitude formation will rely on this representative heuristic (Kahneman & Tversky, 1972). By contrast framing focuses on a concrete technology case. Therefore, we hypothesize that the role of the representative heuristic will be more pronounced in this context (Kahneman, 2003), and that similarity will be more predictive of attitudes than framing (Fig. 1).

RQ3: Which personal traits and beliefs affect perceived usefulness of precision fermentation technology, and how does this perceived usefulness affect attitude to the technology and product purchase intention?

We argue that perceived usefulness is an antecedent of attitude to the technology, which, in turn, affects intention to purchase products where this technology has been employed. We have in the model discussed above identified a range of determinants of technology acceptance and want to test this model in a cross-cultural context.

Next, we present three studies in which participants were exposed to different types of framing ('natural' vs. 'sustainable') and the representative heuristic. They were then asked to evaluate their attitudes towards the novel technology (Studies 1 and 2), as well as various measures of antecedents in the technology acceptance model (Study 3).

3. Study 1: message framing of novel food technology

3.1. Method

Experimental design and stimuli: We experimentally examined how messages related to precision fermentation focusing on natural (vs. sustainable) goal affects consumers' attitudes towards this technology (Fig. 1). Therefore, we applied a between-subjects experimental design where we manipulated goal framing in two conditions: natural vs. sustainable. For the experimental stimuli, we used the same messages where wording was exchanged depending on the experimental

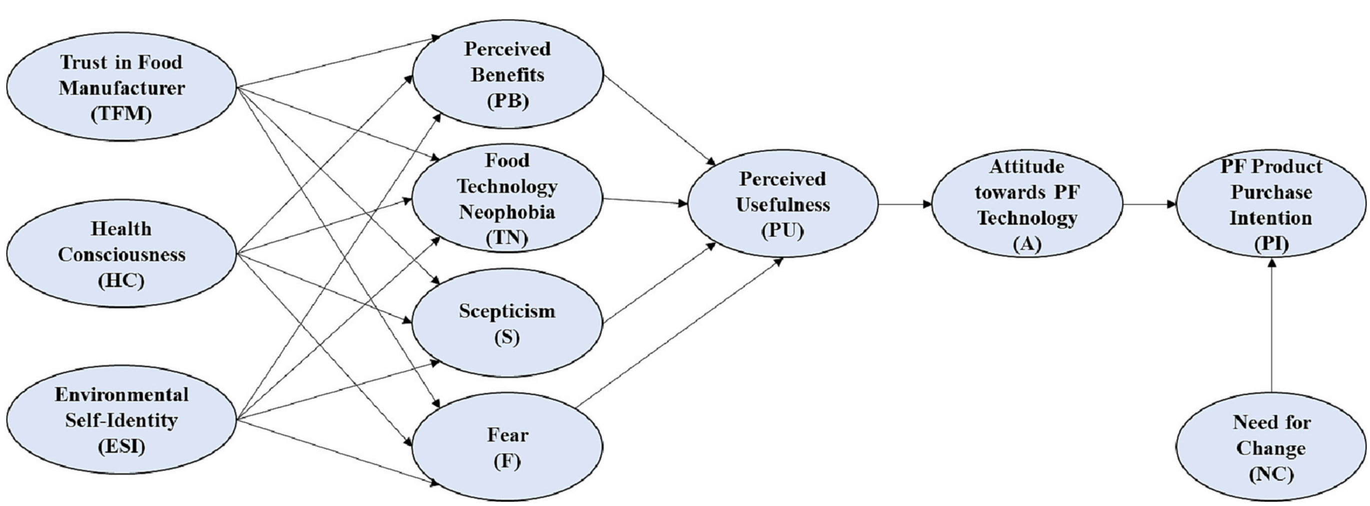

Fig. 2. Technology Acceptance Model (Study 3).

condition. Specifically, for the 'natural' framing we used the wording 'natural and wholesome,' while for the 'sustainable' framing, we used the wording 'sustainable and environmentally-friendly.' Thus, the final messages read: "Precision fermentation is a *natural* and *wholesome* (*vs. sustainable and environmentally-friendly*) *process* that uses yeasts as a factory to produce 100% pure protein."

Pre-test: The experimental stimuli were pre-tested on a total of 83 Danish students ($N_N = 40$; $N_S = 43$) with 56% of females with average age of 25 years ($SD = 3.01$, age range 22 to 38 years). Subjects in each condition provided ratings on 7-point scales to indicate the motivational focus of the message (1 = naturalness; 7 = sustainability) (Banovic & Barone, 2021). The pre-test results showed that after being exposed to natural (vs. sustainable) message content, as expected, subjects in the natural condition scored lower ($M = 3.30$, $SD = 1.38$) than subjects in the sustainable condition ($M = 5.16$, $SD = 1.45$; $t(81) = 5.91$, $p < 0.001$, $d = 1.42$), thereby indicating that participants could read and retain what they had read in their respective messages.

Procedure, measures, and participants: The data for Study 1 were collected through an online survey in Denmark based on its representative adult population in terms of gender and age. After the informed consent, subjects were randomly assigned to one of the two experimental conditions (natural vs. sustainable). They were then asked about the main motivation of the stimulus. As the main goal of the study was to experimentally investigate how messages depicting novel technology and focusing on different goals (natural vs. sustainable) affect consumers' attitudes towards this technology, subjects were asked to rate their attitudes towards precision fermentation technology on a 7-point bipolar scale using three items: negative/positive, unfavourbale/favourable, and bad/good (Kees, Burton, & Tangari, 2010). As an additional check, familiarity with the precision fermentation technology was assessed on a 7-point intensity scale ranging from 1 (not at all familiar) to 7 (very much familiar). The survey finished with the socio-demographic questions. The sample comprised 308 responses ($N_N = 161$; $N_S = 147$), with individuals representing 50% males in terms of gender, in the 20–70 age range ($M = 37.1$, $SD = 14.33$). There were no significant differences between the two conditions in terms of gender ($\chi^2 = 1.72$, $p = 0.423$, $V = 0.03$) and age ($t = 0.923$, $p = 0.357$, $d = 14.33$).

Data analysis: For the manipulation checks of the experimental condition in Study 1, a two-tailed independent sample *t*-test was used, similar to the pre-test. This was followed by testing of the attitude scale reliability (Cronbach alpha, α), after which one-way analysis of variance ANCOVA was conducted to account for the effect of the experimental conditions on the attitude.

3.2. Results: testing of goal framing effect

A two-tailed independent sample t-test, with experimental conditions (goal: natural vs. sustainable) as the independent variable, showed successful manipulation (Fig. 1). Subjects in the natural condition agreed that their stimulus focused on the technology being more natural ($N = 161$, $M = 2.90$, $SD = 1.59$), while participants in the sustainable condition agreed that it focused on the technology being more sustainable ($N = 147$, $M = 4.88$, $SD = 1.54$; $t(306) = 11.02$, $p < 0.001$, $d = 1.57$). As an additional check we found no differences between the experimental groups in terms of familiarity with precision fermentation technology ($M_N = 4.38$, $SD_N = 1.26$; $M_S = 4.45$, $SD_S = 1.28$ $t(306) = 0.501$, $p = 0.501$, $d = 1.27$). To determine whether the experimental conditions affected attitude towards technology, we conducted an ANCOVA with experimental conditions as a fixed factor and attitude towards technology ($\alpha = 0.95$) as a dependent variable. The results showed a significant direct effect of goal condition on attitude ($F(1,301) = 20.99$, $p < 0.001$, $\eta^2 = 0.07$), where subjects in the natural condition reported more positive attitude levels towards technology ($M = 5.19$, $SD = 1.20$) than participants in the sustainable condition ($M = 4.52$, $SD = 1.29$) (Fig. 3). Thus, as presumed, the effect of goal framing on the attitude towards the technology showed that a natural goal had more persuasive effect on attitude when compared to the sustainable goal. This formed the basis for Study 2 where we looked at supressing the effect of goal framing.

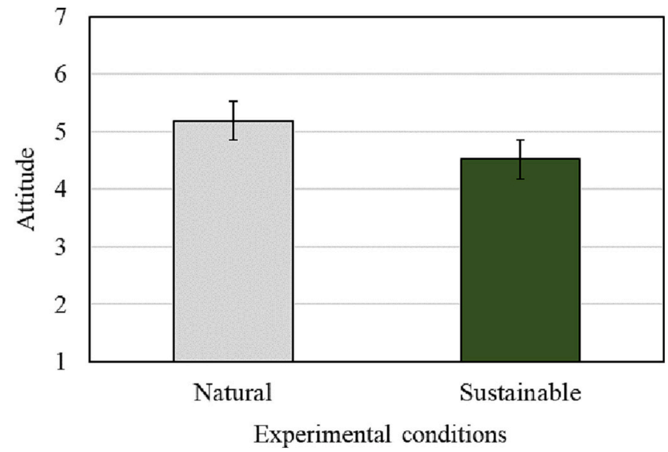

Fig. 3. Effect of experimental conditions on attitude towards precision fermentation technology (Study 1).
The bars display standard errors.

4. Study 2: representative heuristic and attitude towards novel technology

4.1. Method

Experimental design and stimulus: In Study 2, we conducted an experimental investigation to determine whether introducing a message that supports the use of the representative heuristic would be more predictive of individuals' attitude towards the technology compared to the framing (natural vs. sustainable) introduced in Study 1 (Fig. 1). A message designed to support use of a representative heuristic, and thus induce a perception of similarity of novel precision fermentation technology with the conventional technology read:

> "*Fermentation is a traditional method in the food industry for producing food products such as bread, beer, yoghurt, alcoholic beverages and more. While in regular fermentation the consumer consumes the entire fermented mass, in precision fermentation consumer consumes only the desired ingredient. This is done by filtering the fermenter's content to yield 100% pure protein.*"

The message has been carefully developed in collaboration with the company involved in the project to ensure an accurate portrayal of the precision fermentation process. Its primary objective was to provide participants with a clear understanding of the similarities and differences between traditional fermentation and precision fermentation. In traditional fermentation, the entire fermented mass is utilized for production, such as in the case of bread or beer. In contrast, precision fermentation, as suggested by its name, selectively utilizes only the desired ingredient, which, in our case, was protein.

Procedure, measures, and participants: After giving consent, participants were first confronted with the message aiming to assist use of a representative heuristic, presented above. Further, participants were randomly assigned to one of the two experimental conditions (see Study 1), in which goal framing (natural vs. sustainable) was manipulated. After being exposed to their assigned condition, each subject in Study 2 evaluated their attitude towards the novel technology, using the same scale in Study 1. We collected 300 responses from the Danish population to test the effect of the representative heuristic on the attitude towards precision fermentation technology. The final sample resulted in participants equally split into two experimental conditions ($N = 150$ per condition) with 20–70 age range ($M = 47.1$, $SD = 14.78$) and 51/49% male/female ratio. We found no significant differences between the two experimental conditions in terms of gender ($\chi^2 = 0.340$, $p = 0.844$, $V = 0.03$) and age ($t = 0.047$, $p = 0.963$, $d = 14.81$).

Data analysis: Similarly to Study 1, we used a two-tailed independent sample *t*-test for the manipulation check. Then we assessed attitude scale reliability and applied ANCOVA to test if the effect of the experimental conditions on the attitude remained the same or changed due to the use of representative heuristic.

4.2. Results: testing of representative heuristic effect

It is presumed that the effect of goal framing on attitude will be supressed if another message is introduced to assist perceptions towards similarity between the new and the conventional technology, and that any subsequent evaluations will be established on the base of this representative heuristic (Fig. 1). Thus, in making their evaluations, subjects would rather rely on the representative of the initial description, which provides a good exemplar of a known technology category, than on subsequent messages. To examine the impact of the message supporting the use of the representativeness heuristic, we conducted a manipulation check. Prior to presenting the message, we assessed participants' familiarity with precision fermentation technology using a 7-point Likert scale (ranging from 1 – strongly disagree to 7 – strongly agree) and the item 'I am very familiar with precision fermentation technology.' Subsequently, following the message, we again employed a 7-point Likert scale to measure the persuasiveness of the presented message, utilizing the item 'I feel convinced after viewing the message on precision fermentation technology.' The results showed that prior to the message presentation, on average, participants expressed indifference in terms of their familiarity with precision fermentation technology (M = 3.96, SD = 1.07). However, after viewing the message, participants, on average, reported being convinced by the precision fermentation technology message (M = 4.54, SD = 1.23). This indirectly shows that the message facilitated participants' understanding of the technology. We further employed a paired sample t-test, which provided further support for the impact of the message, indicating its persuasive nature (t (299) = 6.32, $p < 0.001$, d = 1.58).

Subsequently, we proceeded with a manipulation check of the experimental stimuli, confirming once more that the manipulation worked as planned ($M_N = 4.01$, $SD_N = 1.60$; $M_S = 4.71$, $SD_S = 1.47$; t (298) = 3.49, $p < 0.001$, $d = 1.54$). Further, we conducted a new ANCOVA to examine if the effect of the goal framing is inhibited by inducing similarity perceptions. We found no significant direct effects of goal condition on attitude ($F(1, 299) = 0.687$, $p = 0.408$, $\eta^2 = 0.02$), and no differences between natural and sustainable condition ($M_N = 4.71$, $SD_N = 1.24$; $M_S = 4.59$, $SD_S = 1.36$), confirming our assumptions for representative heuristic and participants relying on similarity (Fig. 4).

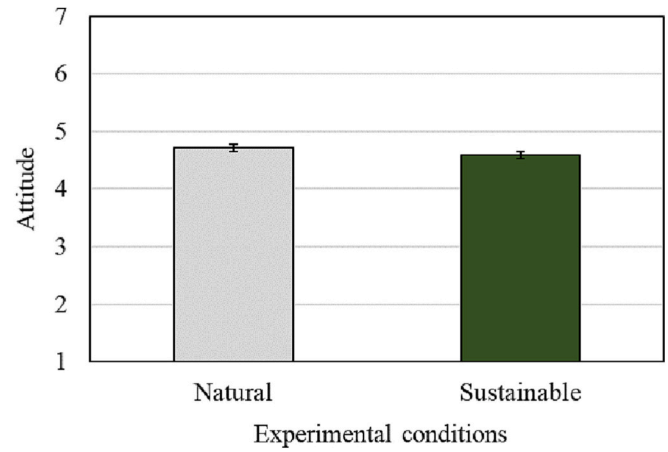

Fig. 4. Effect of representative heuristic on experimental conditions and attitude towards precision fermentation technology (Study 2). The bars display standard errors.

5. Study 3: food technology acceptance model

5.1. Method

Experimental design and stimuli: In Study 3, we evaluated the postulated technology acceptance model (as depicted in Fig. 2) in a cross-cultural context involving three European countries: Denmark, Germany, and Poland.

Procedure, measures, and participants: The conceptual framework in Fig. 2 was tested by measuring eleven constructs that were measured with a total of 45 items (Appendix 1). All items were translated and back-translated to Danish, German, and Polish following the method proposed by Brislin (1980). All preliminary versions of the questionnaire and items within, were first pretested with a convenience sample to identify any issues with item-formulation and language. All exogenous and endogenous variables (Fig. 2) were measured on the pre-validated scales and adapted for the purpose of the survey. With regard to four independent exogenous variables, 'trust in food manufacturers' was measured with 4 items, e.g., 'Food manufacturers take good care of the safety of our food.' that were adapted from the 'food chain trust' scale developed by Benson et al. (2020). 'Health-consciousness' was measured based on the scale by Michaelidou and Hassan (2008) and measured by 4 items, e.g. 'I reflect about my health a lot.' 'Environmental self-identity' contained 3 items from a scale developed by Van der Werff et al. (2013), e.g. 'I see myself as an environmentally-friendly person.' The final exogenous variable 'need for change' was adopted from Wood and Swait (2002) using 4 items related to the willingness of buying new products, e.g., 'When I see a new or different product on the shelf, I often pick it up just to see what it is like.' All abovementioned items of the exogenous variables were measured on a 7-point Likert scale with endpoints ranging from 1- strongly disagree to 7 - strongly agree. As for the four endogenous variables, the 'food technology neophobia' measure was adapted from Cox and Evans (2008) and based on the subscale 'new food technologies are unnecessary.' Further, 'skepticism' was measured with 2 items previously used as measures of skepticism for advertisements (Obermiller & Spangenberg, 1998) (e.g., 'I have doubts in this precision fermentation method'). Statements from both food technology neophobia and skepticism scales were measured on the 7-point Likert scale (i.e., 1- strongly disagree to 7 - strongly agree). The 'perceived benefits' scale consisted of 6 items (Banović, Grunert, Barreira, & Fontes, 2009; Kim & Woo, 2016) measured on a 7-point intensity scale with endpoints ranging from 1 (not at all) to 7 (extremely) (e.g., 'healthy'). The endogenous variable 'fear' was measured based on 5 items (Laros & Steenkamp, 2004) and also assessed on a 7-point intensity scale with endpoints, 1 (not at all) to 7 (extremely) (e.g., 'afraid'). As for the three dependent variables, 'perceived usefulness' was assessed by 6 items (Chin, Johnson, & Schwarz, 2008) and measured on a 7 – point bipolar scale (e.g., 'Using the precision fermentation in the food industry is… ineffective *vs.* effective'). 'Attitude' towards technology was measured in the same way as in Study 1 and 2. Finally, 'purchase intention of products from precision fermentation' technology was based on a scale from Baker and Churchill Jr (1977) which was adapted for the purpose of the study, e.g., 'I would buy a product if produced with precision fermentation technology,' and was measured on a 7-point bipolar scale with endpoints, 1 (definitely no) to 7 (definitely yes).

We collected data through an online survey in Denmark, Germany, and Poland through a certified market research agency to obtain a sample representative of the adult population in terms of gender, age, and region ($N = 3032$) (Table 1). As the focus of the study is on technology acceptance in food production, only respondents who indicated to have full responsibility or shared responsibility for the food household purchases were considered, while individuals who do not partake part in

Table 1
Sociodemographic characteristics of the participants (Study 3).

	Total N = 3032	Denmark N = 1028	Germany N = 1004	Poland N = 1000
Gender (%)				
Female	51.5	51.5	51.2	51.8
Age (mean)	45.7	46.8	46.2	44.1
Education (%)				
Primary school	5.4	8.6	5.2	2.3
Secondary school	34.5	15.7	50.0	38.3
Higher education	20.5	28.9	21.1	11.2
Bachelor	16.1	24.3	11.4	12.5
Master/PhD	23.5	22.6	12.4	35.7
Children (%)				
Have children	60.8	62.8	51.3	68.1
Marital status (%)				
Married/Co-habiting	62.2	62.5	57.0	67.2
Single	34.0	33.4	40.6	27.9
Other (i.e., widowed, divorced)	3.9	4.2	2.4	4.9

food purchases were screened out. The final sample of participants in the study was representative of the Danish, German, and Polish populations in terms of age and gender (Table 1). Although there were no significant differences observed between the countries regarding age and gender distribution, it is worth noting that a slightly higher proportion of highly educated participants was found in Poland (35.7%) compared to Denmark (22.6%) and Germany (12.4%). Furthermore, the distribution of marital status and presence of children varied across the countries. Poland and Denmark had a higher proportion of married participants with children (married: 67.2% and 62.5%, with children: 68.1% and 62.8%, respectively). In contrast, Germany had a higher proportion of single participants (40.6%). The above highlights the demographic characteristics of the sample and provide insights into the variations observed across the countries in terms of education, marital status, and number of children.

Data analysis: The proposed model in Fig. 2 was tested using structural equation modelling (SEM) in AMOS 28.0 as recommended by Byrne (2012), Deng and Yuan (2015), and Steenkamp and Baumgartner (1998). SEM was used as it offers flexibility when modelling the proposed relationships among several observed predictors and criterion variables based on unobserved latent variables, allowing for a moderation by a nominal variable (i.e., country) (Byrne, 2012).

Prior to SEM analyses, variables were assessed for normality, linearity, validity, and multicollinearity (Cohen, Cohen, West, & Aiken, 1983). Additionally, observed variables were mean-centred for more meaningful and interpretable solutions (Algina & Moulder, 2001; Marsh et al., 2007). The postulated model has been tested in two steps as recommended by (Byrne, 2012). Firstly, confirmatory factor analysis (CFA) was conducted to assess the measurement model, including validity of the measures, and the number of underlying factors (i.e., dimensional invariance). The estimated CFA model was further checked for convergent and discriminant validity and reliability as recommended by Bagozzi and Yi (1988) and Hu and Bentler (1999). Standardized factor loadings (SFLs) and construct reliability (CR) of at least 0.70, average variance extracted (AVE) >0.50, and square root of AVE (SQRAVE) should be greater than inter-construct correlations were considered. Common method bias (CMB) test was addressed through common latent factor (CLF) procedure comparing SFLs with and without CLF, and examining the differences in $\chi 2$ (Gaskin & Lim, 2017; Gaskin, Lim, & Steed, 2022; Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). Measurement invariance across groups (countries) was assessed through configural, metric, and scalar invariance to ensure equivalence of latent constructs (Steenkamp & Baumgartner, 1998). Finally, multi-group SEM was used to test the relationships between psychological constructs in the postulated model, including moderation effects (e.g., goal framing, country differences), assessed through critical ratios and $\chi 2$ difference tests (Gaskin, 2019).

To assess the goodness of fit for both the overall measurement model and the full structural model, four groups of indices were utilized (Byrne, 2012): (i) $\chi 2/df$ with values below 5; (ii) comparative fit index (CFI) and Tucker–Lewis Index (TLI) with values above 0.95; (iii) goodness of fit (GFI) and adjusted goodness of fit (AGFI) with values for GFI > 0.95 and AGFI >0.90, and (iv) root mean square error of approximation (RMSEA) with values below 0.05.

5.2. Results: estimation of food technology acceptance model

To further elaborate on the previous notion and examine the robustness of the observed effect, we initially assessed whether participants perceived the information they read about precision fermentation as trustworthy. The results indicated that, overall, participants perceived the information to be trustworthy ($M = 5.00$, $SD = 1.41$). Among the participants, 10.5% perceived the information as 'not at all trustworthy' to 'slightly untrustworthy', 26.0% found it to be 'moderately trustworthy', and the majority, 63.5% rated it as 'trustworthy' to 'extremely trustworthy'. The perception of trustworthiness did not differ between the two experimental groups ($M_N = 5.02$, $SD_N = 1.40$; $M_S = 4.96$, $SD_S = 1.41$; $t\,(3030) = 1.34$, $p = 0.179$, $d = 1.35$), as well as across investigated countries ($F(2,\ 3029) = 0.102$, $p = 0.903$, $\eta^2 = 0.00$). Additionally, trustworthiness was positively correlated with the attitude towards precision fermentation technology ($r = 0.43$, $p < 0.001$). We acknowledge that credibility and trustworthiness are not the same construct, although used interchangeably in the literature (e.g., Thorsøe, 2015). Nevertheless, it has been found that increasing levels of trust are related to source credibility that result in increased persuasion of the message, having positive downstream effects on product attitude and purchase intention (Kim & Kim, 2021). This in particular when providing analog information of a familiar referent that can further enhance the acceptance (Nijssen, Reinders, & Banovic, 2021).

Further, we proceed by estimating measures from the proposed technology acceptance model (Fig. 2) in a cross-cultural context. The initial check of the different factors with independent sample *t*-tests showed no significant differences between the mean values of the experimental conditions across countries (all $p_s > 0.05$) (Table 2). However, one-way ANOVA conducted with country as a factor showed significant differences across countries within experimental conditions and on the pooled sample (Table 2). We further conducted two-way MANOVA with all averaged factors as dependent variables and experimental conditions and country as fixed factors to determine if there is an interaction between the experimental conditions and country on the observed dependent variables presented in Table 2. We found that the interaction effect between the experimental conditions and the country is not significant, ($\Lambda = 0.450$, $p = 0.983$), which indicates that the effect of the experimental conditions on the dependent variables is the same and holds across countries. MANOVA also confirmed that there are no differences between goal framing messages ($\Lambda = 0.889$, $p = 0.543$) and that the differences are only observed at the country level ($\Lambda = 26.99$, $p < 0.001$). As the difference has only been found on the country level, we proceed with model estimation (Fig. 2) on the pooled sample using country as a moderator variable.

Measurement model: We first tested the fit of the measurement model (Table 3). Three observed variables, namely HC4, NC4 and PI4, showed standardized factor loadings (SFLs) below 0.70, and these variables have been removed from further analysis. This also improved initial overall fit of the model ($\chi 2$ (3512) = 10,871.89, $p < 0.001$, $\chi 2/df = 3.10$; $CFI = 0.97$; $TLI = 0.97$; $GFI = 0.93$; $AGFI = 0.91$; $RMSEA = 0.019$) to more satisfactory levels: $\chi 2$ (3020) = 8244.35, $p < 0.001$, $\chi 2/df = 2.73$; $CFI = 0.98$; $TLI = 0.97$; $GFI = 0.95$; $AGFI = 0.92$; $RMSEA = 0.017$). All other SFLs were above 0.70 and significant at $p < 0.001$ level (Table 3). Further, we calculated values for the average variance extracted (*AVE*) and the composite reliability (*CR*) to account for constructs' convergent

Table 2
Observed measures across countries (Study 3).

Measures	Total sample N = 3032 mean (α)			Denmark (DK) N = 1028 mean (α)			Germany (DE) N = 1004 mean (α)			Poland (POL) N = 1000 mean (α)			*F*-test *p – value* (η^2)		
	N^{+}	S	P	N	S	P	N	S	P	N	S	P	N	S	P
Trust in Food Manufacturers (TFM)															
	4.13 (0.91)	4.14* (0.92)	4.13 (0.91)	4.01^{a} (0.90)	3.89^{a} (0.91)	3.95^{a} (0.91)	$4.17^{a,b}$ (0.91)	4.21^{b} (0.90)	4.19^{b} (0.93)	4.23^{b} (0.92)	4.31^{b} (0.93)	4.27^{b} (0.93)	0.023 (0.01)	< 0.001 (0.02)	< 0.001 (0.01)
Health consciousness (HC)															
	5.11 (0.88)	5.09 (0.88)	5.10 (0.88)	5.17 (0.89)	5.21^{a} (0.90)	5.19^{a} (0.90)	5.09 (0.88)	5.00^{b} (0.86)	5.04^{b} (0.87)	5.06 (0.87)	$5.07^{a,b}$ (0.88)	5.06^{c} (0.87)	0.327 (0.001)	0.015 (0.01)	< 0.001 (0.01)
Environmental Self-Identity (ESI)															
	4.82 (0.92)	4.83 (0.92)	4.82 (0.92)	4.42^{a} (0.91)	4.48^{a} (0.92)	4.45^{a} (0.92)	4.96^{b} (0.94)	4.94^{b} (0.93)	4.94^{b} (0.94)	5.07^{b} (0.88)	5.09^{b} (0.91)	5.08^{b} (0.90)	< 0.001 (0.05)	< 0.001 (0.04)	< 0.001 (0.04)
Perceived Benefits (PB)															
	4.64 (0.95)	4.60 (0.94)	4.62 (0.94)	4.45^{a} (0.92)	4.35^{a} (0.92)	4.40^{a} (0.92)	4.58^{a} (0.94)	4.55^{b} (0.96)	4.58^{b} (0.94)	4.90^{b} (0.96)	4.92^{c} (0.97)	4.91^{c} (0.96)	< 0.001 (0.02)	< 0.001 (0.03)	< 0.001 (0.03)
Skepticism (S)															
	3.46 (0.83)	3.51 (0.82)	3.49 (0.83)	3.57^{a} (0.81)	3.68^{a} (0.81)	3.63^{a} (0.81)	3.53^{a} (0.85)	3.59^{a} (0.87)	3.56^{a} (0.81)	3.28^{b} (0.81)	3.26^{b} (0.86)	3.27^{b} (0.83)	<0.001 (0.02)	<0.001 (0.02)	<0.001 (0.01)
Fear (F)															
	2.64 (0.96)	2.73 (0.96)	2.69 (0.96)	2.53^{a} (0.96)	2.69^{a} (0.95)	2.61^{a} (0.96)	2.90^{b} (0.95)	3.00^{b} (0.95)	2.95^{b} (0.95)	2.49^{a} (0.97)	2.51^{a} (0.97)	2.50^{a} (0.97)	< 0.001 (0.02)	<0.001 (0.02)	<0.001 (0.02)
Technology Neophobia (TN)															
	3.75 (0.87)	3.80 (0.88)	3.77 (0.88)	3.44^{a} (0.87)	3.52^{a} (0.87)	3.48^{a} (0.87)	4.14^{b} (0.88)	4.17^{b} (0.89)	4.15^{b} (0.89)	3.67^{c} (0.86)	3.72^{c} (0.87)	3.69^{c} (0.86)	<0.001 (0.04)	<0.001 (0.04)	<0.001 (0.04)
Perceived Usefulness (PU)															
	4.85 (0.96)	4.74 (0.96)	4.79 (0.95)	4.83^{a} (0.94)	$4.71^{a,b}$ (0.94)	4.77^{a} (0.94)	$4.74^{a,b}$ (0.95)	4.58^{a} (0.94)	4.66^{a} (0.95)	4.98^{b} (0.96)	4.93^{b} (0.97)	4.96^{b} (0.97)	0.009 (0.02)	<0.001 (0.02)	<0.001 (0.02)
Attitude (A)															
	4.82 (0.95)	4.73 (0.95)	4.78 (0.95)	4.75^{a} (0.95)	4.58^{a} (0.95)	4.66^{a} (0.95)	4.62^{a} (0.92)	4.57^{a} (0.92)	4.60^{a} (0.92)	5.07^{b} (0.96)	5.01^{b} (0.97)	5.07^{b} (0.96)	<0.001 (0.02)	<0.001 (0.03)	<0.001 (0.02)
Need for Change (NC)															
	3.95 (0.83)	3.90 (0.84)	3.92 (0.84)	3.52^{a} (0.85)	3.55^{a} (0.85)	3.54^{a} (0.85)	3.86^{b} (0.80)	3.79^{b} (0.83)	3.82^{b} (0.82)	4.48^{c} (0.81)	4.37^{c} (0.82)	4.42^{c} (0.81)	< 0.001 (0.08)	<0.001 (0.06)	<0.001 (0.07)
PF Product Purchase Intention (PI)															
	4.30 (0.91)	4.23 (0.93)	4.26 (0.92)	4.04^{a} (0.86)	3.94^{a} (0.89)	3.99^{a} (0.87)	4.17^{a} (0.93)	4.11^{b} (0.94)	4.14^{b} (0.93)	4.70^{b} (0.92)	4.65^{c} (0.94)	4.68^{c} (0.93)	<0.001 (0.01)	<0.001 (0.01)	<0.001 (0.01)

N – Natural experimental condition; S – Sustainable experimental condition; P – Pooled sample.
*Independent samples *t*-test across natural and sustainable experimental conditions show no significant differences within countries, all $p_s > 0.05$.
a,b,cLetters related to Post-hoc Tamhane *t*-test associated to *F*-test; different letters show significant differences across countries at $p < 0.05$ level.

validity, which showed all the values above recommended threshold of 0.50 and 0.70, respectively. Further AVE was greater than maximum-shared variance (MSV), and square root of AVE was greater than inter-construct correlations among eleven latent variables confirming discriminant validity (Appendix 1).

Common method bias test: The results showed differences of <0.20 between standardized regression weights from the model with CLF compared to the standardized regression weights of an unconstrained model (without CLF), thus indicating no bias issues. The bias test further confirmed this thereby demonstrating no significant differences between the constrained, and unconstrained, model ($\Delta\chi 2(52) = 57.17$, $p = 1.000$).

Measurement invariance: Measurement invariance analysis showed that the observed factors were invariant across the three countries (i.e., metric invariance: $\Delta\chi 2(318) = 289.44$, $p = 0.873$; scalar invariance: $\Delta\chi 2$ $(639) = 683.71$, $p = 0.107$) that permitted for a meaningful comparison between the groups (i.e., countries) (Steenkamp & Baumgartner, 1998). The assessed model also showed a satisfactory fit (uncontained model: $\chi 2$ $(2265) = 5145.56$, $p < 0.001$, $\chi 2/df = 2.72$; $CFI = 0.98$; $TLI = 0.97$; $GFI = 0.95$; $AGFI = 0.92$; $RMSEA = 0.020$) that provided a reasonable evidence in support of measurement invariance.

Structural model: Multi-group SEM was applied to estimate the postulated model (Fig. 2) and explore potential differences at the path level among the three countries (DK, DE, and POL). The chi-square difference test investigated whether meaningful comparisons could be made at the model level across countries. Initially, an unconstrained model was estimated allowing path coefficients to vary freely across the countries. Subsequently, a constrained model was computed constraining all path coefficients to be equal across countries. Model comparison analysis showed no significant differences between the models ($p = 1.00$). Local tests comparing specific path coefficients across countries (pairwise comparison) also generally showed no significant differences ($p_s > 0.050$). These findings demonstrated the robustness of the model, leading us to proceed with estimation of the full model without country as the moderator.

The estimated final structural model produced satisfactory overall fit: $\chi 2$ $(2265) = 5145.56$, $p < 0.001$, $\chi 2/df = 2.72$; $CFI = 0.98$; $TLI = 0.97$; $GFI = 0.95$; $AGFI = 0.92$; $RMSEA = 0.020$, with significant path estimates (Fig. 5). As seen from Fig. 5, the results show that 'trust in food manufacturers' strongly positively affects 'perceived benefits' of precision fermentation technology ($\beta = 0.59$, $p < 0.001$), while at the same time it also strongly negatively influences 'skepticism' towards this novel technology ($\beta = -0.70$, $p < 0.001$). Lower levels of 'trust' are associated to higher levels of 'food technology neophobia' ($\beta = -0.24$, p

Table 3
Results of Confirmatory Factor Analysis (CFA) (Study 3).

	Total sample			Denmark			Germany			Poland		
	N = 3032			N = 1028			N = 1004			N = 1000		
	SFL	CR	AVE	SFL	CR	AVE	SFL	CR	AVE	SFL	CR	AVE
Trust in Food Manufacturers (TFM)		0.92	0.73		0.91	0.71						
TFM1	0.91*			0.90			0.91	0.91	0.71	0.93	0.93	0.76
TFM2	0.74			0.75			0.73			0.74		
TFM3	0.87			0.83			0.86			0.90		
TFM4	0.89			0.88			0.88			0.91		
Health consciousness (HC)		0.88	0.70		0.90	0.73		0.88	0.71		0.87	0.69
HC1	0.87			0.83			0.87			0.89		
HC2	0.77			0.85			0.76			0.73		
HC3	0.88			0.87			0.90			0.87		
Environmental Self-Identity (ESI)		0.92	0.79		0.92	0.79		0.94	0.83		0.90	0.75
ESI1	0.89			0.87			0.91			0.88		
ESI2	0.89			0.93			0.92			0.81		
ESI3	0.89			0.86			0.90			0.90		
Perceived Benefits (PB)		0.94	0.74		0.92	0.66		0.94	0.73		0.96	0.82
PB1	0.88			0.84			0.88			0.91		
PB2	0.82			0.74			0.85			0.87		
PB3	0.83			0.75			0.81			0.90		
PB4	0.83			0.77			0.82			0.90		
PB5	0.87			0.86			0.85			0.91		
PB6	0.92			0.90			0.92			0.93		
Skepticism (S)		0.82	0.70		0.81	0.69		0.82	0.69		0.84	0.72
S1	0.84			0.80			0.87			0.83		
S2	0.84			0.86			0.80			0.87		
Fear (F)		0.96	0.82		0.96	0.81		0.95	0.80		0.97	0.85
F1	0.93			0.93			0.91			0.94		
F2	0.87			0.84			0.88			0.90		
F3	0.89			0.91			0.86			0.91		
F4	0.90			0.90			0.91			0.91		
F5	0.92			0.92			0.90			0.95		
Food Technology Neophobia (TN)		0.88	0.64		0.87	0.63		0.89	0.66		0.87	0.62
TN1	0.81			0.83			0.82			0.74		
TN2	0.77			0.77			0.78			0.76		
TN3	0.82			0.79			0.84			0.83		
TN4	0.81			0.79			0.80			0.80		
Perceived Usefulness (PU)		0.95	0.76		0.94	0.72		0.94	0.73		0.97	0.83
PU1	0.89			0.89			0.85			0.93		
PU2	0.84			0.78			0.82			0.89		
PU3	0.84			0.81			0.78			0.90		
PU4	0.92			0.91			0.91			0.94		
PU5	0.87			0.81			0.88			0.90		
PU6	0.89			0.87			0.89			0.90		
Attitude (A)		0.95	0.85		0.95	0.87		0.92	0.79		0.96	0.89
A1	0.94			0.93			0.92			0.95		
A2	0.89			0.92			0.82			0.93		
A3	0.94			0.94			0.92			0.95		
Need for Change (NC)		0.84	0.64		0.88	0.70		0.81	0.60		0.82	0.61
NC1	0.77			0.83			0.75			0.70		
NC2	0.86			0.85			0.83			0.87		
NC3	0.78			0.84			0.73			0.77		
PF Product Purchase Intention (PI)		0.91	0.77		0.88	0.70		0.92	0.80		0.92	0.80
PI1	0.93			0.91			0.93			0.93		
PI2	0.88			0.87			0.90			0.88		
PI3	0.82			0.71			0.85			0.87		

SFL – Standardized Factor Loadings; CR - Composite Reliability; AVE - Average Variance Extracted.
* All SFLs are significant at $p < 0.001$ level.

< 0.001) and ‘fear’ ($\beta = -0.14$, $p < 0.001$), indicating a negative correlation between trust and technology neophobia/fear.

Furthermore, we found a negative relationship between ‘food technology neophobia’ and ‘environmental self-identity’ ($\beta = -0.15$, $p < 0.001$), indicating that participants who are less environmentally conscious exhibit higher levels of neophobia. Similarly, fear is intensified among participants who have lower levels of both health consciousness ($\beta = -0.13$, $p < 0.001$) and environmental consciousness ($\beta = -0.11$, $p < 0.001$).

In terms of ‘perceived usefulness’ of precision fermentation, we found a strong positive influence of ‘perceived benefits’ ($\beta = 0.36$, $p < 0.001$), while ‘fear’ ($\beta = -0.23$, $p < 0.001$), ‘food technology neophobia’ ($\beta = -0.19$, $p < 0.001$) and ‘skepticism’ ($\beta = -0.09$, $p < 0.001$) had a weakening effect. Furthermore, ‘perceived usefulness’ significantly impacts attitude towards precision fermentation technology ($\beta = 0.25$, $p < 0.001$), which in turn is related to purchase intention of products coming from precision fermentation technology ($\beta = 0.80$, $p < 0.001$). Additionally, purchase intention is positively influenced by those participants who have a higher ‘need for change’ ($\beta = 0.25$, $p < 0.001$).

6. Discussion, limitations, and future research

6.1. Discussion

Our study sheds light on the determinants and effects of consumer acceptance and attitude towards precision fermentation technology.

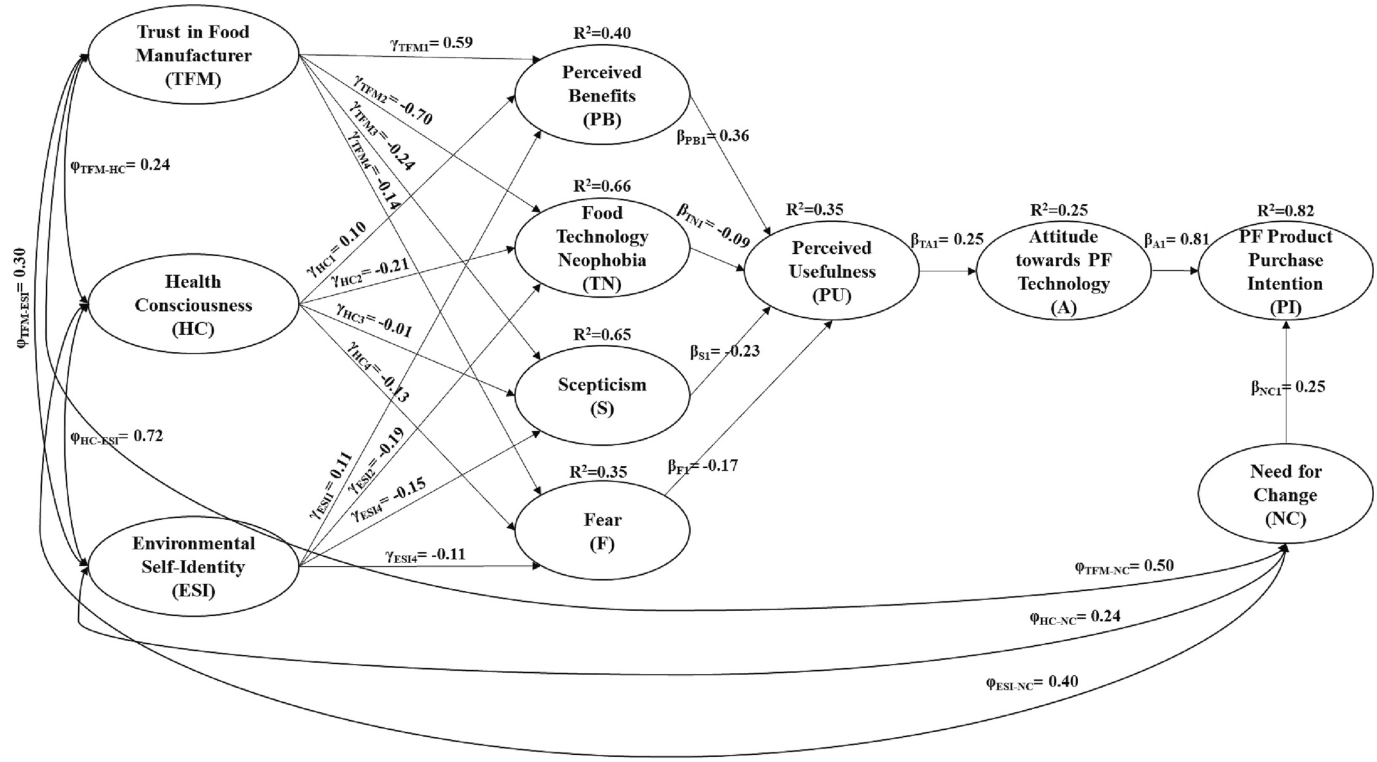

Fig. 5. Results of Structural Equation Modelling (SEM) (Study 3).
In the model γ's and β's are regression coefficients, φ are covariance's.
All the regression coefficients significant at $p < 0.001$, except for γ_{HC3} with the $p = 0.744$.

One crucial aspect we explore is the role of framing and its impact on attitudes towards this innovative technology, showing the importance of considering how various frames can shape the perception of technology. Our findings have shown that using natural (vs. sustainable) goal framing enhances consumer attitudes towards precision fermentation technology. This aligns with previous research that has also highlighted the positive effects of natural framing on individual perceptions (Roman et al., 2017; Rozin et al., 2012). Even though the natural (or sustainable) framing could have potentially evoked negative reactions from consumers, particularly if they disagree (Teeny & Petty, 2021), find it not credible (Walten & Wiedmann, 2022), or view it as paternalistic (Grüne-Yanoff, 2012), our study found that the majority of consumers reacted positively to the use of natural framing, thereby increasing consumers' attitudes towards the technology. These findings suggest that claims that are framed as 'natural' or 'naturally' are more likely to be accepted when they support beliefs about legitimate goals and align with the mindset and values of the consumers. This aligns with a previous study conducted in Europe by Reisch and Sunstein (2016), which explored informational non-paternalistic nudges (such as calorie labels, salt labels, and the 'traffic lights' system labels). Their study revealed strong support among the majority of Europeans for the nudges that have been implemented in the EU with careful regulatory considerations.

It is important to note that while something being sustainable or not can be theoretically measured (e.g., meat consumption), naturalness is often subjectively perceived. The EU has existing legislation on nutritional claims, regulated by (EC) No 1924/2006 and (EU) No 1047/2012 (EC, 2023b), which provides clear guidelines and criteria for objectively assessing and classifying products as 'natural' or 'naturally' containing specific ingredients. This legislation ensures that labelling practices comply with the defined criteria, preventing any misleading or deceptive claims. However, in the context of precision fermentation technology, it is crucial to further establish a comprehensive framework that considers various factors beyond ingredient classification, including ingredient sourcing, production process, and potential environmental impacts (as within the new EU's legislative framework for sustainable food systems) (EC, 2023a). Additionally, consumer perceptions should be taken into account to create a balanced and transparent system. Ultimately, implementing additional legislation to determine the naturalness of products would provide consumers with reliable and accurate information, while also ensuring fair competition among producers.

Additionally, we have shown that incorporating a message that encourages the use of a simple heuristic, specifically the representative heuristic based on similarity of the new technology with traditional technology, can further heighten consumers' attitudes. This approach can be employed as an independent strategy to promote precision fermentation, as suggested by some authors (Kahneman & Tversky, 1972; Read & Grushka-Cockayne, 2011; Siegrist, 2019).

The two most important determinants of acceptance of precision fermentation that we have identified in our model are perceived benefits and technology neophobia. The two determinants are quite different in terms of their implications for perceived usefulness of the technology. Perceived benefits is a bottom-up factor (Scholderer & Frewer, 2003) – the view of the technology and its acceptability is informed by information about potential positive consequences of the application of the technology. This implies that acceptance of precision fermentation can be improved by informing consumers about the technology, particularly its benefits, while also considering relevant insights about message framing. Technology neophobia, on the other hand, is a top-down factor – consumers do not reject precision fermentation because of specific characteristics or risks, but rather because they categorize it as just another instance of new food technology, which is inherently undesirable for people with high technology neophobia. This cannot be mitigated by giving more information about the benefits or lack of risks of the technology. It can, however, be possibly mitigated by encouraging consumers not to categorize the technology as new, in line with the communication tested in study 2.

Both perceived benefits and technology neophobia were strongly influenced by trust in food manufacturers. Trust has previously been shown to be a strong predictor of consumers' confidence in food technologies, i.e., consumers' beliefs that a technology will result in tasty, safe, healthy, sustainable, and authentic food products (Macready et al., 2020). Trust is not easily changed in the short run as it develops gradually over time. However, trust has a cognitive basis (Johnson & Grayson, 2005) that is affected by the actions of food manufacturers, and here the perceived openness and care of food manufacturers has been shown to play a major role (De Jonge, Van Trijp, Goddard, & Frewer, 2008; Macready et al., 2020). Openness about the technologies used, their benefits, and potential risks can contribute to building trust and, over time, increase confidence in novel technologies such as precision fermentation.

We found that both health consciousness and environmental self-identity have a positive impact on the perceived benefits of precision fermentation and also decrease food technology neophobia. Health consciousness and environmental concern are factors that can be expected to lead to an increased interest in characteristics of products and technologies that promote healthier eating and more environmentally friendly food production (Banovic & Barone, 2021; Banovic & Otterbring, 2021). The respondents in this study who displayed greater levels of health and environmental consciousness appear to have acknowledged the positive effects of precision fermentation on the healthiness of food products and their environmental impact.

It is also notable that the relationships described above did not differ between the countries in the study. Culture has otherwise been noted as one of the factors impacting acceptance of new food technologies (Giordano, Clodoveo, De Gennaro, & Corbo, 2018). It is important to note that the findings of this study may not apply universally to all food technologies. This may not apply to all food technologies. Precision fermentation, being relatively unknown concept, and its framing as a non-disruptive technology or as an extension of traditional fermentation, may have contributed to the lack of cultural differences found in this study.

6.2. Limitations and future research

This study focused specifically on one particular technology, precision fermentation, and as such, the results cannot be generalized to other food technologies. However, we do believe that the technology acceptance model has broader applicability, can be further adapted, and should be considered for application and extension to other food technologies. Additionally, it is important to note that while this is a multi-country study, all countries are Western European countries. Therefore, the results should not be generalized to other regions, for example, Asian countries.

We only tested different message framings in the way the technology was presented (natural vs. sustainable), and additionally, manipulated the perceived similarity to existing technology (i.e., representative heuristic). Many other ways of communicating about the technology could be investigated. One particular important point is that we did not mention GMOs in our messages. Ingredients from precision fermentation do not include GMO material, however they have been produced using GMO microorganisms. It is worth noting that mentioning this aspect may influence consumer judgement (see Søndergaard, Grunert, & Scholderer, 2005), as demonstrated in their investigation of enzyme production.

7. Conclusion

Our study provides valuable insights into consumer attitudes towards precision fermentation and offers guidance on promoting acceptance of this innovative technology. One key finding is the impact of framing. Presenting precision fermentation as 'natural' rather than 'sustainable' leads to more positive attitudes. Additionally, leveraging the representative heuristic, which emphasizes familiarity with traditional technologies, independently promotes positive attitudes. This strategy proves effective regardless of the framing used, such that consumers perceive precision fermentation favourably. Furthermore, our cross-cultural food technology acceptance model demonstrates its reliability as a framework for understanding and predicting consumer attitudes and purchase intentions towards products from precision fermentation. Factors such as perceived benefits and technology neophobia, play crucial roles in shaping consumer attitudes. Overall, our findings highlight the importance of framing, the utilization of the representative heuristic, and the consideration of perceived benefits and technology neophobia in shaping consumer attitudes. Effective communication and education can help consumers overcome barriers and embrace the potential of precision fermentation. By implementing these strategies and addressing consumer concerns, we can foster positive attitudes and broader acceptance of precision fermentation.

Credit author statement

Marija Banovic: Conceptualization, Research Design, Methodology, Investigation, Experimental Work, Formal Analysis, Funding Acquisition, Project Administration, Writing - Reviewing & Editing;

Klaus G. Grunert: Conceptualization, Research Design, Methodology, Writing - Reviewing & Editing.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee as outlined in the Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ifset.2023.103435.

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