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TITLE PAGE

Cross-Cultural Consumer Valuation of Precision Fermentation Milk: Effects of Information, Individual Traits, and Labelling Preferences

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Compliance with ethical standards

Ethical approval: The present research has obtained ethical approval from the Research Ethics Committee at Aarhus BSS, Aarhus University, Approval number: BSS-2024-045. Participants were fully informed about the purpose of the study and provided with an explanation of the background and objectives of the research project. 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.

Abstract

The adoption of alternative protein sources, including precision fermentation (PF) milk, emerges as a key strategy for sustainably nourishing a growing population, offering a viable alternative to conventional dairy production. This study investigates how different information framing, on animal welfare, health, and environmental benefits, affects consumer willingness-to-pay (WTP) for PF milk in Denmark (DK), Italy (IT), the United Kingdom (UK), and the United States (US). Using a choice experiment (CE) that examined milk products varying on several attributes, namely type of milk technology, animal welfare information, protein type, Carbon Trust label, and price, we found that consumers generally exhibited reluctance towards PF milk. This reluctance varied by country, the type of benefits provided, and consumer traits. Additionally, latent class analysis identified three consistent consumer segments across all countries, strong traditionalists with strong preferences for conventional cow milk, light traditionalists open to alternatives but price-sensitive, and a third group with inconsistent (random) choices, highlighting both commonalities and cross-country differences in responses to PF milk. Consumer preferences for policy labelling of PF dairy products vary by country, with the US and Italy exhibiting a higher preference for these new products labelled similarly to conventional dairy products. These findings offer valuable directions for effectively communicating the benefits of PF milk products across different cultural contexts. They highlight key marketing strategies for differentiation and competition in a market crowded with conventional dairy and plant-based options. Finally, they underscore important strategic and policy implications for future labelling and regulations of PF milk.

Cross-Cultural Consumer Valuation of Precision Fermentation Milk: Effects of Information, Individual Traits, and Labelling Preferences

1. Introduction

Policy makers and the dairy sector face the critical task of mitigating environmental impacts while fulfilling societal nutritional and animal welfare demands of the increasing population (FAO et al., 2022). In the European countries, the largest livestock greenhouse gas (GHG) emissions are produced from the dairy sector including the enteric fermentation from ruminants (Eurostat, 2022). Given dairy sectors' significant role in offering essential nutrients and contributing to food security and poverty alleviation, sustainable growth in the dairy sector is paramount (FAO, 2023; Humpenöder et al., 2022). This entails not only embracing practices that reduce GHG emissions and foster resilience against climate change (Oyinbo & Hansson, 2024), but also securing the transformation of the dairy sector to ensure healthy, nutritional diets and promote animal welfare in the process (Eurobarometer, 2023; Van Peteghem et al., 2022).

Transition to alternative protein sources is identified as a key strategy for feeding an increasing global population and combating climate change (EC, 2020a), as well as meeting the increasing consumer demand for more environmental friendly (Banovic et al., 2022; Zollman Thomas & Bryant, 2021), healthier, more nutritious (Clegg et al., 2021; Szczepanski et al., 2024), and animal welfare dairy products (Broad et al., 2022; Kilders & Caputo, 2021). Compared to conventional dairy production, alternatives like microbial proteins and animal-free dairy products, derived from precision fermentation (PF) technology, offer substantial environmental benefits by significantly reducing GHG emissions (Humpenöder et al., 2022; Van Peteghem et al., 2022), while also providing potential health and nutritional advantages, such as being lactose-free, free from hormones and antibiotics, and allowing for customized nutrient profiles (GFI, 2023; Sexton et al., 2019), alongside improved animal welfare outcomes (Kilders & Caputo, 2021; Lappi et al., 2022). However, despite these benefits, PF technology faces significant biotechnological challenges related to gene editing, strain optimization, and downstream processing, which currently limit its scalability and commercial viability for food production (Nielsen et al., 2024).

PF is defined as a biotechnological process that uses microorganisms, as bacteria, yeast, or fungi, to produce specific functional ingredients, as proteins, vitamins, or fiber (EFSA, 2023a; GFI, 2022). It enables the production of dairy proteins like casein and whey without animals, creating new commercial opportunities for products like milk, ice cream, yogurt, and cheese, while potentially increasing consumer acceptance (Augustin et al., 2023; Waltz, 2022). The application of PF technology, inspired by traditional fermentation techniques, enhances the sensory attributes, functional properties, and nutritional quality of foods (Jahn et al., 2023; Teng et al., 2021). Nevertheless, the sensory quality of PF-derived products, such as taste and texture, remains a critical factor for consumer acceptance (Boukid et al., 2023), as consumers are generally unwilling to compromise on sensory attributes when choosing food products from alternative proteins (Banovic et al., 2022; Sogari et al., 2023). Thus, assessing the sensory performance of PF products is essential before claiming their potential to replace conventional dairy. This enables the production of sustainable, animal-free alternatives that closely match the taste, texture, and nutrient composition of conventional animal-based products (Lappi et al., 2022; Van Peteghem et al., 2022). However, without comprehensive sensory evaluations, it remains uncertain whether these products can meet consumer expectations, which is a key barrier identified in the adoption of other alternative proteins (Caputo et al., 2022).

PF technology is highlighted as a sustainable, scalable solution that can transform the global food system (Van Peteghem et al., 2022), offering significant economic potential and market relevance, predicted to reach 36.3 billion US dollars by 2030, with a compound annual growth rate (CAGR) of 44% by value (MarketsandMarkets, 2023). Over the last few years, a growing number of new start-up companies (e.g., Perfect Day, Remilk) have invested large amounts in developing PF milk; meanwhile food and drink conglomerates such as Nestlé have announced testing products that use animal-free dairy protein (i.e., whey produced by Perfect Day) (Waltz, 2022). Similarly, the EU has recently committed 50 million euros through the European Innovation Council's (EIC) Work Programme 2024, under Horizon Europe, to support PF startups in scaling up alternative protein production (EIC, 2024).

Despite significant advancements in PF technology (Augustin et al., 2023) and call for microbial-based alternative proteins (EIC, 2024), the European (EU) market remains devoid of food products utilizing this innovative approach. The core of the issue lies in the regulatory obstacles within the EU, particularly concerning the different authorisation frameworks – if PF dairy products (i.e., microbial proteins) contains or not GMOs and labelling uncertainty (Ronchetti et al., 2024). On the other hand, while the United States (US) has seen substantial progress, prompt by Precision Fermentation Alliance (PFA, 2024), with the FDA granting Generally Recognized as Safe (GRAS) status to animal-free dairy proteins as early as 2019 (FDA, 2019, 2024), Europe's startups struggle to navigate the complex and often unclear regulatory landscape for novel foods (Augustin et al., 2023; Ronchetti et al., 2024), highlighting a persistent problem that restrains innovation and market entry for PF products (Banovic et al., 2024). Efforts to address these challenges are underway, with several European startups forming a trade alliance called "Food Fermentation Europe" (FFE) aimed at streamlining the approval process for PF products in the EU

(FFE, 2023). However, the obstacles still remain, as demonstrated by the European Food Safety Authority's (EFSA) unclear requirements under the EU Novel Foods Regulation (EFSA, 2023b). This situation underscores a broader issue of regulatory clarity and support for PF technology in Europe, in stark contrast to the flourishing market for animal-free dairy products in the US, where investment and product launches are on the rise (GFI, 2022). The persistence of the EU’s regulatory barriers not only hampers the introduction of sustainable and innovative food options, such as those coming from PF, but also underscores the need for more transparent and supportive EU policies to foster innovation in food technology.

Besides regulatory hurdles, market challenges for PF technology adoption also persist. While there have been a few consumer studies on the acceptance of PF technology and animal-free dairy (Banovic & Grunert, 2023; Banovic et al., 2024; Broad et al., 2022; Zollman Thomas & Bryant, 2021), none have explored consumer preferences and willingness to pay (WTP) for PF milk in a cross-cultural setting, or compared it to conventional and plant-based milk. These previous studies point to a dichotomy of increasing consumer interest, in the role of PF technology and animal-free proteins in contributing to climate change and animal-welfare mitigation, and health and safety concerns over the use of GMOs (Banovic & Grunert, 2023; Banovic & Grunert, 2024; Zollman Thomas & Bryant, 2021). Other studies highlight a general consumer reluctance to purchase animal-free dairy products from PF, driven by price sensitivity and negative perceptions of PF as artificial and deceptive (Banovic et al., 2024). Nevertheless, these studies highlight the need for more in-depth understanding of consumer preferences for PF dairy products, focusing on perceived health, animal welfare, and environmental benefits. Addressing these gaps is critical for integrating PF technology and animal-free dairy products into the EU’s mainstream food ecosystem, particularly as previous studies show different production methods can affect consumer preferences for associated products (e.g., Balcombe et al., 2021). This information can provide useful information for companies aiming to sell PF milk in different countries and policy makers to design new food policies and regulations.

Among the various types of information that can affect consumer valuation of PF dairy products, animal welfare messages are crucial due to their instant perceived benefits (Broad et al., 2022; Kilders & Caputo, 2021). For example, companies as Perfect Day and Bored Cow have effectively used "*Animal-free dairy milk*" claim to market their products in the US (BC, 2024; PD, 2024). Health-related claims, such as *"Complete protein"* used by the same companies (BC, 2024; PD, 2024), can also affect consumers' valuation for PF dairy products (Clegg et al., 2021; Szczepanski et al., 2024). Furthermore, environmental benefits of PF technology are increasingly relevant (Van Peteghem et al., 2022), with products like *"Strive Freemilk"* by Perfect Day promoting sustainable milk alternatives that supposedly reduce greenhouse gases by 97% (PD, 2022).

While specific labelling claims related to environmental, health, and animal welfare benefits can influence consumer choices, it is important to recognize the complexity created by the multitude of labels often found on food products. Research has shown that consumers may experience confusion or ambiguity when interpreting these labels, which can reduce their effectiveness in guiding sustainable food choices (Cheng et al., 2011; Nguyen & Le, 2020). To address this challenge, recent efforts have focused on developing universal or 'mega' ecolabels that integrate multiple sustainability dimensions into a single, aggregated score (Sonntag et al., 2023). The goal of such labelling systems is to simplify consumer decision-making and promote sustainable consumption more effectively (Torma & Thøgersen, 2021). However, universal labelling systems are still in the early stages of development, and their effectiveness depends on a deeper understanding of how consumers respond to individual labelling elements. Therefore, this study focuses on examining specific information types separately to identify their unique effects on consumer preferences. This approach provides valuable insights that can inform both the design of individual label claims and the development of integrated labelling systems in the future.

Despite above developments, to the best of our knowledge, no studies have yet investigated the effect of animal welfare, health, and environmental informational messages on consumer valuation of PF dairy in a cross-country context, an area critical for developing marketing and communication strategies for PF dairy products. This study addresses existing research gaps by conducting a hypothetical discrete choice experiment (CE) to investigate and compare consumer preferences and WTP for PF milk (which varies across five attributes: type of milk technology, animal welfare information, protein type, Carbon Trust label, and price) among Danish, Italian, British, and American consumers. Additionally, the effects of three experimental framing conditions (i.e. animal-welfare, health, and environmentally friendly) on consumer WTP for PF milk have been tested. Furthermore, consumer heterogeneity and labelling preferences for PF milk were also explored.

While previous research suggests that the effect sizes of information treatments on consumer choices are typically small (e.g., (Grunert & Wills, 2007)), this study ensures adequate statistical power by employing a robust sample size per treatment condition. Each treatment group consists of more than 250 respondents, which allows for the detection of small effect sizes. The sample size is in line with prior studies (e.g., (Chung et al., 2024; Kovacs et al., 2024; Scozzafava et al., 2020) that have employed similar or even smaller sample sizes in comparable experimental settings.

The main product, i.e., milk, was chosen for two main reasons. First, it is the most representative product stimulus which can be produced using PF (Zollman Thomas & Bryant, 2021). Second, it is one of the most important staple foods largely consumed all around the world (FAO, 2023). The selection of Denmark, Italy, the UK, and the US markets for this study is strategic, reflecting diverse regulatory landscapes and market readiness for PF products (i.e. EU, UK, and US) (EFSA, 2023b; FDA, 2024; FSA, 2023). The EU's stringent food regulations, exemplified by Denmark and Italy, provide a contrast to the less restrictive environment in the USA, where the market for such products is rapidly expanding (GFI, 2022). The inclusion of the UK offers a unique perspective post-Brexit, navigating between EU regulations and its own market dynamics (FSA, 2023). Moreover, these markets represent the most relevant initial markets for PF milk given the increasing consumer demands for more sustainable, healthier, and animal welfare food products. This ensures a comprehensive understanding of how regulatory contexts and market availability influence consumer preferences and WTP for sustainable food innovations, as those coming from PF technology.

This study provides several contributions. It delivers crucial insights for the marketing of PF dairy products by identifying how consumer preferences vary under different information framing, specifically concerning animal welfare, health, and environmental benefits, across key markets including Denmark, Italy, the UK, and the US. Further, the comprehensive analysis provided enables marketers to develop targeted strategies that resonate with specific consumer groups in diverse regulatory environments, enhancing market penetration, and acceptance of PF products. Additionally, by showcasing the impact of regulatory frameworks on consumer WTP and preferences, the findings serve as a valuable resource for policymakers. Policymakers can leverage this data to tailor labelling regulations that foster the integration of PF products into the food market.

2. Background

2.1 Consumer awareness and scepticism issues around precision fermentation food products

Main challenges for PF products include lack of public awareness and scepticism. To date only a few studies have investigated consumer preferences and public awareness for PF food products. To illustrate, a study from Banovic and Grunert (2023) conducted in a cross-cultural context (Denmark, Germany, and Poland) has shown that strategic framing using familiarity (i.e., representative heuristics) and information dissemination can mitigate consumers' fear and scepticism about the perceived "artificiality" (i.e., GMOs use) and hesitancy of accepting products from PF technology. This study emphasizes the necessity for precise and effective communication to clarify the raised issues, aiming to alleviate consumer concerns linked to GMOs.

In another study, Banovic and Grunert (2024) assessed the effect of message framing on consumer acceptance of sweet proteins from PF technology in a cross-cultural context (i.e., Denmark, Germany, and Poland). They found that healthiness perceptions had a stronger influence on consumer acceptance than naturalness perceptions. Additionally, factors such as BMI, sweetener usage, anticipatory guilt, and pleasure regulated these effects, underscoring the predominant role of health perceptions in shaping consumer acceptance. Another study by Szczepanski et al. (2024) on microbial protein as a meat alternative has also demonstrated that emphasising the health benefits and essential nutrients of PF products, delivered in more sustainable and ethical ways, can increase consumer acceptance and interest particularly among health-conscious consumers looking for alternatives to traditional animal-based foods.

In terms of the PF dairy products, Broad et al. (2022) explored consumer opinions of these products using focus groups in several countries (i.e., Germany, Singapore, the UK, and the US). They found that consumers were generally open, although with caution, towards PF dairy products. In addition, they found that consumers showed a positive interest about the animal welfare benefits while expressing concerns towards the lack of naturalness and potential human health risks of these products. In another comprehensive cross-cultural study (i.e., Brazil, Germany, India, the UK, and the US) on PF dairy products, Zollman Thomas and Bryant (2021) found that most consumers are willing to try and purchase PF dairy products, perceiving them as tasty as conventional dairy, while also more ethical and environmental-friendly. Finally, study by Banovic et al. (2024) on animal-free dairy in Denmark identified generally low purchase intent and high price sensitivity, attributed to prevalent negative taste perceptions and a lack of awareness. However, they noted that these barriers could be mitigated by enhancing the already positive perceptions of animal-free dairy products in terms of possessing low carbon footprint and being environmentally friendly.

In broader terms, many consumer studies on alternative proteins have identified health, environmental, and animal welfare considerations as key factors influencing consumer acceptance of novel food products. Research consistently shows that ethical and environmental concerns, such as sustainability and reducing the environmental footprint, positively shape consumer perceptions of alternative protein foods (Green et al., 2022; Hadidi et al., 2023). Health-related factors, including the perceived nutritional benefits, safety, and potential health risks, also play a significant role in driving acceptance (Michel et al., 2021). Additionally, animal welfare concerns enhance consumer interest in alternative proteins, as products positioned as cruelty-free or animal-free tend to resonate strongly with ethically motivated consumers (Zollman Thomas & Bryant, 2021). However, despite these positive drivers, consumer scepticism remains a significant barrier, particularly regarding technologies associated with genetic modification (GMOs) and biotechnology. Studies have shown that perceptions of ‘unnaturalness’ and concerns about the safety of genetically engineered ingredients can reduce acceptance of alternative protein products, including those derived from precision fermentation (Siegrist, 2000, 2019; Siegrist & Sütterlin, 2017). Importantly, these perceptions and acceptance levels can vary significantly across different cultural contexts and are influenced by individual consumer characteristics such as personal values, food neophobia, and prior knowledge of food technologies (Bryant et al., 2019; Siegrist & Sütterlin, 2017). Trust in regulatory bodies, transparent labelling, and effective communication strategies are essential to addressing these concerns and mitigating scepticism toward novel food technologies and products. Studies on food labeling and communication strategies suggest that the way information is framed significantly impacts consumer responses. For instance, research has shown that the complexity created by the multitude of labels on food products can lead to consumer confusion and ambiguity, reducing the effectiveness of labels in guiding sustainable food choices (Cheng et al., 2011; Nguyen & Le, 2020). Integrating the above would help contextualize the role of information framing in addressing consumer skepticism towards PF products.

2.2 Regulatory and policy questions around precision fermentation food products

Several policies, initiatives, and regulations are related to PF food production in the EU (Ronchetti et al., 2024). First, the new European Farm to Fork (F2F) strategy promises to make the EU food systems fairer, healthier, and more environmental-friendly (EC, 2020a). Second, the Food 2030 is the EU's research and innovation policy aimed to support the transition of the food systems and ensure consumers have enough affordable, sustainable, nutritious food for a healthy life through 11 different pathways (EC, 2023a). Specifically, the pathway 4 "Alternative proteins and dietary shift" includes the shift from conventional protein diet (e.g., animal) to protein alternative diet (EC, 2020b). Third, another relevant policy related to the PF food products is the European Green Deal focused on ensuring environmental sustainability within the EU (EC, 2019, 2023b). Fourth, the European Innovation Council's Work Programme 2024 also promote the PF food products through the Accelerate Challenge (EIC, 2024).

Regarding the EU's specific regulations, food products derived from PF technology are subject to one of two regulatory frameworks, depending on whether or not the final product contains GMOs (Ballester et al., 2023; Ronchetti et al., 2024). Products with GMOs fall under the Genetically Modified Food and Feed Regulation (GMFR) and require pre-market authorization accordingly (Regulation (EC) No 1829/2003) (EC, 2015). Conversely, if no GMOs are present, the product is regulated under the Novel Food Regulation (NFR), with its specific pre-market authorization procedures (Regulation (EU) 2015/2283) (EFSA, 2023b; EU, 2015). Most of the food products produced using PF, such as milk proteins (e.g., casein, whey) are considered as a novel food in Europe and require pre-market authorization by EU regulators (under NFR) that could last two to three years (EFSA, 2023c). The process for getting a novel food authorized involves submitting a dossier to the European Commission (EC), which European Food Safety Authority (EFSA) evaluates based on scientific evidence and risk assessment methodologies (EFSA, 2023b). After a positive EFSA opinion, EC can authorize the novel food for the whole EU market. Once approved, novel foods may have specific labelling requirements to credibly inform consumers about their nature, safety, properties, or method of production (EC, 2024b). To date, EFSA has assessed several novel food ingredients (e.g. riboflavin or vitamin B2) produced through

PF (EFSA, 2014), and the process involves detailed scientific evaluation to ensure consumer safety (Ballester et al., 2023; EC, 2024a; EFSA, 2023a, 2023c). In addition, as part of the pre-market authorization requirements, companies producing PF products should also comply with the EU labelling regulations and may need mandatory information specified in the authorization process to prevent consumer deception (Article 1, Regulation (EU) No 1169/2011) (Ronchetti et al., 2024).

In the UK, the Food Standards Agency (FSA) has decided to update its regulatory framework (until recently led by EU regulations) for products like ingredients derived from PF and lab-grown meat (FSA, 2023). This decision aims to enable faster process for introducing such innovative foods to the UK market and will fall under the UK Novel Foods regulation which is in accordance with the assimilated EU regulations (Regulation (EU) 2015/2283) (FSA, 2024). Part of this reform includes establishing a new public register for “regulated products” moving away from the existing, more time-consuming procedure, as in the EU, that could move product introductions by up to six months (FSA, 2023).

In the US, under sections 201(s) and 409 of the Federal Food, Drug, and Cosmetic Act (the Act) (FDA) food products or functional ingredients coming from PF technology do not require premarket review and approval by the FDA if they are Generally Recognized As Safe (GRAS), that is, proven to be safe for its proposed usage, and thoroughly demonstrating to meet safety standards (FDA, 2024). This includes both substances with a long history of safe use in food and those determined safe through scientific procedures. PF products, as non-animal whey protein, can achieve GRAS status through this framework, allowing them to be used in food and beverages (FDA, 2019). Currently, PF market, particularly for dairy proteins (i.e., casein, whey) is growing rapidly in the US while in the EU, these new products are almost non-existent (GFI, 2022).

3. Methodology

To address the identified research gap concerning the limited understanding of consumer preferences toward precision fermentation (PF) products, we designed a comprehensive choice experiment to investigate the key attributes driving consumer preferences for PF products (i.e., milk). This study also compares PF milk with existing products on the market, namely conventional and plant-based milk, within a cross-cultural context (Denmark, Italy, the UK, and the US). Furthermore, it considers both mature markets where PF products are already present (e.g., the US) and emerging markets where these products are only beginning to enter (Denmark, Italy, the UK).

3.1 Choice experiment design

In the CE five attributes were used to describe the different milk products, i.e., type of milk technology, animal welfare information, protein type, Carbon Trust label, and price (Table 1). First, type of milk technology was included, as the main aim of the study was to investigate consumer preferences and WTP for PF milk. As comparison to PF milk, both the conventional cow, and plant-based milk (technologies) were included, as the most popular milk types on the market (Broad et al., 2022). Therefore, three levels of milk type were specified: “cow milk”, “plant-based milk”, and “precision fermentation milk”. Second, the information about animal welfare was included because this information is a top concern when consumers are purchasing milk and dairy products (Kilders & Caputo, 2021). Therefore, two levels of animal welfare information were specified by the phrase “100% animal-free” (defined as a production process where no animals were involved) or no information were reported. Third, the information about types of protein was included because this information is a top concern when consumers are purchasing food (Banovic et al., 2022). Therefore, two levels protein type information were specified by the phrase "complete protein" (defined as a protein that contains all the essential amino acids required by the body) or no information were reported. Fourth, the attribute Carbon Trust label was included referring to the environmental impact of food production, transportation, and use of the food products in terms of CO_2 emissions. The information about the environmental impact was presented as it is currently one of the top key concerns of milk/food (Waltz, 2022). Thus, the two levels of this attribute were specified with the Carbon Trust label (reducing CO_2) or no label was used at all. Lastly, four price levels were specified based partly on the current market prices for the milk[1] in retail stores in Denmark (10kr./lt, 15kr./lt, 20kr/lt, and 25kr./lt), Italy (€0.75/lt, €1.50/lt, €2.25/lt, and €3.00/lt), the United Kingdom (£0.50/lt, £1.25/lt, £2.00/lt, and £2.75/lt), and the United States ($0.75/lt, $3.50/lt, $6.25/lt, and $9.00/lt).

--Insert Table 1--

The selected attributes and their levels were then used to generate an optimal orthogonal (OOD) design using Ngene 1.2.1 (ChoiceMetrics, Sidney, Australia) that resulted in the creation of 24 choice sets, which were then divided into two blocks of twelve choice tasks each to prevent respondents' fatigue. OOD designs are largely used in choice experiments (e.g., DeLong et al.,

[1]The prices for milk were based on those recorded in various stores in Denmark, Italy, the UK, and the US, including grocery stores, farmers' markets, specialty stores, organic stores, and supermarkets. For PF milk, prices were based on real market data from the US, supplemented by information from the US annual report on milk prices. For Denmark, Italy, and the UK, PF milk prices were estimated based on US prices, adjusted to reflect potential market differences.

2021; Kaminski, et al. 2018). In addition, our design got a very good D-optimality (97.90%). Each choice task was composed of two product alternatives (options A and B), and an "opt-out" option (option C) (see example in Figure 1). The choice tasks within each block were randomly presented to respondents.

--Insert Figure 1--

The CE was introduced to the respondents with the clear explanation and description of the attributes, and levels. Before the choice tasks, participants were instructed to imagine themselves shopping in a grocery store, along with the guidance on how to complete the CE. A cheap talk (CT) script was also included to mitigate hypothetical bias (Carlsson et al., 2005). Upon completion of the choice tasks, the respondents were asked to complete a questionnaire to collect information on their attitudes and socio-demographics. Specifically, questions covered socio-demographic characteristics (i.e. age, gender, income, and education), familiarity with PF milk, and attitudes including neophobia toward new foods using the food technology neophobia scale (FTNS) (Cox & Evans, 2008), pro-animal welfare attitude using the animal well-being (ANIMAL WELFARE) scale (Kendall et al., 2006), pro-environmental attitude using the eating related eco concern (ECO) scale (Qi et al., 2022), and pro-health attitude using the general health interest (HEALTH) scale (Roininen, 2001). The master survey was initially developed in English and then translated into the official languages of the countries where English is not the native language (i.e., Denmark and Italy).

3.2 Experimental treatments and research hypotheses

To test the research hypothesis, a between-subjects design was implemented based on the use of four CE treatments (Figure 2). Hence, each respondent was randomly assigned to only one of the CE treatments. The four treatments differed in terms of the information given about PF milk prior the series of choice tasks. Treatment 1 was the control treatment, named "CONTROL" where 1,094 participants (DK=292, IT=265, UK= 282, and US=255) were given general information about the milk products. In Treatment 2, named "ANIMAL WELFARE", 1,105 consumers (DK=293, IT=264, UK=288, and US=260) were provided general information about the milk products, and supplied with additional information about the animal welfare benefits of PF milk. In Treatment 3, named "HEALTH", 1,062 consumers (DK=292, IT=264, UK=268, and US=238) were provided general information about the milk products, and supplied with additional information about nutritional and health benefits of PF milk. In Treatment 4, named "ENVIRONMENT", 1,100 consumers (DK=290, IT=265, UK=292, and US=253) were provided general information about the milk products, and supplied with additional information about the environmental benefits of PF milk.

--Insert Figure 2--

With these CE treatments, a series of hypotheses were constructed to examine whether the information about the benefits of the PF milk would affect consumers' marginal willingness to pay (mWTP) for these new products. To determine the effect of the different types of information, the estimates were compared from the four treatments. Specifically, the following six comparisons were performed:

i) animal welfare information would affect respondents' mWTP for PF milk (i.e., CONTROL vs. ANIMALWELFARE): H_{01}: mWTP ^{ANIMAL} > mWTP^{CONTROL};

ii) health information would affect respondents' mWTP for PF milk (i.e., CONTROL vs. HEALTH): H_{02}: mWTP ^{HEALTH} > mWTP^{CONTROL};

iii) environmental information would affect respondents' mWTP for PF milk (i.e., CONTROL vs. ENVIRONMENT): H_{03}: mWTP ^{ENVIRONMENT} > mWTP^{CONTROL};

iv) consumer evaluation for PF milk differs when health information vs. animal welfare information was provided (i.e., ANIMAL WELFARE vs. HEALTH): H_{04}: mWTP^{HEALTH} ≠ mWTP^{ANIMAL};

v) consumer evaluation for PF milk differs when environmental information vs. animal welfare information was provided (i.e., ENVIRONMENT vs. ANIMAL WELFARE): H_{05}: mWTP^{ANIMAL} ≠ mWTP^{ENVIRONMENT};

vi) consumer evaluation for PF milk differs when health information vs. environmental information was provided (i.e., HEALTH vs. ENVIRONMENT): H_{06}: mWTP^{ENVIROMENT} ≠ mWTP^{HEALTH}.

3.3 Data

The data used in this study are drawn from an online survey involving a total of 4,361 participants (DK=1,167, IT=1,058, UK=1,130, and US=1,006) using the online platform Qualtrics LLC (Provo, US) and the marketing research company Norstat (Aarhus, Denmark). Informed consent was obtained from all participants in the study, which was previously approved by an institutional ethical clearance board. Only consumers who were at least 20 years old, who were main responsible for food purchases in their household and purchased cow's milk and plant-based milk at least once a month were included in the study. Respondents were recruited by employing a quota sampling technique for gender, age, and region, as stratification dimensions to secure a representative sample from each country.

To ensure data quality, a series of quality control procedures were implemented during and after data collection. The survey incorporated embedded attention and consistency checks designed to identify non-attentive respondents, who were excluded from the analysis. Following data collection, the dataset was further screened for outliers and irregular response patterns (e.g., straightlining or excessively short or long completion times). Completion time thresholds were defined using the mean ± 2 standard deviations; responses completed in under 10 minutes or exceeding 30 minutes were flagged as atypical and excluded from the final dataset. Observations that did not meet these established quality criteria were removed to minimize measurement error and enhance the reliability of the results.

The final samples were composed of 4,361 participants (Table 2). Further, the results show that consumers in the four countries did not differ in terms of age, gender, education, and income across the four treatments (Appendix A). Even though no significant differences were found, we still account for participants' characteristics when testing the effect of consumer background on preferences for PF milk to ensure a comprehensive analysis of potential influences.

--Insert Table 2--

4. Econometric analysis

To test the research hypotheses, the effect of the information treatments on WTP for PF milk was estimated using the Discrete Choice Models (DCMs) that are normally used to analyse choice data (Hensher et al., 2015). Specifically, DCMs are based on modelling “utility”, that it is the net benefit a subject obtains from selecting a specific product in a choice situation, as a function of the attributes which characterize the products under consideration (Hensher et al., 2015). Indeed, consistent with the Lancaster Theory (Lancaster, 1966), DCMs assume that the total utility consumers derive from a product can be segregated into the marginal utilities given by the attributes of a product.

In this study we used the Mixed Logit (MIXL) model with specification of the utility function in WTP space which provides estimates directly in WTP terms (i.e. currencies). The specification of the utility (U) function in our study can be defined as follows:

$$U_{njt} = \alpha_n(ASC - PRICE_{njt} + \theta_{n1}PLANT_{njt} + \theta_{n2}PRECISION_{njt} + \theta_{n3}\,ANIMAL_{njt} + \theta_{n4}\,PROTEIN_{njt} + \theta_{n5}CARBON_{njt}) + \hat{I}_{njt} \qquad (1)$$

where n refers to individual, j denotes each of the three alternatives available in the choice set, t is the number of choice occasions, and α_n is the price scale parameter that is assumed to be random, and to follow a log-normal distribution. The ASC is the alternative constant indicating the selection of the opt-out option. The price (PRICE_{njt}) attribute is represented by four experimentally defined price levels (i.e., Denmark: 10kr./lt, 15kr./lt, 20kr/lt, 25kr./lt; Italy: €0.75/lt, €1.50/lt, €2.25/lt, €3.00/lt; UK: £0.50/lt, £1.25/lt, £2.00/lt, £2.75/lt; US: \$0.75/lt, \$3.50/lt, \$6.25/lt, and \$9.00/lt). PLANT_{njt} is a dummy variable representing the type of milk technology, taking the value of 0 if it is cow milk or 1 if it is plant milk. $\mathrm{PRECISION}_{njt}$ is a dummy variable representing the type of milk technology, taking the value of 0 if it is cow milk or 1 if it is PF milk. ANIMAL_{njt} is a dummy variable for information about the use of animal in milk production taking the value of 0 if no information is reported, and 1 if the phrase "100% animal free" is stated. $PROTEIN_{njt}$ is a dummy variable for information about the type of protein of the milk products taking the value of 0 if no information is reported, and 1 if the phrase "Complete protein" is stated. $CARBON_{njt}$ is a dummy variable representing the "Carbon Trust label" taking the value of 0 if no information is reported, and 1 if the Carbon Trust label is reported. Finally, $\hat{I}_{njt}$ is an unobserved random term that is distributed following an extreme value type I (Gumbel) distribution, independent and identically distributed (i.i.d.) over alternatives. The parameters corresponding to the three non-price attributes were modelled as random parameters assumed to follow a normal distribution, while the opt-out parameter was modelled as a fixed parameter.

The differences in the mWTPs among the four treatments involved in our six hypotheses (i.e. H_{01}, H_{02}, H_{03}, H_{04}, H_{05}, and H_{06}) can be tested by conducting pairwise tests using data from the two respective treatments involved in the particular hypothesis (Table 4). Then, following De-Magistris et al. (2013) and Asioli, Fuentes-Pila, et al. (2022), interactions were created between the non-price attributes, and the treatment (*dtreat)* parameters, which were modelled as a fixed parameters. The focus of the interaction analysis was to explore how non-price attributes interact with treatment effects, providing additional insights beyond the direct influence of price. The interaction effects were specified as dummy variables to differentiate one treatment over the other treatment (*dtreat*). Accordingly, the model can be specified as follows:

$$U_{njt} = \alpha(ASC - PRICE_{njt} + \theta_{n1}PLANT_{njt} + \theta_{n2}PRECISION_{njt} + \theta_{n3}\, ANIMAL_{njt} + \theta_{n3}\, PROTEIN_{njt} + \theta_{n4}CARBON_{njt} + ð_1\, (PLANT_{nj} * dtreat) + ð_2\, (PRECISION_{nj} * dtreat) + ð_3\, (ANIMAL_{nj} * dtreat) + ð_4\, (PROTEIN_{nj} * dtreat) + (CARBON_{nj} * dtreat)\hat{I}_{njt} \quad (2)$$

where *dtreat* is coded as 1 for the first treatment in the analysed hypothesis, and 0 otherwise. The significance of the estimated ð coefficients, and their signs indicate the effect of the treatment on the mWTPs for the attribute of interest.

The MIXL model in WTP space was estimated using the Stata module *mixlogitwtp*. Different MIXL models were run using different number of draws both with correlated and not correlated variables. Based on logL, AIC, and BIC parameters, the best model was five hundred Halton draws with correlated variables that were used in the simulations.

Finally, in order to investigate consumer heterogeneity preferences, we employed the latent class logit (LCL) model in preference space {Greene, 2003 #859} to identify and characterize different consumer segments. The LCL model assumes that the overall population can be divided into two or more segments by assuming constant model parameters within each segment, capturing consumer heterogeneity by assuming a mixed distribution for the clusters . The probability of class membership *s* depends on individual *n* choosing alternative *j* at time *t*, which consists of a certain set of observable attributes *x*' (Greene & Hensher, 2003):

$$Prob_{jnt|s} = \frac{exp(\boldsymbol{x}'_{ntj}\boldsymbol{\beta}_s)}{\sum_{j=1}^{Jn} exp(\boldsymbol{x}'_{ntj}\boldsymbol{\beta}_s)} \qquad (3)$$

where $s = 1, \ldots S$ represents the number of classes, β'_s is the fixed (constant) parameter vector associated with class *s* and x_{njt} is a vector of attributes associated with each product. Then, in order to characterize the different consumer segments, we used the following four independent variables, namely AGE, FTNS, FAMILIARITY and ECO. AGE represents the age of the consumer, FAMILIARITY is the familiarity level of the consumers with PF milk taking the value from 1 (Very unfamiliar) to 7 (Very familiar), FTNS is the food technology neophobia scale taking the value from 1 (Strongly disagree) to 7 (Strongly agree), ECO is the pro-environmental attitude taking the value from 1 (Strongly disagree) to 7 (Strongly agree).

To estimate the LCL model, we used the expectation–maximization (EM) algorithm, which allows for a good numerical stability and good performance in terms of runtime (Train 2008). The LCL model was estimated using the modules *lclogit2*, *lclogitml2* and *lclogitwtp* (Hong Il, 2020) on Stata. All the models were estimated using Stata 18.0 software (Stata-Corp LP, College Station, USA).

4. Results

4.1. mWTP estimates: Denmark, Italy, the UK, and the US

The results from the estimation of the MIXL models using Equation (1) in WTP space using the main effects for Denmark, Italy, the UK, and the US are shown in Table 3. Specifically, the estimates (mWTP) for PLANT, PRECISION, ANIMAL, PROTEIN, CARBON, PRICE, OPT-OUT, and significances for the attributes (*p*-value) were reported.

--Insert Table 3—

Overall, results show that in all the four countries and treatments, the mean estimate for the OPT-OUT option is negative and significant suggesting that participants tended to prefer one of the two product alternatives as opposed to the opt-out option. In general, participants strongly preferred cow milk when compared to plant-based milk, Table 3. However, preferences for labelling information about animal welfare, protein type, and carbon trust information depended on the treatment, and the countries. Further, in all four countries and treatments, the mean estimates for PLANT and PRECISION are strongly negative and significant, indicating that plant-based milk is less disliked than PF milk (e.g., treatment – environment, for PLANT: β_{DK} = -23.98; β_{IT} = -0.59; β_{UK} = -1.70; β_{US} = -4.40; for PRECISION: β_{DK} = -23.83; β_{IT} = -0.53; β_{UK} = -3.10; β_{US} = -9.02), Table 3. However, the magnitude of this effect varies depending on the country and treatment. For Denmark, Italy and the UK, participants disliked milk labelled with the claim "100% animal free", while only Italian participants preferred milk labelled with the claim "complete protein". Similarly, Italian participants valued more milk branded with the Carbon Trust label, while for the UK this preference was dependent on the treatment.

Next, we tested the hypothesis that the information provision about PF milk significantly affect mWTP estimates (Table 4). In Denmark, Italy, and the UK, we found that by providing animal welfare (except for the UK), health, and environmental benefit information of PF milk will increase consumer mWTP for such products (i.e., hypothesis H_{01}, H_{02}, and H_{03}), while when comparing the different types of information provision, we can find some differences among the countries. Specifically, in Denmark, mWTP will be higher when participants are provided with information about health benefits compared to when animal welfare and environmental information is provided. In Italy, mWTP will be higher when consumers are provided with information about health benefits compared to when animal welfare information is provided while participants mWTP is higher when animal welfare information is provided compared to environmental information. In addition, in the USA, consumer mWTP for PF milk is higher when participants are provided with information about animal welfare or environment compared to when health benefits information is provided.

--Insert Table 4—

4.2 Estimation results from latent class Logit (LCL) model.

To investigate consumer heterogeneity, we estimated the LCL models for each country for the control treatment, only. In order to account for data quality (Asioli & Jaeger, 2025), we used the method developed by Malone and Lusk (2018) consisting on estimating a latent class choice model allowing for a random response share (RRS) where the probability of class-membership for one class is determined completely by the random utility term consisting on systematic utility constrained to zero for all attribute parameters. This approach is increasingly used {Lagerkvist, 2020 #857} to provide more reliable estimation. Thus, we use this approach and include one class with random choice in each model. Based on the BIC and AIC values and the size of the segments and the need to provide more meaningful and interpretable results {Chapman, 2015 #858}, we choose the three-clusters solution for all the countries.

For Denmark, the results of the LCL model with the three-clusters solution are reported in Table 5, including the regression coefficients for PLANT, PRECISION, ANIMAL, PROTEIN, CARBON, PRICE, OPT-OUT, and the individual consumer characteristics (i.e. AGE, FTNS, FAMILIARITY and ECO) as well as the corresponding standard errors (SEs) and significances for the attributes (*p-values*). Group 1 ('Strong Traditionalists, Unethical & Economical Consumers': 160 consumers – 55%) is the largest group of consumers; they have strong preferences for cow milk with low price and labelled without the claim "100% animal free". These consumers tend to be older and have lower ecological attitude than individuals in group 2. Group

2 ('Light Traditionalists & Economical Consumers': 85 consumers – 29%) include consumers who have light preference for low price cow milk. Finally, a relatively small proportion (47 consumers – 16%) of individuals were classified as making inconsistent (*random)* choices. The class membership variables reveal that individuals in this group are characterized as being younger, have lower degree of neophobia towards new food technologies, have higher familiarity for PF milk and have higher ecological attitude than consumers in group 1.

--Insert Table 5—

For Italy, the results of the LCL model with the three-clusters solution are reported in Table 6. Groups 1 ('Strong Traditionalists, Economical & Unethical Consumers': 89 consumers – 33.60%) includes consumers they have strong preferences for low price cow milk without the claim "100% animal free". These consumers tend to have higher neophobia towards new food technologies, have lower familiarity with PF milk and have lower ecological attitude than consumers in group 2. Group 2 ('Traditionalists, Economical & Ethical Consumers': 107 consumers – 40.20%) include consumers who are indifferent between cow and plant-based milk, but dislike PF milk, but have preference for low price milk labelled with the claim "100% animal welfare". Finally, a relatively large proportion (69 consumers – 26.20%) of individuals were classified as making inconsistent (*random)* choices.

--Insert Table 6—

For the United Kingdom, the results of the LCL model with the three-clusters solution are reported in Table 7. Groups 1 ('Strong Traditionalists, Economical & Unethical Consumers': 135 consumers – 48.00%) includes consumers they have strong preferences for cow milk of low price labelled without the claim "100% animal free". These consumers tend to be older, have higher degree of neophobia towards new food technologies, have lower familiarity with PF milk and have lower ecological attitude than consumers in group 2. Group 2 ('Light Traditionalists, Economical & Environmental Consumers': 127 consumers – 44.90%) include consumers who are indifferent between cow and plant-based milk, but dislike PF milk, but have preference for low price milk branded with the Carbon Trust label. Finally, a small proportion (20 consumers – 7.20%) of individuals were classified as making inconsistent (*random)* choices.

--Insert Table 7—

For the United States, the results of the LCL model with the three-clusters solution are reported in Table 8. Groups 1 ('Strong Traditionalists & Economical Consumers': 65 consumers – 25.60%) have strong preferences for cow milk of low price, disliking both plant-based and PF milk. These consumers tend to have higher neophobia towards new food technologies, less familiar with PF milk. and have lower ecological attitude than individuals in group 2. Group 2 ('Light Traditionalists, Ethical, Healthy & Environmentally friendly Consumers': 131 consumers – 51.30%) include consumers who have preference for cow milk and have preference for milk labelled with the claims "100% animal free milk" and "complete protein" and branded with the Carbon Trust label. Finally, a relatively large proportion (59 consumers – 23.00%) of individuals were classified as making inconsistent (*random)* choices. The class membership variables reveal that individuals in this class are characterized as being lower familiarity for PF milk than respondents in group 2.

--Insert Table 8—

Finally, the policy labelling preferences were investigated (Table 9). The participants were asked "*How much do you support or oppose that any milk-derived product from "precision fermentation" source should be labelled as 'milk', 'yogurt', 'butter', and 'cheese'?*" using a scale from 1 (Strongly Oppose) to 7 (Strongly Support). Results showed that both in Italy and the US on average participants supported more strongly any milk-derived product from "precision fermentation" source should be labelled as 'milk', 'yogurt', 'butter', and 'cheese' while in Denmark and the UK tend to support less the use of conventional (cow) dairy products labelling on PF dairy products labelling.

--Insert Table 9--

5. Discussion

We investigated and compared WTP for PF milk among Danish, Italian, British, and US consumers across four experimental treatments that used information framing based on animal welfare, health, and environmental benefits, along with a control condition. We found several interesting outcomes.

First, our results show that across the four countries and treatments, consumers strongly reject PF milk, with relatively large negative coefficients, indicating a strong aversion compared to conventional milk. In contrast, the rejection of plant-based milk is less pronounced, with smaller negative coefficients, suggesting a moderate level of consumer acceptance relative to PF milk (Section 4.3). Similarly, Broad et al. (2022), Zollman Thomas and Bryant (2021), and Banovic et al. (2024) found that the conventional dairy products were preferred over hybrid and plant-based dairy alternatives. This finding could be explained by the fact that the market for PF milk is still small in the US and does not exist at all in Denmark, Italy, and in the UK (GFI, 2022) and because of the low consumer familiarity with the PF technology (Banovic & Grunert, 2023).

Second, the preference for conventional cow milk and the rejection of PF milk are substantial in all markets, reflecting not only statistical significance but also meaningful effect sizes in consumer choices. For example, the effect of the "100% animal-free" label in Denmark, Italy, and the UK shows a moderate negative impact, while claims like "complete protein" in Italy and the Carbon Trust label in the UK and Italy show small to moderate positive effects, highlighting nuanced consumer responses to these attributes. This finding can be explained by the growing consumer awareness that many current alternatives, as plant-based, do not provide complete proteins, leading to a preference for options that offer higher protein content needed for optimal health (Banovic et al., 2022). The positive and significant coefficient for the Carbon Trust label suggests that this label increases consumers' willingness to pay (WTP) for a product, regardless of whether it is PF milk, cow milk, or plant-based milk. This finding can be partially corroborated with previous study on meat alternatives where it was found that British consumers prefer alternatives with Carbon Trust label (Asioli, Banovic, et al., 2022).

Third, results indicate that the impact of framing benefit information about PF milk varies depending on the type of message and the country. This finding is supported by previous research

(Banovic & Grunert, 2023) which shows that the type of communication used influences consumer valuation of PF technology and products. Specifically, we found that in Denmark, Italy, and the UK, the provision of animal welfare (except for the UK), health, and environmental benefit information of PF milk increase consumer valuation for such products compared to providing no information. Interestingly, in the US no benefit information about PF milk increases consumer valuation for PF milk compared to presenting no information. Furthermore, in Denmark, consumer valuation for PF milk is higher when information on health benefits is provided, compared to information on animal welfare and environmental benefits. Also, in Italy, consumer WTP for PF milk increases when the health benefits information is provided, compared to when animal welfare information is given, and their WTP is higher for animal welfare information than for environmental information. In the US, consumer valuation for PF milk is higher when information about animal welfare or environment benefits is provided, compared to when health benefits information is given.

While our study design ensures a robust sample size per treatment (e.g., Chung et al., 2024; Kovacs et al., 2024; Scozzafava et al., 2020), which mitigates some concerns related to statistical power and response validity.

Fourth, across all four countries, a three-cluster solution was selected, and the presence of consistent segment patterns, s*trong traditionalists* - with strong preferences for conventional cow milk, *light traditionalists* - open to alternatives but price-sensitive, and a third group displaying random or inconsistent choices, highlights both shared and different consumer responses to PF milk. While the segment structure was stable, cross-country differences emerged in the size and characteristics of each segment. For instance, the proportion of inconsistent choosers was notably higher in Italy and the US compared to the UK, suggesting varying levels of consumer uncertainty or unfamiliarity with PF milk. Moreover, ethical and environmental values appeared more salient among *light traditionalists* in the US and UK than in Denmark and Italy. This segments provide valuable insights for tailoring marketing strategies, as they capture not only preference structures but also levels of engagement with emerging food technology {Banovic, 2023 #596}.

Finally, we found that consumers in Italy and the US more strongly support the labelling of any milk-derived product from "precision fermentation" as "milk", "yogurt", "butter", and "cheese". Conversely, in Denmark and the UK, there is less support for using traditional dairy product labelling on PF dairy products.

These findings have significant implications for food businesses aiming to produce and commercialize PF milk. First, it is crucial to inform consumers about the benefits of PF milk, potentially through targeted communication campaigns and food labels. However, the effectiveness of these communications varies by country, emphasizing the need for tailored strategies. Specifically, campaigns in Denmark, Italy, and the UK should focus more on health benefits, whereas in the US, emphasis on animal welfare or environmental benefits might be more effective. Second, targeting the initial sales of PF milk to specific consumer segments particularly *light traditionalist*, who are more receptive to new products is vital. In all four countries, early sales efforts should focus on consumers with lower food technology neophobia, high familiarity with PF milk, and stronger pro-environmental attitudes, while in Denmark, Italy, and UK, younger consumers within this segment represent especially promising targets.

Finally, in the Italian and British markets, it is advisable to use the "Carbon Trust label" on PF milk labels, and in Italy, the claim "Complete protein" should be highlighted to increase consumer acceptance of these products.

6. PRACTICAL and Policy implications

Several policy implications can be derived from this study. First, the observed differences in consumer valuation for PF milk among countries, treatments, and consumer segments, as *light traditionalists* (vs. *strong traditionalists*), that exhibit a higher preference for PF milk, and contexts where acceptance of PF milk can be fostered. From a practical standpoint, businesses and marketers can leverage these insights to develop targeted communication strategies tailored to different consumer segments, emphasizing the attributes most valued by specific segments, such as health benefits, environmental sustainability, or animal welfare. This indicates potential for promoting PF milk as part of a shift toward more sustainable and healthy diets through targeted strategies and policy interventions in the investigated countries.

These outcomes are crucial for more effectively designing policies in the EU, UK, and US that could foster dietary shifts by incorporating PF milk and potentially other PF dairy products. For example, the EU's Food 2030 Pathway for Action, which focuses on "Alternative Proteins and Diet Shift" (EC, 2020b), should incorporate recommendations in its research and innovation policy that emphasize the importance of tailoring new product development and commercialization processes to consumer segments. Specifically, these segments include consumers who are younger, are more familiar with PF technology, those less neophobic towards new food technologies, and those with higher pro-environmental attitudes.

In the UK, while following regulations similar to the EU, there is a distinct push to expedite the approval of PF products. UK policy could benefit from emphasizing the need to align new product development and commercialization strategies with the preferences of key consumer segments to enhance acceptance and integration of PF milk into the market. Practically, this could involve collaborative efforts between industry stakeholders and consumer researchers to design sensory trials and product-testing initiatives that address consumer concerns about taste, texture, and product familiarity, which are critical for acceptance of alternative proteins (Michel et al., 2021).

In the US, where PF products have already been approved and granted GRAS status, policies could focus on encouraging the expansion of PF product lines. This can be achieved by supporting marketing efforts tailored to consumer groups that are more likely to embrace such innovations, thereby maximizing consumer acceptance and driving broader dietary shifts towards sustainable alternatives. This is corroborated by other studies (Banovic & Grunert, 2023; Zollman Thomas & Bryant, 2021) which showed that there is a potential for government-led public awareness campaigns to educate consumers about the benefits of PF products. These campaigns could specifically focus on the health benefits of PF milk in Denmark, Italy, and the UK, as well as on the environmental impact and animal welfare improvements across all countries, in alignment with the EU's Farm to Fork Strategy (EC, 2020a). In the UK (FSA, 2024) and the US (FDA, 2024), such campaigns could aim to reduce consumer hesitance and increase the adoption these new products. Additionally, public health campaigns could benefit from incorporating behavioral nudges to encourage trial and repeated consumption of PF products, leveraging proven techniques such as social norms marketing and framing effects (Thøgersen & Zhou, 2021).

Given the positive reception to health benefits information in Europe, policymakers could integrate PF products into broader health policies, enhancing public health outcomes, as in the "Food-Based Dietary Guidelines" (EC, 2021). Additionally, considering the favourable impact of environmental framing on consumer valuation for PF milk, policymakers could also align PF products with broader environmental policies such as the European Green Deal initiative (EC, 2019). This integration could extend to recognizing and promoting these new products within carbon reduction strategies and sustainability initiatives. Furthermore, as animal welfare is particularly valued by consumers in Denmark and Italy (Eurobarometer, 2023), policy implications may include the development of ethical guidelines for PF processes.

Given the challenges faced by the traditional dairy sector (Rieger et al., 2023), policy makers can support those producers wish to move from traditional dairy production to PF milk production through financial incentives to purchase new equipment, training, consultancy, etc. needed to develop and market PF milk. Furthermore, policy makers should increase funding resources for PF milk producers to conduct more consumer and marketing research to gather more refined information about consumer preferences for PF milk. Such effort can support practical initiatives like sensory testing, and pilot programs to assess the effectiveness of different product positioning strategies across markets. This information could be used to increase the consumer's acceptance towards such products by understanding, for example, how to nudge them or which specific labelling information they prefer. Such policies could also help reduce production costs and, consequently, retail prices, making these products more accessible to a wider range of consumers, answering price sensitivity issues (Zollman Thomas & Bryant, 2021).

The fact that consumers in all countries tend to value PF milk significantly differently than conventional cow-milk suggests a need for labelling regulations in those countries to help consumers make more informed purchase decisions by allowing them to identify PF milk more clearly. Indeed, consumers are likely to demand transparency and the right to know what they are purchasing, especially for the consumers who strongly like or dislike PF milk. Thus, it is of crucial importance that policy makers support the establishment of a regulatory framework controlled by authorities to ensure effective and standardized PF milk labelling that consumers can trust and use to make more informed choices. Practically, this could involve the co-creation of labelling guidelines with consumer input to enhance trust and reduce skepticism about PF products, as labelling clarity has been shown to influence purchase intentions (Nguyen & Le, 2020).

We found that consumers are willing to pay a premium price for PF milk with a lower carbon footprint which depends on the country. Thus, EU and UK governments should increase their investments and support the reduction of carbon footprint for PF milk producers to allow them the adoption of Carbon Trust label. Fifth, policymakers could consider updating regulatory frameworks to ensure faster and more transparent processes for approval of PF products (particularly in Europe), as more comprehensive labelling (both the US and the EU).

Finally, this study highlights cross-cultural differences in consumer preferences and WTP, suggesting the need for international collaboration to develop global standards and trade policies for PF products. Such efforts could facilitate the international exchange of these products, ensuring safety, quality, and fairness in trade. By addressing the above areas, policymakers cannot only support the growth of the PF industry but also ensure that consumer interests in sustainability issues are adequately protected and promoted (JRC, 2022).

7. ConclusionS & FUTURE RESEARCH DIRECTIONS

In conclusion, our results show that consumer valuation for PF milk varies based on their country of residence, age, familiarity with PF milk, level of neophobia towards new food technologies, pro-environmental attitudes, and the type of benefit information provided about PF milk. These findings align with existing consumer research on alternative proteins, where factors such as food neophobia, perceived naturalness, and trust in food systems have been shown to influence acceptance (Siegrist & Hartmann, 2019; Michel et al., 2021). These insights into consumer preferences are useful for designing effective communication strategies that highlight the potential benefits of PF milk to the public, thereby maximizing its commercial viability.

Moreover, our study contributes to the broader consumer research on alternative proteins by demonstrating how individual characteristics, such as environmental values and technology acceptance, interact with cultural contexts to shape preferences for PF products. This study is among the first to explore the consumer preferences and WTP for PF milk in a cross-cultural setting. The inclusion of different countries, which vary in terms of eating habits, food culture, and policy regulation towards novel technologies like PF, allowed for an in-depth cross-country comparison.

Further research should consider real-life settings (e.g., stores) to capture the real consumer shopping behavior and thus further enhance the external validity of our results. For example, by conducting non-hypothetical experiments using experimental auctions, multiple price list or real choice experiments (RCE) combined with sensory tests of PF milk. Researchers can better understand the role of sensory attributes, such as taste and texture, which have been identified as critical determinants of consumer acceptance in alternative protein studies (Michel et al., 2021). This would also test the robustness of our findings.

In addition, future works should investigate other types of PF dairy products (e.g., cheese, yogurt, etc.) or other PF foods given the increasing number of PF food products under development (GFI, 2022). Finally, considering the ongoing debate about labelling of PF dairy alternatives (Ronchetti et al., 2024), future research should explore how information framing, eco-labelling, and naming strategies influence consumer perceptions, building on existing literature on food labelling and sustainability claims (Nguyen & Le, 2020; Torma & Thøgersen, 2021). Given the ongoing debates over the use of animal-based terms (e.g., meat, beef, milk, cheese) for alternatives no-animal products (GFI, 2022) , it would be interesting to assess how different naming and terms for PF technology could affect consumer valuation of such new products.

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List of Figures

Figure 1. Example of the choice task.

TREATMENT/NAME | **DESCRIPTION OF FRAMING**

1. CONTROL (Only CE questions)

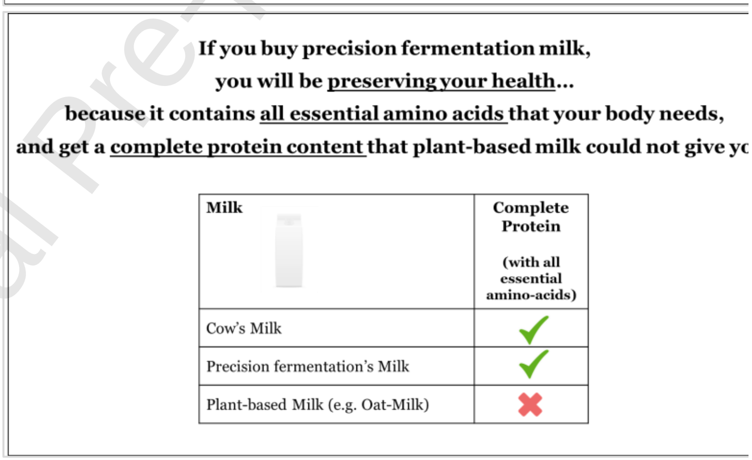
No message. Instructions to proceed to the next frame.

2. ANIMAL WELFARE INFORMATION

(CE questions + Animal welfare information)

3. HEALTH INFORMATION

(CE questions + Nutritional information)



4. ENVIRONMENTAL INFORMATION

(CE questions + Environmental information)

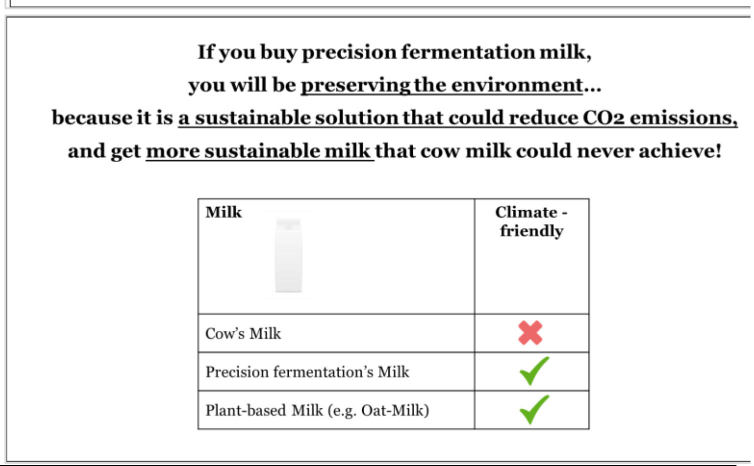


Figure 2. Informational treatments.

LIST OF TABLES

Table 1. Attributes and levels.

ATTRIBUTES	LEVELS			
Type of milk technology	Cow milk Precision fermentation milk Plant-based milk			
Animal welfare	No information "100% animal free"			
Protein type	No information "Complete protein"			
Carbon Trust label	No label reported CARBON TRUST REDUCING CO2			
	DK	**IT**	**UK**	**US**
Price	10 kr/lt 15 kr/lt 20 kr/lt 25 kr/lt	0.75 €/lt 1.50 €/lt 2.25 €/lt 3.00 €/lt	£0.50/lt £1.25/lt £2.00/lt £2.75/lt	$0.75/lt $3.50/lt $6.25/lt $9.00/lt

Table 2. Socio-demographic characteristics of the participants across countries.

VARIABLES	DK (N = 1,167)	IT (N= 1,058)	UK (N = 1,130)	US (N= 1,006)
Gender (%)				
- Male	46.9	49.9	50.3	46.8
Age (mean)	45.2	46.5	45.9	44.5
Education (%)				
- Primary school	9.3	8.6	1.0	0.6
- Secondary school	17.5	14.6	19.9	23.3
- Higher education	33.3	37.3	27.9	20.5
- Bachelor	23.3	11.7	32.6	42.6
- Master/PhD	14.7	27.9	14.3	10.9
Income before tax (%) *(UK in £; US in $; DK starting from 100K per category in DKK)*				
- Less than 10,000 €	2.9	8.7	5.8	4.9
- 10,000 € - 29,999 €	18.5	33.0	26.3	13.5
- 30,000 € - 49,999 €	25.5	26.3	27.8	13.7
- 50,000 € - 69,999 €	14.0	10.0	14.6	13.9
- 70,000 € - 89,999 €	13.0	2.6	7.8	14.1
- 90,000 € - 149,999 €	9.7	2.0	7.6	32.8
- more than 150,000 €	1.7	0.6	1.5	3.7
- I do not want to declare	14.6	16.9	8.6	3.3
Household size (%)				
- ≤ 2 people	25.9	42.0	19.7	37.1
- 3 to 5	69.0	57.2	71.9	60.0
- ≥ 6	5.1	0.8	8.4	2.9

Table 3. Estimated mWTP space from MIXL models for Denmark (DK), Italy (IT), the UK, and the US.

Attribute	TREATMENT: CONTROL				TREATMENT: ANIMAL				TREATMENT: HEALTH				TREATMENT: ENVIRONMENT			
	DK N=292) mWTP: kr./lt (SE)	IT N=265) mWTP: €/lt (SE)	UK N=282) mWTP: £/lt (SE)	US N=255) mWTP: $/lt (SE)	DK N=293) mWTP: kr./lt (SE)	IT N=264) mWTP: €/lt (SE)	UK N=288) mWTP: £/lt (SE)	US N=260) mWTP: $/lt (SE)	DK N=292) mWTP: kr./lt (SE)	IT N=264) mWTP:€/ lt (SE)	UK N=268) mWTP: £/lt (SE)	US N=238) mWTP: $/lt (SE)	DK N=290) mWTP: kr./lt (SE)	IT N=265) mWTP:€/ lt (SE)	UK N=292) mWTP: £/lt (SE)	US N=253) mWTP: $/lt (SE)
Plant	-27.14***	-0.55***	-4.30***	-11.36***	-35.68***	-0.60***	-1.40***	-3.06**	-27.85***	-1.09***	-3.12***	-14.75***	-23.98***	-0.59***	-1.70***	-4.40***
	(0.49	(0.12)	(0.45)	(2.09)	(3.35)	(0.15)	(0.26)	(1.24)	(2.36)	(0.11)	(0.33)	(2.19)	(1.90)	(0.11)	(0.23)	(1.46)
Precision	-34.19***	-1.97***	-5.60***	-17.43***	-31.20***	-0.98***	-2.40***	-7.08***	-20.82***	-0.67***	-2.84***	-13.37***	-23.83***	-0.53***	-3.10***	-9.02***
	(3.09	(0.25)	(0.51)	(2.90)	(2.32	(0.11)	(0.22)	(1.54)	(1.50)	(0.11)	(0.27)	(2.01)	(1.93)	(0.09)	(0.27)	(1.80)
nimal	-9.56***	-0.24**	-0.83***	-1.01	-8.50***	-0.16**	-0.51***	0.04	-4.35***	-0.33***	-0.47***	0.27	-7.80***	0.01	-0.67***	1.33*
	(1.20	(0.09)	(0.13)	(0.94)	(0.87)	(0.06)	(0.09)	(0.75)	(0.56)	(0.06)	(0.12)	(0.66)	(0.75)	(0.06)	(0.10)	(0.77)
rotein	-0.79	0.22***	0.14	1.08	-0.64	0.16**	-0.11*	0.34	0.60	0.30***	0.33***	0.07	-0.35	0.18***	-0.11	0.38
	(0.54	(0.06)	(0.10)	(0.85)	(0.61)	(0.06)	(0.07)	(0.55)	(0.48)	(0.06)	(0.09)	(0.78)	(0.53)	(0.05)	(0.08)	(0.58)
arbon	-1.14*	0.26***	0.37***	1.76	-0.68	0.37***	0.05	1.58*	-0.65	0.26***	0.13***	0.80	1.08**	0.34***	0.08	1.68*
	(0.60	(0.07)	(0.12)	(1.28)	(0.63)	(0.06)	(0.09)	(0.92)	(0.48	(0.06)	(0.10)	(1.16)	(0.47)	(0.07)	(0.08)	(0.86)
rice	-1.59***	0.54***	0.17	-2.31***	-1.73***	0.41***	0.22***	-1.99***	-1.46***	0.48***	0.07	-2.28***	-1.52***	0.32***	0.25***	-1.99***
	(0.08	(0.09)	(0.10)	(0.15)	(0.08)	(0.08)	(0.07)	(0.12)	(0.07	(0.09)	(0.09)	(0.16)	(0.09)	(0.08)	(0.08)	(0.13)
ptout	-25.62***	-2.11***	-3.46***	-19.80***	-26.92***	-2.08***	-2.87***	-12.19***	-25.26***	-2.20***	-3.28	-16.24***	-25.83***	-2.10***	-3.00***	-12.97***
	(0.49)	(0.04)	(0.14)	(2.42)	(0.60)	(0.05)	(0.08)	(1.12)	(0.46)	(0.03)	(0.14)	(1.99)	(0.47)	(0.05)	(0.08)	(1.32)
Model fit statistics																
. obs.	10,512	9,540	0,152	9,180	10,548	9,504	10,368	9,360	10,512	9,504	9,648	8,568	10,440	9,540	10,512	9,108
ald chi2	3588.83	3446.95	310.95	49.66	2357.48	2851.34	2123.40	286.91	3940.31	5102.94	1242.38	225.25	3769.00	2791.17	2346.69	244.67
rob > chi2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ogL	-2255.31	-2403.80	-2207.72	-2532.38	-2275.72	-2447.58	-2473.55	-2589.10	-2278.09	-2417.78	-2239.03	-2345.88	-2349.05	-2555.10	-2500.56	2410.701
f	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
IC	4566.61	4863.61	4471.42	5120.76	4607.43	4951.17	5003.10	5234.19	4612.17	4891.55	4534.05	4747.77	4754.09	5166.21	5057.17	4877.402
IC	4769.90	5064.18	4673.74	5320.25	4810.82	5151.63	5206.00	5434.23	4815.46	5092.02	4734.94	4945.33	4957.19	366.78	5260.46	5076.676

Note. Asterisks indicate *p < 0.1, **p < 0.05, and ***p < 0.01; mWTP: marginal willingness to pay; SE: standard error; N. obs: number of observations; Wald chi2: Wald test; logL: log likelihood function; df: degree of freedom; AIC: Akaike's information criterion; BIC: Bayesian information criterion.

Table 4. Hypothesis test across four treatments and countries (Precision X dtreatment).

Hypothesis test	DK WTP: kr./lt (SE)	IT WTP: €/lt (SE)	UK WTP: £/lt (SE)	US WTP: $/lt (SE)
H_{01}: $mWTP^{ANIMAL} > mWTP^{CONTROL} = 0$	7.38***	1.29***	0.40	3.56
	(2.38)	(0.11)	(0.33)	(2.31)
H_{02}: $mWTP^{HEALTH} > mWTP^{CONTROL} = 0$	10.72***	1.82***	1.65***	-0.78
	(2.02)	(0.12)	(0.36)	(1.97)
H_{03}: $mWTP^{ENVIRONMENT} > mWTP^{CONTROL} = 0$	5.95***	1.16***	0.92***	3.38
	(1.95)	(0.16)	(0.27)	(2.71)
H_{04}: $mWTP^{HEALTH} \neq mWTP^{ANIMAL} = 0$	5.04***	0.25**	0.50*	-4.43**
	(1.44)	(0.10)	(0.29)	(2.19)
H_{05}: $mWTP^{ANIMAL} \neq mWTP^{ENVIRONMENT} = 0$	1.15	0.76***	0.14	-1.14
	(1.43)	(0.15)	(0.23)	(1.81)
H_{06}: $mWTP^{ENVIRONMENT} \neq mWTP^{HEALTH} = 0$	- 4.10***	0.09	-0.50*	5.17**
	(1.38)	(0.11)	(0.27)	(2.17)

Note. Asterisks indicate *p < 0.1, **p < 0.05, and ***p < 0.01; mWTP: marginal willingness to pay.

Table 5. Estimation results from Latent Class Logit (LCL) model for Denmark.

ATTRIBUTE	GROUP 1 Strong Traditionalists, Unethical & Economical Consumers (*N = 160*)		GROUP 2 Light Traditionalists & Economical Consumers (*N = 85*)		GROUP 3 Random Choice (*N = 47*)	
	Coefficient (SE)	***p-value***	**Coefficient (SE)**	***p-value***	**Coefficient (SE)**	***p-value***
Plant	-5.71 (0.52)	0.00	-0.42 (0.18)	0.02	0	.
Precision	-6.42 (0.74)	0.00	-1.58 (0.17)	0.00	0	.
Animal	-1.89 (0.18)	0.00	0.16 (0.12)	0.18	0	.
Nutrition	-0.17 (0.12)	0.17	0.21 (0.10)	0.05	0	.
Carbon	0.06 (0.12)	0.60	-0.11 (0.10)	0.27	0	.
Price	-0.09 (0.02)	0.00	-0.23 (0.02)	0.00	0	.
Optout	-2.41 (0.38)	0.00	-4.68 (0.32)	0.00	0	.
Individual characteristics						
Age	0	.	-0.06 (0.01)	0.00	-0.05 (0.01)	0.00
FTNS	0	.	-0.34 (0.20)	0.10	-0.73 (0.28)	0.01
FAMILIARITY	0	.	0.05 (0.17)	0.75	0.43 (0.17)	0.01
ECO	0	.	0.48 (0.14)	0.00	0.50 (0.19)	0.01
Model fit statistics						
BIC	5107.34					
AIC	5019.10					

mWTP = marginal willingness to pay; SE = standard error; BIC = Bayesian information criterion; AIC = Akaike's information criterion.

Table 6. Estimation results from Latent Class Logit (LCL) model for Italy.

ATTRIBUTE	GROUP 1 Strong Traditionalists, Unethical & Economical Consumers (*N = 89*)		GROUP 2 Light Traditionalists & Economical Consumers (*N = 107*)		GROUP 3 Random Choice (*N = 69*)	
	Coefficient (SE)	***p-value***	**Coefficient (SE)**	***p-value***	**Coefficient (SE)**	***p-value***
Plant	-3.24 (0.34)	0.00	0.32 (0.16)	0.06	0	.
Precision	-5.93 (1.17)	0.00	-0.36 (0.14)	0.01	0	.
Animal	-1.50 (0.23)	0.00	0.48 (0.10)	0.00	0	.
Nutrition	0.18 (0.16)	0.27	0.19 (0.10)	0.06	0	.
Carbon	0.15 (0.15)	0.31	-0.09 (0.10)	0.38	0	.
Price	-0.68 (0.15)	0.00	-1.76 (0.11)	0.00	0	.
Optout	-1.51 (0.39)	0.00	-3.02 (0.22)	0.00	0	.
Individual characteristics						
Age	0.02 (0.01)	0.22	0	.	-0.02 (0.26)	0.27
FTNS	0.92 (0.01)	0.00	0	.	0.26 (0.21)	0.20
FAMILIARITY	-0.41 (0.14)	0.00	0	.	0.06 (0.11)	0.55
ECO	-0.54 (0.17)	0.00	0	.	0.09 (0.19)	0.63
Model fit statistics						
BIC	5445.00					
AIC	5359.09					

mWTP = marginal willingness to pay; SE = standard error; BIC = Bayesian information criterion; AIC = Akaike's information criterion.

Table 7. Estimation results from Latent Class Logit (LCL) model for United Kingdom.

ATTRIBUTE	GROUP 1 Strong Traditionalists, Unethical & Economical Consumers (*N = 135*)		GROUP 2 Light Traditionalists & Economical Consumers (*N = 127*)		GROUP 3 Random Choice (*N = 20*)	
	Coefficient (SE)	***p-value***	**Coefficient (SE)**	***p-value***	**Coefficient (SE)**	***p-value***
Plant	-4.51 (0.34)	0.00	0.07 (0.11)	0.50	0	.
Precision	-5.36 (0.41)	0.00	-0.90 (0.14)	0.00	0	.
Animal	-1.27 (0.17)	0.00	0.07 (0.07)	0.32	0	.
Nutrition	-0.14 (0.14)	0.30	0.17 (0.06)	0.10	0	.
Carbon	-0.16 (0.13)	0.23	0.41 (0.07)	0.00	0	.
Price	-0.38 (0.10)	0.00	-0.72 (0.08)	0.00	0	.
Optout	-2.31 (0.26)	0.00	-2.33 (0.16)	0.00	0	.
Individual characteristics						
Age	0	.	-0.05 (0.01)	0.00	-0.07 (0.04)	0.09
FTNS	0	.	-0.78 (0.23)	0.00	-1.04 (0.58)	0.07
FAMILIARITY	0	.	0.27 (0.13)	0.03	0.61 (0.23)	0.22
ECO	0	.	0.58 (0.15)	0.00	0.39 (0.32)	0.28
Model fit statistics						
BIC	5097.32					
AIC	5010.00					

mWTP = marginal willingness to pay; SE = standard error; BIC = Bayesian information criterion; AIC = Akaike's information criterion.

Table 8. Estimation results from Latent Class Logit (LCL) model for United States.

ATTRIBUTE	GROUP 1 Strong Traditionalists, Unethical & Economical Consumers (*N = 135*)		GROUP 2 Light Traditionalists & Economical Consumers (*N = 127*)		GROUP 3 Random Choice (*N = 20*)	
	Coefficient (SE)	***p-value***	**Coefficient (SE)**	***p-value***	**Coefficient (SE)**	***p-value***
Plant	-3.36 (0.33)	0.00	-0.27 (0.08)	0.00	0	.
Precision	-3.39 (0.36)	0.00	-0.47 (0.08)	0.00	0	.
Animal	-0.36 (0.19)	0.05	0.17 (0.05)	0.00	0	.
Nutrition	-0.10 (0.17)	0.56	0.14 (0.05)	0.01	0	.
Carbon	-0.09 (0.16)	0.57	0.43 (0.06)	0.00	0	.
Price	-0.20 (0.03)	0.00	-0.00 (0.01)	0.98	0	.
Optout	-1.87 (0.29)	0.00	-2.99 (0.26)	0.00	0	.
Individual characteristics						
Age	-0.02 (0.02)	0.77	0	.	-0.02 (0.02)	0.29
FTNS	0.65 (0.30)	0.03	0	.	0.55 (0.30)	0.07
FAMILIARITY	-1.16 (0.26)	0.00	0	.	-0.44 (0.11)	0.00
ECO	-0.41 (0.19)	0.03	0	.	-0.08 (0.17)	0.65
Model fit statistics						
BIC	5279.90					
AIC	5194.91					

mWTP = marginal willingness to pay; SE = standard error; BIC = Bayesian information criterion; AIC = Akaike's information criterion.

Table 9. Policy labelling preferences.

VARIABLE	DK (N=292)		IT (N=265)		UK (N=282)		US (N=255)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Labelling	3.22	(1.70)	4.74	(1.96)	3.71	(1.75)	4.85	(1.94)

CREDIT AUTHOR STATEMENT

Marija Banovic: Conceptualization, Data collection, Methodology, Supervision, Funding, Validation, Data Analysis, Writing - review & editing**. Daniele Asioli:** Conceptualization, Methodology, Formal Data Analysis, Software, Validation, Writing - review & editing**. Giovanni Sogari:** Conceptualization, Validation, Writing - review & editing.

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HIGHLIGHTS

- Precision fermentation (PF) milk is a sustainable, nutritious cow milk alternative.
- General cross-cultural consumer reluctance toward PF milk.
- Benefit framing, familiarity, and pro-environmental attitudes boost preferences.
- Consumer labelling preferences for PF milk vary by country.
- Important industry and policy implications are discussed.