



How consumers perceive the use of bioprocessing and non-thermal technologies to develop minimally processed plant-based foods: Insights from a qualitative study

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ABSTRACT

Consumers' negative image of currently available plant-based foods (PBFs) as ultra-processed and unhealthy is hampering the transition towards more plant-based diets. A qualitative approach was applied across four European countries – Switzerland, Finland, Portugal and Romania – to explore consumers' views on minimal processing methods and PBFs produced using these methods. Semi-structured in-person interviews were conducted with meat eaters (omnivores and flexitarians). The aim was to reveal and understand their attitudes, perceptions and expectations regarding minimal processing technologies (fermentation, germination, high-pressure processing, pulsed electric field and ultrasound) to produce PBFs. For many interviewees, the perceived level of processing was an important consideration in food choice. Four main themes relevant for the acceptance of minimal processing technologies were identified: i) familiarity and knowledge; ii) benefits perception; iii) perceived risks, concerns and doubts about food safety, resource efficiency and performance; and iv) interest and general attitude. Most interviewees appeared open to using the addressed technologies to produce minimally processed plant-based options. Meat and dairy alternatives and snacks are examples of minimally processed foods that they would be willing to consume. The study provides in-depth insights into the psychological, social and environmental factors that contribute to the acceptance of minimal processing technologies and PBFs. The results can support researchers and the food industry in designing suitable minimally processed PBFs that align with consumers' expectations.

1. Introduction

Worldwide, many consumers are increasingly seeking to reduce animal-based food consumption and eat more plant-based foods (PBFs); however, there are still barriers and conflicts that hinder large-scale consumption of PBFs, such as the processed status and the excess of additives used (Johansson et al., 2025; Hötzel and Vandresen, 2022; Onwezen and Dagevos, 2024). Drolet-Labelle et al. (2023) reported that the amount of salt and additives acts as a barrier to the consumption of processed PBFs. Chezan et al. (2022) revealed that European consumers value plant-based meat substitutes that are less processed, besides

perceiving them as healthier.

Minimal processing technologies such as fermentation and high-pressure processing are potential means to alleviate these barriers related to the perception of “ultra-processed” for consumers interested in processed PBFs. In contrast to highly processed foods, minimally processed PBFs developed with these technologies are not expected to differ significantly from unprocessed foods regarding intrinsic characteristics (Ahrné et al., 2025; McCausland et al., 2026). Minimal processing technologies may even improve sensory and nutritional characteristics of the foods, e.g. by increasing bioavailability of nutrients while ensuring food safety of the products (Melios et al., 2025).

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Therefore, processing can also have a positive influence on product characteristics. Consequently, when making food choices, consumers should consider not only the level of processing but also the formulation of the food, as this can also positively or negatively influence the final product (Ahrné et al., 2025).

In this cross-cultural consumer study conducted in Switzerland, Finland, Portugal and Romania, we aim to explore consumers' perceptions, attitudes and expectations towards five minimal processing technologies used to develop PBFs in the Horizon Europe Project 'Sustain-a-Bite': two natural bioprocessing technologies (fermentation and germination) and three non-thermal technologies (high-pressure processing-HPP, ultrasound-US and pulsed electric field -PEF). Previous literature has reported that some consumers are sceptical about certain emerging food technologies (Lee et al., 2015; Perrea et al., 2015) and that food technology neophobia tends to vary depending on the cultural background, for example. Therefore, it seems reasonable to explore, through a cross-cultural study, consumers' views and attitudes towards these technologies before developing minimally processed PBFs.

Comparing these countries will give us a clearer picture of consumers' awareness and interest in PBFs made with innovative and more sustainable technologies. The results can support the food system actors in targeting omnivores and flexitarians with more sustainable, minimally processed PBFs. The present findings can also support campaigns aimed at increasing consumers' knowledge of the technologies applied to food development, resulting in greater transparency.

2. Background

Animal-based food production and consumption are among the strongest contributors to the environmental burdens generated by the current agrifood system. It has been reported that the animal-based food industry is the primary contributor to greenhouse gas (GHG) emissions from food production (Boaitey et al., 2025; Granato and Wassmann, 2024; Saini et al., 2024). On the other hand, PBFs have been reported to significantly reduce GHG emissions beyond land and water use compared with traditional animal-based foods (Saini et al., 2024). Therefore, recent studies have advocated reducing animal-based meat and dairy and promoting more sustainable protein sources (Giacomuzzo et al., 2024; Granato and Wassmann, 2024).

Recent reports also revealed that, in addition to consumers from the European Union who reported being committed to reducing meat consumption (GFI, 2024), a large share of Swiss consumers have taken specific actions to reduce their meat consumption (Lucas et al., 2025).

Plant-based consumption is often motivated by utilitarian benefits related to health (Boaitey et al., 2025; Hunter et al., 2024), food safety and the environment (Boaitey et al., 2025; Ford et al., 2024). At the same time, the greatest barriers to processed PBF consumption are their status as highly processed foods and their extensive use of additives, leading many consumers to perceive them as unhealthy and therefore avoid them (Granato and Wassmann, 2024; Hässig et al., 2023). Furthermore, lower-than-expected sensory quality and high price are also recognised as typical barriers (Granato and Wassmann, 2024; Johansson et al., 2025; Saini et al., 2024). However, consumers' perceptions also vary depending on the main ingredient or processing technology used, and these perceptions can be improved by providing information (Etter et al., 2024; Lee et al., 2015; Martins et al., 2019).

Therefore, this study aimed to investigate, through qualitative interviews, how consumers perceive the use of bioprocessing and non-thermal technologies to develop minimally processed plant-based foods. A qualitative approach was chosen to enable us to gain new insights into unfamiliar topics, such as minimal processing technologies, without limiting consumers' answers (Tan et al., 2015). It also allows the identification of themes that may not have been considered in the design of quantitative studies (Banovic et al., 2018; Hunter et al., 2024).

3. Methods

3.1. Participants and recruitment

At least 10 meat eaters per country (Switzerland-CH, Finland-FI, Portugal-PT and Romania-RO), without any background in food science and technology and without any university affiliation as students or employees, were recruited. These target consumers (omnivores and flexitarians) were chosen first because they represent the largest share of European consumers (GFI, 2024) and second because we aim to significantly impact food system transformation by promoting reductions in animal-based food consumption and production.

The recruitment was conducted by consumer testing agencies, except for Switzerland, where a university consumer database was used. The number of interviewees was selected to achieve saturation (i.e., no new themes emerged) (Yan et al., 2024). Eligible interviewees were required to be at least partially responsible for purchasing or preparing food in their households. In addition, the acculturation factor was considered by limiting participation to consumers having citizenship in the country or at least 10 years of residence. The recruitment also aimed for a balanced sample across sex, age groups, place of residence and diet type. The sociodemographic characteristics of the interviewees are displayed in Table 1.

Table 1
Socio-demographic profile of the interviewees (by percentage within each country subsample).

Characteristics	Frequency (%)			
	CH (n = 11)	FI (n = 10)	PT (n = 13)	RO (n = 12)
Sex				
Female	45.5	50.0	53.8	50.0
Male	54.5	50.0	46.2	50.0
Age				
18–39 years old	45.5	50.0	46.2	33.3
40–59 years old	36.3	40.0	38.4	58.4
> 60 years old	18.2	10.0	15.4	8.3
Diet type				
Omnivore*	45.5	50.0	69.3	50.0
Flexitarian**	54.5	50.0	30.8	50.0
Education level				
Mandatory school	-	-	-	8.3
Secondary level II (vocational education)	36.4	10.0	-	-
Secondary level II (general education)	-	40.0	15.4	33.3
Tertiary degree (higher vocational education)	27.3	20.0	7.7	8.3
Tertiary degree (Applied school/University)	36.4	30.0	76.9	50.0
Employment status				
Not working (student, retired, unemployed)	18.2	60.0	7.7	16.7
Part-time	45.5	30.0	7.7	8.3
Full-time (≥90%)	36.4	10.0	84.6	75.0
Residence place				
Urban area (city)	27.3	70.0	53.8	50.0
Suburban area (agglomeration)	54.5	10.0	30.8	41.7
Rural area (countryside)	18.2	20.0	15.4	8.3
Responsible for buying food				
Me	54.5	40.0	38.5	75.0
Someone else	-	-	7.7	-
Me together with someone else	45.5	60.0	53.8	25.0
Responsible for preparing the meals				
Me	63.6	50.0	46.2	66.7
Someone else	-	10.0	23.1	16.7
Me together with someone else	36.4	40.0	30.8	16.7

Please note: *diet with meat, fish and/or seafood **diet mainly vegetarian (plant-based) with occasional meat or fish consumption.

3.2. Data collection

Before the interviews, the principal investigator of the project (T.A. B.) was responsible for providing clarifications and training to the interviewers. All translations of the interview guide from English to German, Finnish, Portuguese and Romanian were checked by native speakers and back-translated to ensure accuracy. A pilot interview was conducted in each country to test the timing, understanding and validity of the questions. One question was rewritten after the pretest to facilitate comprehension.

The individual semi-structured interviews took place in January–February 2025 and were conducted in a private space in the university's facilities by experienced interviewers involved in the project (native speakers).

Participants were welcomed, signed the informed consent and confidentiality agreement form, and were informed, as an icebreaker, about the aim of the study, that the interviews would be recorded, and, to establish confidence, that there were no right or wrong answers. They could withdraw at any time without providing a reason.

Questions related to PBFs and technologies were queried in the interviews in four parts (Table 2). These questions were developed to reveal not only the perceptions, attitudes and expectations but also associations, emotions, feelings, knowledge and involvement regarding technologies for producing more sustainable, nutritious and safe, minimally processed PBFs. The aim of Part 1 was to warm up by discussing general food habits and to guide the interviewees towards the study's main subject. In Part 2, the dietary habits of currently available processed plant-based options were explored. Interviewees' familiarity and perceptions regarding plant-based ingredients applied in the Sustain-a-Bite Horizon Europe project (sustain-a-bite.eu) were also explored in this section. Part 3 explored consumers' perceptions and attitudes towards the five minimal processing technologies for the development of new minimally processed PBFs. Finally, the aim of Part 4 was to reveal participants' preferences and the types of minimally processed PBFs they would be interested in consuming.

The follow-up questions 'why?' and 'how?' were queried, when necessary, allowing us to better understand the reasons behind their

comments, to maintain the interviews smoothly and keep the answers on track with the desired research aim. Written descriptions of fermentation, germination, HPP, US and PEF, along with their benefits, were introduced as *stimuli* (see supplementary material). The interviews (N = 46) lasted an average duration of 59 min and ranged up to 115 min. In the end, a short survey was given to the interviewees covering sociodemographic characteristics such as sex, education level and place of residence (see Table 1). The participants received a supermarket or shopping voucher as compensation.

3.3. Data analyses

The interview recordings were transcribed verbatim from native languages (Swiss German, Finnish, Portuguese and Romanian) and translated into English by native speakers who were researchers involved in the study in each country. Numbers were assigned to participants to maintain the confidentiality of their identities. Transcripts were coded manually and using MAXQDA 24 to assist with data organisation. Data from part 3, "General attitudes and perceptions towards minimal processing food technologies" (see Table 2), which addressed the main research questions of this study, were analysed using the six phases of reflexive thematic analysis (inductive approach), including critical reflection (Braun and Clarke, 2006). This approach allows for the exploration of topics emerging from the interview responses without the need for a predetermined theoretical framework. Initially, a familiarisation with all transcripts from four countries was performed, followed by coding, theme generation, revision, theme definition, description and interpretation. The final themes were revised and validated by the researchers involved in the project. Quotes were used to support the definitions and general discussions of themes (Ford et al., 2024). Information collected from Parts 1, 2 and 4 (see Table 2) was used as complementary or background information and, therefore, was not coded using reflexive thematic analysis. Country of residence, sex and age group were mentioned in the interviewees' quotes. Sociodemographic variables (see Table 1) were analysed using descriptive statistics (IBM SPSS version 29).

4. Results

4.1. Perceptions and attitudes towards minimal processing technologies to develop minimally processed PBFs

During the reflexive thematic analysis, four core themes emerged regarding perceptions of minimal processing technologies (Table 3). These can be considered drivers of or barriers to the acceptance of these technologies for food production.

4.1.1. Theme 1 – familiarity and knowledge as drivers towards minimal processing technologies' acceptance

In all four countries, all participants reported not being familiar with the term "minimal processing technologies" (Table 3, Theme 1: Familiarity and knowledge). Despite that, numerous participants perceived minimal processing technologies positively. They often mentioned perceiving these technologies as better than ultra-processing ones:

"I haven't heard... At least not in that form. I would assume that it would then be a bit of the opposite of highly processed products ..." (FI, female, 18-39)

"Well, I believe that they are... or rather... the process is much better than the highly processed one." (RO, male, 18-39)

Regarding the specific minimal processing technologies explored, the terms fermentation and germination were familiar to most interviewees. Fermentation was generally more familiar than germination.

Table 2
The interview frame with the main discussion topics.

Part	Main questions
1. Warm-up and food consumption behaviour	What does your diet look like? What is important to you in your diet?
2. General attitudes and perceptions towards PBFs and ingredients	• Consumption habits of processed PBF products • Familiarity and perceptions of plant-based ingredients
3. General attitudes and perceptions towards minimal processing food technologies	What thoughts and feelings come to your mind when thinking of: • minimal processing technologies? • *fermentation? • *seed germination/sprouting? • *high-pressure processing? • *pulsed electric fields? • *ultrasound? Overall, what do you think about using these technologies to produce affordable, tasty and sustainable minimally processed PBFs made from healthy ingredients?
4. Preference for the type of food to be developed with minimal processing technologies	If a combination of such minimal processing technologies results in a plant-based, tasty, healthy and sustainable food that is safe to eat and has a reasonable shelf life, would that interest you? What type of food should it be like?

Note: * Before each question 'What thoughts and feelings come to your mind when thinking of: fermentation/seed germination/high pressure processing/pulsed electric field/ultrasound', the written definition '*stimuli*' (see supplementary material) was provided.

Table 3

Themes, categories and key findings regarding perceptions and attitudes towards minimal processing technologies (fermentation, germination, HPP, US and PEF) in CH, FI, PT and RO.

Theme	Category	Key findings
1-Familiarity and knowledge	Unfamiliarity and lack of knowledge about terms and technologies	- A lack of familiarity and knowledge about the terms minimal processing technologies, seed bioactivation, HPP, PEF and US in the food context. - A lack of knowledge results in scepticism from some consumers. - Some participants would like to know if some products already use these non-thermal technologies and if there is a label for these products informing this (interested in transparency).
	Familiarity with bioprocessing technologies	- In general, participants from all the countries were familiar with fermentation and/or fermented products. - Germination/germinated products were familiar to some, but not as much as fermented products/fermentation. - Some participants recognised fermented products but not the technology behind the products' development.
	Knowledge influences attitude	- For most participants, after receiving information, they perceived all five minimal processing technologies as more positive, more natural and healthier than the ultra-processing ones and showed an openness to consume products made using these technologies. - After receiving information, some non-thermal technologies were still described as too abstract by a few participants. The methods were not easy to comprehend for some people (How to destroy microorganisms without heat? How is heat not generated? How do they affect only the bad parts of the product, without destroying good things?).
2-Benefits perception	Less processing	- Participants perceived minimal processing technologies to have minimal processing involved/with few processing steps and resources needed.
	Naturalness/healthiness	- Participants in general perceived fermentation and germination as healthier and natural, and often mentioned benefits for the body, such as intestinal health and digestibility. These technologies were seen as 'old' technologies and trustworthy. - Non-thermal technologies (HPP, PEF, US) were also perceived as more natural (preserve without heat and release healthy compounds).
	Safe process	- Most participants perceived no risks from the application of non-thermal technologies after receiving information.

Table 3 (continued)

Theme	Category	Key findings
3-Perceived risks, concerns, and doubts	Sensory attributes	- Especially for foods developed with natural bioprocessing, the participants perceived positive sensory attributes (taste, flavour, texture and appearance).
	Food safety	- When forced to indicate concerns, a few of the participants expressed food safety concerns about fermented and germinated products.
	Sustainability/resource efficiency	- Some Swiss and Finnish participants mentioned concerns regarding the energy expenditure of the non-thermal technologies more often than the participants in Romania and Portugal.
	Performance	- For a few participants, the use of non-thermal technologies may modify the original food structure or result in long-term consequences of using it. A few reported not trusting that microbiological contamination can be removed without heat. - A few participants do not think that non-thermal technologies are useful in conserving the products. - A few participants found that there is no need for an extended shelf life.
4-Interest and general attitude	Close to natural	- The largest share of the participants was interested in eating foods produced with minimal processing technologies because they are close to natural products.
	Familiarity	Familiar technologies are more easily accepted: - Old technologies (e.g. fermentation) are easier to accept compared to emerging non-thermal technologies. - Among non-thermal technologies, HPP is preferred because it sounds more familiar to some participants.
	Trust	- Some more sceptical participants described that they trust the food industry and their own country's regulation and approval for safe technologies.

"I think it's a very good method (fermentation). A sensible method..." "This (method) is only positive, and it has been used for centuries" (FI, male, 18-39)

In all the countries, respondents mentioned several examples of fermented products. The most often mentioned products they use themselves daily were yoghurt, sourdough bread and cheese. However, many other fermented products were also mentioned, for example, pickles, kimchi, sauerkraut, kombucha, tofu, fermented milk and beer. This was evidenced by the following quotes:

"(fermented products consumed) yoghurt, bread, beer, kombucha, pickles and cheese". (PT, female, 18-39)

"..Reminds me of sauerkraut. I've been eating it all my life. It is healthy and good for the body. In addition, it will keep for a long time ..." (FI, male, 60+)

Among the germinated foods mentioned in the participants' diets were cress seeds, bean sprouts, and mung bean sprouts and shoots. However, they described consuming them hardly ever.

Some participants were unaware of the minimal processing technology used in the fermented foods they had already consumed. These participants reported unknowingly eating fermented products:

"... since it is used in so many products that we normally consume and I didn't even know about it, nor did I think about it (...) If we like these products so much and they use this technology, let them continue. But I had no idea." (PT, male, 18-39)

"... If I then find out that fermentation has been used in it, then I would consider it a positive addition, even if it hadn't affected my purchase decision ..." (FI, female, 18-39)

The results revealed that, after receiving information on these two natural bioprocessing technologies, the interviewees continued to be interested or were even more interested in foods produced with these technologies.

Regarding non-thermal technologies (HPP, PEF and US), almost all the interviewees perceived them as odd in the context of food, with a first impression, just by hearing the nomenclature. Given the lack of previous knowledge, the terms 'electricity' and 'high pressure' created negative associations for some consumers, as well as associations with highly processed foods:

"... just the idea of killing germs with electricity is bizarre...Just the idea, which I find a bit strange (...), but risks...I can't imagine that there are risks involved." (CH, female, 60+)

"... High processing... what is it like? With high pressure. I get the idea that it would be a highly processed product. Or that requires sophisticated technology to process it ..." (PT, male, 40-59).

"... Just hearing "high pressure"... my gut reaction was to associate it with homogenization. Just like... it gets compressed, and in my mind, that means nutrients get crushed and disappear. But yeah, that's probably completely wrong ..." (CH, male, 18-39)

"... hearing the term (high pressure) sounds like something negative... It sounds like the product has been altered, something like that, it's not one hundred percent ..." (PT, male, 18-39)

After being informed (see supplementary material) and asked the question 'What thoughts and feelings come to your mind when thinking of...' (Table 2), for a few participants, the idea of preserving without heating was still difficult to understand (Table 3, Theme 1: Familiarity and knowledge):

"I can't imagine how (PEF) it's supposed to work and how no heat is generated and that the harmful germs would then be eliminated, because otherwise it might be something for replacement therapy with antibiotics, if it's not thermal...but basically, if it works and the harmful germs are removed...for me the question is always what does it do to the good germs or the good things?..." (CH, female, 40-59)

"Oh, Ok. I'm a little doubtful because it's without heat, and it removes harmful germs...I always have the idea that for germs, you need that heat, to really eliminate them." (PT, male, 40-59)

PEF and US were considered particularly difficult to picture in the context of food processing (see 4.1.3, Theme 3) compared with high-pressure processing (HPP), probably because consumers were more familiar with the pressures used in food processing. According to the findings, it seems that electricity and food belong to different worlds in many people's minds; thus, even though most people do not directly oppose this technology, this discrepancy needs to be taken into account in the communication of these technologies to consumers:

"So when I first heard pulsed electric field, I thought it sounded very esoteric. But then I read it, and somehow it sounds like something

real, electricity. ... Yes, I've never heard of that before. (...) But I imagine... that harmful germs are killed by the electricity. Funny, is that real?" (CH, female, 18-39)

Despite some consumers being cautious, the majority of participants from all four countries seemed to respond positively after learning about the benefits of these technologies in producing affordable, tasty and sustainable minimally processed PBFs made from healthy ingredients (please see 4.1.2, Theme 2).

"... the first time I heard this term (PEF), it didn't seem trustworthy, but after you explained it, yes, it sounds like a very good idea." (RO, female, 18-39)

"... I learned about some new things... I think that the next time I go shopping I'll be looking at things and trying to see where there are the PEFs, all that, the HPPs... create that interest." (PT, male, 40-59)

4.1.2. Theme 2 – benefits perception as drivers towards minimal processing technologies' acceptance

In general, minimal processing technologies were perceived positively (Table 3). The interviewees from all countries perceived minimal processing technologies as not much processed and less invasive, and consequently more acceptable than ultra-processing ones. Healthiness and naturalness were also associated with foods produced using these methods:

"I actually have a positive attitude towards this (minimal processing technologies). As little effort as possible is needed to produce food in a consumer-friendly way" (CH, male, 40-59)

"More positive, that's what it seems to me. Less intervention, more natural products, so to speak ..." (PT, female, 18-39)

"It (minimal processing technologies) is very beneficial, very good, healthy, healthier, and the quality of the product is better, almost natural." (RO, female, 18-39)

Most of the interviewees in all four countries perceived fermentation and germination as healthy and natural, and some trusted them because they had been used for a long time. This was evidenced by the following quotes:

"... this (fermentation) is the natural way of creating the product or making it processed. While in the laboratory, they are separated artificially; these are the microorganisms that take that and do it naturally ..." (PT, male, 18-39)

"Just like fermentation, (germination) it's actually something natural. It happens without you having to add anything to it, and I think you should keep on using this process." (CH, male, 40-59)

Intestinal health and improved digestibility were highlighted many times as advantages of these technologies:

"Yes, and I have the feeling that when you cook the cabbage or eat it raw, you're eating a healthy vegetable. And if you leave it in the sauce for a bit, let it ferment, then you're eating a healthy vegetable with bacteria that promote intestinal health" (CH, female, 40-59)

"Well, nutrients become easier (with germination) for the body to use and better digest. That does sound pretty useful ..." (FI, female, 18-39)

"Lactobacilli. Yes, natural(...) Letting nature do its thing in a controlled way. Exactly." (CH, male, 18-39)

Advantages commented upon after receiving information (see supplementary material) on non-thermal technologies (HPP, PEF and US) include being a gentle method and more natural, which preserves sensitive ingredients and releases healthy compounds, as evidenced by the following quotes:

"... So yes, it sounds good to be able to preserve those original properties (with HPP) and not lose some vitamin C or other important vitamins." (FI, male, 18-39)

"... For me, the main benefit is the expiration date and bioactive compounds (retention) ..." (PT, male, 40-59)

"If (ultrasound) it can be used to examine the human body (refers to medical imaging), and if it is just sound with different frequencies... then (it is) kind of a natural thing. It sounds good and great how many things it can be used for ..." (FI, female, 18-39)

"... Although I didn't think that it (ultrasound) would be without heat either. But it goes in relation to what I was thinking, it will release healthier compounds, it will improve the shelf life, it will improve the stability of some dairy formulas, yes (find it positive) ..." (PT, male, 40-59)

4.1.3. Theme 3 – perceived risks, concerns and doubts as barriers towards minimal processing technologies' acceptance

During the interviews, as part of the follow-up questions, participants were required to disclose the perceived risks associated with minimal processing technologies. Most of the participants said they do not see any risks in the use of the natural bioprocessing technologies, fermentation and germination:

"... they've always been known to be very beneficial... cheese... I mean, I don't think... that products made through fermentation are harmful, they are good" (RO, female, 18-39)

However, a few mentioned food safety and a lack of hygiene or contamination by other microorganisms during the processes as potential risks:

"(..) There is some risk in that home germination... and probably also in those commercial (products) I think there is a risk of salmonella. ..." (FI, female, 40-59)

Regarding non-thermal technologies, a few participants in the four countries (mostly from Switzerland and Finland) expressed concerns about high energy consumption and the conditions and resources needed to apply these technologies in food development, as well as some difficulty in imagining how the mechanisms work (lack of knowledge, please see 4.1.1, Theme 1).

"... It (HPP) just sounds like an incredible amount of energy that has to be expended ..." (CH, male, 18-39)

"... Sounds a bit strange - Ultrasound. Even though it's not the same thing, but somehow it comes to mind what they are now, you know, X-ray machines, it makes me wonder if this could include somehow the same kind of risks as X-rays have for humans ..." (FI, female, 40-59)

A minority of the participants remained sceptical towards non-thermal technologies (Table 3), because they questioned the need to extend the shelf life of juices and milk, which were described as application examples (see supplementary material):

"... I still have the impression that you're intervening in something where you have to think about whether it's really necessary. Why does a fresh juice or smoothie need this? Can you not just consume it as it is, and it just has a shorter shelf life, and then it's just...you just accept it as it is." (CH, male, 40-59)

"... I don't feel it's helpful / needed. I prefer to squeeze the juice out of the fruit itself, and there are so many other ways to do it, which also preserve the good things from there. ... And then that pulsed electric field technology is so far away... But possibly I didn't get the right (impression) ..." (FI, male, 18-39)

"I'm still a bit sceptical about that...why exactly is it needed? (...) Does milk even have to have a shelf life of three months? And I simply don't believe that it's necessary. That's why I'm rather sceptical." (CH, male, 40-59)

4.1.4. Theme 4 – interest and general attitude as drivers towards minimal processing technologies' acceptance

The largest share of the participants expressed positive attitude towards and interest in the general idea of using the five minimal processing technologies to produce PBFs, when their overall opinion about and interest was probed about "... these five technologies to produce affordable, tasty, and sustainable minimally processed PBFs made from healthy ingredients (...) and which result in food that is (...) safe to eat and has reasonable shelf-life". This is evidenced by the following quotes:

"I like them (bioprocessing and non-thermal technologies) very much. In general, I like that we strive and focus on this kind of thing, that we really aim to process as little as possible - minimally - I really like it if the food industry adopts these (methods) more." (FI, male, 40-59)

"I have a positive opinion because, by using these technologies, it is certainly possible to achieve products that are optimal both in terms of nutrition and reduced costs." (RO, male, 18-39)

"... All of this seems valid to me, as long as you don't add a set of chemicals, additives, a set of things." (PT, male, 18-39)

"I think it's a really good thing, because all of them (minimal processing technologies) somehow improve the properties of foods, so it's a good thing, especially if it's cheap and just a little processed. I don't see anything negative in it." (FI, female, 18-39)

"I would be open to trying those products, as the methods seem natural, so to speak... The products wouldn't lose their nutrients, vitamins, texture, or taste... Also, the longer shelf life would be an advantage as well ..." (RO, female, 18-39)

"... It would help me to increase my consumption of plant food even more, in the future." (FI, male, 18-39)

Regarding the preferred non-thermal technologies, the majority of the participants were more open to HPP than to US and PEF. Among the reasons for this preference, there was the observation that consumers probably relate to the pressure cooker used in many households:

"Yes, so I have the feeling that they all (non-thermal methods) have advantages, otherwise they probably wouldn't exist. It's just a bit of a subconscious thing. Electricity and ultrasound somehow have nothing to do with food. Pressure does, there are also these pressure cookers. (...) But in principle, if it works, I'm kind of okay with all three". (CH, female, 18-39)

"Each of those has slightly different effects, but they all seem to be processing methods aimed at eliminating bacteria, microbes, and improving shelf life. Maybe that high-pressure treatment sounds the easiest to approach... When you compare it to a pressure cooker, it sounds the most familiar. Similarly, ultrasound technology, when associated with healthcare and health, sounds the most approachable. But when you read more about electric field treatment, it doesn't sound particularly scary either. Maybe it's just something new that you haven't come across before. The good thing about all of them is that they retain some good substances in the food." (FI, female, 18-39)

"The one that I think conveys the most confidence and... that I see the most benefits is processing with high pressure ..." (PT, male, 40-59)

"I don't know... the first one would be high-pressure processing... it would be my top choice... It seems healthier, so to speak... the process itself ..." (RO, female, 18-39)

“Yes, most likely (preferred) the high-pressure processing, i.e. HPP... With the other two, I feel like that there's too much energy in them.” (CH, male, 40-59)

Despite a few participants presenting concerns towards non-thermal technologies (see Table 3, Theme 3), some of those said they trusted the food industry and their country's legislation, regulation (food authorities) and control and therefore trusted all the technologies approved for use in the food industry:

“... I'm just not very familiar with it, and that's why I trust these people who are more familiar with it and the food authorities or those who authorise it ...” (CH, female, 18-39)

4.2. Consumers' expectations for minimally processed PBFs

Finally, the participants were asked which types of foods they would prefer to use in each category (solid, semi-solid and liquid) if developed using minimal processing technologies. The following quotes support our analysis of which types of products the interviewees would prefer to be produced with minimal processing technologies and why:

“... meat substitutes that somehow...so that you don't have meat and yet have something that has a long shelf life, that provides the desired nutrients, that gives the flavour...and so you can use exactly these combinations. Flavour with fermentation and shelf life in large quantities with a non-thermal process and superfoods power from... exactly, just the best of everything.” (CH, male, 18-39, omnivore)

“... I think there is still room for improvement in those plant-based cheeses...Well, well, well, maybe those yoghurts or products similar to them...” (FI, female, 18-39, flexitarian)

“Because drinks of plant origin (...) are very sweet. (...) Maybe if there were a more natural product of plant origin, thanks to one of these processes, that would be something that I think would be good.” (PT, female, 18-39, omnivore)

“... an alternative to meat, to what we usually eat. And maybe also a more plant-based yoghurt, to try eating that as well ...” (RO, female, 18-39, omnivore)

“... Preferably maybe snack bread, yoghurt-type product or something like that. (Anyway) some snack.” (FI, male, 18-39, omnivore)

“I would ... say snacks and smoothies. All of them.” (RO, male, 18-39, omnivore)

“... And to replace meat, perhaps, for example (...) For example, vegetable burgers and different things like that.” (PT, female, 18-39, omnivore)

5. Discussion

5.1. Perceptions and attitudes towards minimal processing technologies

Our findings allowed us to identify several factors related to the acceptance of natural bioprocessing and non-thermal technologies. Most importantly, we identified that all five technologies have the potential to be accepted. Consumers were, in general, familiar with and open towards fermentation and germination. However, despite some participants claiming to know about germinated products, their benefits were not well known.

The unfamiliarity with non-thermal technologies (HPP, PEF and US) was widespread across all four countries, which may have supported the initial scepticism. Similarly, in a qualitative study by Perrea et al. (2015), consumers expressed concerns about the performance of ultrasound (US) technology (e.g., changes in food structure). The authors also found that certain UK and Chinese consumers had difficulty trusting US

technology due to its complexity. In general, consumers' perceptions tend to vary according to the technology applied to food (Martins et al., 2019) and, the way in which technologies are introduced to consumers also influences their attitudes (Jaeger et al., 2015).

In the current study, after being informed about the technologies (see stimuli presented, supplementary material), the majority of participants showed interest in applying all five technologies to develop minimally processed PBFs, mainly because they perceived these as gentler methods that could yield healthier and more natural food products (please see 4.1.4 and Table 3).

In all the countries, HPP was perceived more positively than PEF or US, in agreement with the previous literature (Sonne et al., 2012; Melios et al., 2025). Associations with a familiar device, a pressure cooker, may have contributed to the higher acceptance of HPP. While PEF elicited some negative associations (e.g. strange, abstract and not natural), contributing to a higher level of scepticism. Corresponding negative views about PEF have also been found by other studies. In their qualitative study, Sonne et al. (2012) found their interviewees sceptical about apple juice processed with PEF technology. This was attributed to the difficulty in understanding how exactly the method works, or doubts about the long-term consequences of using it. Our study also revealed that the nomenclature and technological description (see supplementary material) related to pulsed electric field can elicit negative associations or be viewed, by some consumers, as somehow incompatible with food. Previous studies also highlighted that the terminology of ‘Pulsed Electric Field’ may have contributed to the general scepticism (Jaeger et al., 2015; Melios et al., 2025). Regarding perceptions about the US observed in the current research, in some cases, the fact that it is used in the healthcare/medical/dentistry field appeared to create trust and contribute to a positive attitude, while in other cases, the association with machines used in hospitals contributed to a negative perception in the food context. Similarly, Monteiro et al. (2022) evaluated Brazilian consumers' perceptions of technologies such as ‘ultraviolet radiation’ or ‘ultrasound’ applied to foods. Despite some positive associations, the authors observed more negative associations, unfamiliarity and concern from the respondents about the technologies, especially regarding ultrasound. The study suggests that providing information on the benefits of these technologies may overcome rejection by certain groups.

According to Lee et al. (2015), manufacturers can play an important role in labelling these products and offering transparency to consumers. The findings suggest greater investment in campaigns and improvements to food labelling. Innovative approaches to increase consumers' knowledge are urged. Public, private and academic sectors should collaborate.

5.2. Practical applications and strategies to promote the consumption of minimally processed PBFs

The present study has numerous outcomes that can be applied in practical settings, which are especially important for researchers, marketers and the food industry. Highly processed PBFs can be a barrier to reducing animal-based options and eating more PBFs. However, even though minimal processing technologies emerge as an alternative to highly processed ones, the lack of knowledge about non-thermal technologies and about the benefits of natural bioprocessing technologies may limit their acceptance.

Informing consumers that minimal processing technologies are used, as well as communicating the characteristics of the raw materials and formulation (e.g. organic, locally produced, country-made, few ingredients, free from additives, low in fat, sugar and salt, and high in protein) can increase interest in PBFs. Efforts should be made to communicate through campaigns the benefits of these minimally processed PBFs, such as their healthy and sustainable advantages, and inform consumers about the benefits of fermented and germinated foods (e.g., they improve digestibility). Communicating the benefits of non-thermal technologies over traditional thermal ones (e.g., they do not

destroy sensitive nutrients) could also result in consumers' higher interest in minimally processed PBFs. The benefits of these products may be communicated through attractive packaging and advertisements. A similar approach has been suggested by previous research (Kuosmanen et al., 2025; Sonne et al., 2012).

Perceived benefits and perceived risks were found to be one of the main drivers and barriers, respectively, to the adoption of minimal processing technologies. These findings align with those of Siegrist (2008) regarding the acceptance of new food technologies. For this reason, highlighting the benefits of fermented and germinated products may result in higher interest. Furthermore, as non-thermal technologies (HPP, PEF and US) are difficult for many consumers to understand, informational campaigns implemented across different settings (e.g. digital, supermarkets and school-based) and promoted by different actors (food authorities and the private sector) focusing on the advantages of using non-thermal processing technologies rather than their mechanisms can reduce scepticism. Previous research has highlighted the importance of informing consumers about tangible advantages and multifaceted arguments (Onwezen and Dagevos, 2024). According to Siegrist (2008), informing consumers (through a trusted source) about the tangible benefits of new technologies can support consumer acceptance. These campaigns and the use of alternative terminology for technologies (Jaeger et al., 2015; McCausland et al., 2026; Melios et al., 2025), can not only empower consumers to make more informed choices and avoid confusion (e.g. high pressure vs high processing) but also result in a higher acceptance of minimally processed PBFs produced using bioprocessing and non-thermal technologies.

Finally, participants were also able to choose solid, semi-solid and liquid food models that they would be open to consuming if minimally processed. The choice of food prototypes may result from individual eating experiences with certain foods already on the market, consistent with previous literature (Tan et al., 2015). These findings contribute to informing application-oriented works in the development of minimally processed PBFs.

The findings add to the limited available literature regarding consumers' perceptions of minimal processing technologies applied to food. The current research is very comprehensive, allowing us to shed light on acceptable technologies, while also supporting minimally processed PBFs marketing and communication strategies, which can be very useful to stakeholders and to the actors involved in PBFs development.

5.3. Limitations and future research

Despite these interesting findings, this study has limitations. The results cannot be generalised to their respective countries' populations, as this is an exploratory qualitative study. Thus, we suggest that future studies should conduct quantitative research with a larger population and a representative sample from each country (e.g. nationwide surveys) (Lucas and Brunner, 2024a; Lucas and Brunner, 2024b). This will enable us to confirm the findings and draw conclusions about the interest in and acceptance of the technologies and products using a representative sample from each country. We also suggest that future quantitative studies evaluate psychological constructs, such as food neophobia and food technology neophobia among consumers. In addition, as the findings are based on self-reported measures following the provision of information/*stimuli*, they may be subject to response bias. To reduce bias and bridge the gap between intention and behaviour, we suggest that future research uses experimental designs and implicit measurements such as the Implicit Association Test. Furthermore, we recommend that intervention studies be conducted across different countries.

6. Conclusions

This study used semi-structured interviews to explore meat consumers' perceptions of five minimal processing technologies (fermentation, germination, HPP, US and PEF) used to develop minimally

processed PBFs. The results showed that natural bioprocessing technologies and non-thermal technologies would be accepted by the majority of the participants for application in minimally processed PBF development in all evaluated countries. However, campaigns to inform and familiarise consumers with these products and technologies are needed. The findings shed light on potential prototypes that can serve as starting points for more comprehensive research on the topic. The next step would be to conduct quantitative and intervention studies. Food producers, researchers and marketers can use the findings to accelerate the development and commercialisation of innovative minimally processed PBFs aligned with consumers' needs, supporting the transformation to a more sustainable food system and, consequently, the achievement of the Sustainable Development Goals proposed by the United Nations (United Nations, 2023).

CRedit authorship contribution statement

Bárbara Franco Lucas: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Anne-Kristiina Arvola:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Data curation, Conceptualization. **Sofia A. Sousa:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Conceptualization. **José Carlos Ribeiro:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Conceptualization. **Gabriela Daniela Criveanu-Stamatie:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Conceptualization. **Denisa Eglantina Duta:** Writing – review & editing, Visualization, Validation, Resources, Methodology, Investigation, Funding acquisition, Conceptualization. **Luís Miguel Cunha:** Writing – review & editing, Visualization, Validation, Resources, Methodology, Investigation, Funding acquisition, Conceptualization. **Kyösti Pennanen:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Funding acquisition, Conceptualization. **Thomas A. Brunner:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Ethical statement

All participants signed informed consent forms before participating in the interviews and completing the socio-demographic survey. During data processing, codes were used to prevent participant identification and protect personal information. The study was approved (reference number EAB2024_021) and conducted in accordance with the Guidelines for Ethical Conduct in Research of the Bern University of Applied Sciences and the standards of the Declaration of Helsinki.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.clrc.2026.100496>.

Data availability

The authors do not have permission to share data.

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