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Consumer perception of risk towards new sustainable non-thermal food processing technologies: A cross-cultural study between Portugal, Germany, and the UK

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ABSTRACT

Consumers are interested in sustainable and safe food with positive sensory attributes, either minimally processed or incorporating sustainable processes. However, the introduction of new food technologies may generate concern among consumers. This study aims to identify ways to decrease consumers' risk perception of new technologies: High pressure, Non-thermal Plasma, Pulsed Electric Field, and Ultrasound. This cross-cultural study was conducted in three contrasting countries: Portugal, Germany, and the United Kingdom, recruiting over 400 consumers per country. The survey presented twelve constructs based on the Ecological Framework, which was used to predict perceived risk. Factors affecting such perception varied both for technologies and countries, as shown by a multiple regression model. Food technology neophobia, perceived relative severity, and trust were common factors across all countries. This study demonstrates that developing and producing new products using non-thermal technologies should consider the country's consumers' risk perception factors.

1. Introduction

Over the last few years, there has been an increased interest in sustainable, safer, healthier, and more nutritious food products, which are either minimally processed or use more sustainable manufacturing processes, do not contain additives, and assure positive sensory qualities as well as extended shelf life (Demartini et al., 2019; Hicks et al., 2009; Martins et al., 2019; Monteiro et al., 2022; Rastogi, 2011; Vidigal et al., 2015). This interest has led to the development of new sustainable food technologies to replace conventional processing methods, with an increased focus on non-thermal technologies (Deliza et al., 2005).

In non-thermal technologies, the products are submitted to the treatment for a very short duration (e.g., seconds), and temperature is not the main pathway for the inactivation of micro-organisms and enzymes, maintaining product freshness and organoleptic characteristics similar to the raw material (Martins et al., 2020; Olsen et al., 2010; Song et al., 2022; Wang et al., 2016). These technologies include processes such as high hydrostatic pressure (HPP), ultrasound (US), non-thermal atmospheric plasma (NTP), and pulsed electric field (PEF).

However, when applying new technologies, it is important to consider that food innovation is not always well accepted by consumers, even though it may be essential to meet food production demands (Rabadán, 2021; Rabadán & Bernabéu, 2021). Consumers are often sceptical around new technologies due to their potential risks and lack of perceived benefits, which can lead to a low level of acceptance of products produced with these technologies (Cox et al., 2007; Egolf et al., 2019; McKenzie et al., 2021; Vidigal et al., 2015), having been previously demonstrated in European projects such as the Novel Q (Sonne et al., 2012).

The study conducted by Sonne et al. (2012), as part of the EU research project Novel Q (2006–2011), indicated that although consumers in Norway, Denmark, Hungary and Slovakia recognise and appreciate the benefits of juices processed by HPP and PEF, they are still sceptical about both technologies, particularly PEF. To achieve a high success rate in the market, it is necessary to understand consumer attitudes and perceptions towards new food technologies (Coutinho et al.,

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2021; Dijksterhuis, 2016; Roselli et al., 2018; Santeramo et al., 2018; Tsimitri et al., 2022). Consumers determine whether a technology or product will be a success or failure in the market, as their opinion can significantly prevent a technology from being successful, as has been the case for irradiation and genetic modification (GM) (Fischer et al., 2013; Perez et al., 2021; Vidigal et al., 2015). Therefore, in the initial stage of the product development process, it is important to consider consumers' perspectives and how they build their beliefs and attitudes regarding new technology-driven food products (Coutinho et al., 2021; Lee et al., 2021; Olsen et al., 2010; Roselli et al., 2018; van Kleef et al., 2005). The decision-making process is complex and influenced by many factors, such as the characteristics of the product (sensory and non-sensory), the individuals (physiology, attitudes, experiences, knowledge, etc.), and the context in which the choices are made (place, time, social context, culture, etc.) (Ali et al., 2021; Deliza & Ares, 2018).

Kamrath et al. (2019) systematically reviewed the key factors of supply chain actors' new food technology evaluations and analysed the significant relationships between variables. They proposed an ecological framework that describes the multiple influences on people's evaluation of new food technologies, categorising these as individual, social, physical, and macro-level environments.

The lack of understanding regarding consumer perception of new food products and technologies is one of the main reasons for the high failure rate of many new products launched on the market. Additionally, a product that uses a new food processing method poses a further challenge since consumers may be unfamiliar with its application and function. Therefore, concerns over these new products are intrinsically linked to their perceived risk (Cardello et al., 2007; Deliza & Ares, 2018).

Perceived risk is a key factor influencing consumer acceptance and use of products developed through innovative technology (Ali et al., 2021; Cardello et al., 2007; Costa-Font & Gil, 2009). Risk is much more linked to consumers' opinion about the technology itself, and Bredahl (2001) research showed that consumers' intention to purchase GM food is influenced by risk perception, which is affected by knowledge associated with the technology. As Cardello et al. (2007) pointed out, the assessment of the perceived risks associated with the technology being studied (PEF, HPP, irradiation, heat pasteurisation, ionising energy, genetic modification, cold preservation) was the factor that had the most significant influence on whether consumers were willing to use them.

People usually fear novel foods and novel food technologies, so it is necessary to decrease these fears to improve their attitudes and perceptions. This can be done by increasing their knowledge of and experience with these foods and technologies (Caulier et al., 2020). Kim and Boyd (2006) found that insufficient information and a lack of consumer understanding of GM food products negatively impacted their attitudes, perceptions, and interests. Different studies have reported that clear and transparent information on benefits and safety concerns positively influences consumers' acceptance, purchase, and use of foods processed by new technologies (Bruhn, 1995; Cardello et al., 2007; Deliza et al., 2003; Hashim et al., 1996; Jaeger et al., 2004; Lusk et al., 2004; Pohlman et al., 1994; Schutz & Cardello, 1997; Sonne et al., 2012).

As part of the EU research project Novel Q (2006–2011), Nielsen et al. (2009) showed that to improve the acceptance of products produced by HPP and PEF, it is necessary to highlight the health, environmental and taste benefits of the product, as well as addressing safety issues through clear labelling and consumer education. However, it is not only the information that is important but also the consumers' trust in the information source (Ali et al., 2021; Bruhn, 2016; Fife-Schaw et al., 2008). When people trust the source – whether people or institutions - that are providing them with the information, they consider them well-informed and to provide thoroughly researched information (Tonsor et al., 2009). It has also been shown that there is an inverse relationship between the risks and benefits perceived by consumers, and such a negative correlation demonstrates that people cannot consider both dimensions separately (Alhakami & Slovic, 1994; Traill et al., 2004).

The food neophobia factor, which is an established psychological construct that characterises a person's tendency to avoid or reject unfamiliar foods or foods from other cultures, is a key predictive factor for the failure to accept new foods (Lee et al., 2021; Martins et al., 2019; Pliner & Hobden, 1992; Vidigal et al., 2015). While the Food neophobia scale (FNS) is suitable for evaluating novel food products, the food technology neophobia scale (FTNS) developed by Cox and Evans (2008) provides a better measure of consumers' fear towards food products manufactured by new technologies. The FTNS has previously been used to assess consumer reactions to different technologies such as GM, nanotechnology, HPP, 3D printing, ohmic heat, and cultured meat (Boereboom et al., 2022; Caulier et al., 2020; Coimbra et al., 2020; Evans et al., 2010; Kim et al., 2014; Matin et al., 2012; Sodano et al., 2016; Vidigal et al., 2015).

Lastly, the acceptance of new technologies is also affected by culture and nationality, some of the main factors affecting the perception and acceptability of risk (Breakwell, 2000). For example, Europeans seem to be more ambivalent, critical and averse to products made with new technologies (e.g. GMO food, irradiated food) than Americans or Chinese (Loebnitz & Grunert, 2014; Lusk et al., 2004; Lusk & Rozan, 2005; Monteiro et al., 2022; Yano et al., 2021; Zaikin & McCluskey, 2013). Acceptance levels towards new technologies can vary within European countries, with consumers being more open to these technologies in some countries than others (Nielsen et al., 2009; Olsen et al., 2010). As shown in the study by Nielsen et al. (2009), Northern Europeans (e.g. Norwegians) tended to have a more positive relationship with fresh and minimally processed juices and preferred HPP and PEF-produced products. Eastern European consumers (e.g. Hungary and Slovakia) tended to be more sceptical about such technologies being more price sensitive, demonstrating a lower willingness to pay a premium for HPP and PEF products. Moreover, as enhanced in the review work by Cunha et al. (2018), food choice criteria vary by country.

Through the Marie Curie initial training network TRANSIT, the authors took the opportunity to have a clear picture of the varying perspectives of European consumers towards new food processing technologies. A cross-cultural study was designed and performed with consumers from three different regions of Europe (Northern Europe – UK; Southern Europe – Portugal; Western Europe – Germany) to gain further understanding of consumers' risk perception of novel sustainable non-thermal technologies (high pressure, non-thermal plasma, pulsed electric field, and ultrasound). When comparing food choice criteria within these three countries, it is possible to identify that Portuguese consumers' main driver of food choice is Price, while Sensory Appeal is the major driver for German and UK consumers. Additionally, Weight Control is more valued in Portugal and less in Germany, and German and UK consumers prize convenience more than the Portuguese (Markovina et al., 2015).

Besides assessing consumers' attitudes and perceptions towards novel non-thermal technologies, this study focused on cross-cultural differences and determined the main factors that affect risk perception in Portugal, the United Kingdom and Germany.

2. Materials and methods

2.1. Participants

A total of 2562 participants accessed the web-based questionnaire, and 1245 responses were considered valid after the validation criterion verification. Participants were eligible for participation if they were citizens (18–69 years old) and spoke the language of the country where the study occurred. The quota selection was applied, considering age ($\leq$ 35, 36–50 and $>$ 50), sex (female and male) and education (with or without university studies). Considering that four different questionnaires were applied (one for each assessed technology) for each country, the quota ($n = 15$) dimension was defined as at least 7–8 participants for

each questionnaire. Furthermore, to obtain better data set quality, additional exclusion criteria were applied according to Jaeger and Cardello (2022): incomplete questionnaire responses; failure in the verification check question; short-time response (questionnaire completed with a duration shorter than 50% of the median of the country); identical responses for the question after the prime and displays of suspicious behaviours such as "straight-lining", which can be defined as repeatedly selecting the same option for all questions in a scale (Behrend et al., 2011; Maniaci & Rogge, 2014). Table S1 shows the participation rate in each country.

420 valid responses were retained for Portugal, 416 for the United Kingdom and 409 for Germany (Table S1). Participants were recruited through the Sense Test (sensory evaluation and consumer perception company) database (for Portugal), the University of Reading database and mailing lists (for United Kingdom participants), and social media, Prolific and Positly database (for United Kingdom and German participants). At the recruitment stage, consumers were informed about the overall goal of the study, and all participants received a small financial compensation for their participation,

The study was given a favourable opinion for conduct by the Ethical Committee of the University of Reading, UK (authorisation number SREC 45/2022), the Ethical Committee from DIL, Germany (authorisation number 06/2023), and the Ethical Committee of the Faculty of Sciences, University of Porto, Portugal (authorisation number CE2023/P64). Adherence to the Helsinki protocol was guaranteed by complete confidentiality, and informed consent was obtained at the beginning of the study. Additionally, in Portugal, the work was undertaken by Sense Test, ensuring the protection and confidentiality of data through the authorisation 2063/2009 of the National Data Protection Commission and accomplished internal conduct, following General Data Protection Regulation standards and implementation of informed consent.

2.2. Questionnaire development

The questionnaire included twelve constructs, as shown in Table 1. These constructs were selected based on a systematic review performed by Kamrath et al. (2019), which proposed an ecological framework that describes the multiple influences on people's evaluation of new food technologies, categorising these as individual, social, physical, and macro-level environments. The constructs presented in Table 1 are related to each environment in the ecological framework. As this study focused on four non-thermal technologies, four questionnaires were applied in each country, each focusing on one specific technology. The questionnaire was composed of variables related to consumers' psychological traits and consumption-related decisions (green scale (GS), perceived vulnerability (PV), food neophobia scale (FNS) and food technology neophobia scale (FTNS)), and constructs focused on the technology under analysis (familiarity (Fam), attitudes, subjective norm (SN), perceived benefits (PB), self-efficacy (SE), Trust (Tr), perceived risk (PR) and perceived relative severity (PRS)). Additionally, to check whether the respondents read the questions, the following statement was integrated into the middle of the questionnaire: "Please now click on 'strongly agree' on the far right to prove that you read the text".

The GS, PV, FNS, FTNS, SN, PB, SE, Trust, and PR were assessed on a 7-point Likert scale ranging from '1 - totally disagree' to '7 - totally agree'. The order of the statements within each construct was randomised across participants.

Familiarity was assessed on a five-point category scale adapted from Lampila and Lahteenmaki (2007), in which participants had to answer the question "Are you familiar with foods produced by NAME OF THE TECHNOLOGY?" with one of the following options, ranging from: "I do not recognise the concept"; "I recognise the concept, but I do not know what it means"; "I recognise the concept, and I know what it means"; "I recognise the concept, know what it means and know people that have tasted food products using this technology"; "I recognise the concept, know what it means and have tasted food products using this technology".

Table 1
Constructs used in the questionnaire.

Constructs	Number of items	Reference
Green scale (GS)	6	(Haws et al., 2014)
Perceived Vulnerability (PV)	4	(Pang et al., 2021)
Food neophobia scale (FNS)	5	(Pliner & Hobden, 1992)
Food technology neophobia scale (FTNS)	4	(Cox & Evans, 2008)
Familiarity (Fam)	1	(Adapted from Lampila & Lahteenmaki, 2007)
Attitudes	13	(Adapted from Sousa et al., 2021)
Artificial × Natural		
Do not respect the environment × Environment friendly		
Bad × Good		
Unpleasant taste × Pleasant taste		
Unhealthy ×Healthy		
Traditional × Modern		
Unique × Current		
Convenient × Inconvenient		
High quality × Low quality		
Hygienic × Unhygienic		
Nutritious × Poor in nutrients		
Easily available × Hardly available		
Has additives × Has no additives		
Subjective norm (SN)	2	(Adapted from Izquierdo-Yusta et al., 2022)
Perceived benefits (PB)	4	(Adapted from Yao & Jiang, 2016; Ali et al., 2021)
Self-Efficacy (SE)	3	(Adapted from Pang et al., 2021)
Trust (Tr)	2	(Adapted from Sapp & Downing-Matibag, 2009)
Perceived risk (PR)	4	(Adapted from Sapp & Downing-Matibag, 2009)
Perceived relative severity (PRS)	1	(Adapted from Crowley et al., 2013)

In line with previous studies by Dupont et al. (2022), Sousa et al. (2021), Bryant et al. (2019) and Hartmann et al. (2015) where attitudes towards a cultured meat burger were measured using a semantic differential, a similar approach was taken for the technologies under study. Attitudes towards processing technologies were measured using thirteen semantic attributes represented by pairs of opposite adjectives, verbally anchored to the extreme values, and graded on a 7-point bipolar scale (Table 1).

PRS was assessed on a seven-point category scale adapted from Crowley et al. (2013), where consumers answered the question "A possible illness from eating food produced by NAME OF THE TECHNOLOGY would be?" with one of the following options, ranging from: "Much less severe" to "Much more severe".

The questionnaire was initially written in English, so it was translated and back-translated by trained native speakers into German and Portuguese to ensure accuracy and preserve its original meaning (Su & Parham, 2002).

Following the technology-focused questionnaire, questions related to sociodemographic factors followed, including age, sex, nationality, place of residence, net monthly income, education, professional activity, household size, the presence of children in the household, health status, and whether the participant had a food-related job.

2.3. Data collection

Data were collected between January and June 2023. All participants completed a short screening questionnaire to evaluate eligibility

for study participation and forwarded it to the informed consent page, which they needed to authorise before starting the study. The consent and the questionnaire were administered using the Compusense20 software (Compusense, Guelph, ON, Canada). For the sampling in each country, a minimum sample size of 360 (90 for each technology questionnaire) was defined. In this case, there was a 95% chance that the actual value of a proportion is within ±5.17% or less of the measured/surveyed value. As such, participants were first randomly allocated into four groups, with 90 people in each group, and then the groups were randomly assigned to a different technology.

2.4. Data analysis

Data had to be transformed and recoded to be analysed as follows:

- Age was divided into three groups: 18–35; 35–50 and ≥ 50;
- Maximum level of educational achievement was divided into two groups: higher education (graduate and post-graduate degree) and lower education (less than high school, high school, technical/professional degree, and some college/no degree).
- The number of children in the household was divided into two: having and not having children.
- Income was converted into income per capita by dividing the average pay by the number of people in the household.
- Food-related work was divided into two groups: working in a food-related field (Market research, Sensory research or tasting panels, Nutrition and Food Manufacture) and not working in a food-related field (none of the above).

2.4.1. Statistical analysis

Regarding the respondents' perception of novel non-thermal food technologies, an Exploratory Factor Analysis (EFA) using Principal Components Analysis (PCA) with varimax rotation was conducted to determine the most appropriate factor solution. Cronbach's α internal consistency was used to justify the development of a composite variable for each factor. A Kruskal-Wallis test was used to determine the differences between opinions of the technologies. Multiple Linear regression analysis, following a stepwise procedure, was applied to further examine how trust and perceived risk may be affected by different attitudes and personality traits. To prevent multicollinearity effects, which would artificially increase the importance of some variables, the VIF of each construct was calculated, and the results were within the acceptable range of 0.8 to 10, showing a correlation between the variables (Field, 2013). As a result, it can be assumed that there is no multicollinearity between the independent variables. All statistical tests were applied at a 95% confidence level and were conducted using IBM SPSS Statistics (version 28) (IBM Corporation; NY, USA).

Hierarchical cluster analysis (HCA) using Euclidean distances and Ward's method with entropy for cluster definition was applied to identify groups of participants through their responses to the questionnaire (Liang et al., 2012). After obtaining the clusters, the individual participants were identified, and then a Kruskal-Wallis test was used to determine the difference between the groups. These statistical tests were applied at a 95% confidence level, and this analysis was performed using XLSTAT statistical software version 2023.

3. Results and discussion

3.1. Sample characterisation

Table 2 shows the sociodemographic characteristics of the participants in the three countries. In Portugal, females were slightly more represented (53%), whereas sex is balanced over the age groups. In general, respondents were formally employed (52%), while in the majority, they had a household size of more than three persons (34%) but no children (64%). Most respondents did not work in food-related areas (94%), with a median income of € 1081–1530 (29%). Regarding the place of residence, most of them lived in the Porto Area (95%).

Regarding the UK, males were slightly more represented (53%), while most participants were younger than 35 years (39%). In general, respondents were formally employed (68%) and had a household size of three persons (34%) but with no children (42%). Most respondents did not work in food-related areas (78%) and presented a median income of £ 2300–3000 (37%). Regarding the place of residence, most of them lived in South England (59%) either in the city or town centre (43%) or in a suburb of the city (43%).

German sociodemographic data indicates that sex and age were quite

Table 2
Sociodemographic characteristics by country.

Variables	Categories	Portugal (*n* = 420)		UK (*n* = 416)		Germany (*n* = 409)	
		n	%	n	%	n	%
Sex	Female	225	53.6	194	46.6	199	48.7
	Male	195	46.4	222	53.4	210	51.3
Age (years old)	<35	145	34.5	160	38.5	153	37.4
	36–50	126	30.0	118	28.4	113	27.6
	>50	149	35.5	138	33.2	143	35.0
Education	Non-University	221	52.6	207	49.8	224	54.8
	University	199	47.4	209	50.2	185	45.2
Professional activity	Employed	230	51.9	281	67.5	252	61.6
	Self-employed	46	10.4	56	13.5	33	8.1
	Student	43	9.7	14	3.4	58	14.2
	Retired	62	14.0	46	11.1	50	12.2
	Unemployed	62	14.0	19	4.6	16	3.9
Household size	1	47	12.0	36	11.1	133	34.5
	2	124	31.6	77	23.8	145	37.6
	3	134	34.1	110	34.1	64	16.6
	4 or more	88	22.4	100	31.0	44	11.4
Children	0	271	64.5	173	42.1	319	78.2
	1	91	21.7	132	32.1	46	11.3
	2	51	12.1	90	21.9	26	6.4
	3	6	1.4	14	3.4	14	3.4
	4 or more	1	0.2	2	0.5	3	0.7
Food-related work	Market research	6	1.4	24	5.8	1	0.2
	Sensory research or tasting panels	12	2.9	18	4.3	1	0.2
	Nutrition	3	0.7	31	7.5	20	4.9
	Food Manufacture	6	1.4	18	4.3	15	3.7
	None of the above	393	93.6	325	78.1	372	91.0
Income *	1st quintile	30	7.1	30	7.2	70	17.1
	2nd quintile	117	27.9	80	19.2	56	13.7
	3rd quintile	123	29.3	153	36.8	54	13.2
	4th quintile	102	24.3	130	31.3	71	17.4
	5th quintile	48	11.4	23	5.5	158	38.6
Place of residency PT	Porto metropolitan area	400	95.2				
	Other regions of Portugal	20	4.8				
Place of residency UK	South-East England			171	58.9		
	Other regions of UK			245	41.1		
Place of residency DE	Niedersachsen					93	22.7
	Other regions of Germany					316	77.3
Type of residency	City or Town Centre			177	42.5	230	56.2
	Suburb of City			178	42.8	86	21.0
	Rural			61	14.7	93	22.7

PT – (1st quintile: <680€; 2nd quintile: 680–1080€; 3rd quintile: 1081–1530€; 4th quintile: 1531–2240€; and 5th quintile: >2240€); UK - (1st quintile: <£ 1500; 2nd quintile: £ 1500–2300; 3rd quintile: £ 2300–3000; 4th quintile: £ 3000–5000; and 5th quintile: >£ 5000); DE - (1st quintile: <1358€; 2nd quintile: 1358–1833 €; 3rd quintile: 1834–2366 €; 4th quintile: 2367–3174€; and 5th quintile: >3175€);

balanced (49% males and 51% females). In general, respondents were formally employed (62%) and had a household with two persons (38%) but no children (78%). Most respondents did not work in food-related areas (91%), with a median income higher than 3175€ (39%). Most residents lived outside the Niedersachsen area (77%) and in a city or town centre (56%).

3.2. Variables' consistency and sample adequacy

Table 3 shows the results of the explained variance, Kaiser-Meyer-Olkin (KMO) measure of adequacy for factor analysis and the α-Cronbach for the reliability analysis, while Table S2 shows the results of the factor loading mean and standard deviation for Portugal, the UK and Germany. All constructs of Portugal, the UK and Germany are unidimensional and presented an explained variability between 52 and 95%, which was considered good since significant variations were observed in the use of the scales, and explanations of 30–50% have been previously reported in consumer studies (Coimbra et al., 2020; Coutinho et al., 2021). All constructs presented a Cronbach's α >0.5, which suggests that they have acceptable levels of internal consistency (Ekolu & Quainoo, 2019). The attitude was not analysed in FA because this construct can bring much information about how consumers view the technologies, and they will be used as independent variables.

KMO, which measures the sampling adequacy test of all constructs, was higher than 0.5, which is the recommended threshold level by Sheridan (2005), Hair et al. (2006) and Khayat (2015). For the analysis of the perceived risk, four terms were initially assessed, but only the first three terms were used for further analysis since the fourth item score needed to be reverted and brought too much variability to the responses.

3.3. Factors that influence consumers' perception

For Portugal and Germany, there were significant differences in Familiarity between technologies, with HPP presenting the higher scores for both countries (Table 4). However, while HPP presented higher scores for Portugal than all the other technologies, for Germany, there were no significant differences between HPP and the US.

The higher Familiarity with HPP can be due to the fact that there are food products manufactured with HPP in the market, such as the ones produced by Compal (PT), So Natural (PT), Sopas Graciete (PT), Bell Food Group (DE), and Rohstoff (DE) (Compal, 2024; Hiperbaric, 2024). Furthermore, when looking at the attitudes towards non-thermal technologies (Figs. 1 A and C) for Portugal and Germany, respectively, it can be observed that the Portuguese and Germans think that HPP is more easily available, and Germans also think that it is a more current technology. Such factors may lead to greater familiarity with this technology. Furthermore, German consumers' high Familiarity with the US could be related to people's knowledge of the US within the medical field but not in the food area (Monteiro et al., 2022; Phillips & Harmon, 2024).

For Germany, there were also significant differences for Self-efficacy (SE) (higher scores for HPP than PEF and US), SN (higher scores for NTP and US than for PEF) and Perceived Risk, although no significant difference between the means was observed.

Self-efficacy indicates "a person's assessment of the ease or difficulty of performing a specific action" related to purchasing products produced by the analysed non-thermal process. In this case, German consumers think buying products treated by HPP is easier than PEF and US (Tanveer et al., 2021). This can be associated with consumers' attitudes

Table 4
Mean and SD values of the responses of the questionnaire per technology for each country.

Portugal (n = 420)				
Constructs	HPP (n = 113)	NTP (n = 95)	PEF (n = 103)	US (n = 109)	*P*-value
SN	3.8 ± 1.34	3.9 ± 1.32	3.9 ± 1.54	3.9 ± 1.32	0.881
PB	4.0 ± 1.31	4.0 ± 1.14	3.7 ± 1.28	3.8 ± 1.29	0.282
SE	5.0 ± 1.31	4.7 ± 1.41	4.5 ± 1.55	4.7 ± 1.47	0.222
Trust	5.0 ± 1.49	5.2 ± 1.33	5.0 ± 1.51	4.9 ± 1.58	0.851
PR	3.5 ± 1.54	3.5 ± 1.18	3.5 ± 1.38	3.4 ± 1.42	0.964
Familiarity	**2.0 [a] ± 1.39**	**1.3 [b] ± 0.65**	**1.4 [b] ± 0.95**	**1.4 [b] ± 0.92**	**<0.001**
PRS	3.8 ± 1.45	3.6 ± 1.27	4.0 ± 1.31	3.9 ± 1.39	0.324
UK (n = 416)					
Constructs	**HPP (n = 102)**	**NTP (n = 113)**	**PEF (n = 101)**	**US (n = 100)**	**P-value**
SN	4.0 ± 1.05	3.8 ± 1.09	3.9 ± 1.23	3.9 ± 1.08	0.417
PB	3.9 ± 1.17	3.9 ± 1.16	4.0 ± 1.16	3.9 ± 1.08	0.823
SE	4.6 ± 1.29	4.2 ± 1.20	4.5 ± 1.17	4.2 ± 1.22	0.054
Trust	4.5 ± 1.34	4.3 ± 1.47	4.4 ± 1.22	4.4 ± 1.36	0.806
PR	3.9 ± 1.24	3.7 ± 1.03	3.7 ± 1.01	3.8 ± 1.13	0.668
Familiarity	2.6 ± 1.48	2.3 ± 1.53	2.2 ± 1.34	2.5 ± 1.55	0.099
PRS	3.7 ± 1.25	3.7 ± 1.10	3.6 ± 1.11	3.6 ± 1.20	0.615
Germany (n = 409)					
Constructs	**HPP (n = 97)**	**NTP (n = 99)**	**PEF (n = 102)**	**US (n = 111)**	***P*-value**
SN	**3.7 [a,b] ± 1.26**	**3.9 [a] ± 0.98**	**3.3 [b] ± 1.24**	**3.8 [a] ± 1.40**	**0.004**
PB	3.6 ± 1.08	3.7 ± 0.92	3.4 ± 1.26	3.5 ± 1.24	0.446
SE	**4.3 [a] ± 1.33**	**4.1 [a,b] ± 1.22**	**3.5 [b] ± 1.32**	**3.7 [b,c] ± 1.35**	**<0.001**
Trust	4.4 ± 1.52	4.1 ± 1.38	4.0 ± 1.63	4.3 ± 1.59	0.107
PR	**3.3 [a] ± 1.34**	**3.7 [a] ± 0.87**	**3.2 [a] ± 1.26**	**3.3 [a] ± 1.41**	**0.042**
Familiarity	**2.0 [a] ± 1.14**	**1.3 [b] ± 0.77**	**1.4 [b] ± 0.80**	**1.8 [a] ± 0.97**	**<0.001**
PRS	3.6 ± 1.37	3.6 ± 1.11	3.6 ± 1.48	3.5 ± 1.47	0.948

SN, PB, SE, Trust and PR were evaluated using seven-point Likert scales ranging from 1 = strongly disagree to 7 = strongly agree.
Familiarity is a choose-one question (1-"I do not recognise the concept" to 5 - "I recognise the concept, know what it means and have tasted food products using this technology"); PRS is a choose-one question from 1 - "Much less severe" to 5 - "Much more severe").
a-b Means within the same column with different letters are significantly different (Kruskal-Wallis with Dunn pairwise comparison analysis $p < 0.05$).

Table 3
Factor analysis explained variance, KMO and α-Cronbach of each construct in each country.

	Portugal (n = 420)			UK (n = 416)			Germany (n = 409)		
Factor	Explained variance	Cronbach's α	KMO	Explained variance	Cronbach's α	KMO	Explained variance	Cronbach's α	KMO
GS	64.53%	0.889	0.891	64.33%	0.889	0.895	72.54%	0.924	0.916
PV	74.38%	0.885	0.819	74.96%	0.889	0.841	84.35%	0.938	0.852
FNS	64.93%	0.859	0.845	59.09%	0.823	0.813	52.79%	0.771	0.744
FTNS	70.61%	0.861	0.802	59.80%	0.774	0.717	71.57%	0.866	0.804
SN	64.15%	0.719	0.637	64.79%	0.726	0.653	67.55%	0.759	0.679
PB	71.32%	0.862	0.795	68.94%	0.849	0.817	75.30%	0.890	0.809
SE	64.60%	0.718	0.595	60.58%	0.654	0.553	60.56%	0.667	0.590
Trust	94.97%	0.947	0.500	85.89%	0.836	0.500	94.58%	0.943	0.500
PR	81.88%	0.889	0.708	66.10%	0.743	0.678	79.69%	0.872	0.704

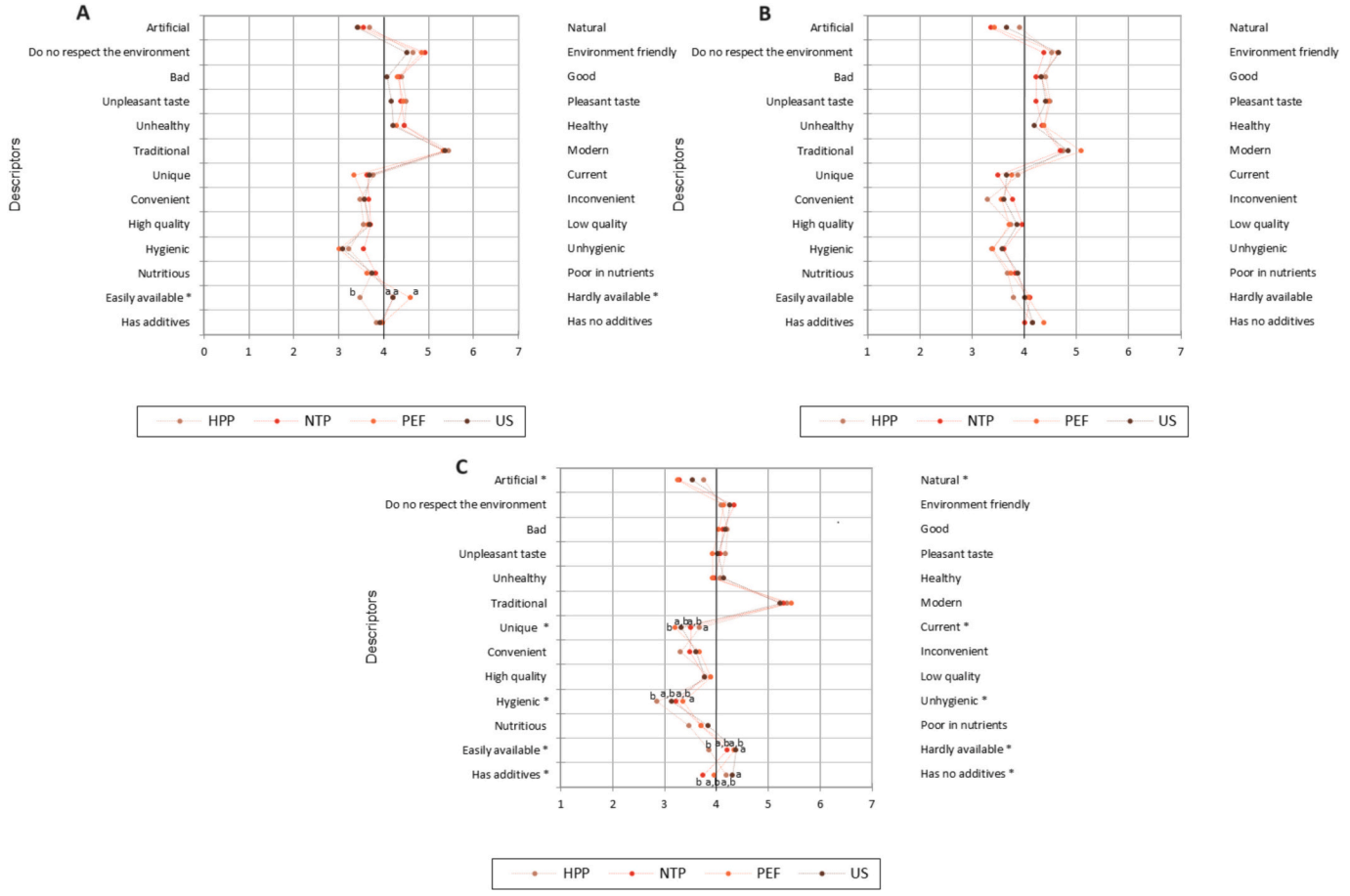

Fig. 1. Semantic differential chart displaying the thirteen adjective pairs describing the attitudes towards the non-thermal technologies in Germany. The black line at scale point 4 marks the scale centre. Items with * are significantly different (Kruskal-Wallis with Dunn pairwise comparison analysis $p < 0.05$). The pairs of adjectives represent the scale endpoints (e.g.. 1 = hygienic and 7 = unhygienic) A – Portugal; B – United Kingdom; C - Germany.

since PEF is perceived as a more Unique and less Hygienic technology, and the US is perceived as a more Hardly Available technology (Fig. 1C).

A subjective norm is an individual assessment of behaviour that other people influence; in other words, people tend to embrace a behaviour if they feel that important people approve of it (Shin & Hancer, 2016). There would be a greater influence on the consumption of food processed by NTP and the US than PEF.

German participants also considered PEF to be more a Unique technology (relative to HPP), HPP more Hygienic (relative to PEF, although all technologies presented means lower than 4.0), and NTP a process that has more Additives (relative to the US) Fig. 1C). According to Jan et al. (2017), non-thermal processed foods can have an extended shelf-life without adding preservatives or additives, suggesting the lower knowledge of NTP by German consumers.

In the UK, there were no significant differences between non-thermal technologies for any variables or attitudes (Fig. 1B).

3.4. Factors that influence consumers' perception of technologies across countries

Considering differences between countries for each technology (Table 5), there are differences between the responses for each technology in Portugal, Germany and the UK. Portuguese had higher scores for Trust than the Germans and British for all the assessed technologies, while the British presented higher Familiarity scores for all non-thermal technologies than the Portuguese and Germans. Portuguese also presented the highest scores for SE for all technologies. Furthermore, except for NTP, the British had higher PR scores than the Germans. There are also differences in PB for HPP and PEF, with German exhibiting the lowest scores and for SN, where German once again had the lowest scores.

British exhibited higher Familiarity with all the technologies. However, the mean of the responses ranged from "I don't recognise the concept" to "I recognise the concept, but I don't know what it means" which is in line with the study conducted by Nielsen et al. (2009) and Sonne et al. (2012), who found that consumers generally display a low knowledge or familiarity towards HPP and PEF technologies. Familiar foods are generally more accepted; however, consumers may find it more acceptable if they have information about their benefits (Jeong & Lee, 2021). This shows that although the technologies are not very familiar, they can be accepted if consumers are given information about their benefits, and from the results of this research, it can be seen that consumers already have a slightly positive attitude towards the technologies.

According to Castell-Perez and Moreira (2021), it is easier for consumers to accept a new technology if respected leaders endorse it they trust. The results show that Portuguese consumers are more trustful of scientists and public health officials than German and British consumers, which could lead to an easier acceptance of these technologies.

Portuguese consumers have a higher SE for all technologies. Such SE can be considered one of the main predictors of purchase intention and can be included in the customer confidence-building process to reduce uncertainty. Customers who show high levels of SE are more trusting and willing to invest considerable effort to successfully complete a transaction (Pang et al., 2021).

The results showed that German consumers had the lowest

Table 5
Mean and SD values of the responses of the questionnaire per country for each technology.

	HPP (n = 312)			
Constructs	Portugal (n = 113)	Germany (n = 97)	UK (n = 102)	P-value
SN	3.8 ± 1.34	3.7 ± 1.26	4.0 ± 1.05	0.149
PB	**4.0 [a] ± 1.31**	**3.6 [b] ± 1.08**	**3.9 [a,b] ± 1.17**	**0.044**
SE	**5.0 [a] ± 1.31**	**4.3 [b] ± 1.33**	**4.6 [b] ± 1.29**	**0.002**
Trust	**5.0 [a] ± 1.49**	**4.4 [b] ± 1.52**	**4.5 [b] ± 1.34**	**0.011**
PR	**3.5 [a,b] ± 1.54**	**3.3 [b] ± 1.34**	**3.9 [a] ± 1.24**	**0.022**
Familiarity	**2.0 [b] ± 1.39**	**2.0 [b] ± 1.14**	**2.6 [a] ± 1.4**	**0.001**
PRS	3.8 ± 1.45	3.6 ± 1.37	3.7 ± 1.25	0.682
	NTP (n = 307)			
Constructs	Portugal (n = 95)	Germany (n = 99)	UK (n = 113)	P-value
SN	3.9 ± 1.32	3.9 ± 0.98	3.8 ± 1.09	0.564
PB	4.0 ± 1.14	3.7 ± 0.92	3.9 ± 1.16	0.189
SE	**4.7 [a] ± 1.41**	**4.1 [b] ± 1.22**	**4.2 [b] ± 1.20**	**0.001**
Trust	**5.2 [a] ± 1.33**	**4.1 [b] ± 1.38**	**4.3 [b] ± 1.47**	**<0.001**
PR	3.5 ± 1.18	3.7 ± 0.87	3.7 ± 1.03	0.701
Familiarity	**1.3 [a] ± 0.65**	**1.3 [a] ± 0.77**	**2.3 [a] ± 1.53**	**<0.001**
PRS	3.6 ± 1.27	3.6 ± 1.11	3.7 ± 1.10	0.897
	PEF (n = 306)			
Constructs	Portugal (n = 103)	Germany (n = 102)	UK (n = 101)	P-value
SN	**3.9 [a] ± 1.54**	**3.3 [b] ± 1.24**	**3.9 [a] ± 1.23**	**0.003**
PB	**3.7 [a,b] ± 1.28**	**3.4 [b] ± 1.26**	**4.0 [a] ± 1.16**	**0.005**
SE	**4.5 [a] ± 1.55**	**3.5 [b] ± 1.32**	**4.5 [a] ± 1.17**	**<0.001**
Trust	**5.0 [a] ± 1.51**	**4.0 [b] ± 1.63**	**4.4 [b] ± 1.22**	**<0.001**
PR	**3.5 [a,b] ± 1.38**	**3.2 [b] ± 1.26**	**3.7 [a] ± 1.01**	**0.010**
Familiarity	**1.4 [b] ± 0.95**	**1.4 [b] ± 0.80**	**2.2 [a] ± 1.34**	**<0.001**
PRS	4.0 ± 1.31	3.6 ± 1.48	3.6 ± 1.11	0.247
	US (n = 320)			
Constructs	Portugal (n = 109)	Germany (n = 111)	UK (n = 100)	P-value
SN	3.9 ± 1.32	3.8 ± 1.40	3.9 ± 1.08	0.929
PB	3.8 ± 1.29	3.5 ± 1.24	3.9 ± 1.08	0.077
SE	**4.7 [a] ± 1.47**	**3.7 [c] ± 1.35**	**4.2 [b] ± 1.22**	**<0.001**
Trust	**4.9 [a] ± 1.58**	**4.3 [b] ± 1.59**	**4.4 [b] ± 1.36**	**0.002**
PR	**3.4 [a,b] ± 1.42**	**3.3 [b] ± 1.41**	**3.8 [a] ± 1.13**	**0.030**
Familiarity	**1.4 [c] ± 0.92**	**1.8 [b] ± 0.97**	**2.5 [a] ± 1.55**	**<0.001**
PRS	3.9 ± 1.39	3.5 ± 1.47	3.6 ± 1.20	0.100

perception of benefits for HPP and PEF. According to Siegrist (2008) perceived benefit is a significant factor influencing acceptance of new foods, and Brown and Ping (2003) showed the importance of perceived benefits for the acceptance of GM food. This indicates that it is important for consumers to understand the benefits of the technologies studied to improve their acceptance.

Only for PEF was a significant difference found in SN, showing that German consumers would not be very willing to be influenced to consume products from this technology, according to previous literature (Deliza & Ares, 2018).

As for attitudes towards HPP, NTP, PEF and US (Fig. 2 A, B, C and D, respectively), there were similarities across technologies. Except for the US, Portuguese consumers consider non-thermal technologies more Environmentally Friendly than German consumers. Furthermore, British consumers consider non-thermal technologies less novel than Portuguese and German consumers, as they consider HPP, NTP, and US less modern and PEF less unique. Other significant differences were observed for Hygienic (HPP – German with higher scores than Portugal), Healthy (NTP – Portuguese with higher scores than German), Tasty (PEF – Portuguese and British with higher scores than German) and Availability (PEF – British with higher scores than Portuguese). It can be seen that attitudes towards all four technologies in the three countries leaned towards a more positive side. This was similar to previous studies by Delgado-Gutierrez and Bruhn (2008) (HP, PEF, and OH) and Nielsen et al. (2009) (HPP and PEF). The main negative attitude is that the consumers believed that all of these technologies are artificial, which was also found in the study by Sonne et al. (2012), where some consumers showed concern about the naturalness of foods processed with HPP and PEF and that such methods could be excessively industrial or artificial. In this study, we found few differences in attitudes towards the technologies studied, unlike Monteiro et al. (2022), which showed that US-treated food had a high frequency of mentions with negative association and negative effects (Diseases and Health damage) were high.

Overall, in all three countries, high pressure is the technology with the most positive results compared to the other technologies. The main reason for this is the fact that HPP is currently a well-accepted technology, which is already well integrated into the market, and consumers can see the benefits without the associated risks, the biggest perceived risk being about food safety due to the lack of understanding of how a non-thermal treatment works and how it affects product preservation (Nath et al., 2019).

Few studies have assessed consumer perception of non-thermal plasma, yet Coutinho et al. (2021) studied consumer perception of cold plasma processing of chocolate milk drinks in Brazil. The main concern identified in their study was the potentially harmful impact of technology on their health, product quality, and environment. Consumers are concerned about the risks this technology can bring, and our results make it possible to understand which factors affect the perception of risk.

3.5. Main factors that explain consumers' risk perception

A regression analysis approach was performed to evaluate the determinants of perceived risk in each country and technology studied, using the constructs present in the questionnaire, attitudes (used individually, with each semantic pair as a factor) and sociodemographic data. Identifying the main factors influencing risk perception related to the different technologies will make it easier to work on strategies to increase confidence and decrease the perceived risk for each technology.

Only in Germany was a difference in perceived risk between technologies (Table 4). However, when comparing the perceived risk between countries (Table 5), Germany has the lowest scores for HPP, PEF and US. Although the perception of risk was similar between technologies and countries, it is interesting to understand which factors affect it and what the differences might be. Through regression analysis, it was possible to determine the factors which significantly ($p < 0.05$) affected the perceived risk for each technology in Portugal, United Kingdom and Germany (Tables 6, S3, S4 and S5). Both country and culture are relevant factors in the perception of risk for each technology since different factors affect the perception of risk in each country. This agrees with the study by Kahan (2012), who showed that risk perceptions are influenced by cultural values, which play an important role in guiding attitudes towards controversial social issues.

3.5.1. Portugal

Regarding factors associated with increased Perceived Risk for Portuguese consumers, FTN was present in the overall model (Table 6) and for each technology individually (Table S3). Furthermore, higher PRS and less hygienic scores were associated with higher Perceived Risk at an overall model and for the technologies PEF and US (Table S3).

As for factors negatively correlated with Perceived Risk, Perceived Benefit, Trust, Familiarity, Environment, Current and Natural were associated with an overall model and with at least one technology.

Some sociodemographic variables were also identified as significant factors, as Higher Education is negatively correlated with Perceived Risk for HPP.

The β values given in Table 6 seem to indicate that FTNS (β = 0.360) was the most important predictor of risk in Portugal. For specific technologies, the most important factor for HPP was Trust (β = -0.319); for NTP, it was FTNS (β = 0.464); for PEF, it was both less Hygienic and GS (β = 0.267); and for the US, it was PRS (β = 0.408).

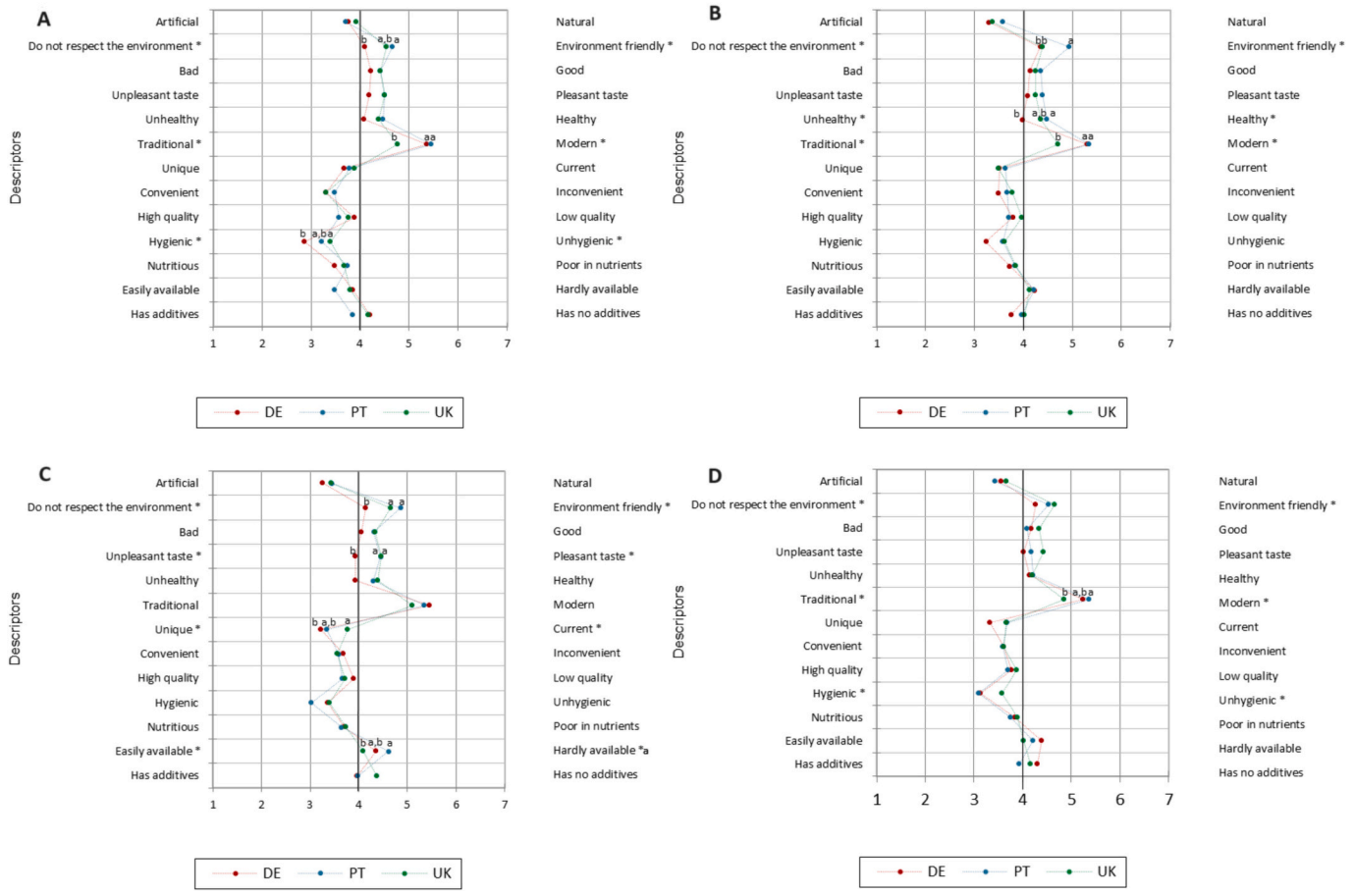

Fig. 2. Semantic differential chart displaying the thirteen adjective pairs describing the attitudes towards the US. The black line at scale point 4 marks the scale centre. Items with * are significantly different (Kruskal-Wallis with Dunn pairwise comparison analysis $p < 0.05$). The pairs of adjectives represent the scale endpoints (e.g.. 1 = hygienic and 7 = unhygienic) and DE, PT and UK represents the countries in the study, being Germany, Portugal and United Kingdon respectively. A – HPP; B- NTP; C – PEF and D - US.

3.5.2. *United Kingdom*

For British consumers, only PRS (HPP and US), FTNS (PEF, NTP and US), and Modern (HPP, PEF and NTP) were positively associated with higher Perceived Risk at an overall model and with at least one technology (Table 6). Furthermore, the presence of Additives (NTP and PEF) was negatively associated with Perceived Risk for more than one non-thermal technology (Table S4).

Regarding factors that negatively correlated with PR; Trust (NTP) and Healthy (PEF and US) were significant factors at an overall model and at least with one technology.

Some factors presented both positive and negative correlations to different technologies: PV (HPP: -0.333; US: 0.152); SE (HPP: -0.175; US: 0.178); Unhealthy × Healthy (NTP: 0.212; PEF: -0.181; US: -0.473); Do Not Respect The Environment × Environment Friendly (NTP: -0.135; US: 0.169) and Sex (PEF: 0.478; US: -0.426). This difference shows that each technology is different, and the consumers have different factors with different correlations that are important to their risk perception.

As for sociodemographic factors, besides high income, sex (feminine) was positively correlated to perceived risk in PEF and negatively correlated for US, and working in a food related field is positively correlated to perceived risk of NTP.

The beta values given in Table 6 seemed to indicate that PRS (β = 0.360) was a more important predictor of perception of risk in the UK overall and for HPP (β = 0.545). For NTP and PEF, the most important predictor was FTNS (β = 0.367; 0.384 respectively), and for the US, it was Unhealthy (β = -0.534).

3.5.3. *Germany*

For German consumers, there were no common factors among the four technologies (Table 6), but PRS (HPP, PEF and US), FTNS (NTP and US) and Low Quality (HPP and US) were positively associated with Perceived Risk at an overall model and with more than one technology (Table S5). Additionally, PB and SE were positively correlated with Perceived Risk at an overall model and with one technology (US and PEF, respectively).

Trust was negatively correlated with Perceived Risk in an overall model, and this factor also influenced HPP and PEF. SN has a negative effect on NTP and does not Respect The Environment for PEF. Regarding sociodemographic factors, having children in the household was negatively correlated with Perceived Risk for HPP.

The β values given in Table 6 indicate that PRS was the most important predictor of risk at an overall model (β = 0.432) and for HPP (β = 0.444), PEF (β = 0.571) and US (β = 0.511), while for NTP FTNS was the most important predictor (β = 0.237).

Some factors are associated with Perceived Risk for all the countries, such as FTNS and PRS, which had a positive correlation and Trust which had a negative correlation. FTNS was the most important for PT while PRS was the most important factor for the UK and DE. It was expected that FTNS would be present, given that this is a factor that is associated directly with technology, and the greater the neophobia towards new food technologies, the greater the perception of risk towards them. The factors affecting risk perception for each technology were different within the same country, since these technologies are different from each other, thus affecting the way consumers perceive each of them.

Table 6
Summary of the multiple linear regression analysis for the variables predicting consumers' perceived risk about non-thermal technologies per coutntry.

Dependent Variable: Perceived Risk				
Portugal (n = 420)		Adjusted R Square: 0.455		
Predictors:	Unstandardised Coefficients		Standardised Coefficients	P-value
	B	Std. Error		
(Constant)	0.873	0.461		0.059
FTNS	0.280	0.035	0.310	<0.001
PRS	0.263	0.043	0.258	<0.001
GS	0.201	0.051	0.145	<0.001
Hygienic × Unhygienic	0.188	0.031	0.241	<0.001
Unpleasant taste × Pleasant taste	0.153	0.045	0.156	0.001
Artificial × Natural	-0.080	0.033	-0.098	0.018
Do not respect the environment × Environment friendly	-0.110	0.036	-0.136	0.002
Familiarity	-0.123	0.049	-0.094	0.012
Trust	-0.160	0.039	-0.171	<0.001
United Kingdom (n = 416)		Adjusted R Square: 0.301		
Predictors	**Unstandardised Coefficients**		**Standardised Coefficients**	P-value
	B	**Std. Error**		
(Constant)	1.620	0.426		<0.001
PRS	0.256	0.042	0.271	<0.001
FTNS	0.225	0.042	0.233	<0.001
SN	0.145	0.048	0.146	0.003
Nutritious × Poor in nutrients	0.130	0.039	0.158	0.001
Traditional × Modern	0.108	0.029	0.155	<0.001
Per capita net income (Pounds/household member)	0.000	0.000	-0.091	0.034
Trust	-0.096	0.040	-0.117	0.017
Unhealthy × Healthy	-0.117	0.040	-0.137	0.004
Education Level (1 – Yes; 0 – No)	-0.220	0.092	-0.100	0.018
Germany (n = 409)		Adjusted R Square: 0.416		
Predictors:	**Unstandardised Coefficients**		**Standardised Coefficients**	P-value
	B	**Std. Error**		
(Constant)	1.133	0.441		0.011
PRS	0.395	0.038	0.432	<0.001
High quality × Low quality	0.198	0.045	0.186	<0.001
PB	0.171	0.053	0.156	0.001
FTNS	0.152	0.036	0.183	<0.001
Do no respect the environment × Environment friendly	-0.118	0.045	-0.107	0.009
Trust	-0.146	0.041	-0.179	<0.001

This study shows that strategies to minimise the perceived risk of these technologies should consider the technology itself and the country studied, tailoring the message and marketing strategies.

Studies with GM food (Traill et al., 2004) and nanotechnology (Siegrist et al., 2008) show that a low level of trust in institutions is associated with a higher level of risk perception for GM foods, which is in accordance with what we see for the countries studied and for some of the technologies (HPP and PEF – PT and DE; and NTP – UK).

The negative correlation between PR and PB seen in HPP (PT) is similar to what happens with GM food (Siegrist, 2000; Siegrist et al., 2007; Traill et al., 2004) and nanotechnology (Siegrist et al., 2008). However, for all technologies, in German, there is a positive correlation between PR and PB which is not common, and it should be considered in more in-depth because it could be correlated to a lower perception of the benefits, as seen in Table 6 for HPP and PEF (Alhakami & Slovic, 1994; Klerck & Sweeney, 2007).

It was expected that familiarity would be an important factor in risk perception due to its relationship with knowledge. However, this was only seen in Portugal (for all technologies) (Coppola et al., 2014).

The FNS and FTNS measure fear of novel foods and food technologies respectively, and a positive relationship between them and the perceived risk was expected, as also seen by Chen (2018) with GMOs, where the rejection of food from new technologies (FTNS) influences people's perception of risk (Rembischevski & Caldas, 2020).

3.6. Consumer segments perception

Across all countries, two consumer segments resulted from the cluster analysis. The aim of the segmentation was to identify segments of consumers that differed in their risk perception towards the novel food technologies. Two groups were identified: Cluster One was characterised by trusting and positive consumers, while Cluster Two was by risk and negative consumers. Table S6 shows the sociodemographic characteristics of the two groups, with the first group presenting a greater proportion of younger (42%) and Portuguese (40.5%) consumers with higher education (53.2%), while the second cluster had a greater proportion of older (42.0%) and British (44.8%) consumers without higher education (60.6%). Both clusters had a similar proportion of German consumers (33.7% in the first cluster and 31.6% in the second cluster), and that assessed technology and interaction between technology and country had no impact on the composition of the clusters.

The characteristics of each group are presented in Table 7. Both groups are very different from one another, the first cluster presenting a more positive opinion towards the non-thermal technologies, having

Table 7
Mean and SD values of the responses of each cluster.

Constructs	Cluster 1 (*n* = 738) Trusting and positive	Cluster 2 (*n* = 507) Risk and negative	p-value
GS	**5.5** ^{a} **± 1.0**	**4.7** ^{b} **± 1.3**	**<0.001**
PV	**5.7** ^{a} **± 1.2**	**4.6** ^{b} **± 1.5**	**<0.001**
FNS	**3.0** ^{b} **± 1.2**	**4.0** ^{a} **± 1.3**	**<0.001**
FTNS	**3.1** ^{b} **± 1.2**	**4.6** ^{a} **± 1.2**	**<0.001**
Artificial × Natural	**3.8** ^{a} **± 1.6**	**3.2** ^{b} **± 1.6**	**<0.001**
Do not respect the environment × Environment friendly	**4.8** ^{a} **± 1.3**	**4.1** ^{b} **± 1.4**	**<0.001**
Bad × Good	**4.6** ^{a} **± 1.2**	**3.7** ^{b} **± 1.3**	**<0.001**
Unpleasant taste × Pleasant taste	**4.5** ^{a} **± 1.2**	**3.9** ^{b} **± 1.3**	**<0.001**
Unhealthy ×Healthy	**4.6** ^{a} **± 1.3**	**3.7** ^{b} **± 1.4**	**<0.001**
Traditional × Modern	**5.3** ^{a} **± 1.6**	**5.0** ^{b} **± 1.6**	**<0.001**
Unique × Current	**3.5** ^{b} **± 1.5**	**3.8** ^{a} **± 1.5**	**<0.001**
Convenient × Inconvenient	**3.3** ^{b} **± 1.3**	**4.0** ^{a} **± 1.4**	**<0.001**
High quality × Low quality	**3.4** ^{b} **± 1.3**	**4.3** ^{a} **± 1.3**	**<0.001**
Hygienic × Unhygienic	**3.0** ^{b} **± 1.6**	**3.7** ^{a} **± 1.5**	**<0.001**
Nutritious × Poor in nutrients	**3.4** ^{b} **± 1.4**	**4.2** ^{a} **± 1.4**	**<0.001**
Easily available × Hardly available	**4.0** ^{b} **± 1.6**	**4.2** ^{a} **± 1.6**	**0.030**
Has additives × Has no additives	**4.3** ^{a} **± 1.5**	**3.6** ^{b} **± 1.6**	**<0.001**
SN	**4.1** ^{a} **± 1.2**	**3.5** ^{b} **± 1.3**	**<0.001**
PB	**4.1** ^{a} **± 1.0**	**3.3** ^{b} **± 1.3**	**<0.001**
SE	**4.4** ^{a} **± 1.4**	**4.2** ^{b} **± 1.3**	**<0.001**
Trust	**5.0** ^{a} **± 1.3**	**3.8** ^{b} **± 1.4**	**<0.001**
PR	**3.2** ^{b} **± 1.2**	**4.0** ^{a} **± 1.2**	**<0.001**
Familiarity	1.8 ± 1.2	2.0 ± 1.3	0.100
PRS	**3.5** ^{b} **± 1.2**	**4.0** ^{b} **± 1.3**	**<0.001**

SN, PB, SE, trust and PR were evaluated using seven-point Likert scales ranging from 1 = strongly disagree to 7 = strongly agree.
Attitudes are 7 point scale with the pairs of adjectives represent the scale end-points (e.g.. 1 = hygienic and 7 = unhygienic).
Familiarity is a choose-one question (1-"I do not recognise the concept" to 5 - "I recognise the concept, know what it means and have tasted food products using this technology"); PRS is a choose-one question from 1 - "Much less severe" to 5 - "Much more severe").
a-b Means within the same column with different letters are significantly different (Kruskal-Wallis with Dunn pairwise comparison analysis $p < 0.05$).

more positive attitudes, higher Trust, SN, SE and PB. Whereas the second cluster presented a more negative opinion, with higher neophobia (FNS and FTNS), having a more negative attitude and higher perceived risk and perceived risk severity.

The results presented here are in line with the work of Schnettler et al. (2013), where it was shown that the consumer group with the highest FNS score had a higher proportion of older consumers (≥55) and were not willing to purchase foods or packages produced with nanotechnology (novel technologies), while the group with the lowest FNS score had a higher proportion of younger consumers (<35) who were willing to purchase foods or packages produced with nanotechnology (novel technology). Some studies also showed that neophobia is influenced by education level, where those with higher degrees of education seems to be neophilic, being more open to new food products and technologies (Cattaneo et al., 2019; Evans et al., 2010; Vidigal et al., 2015). Vasquez et al. (2022) showed a similar result regarding neophobia and attitudes, where consumers who were neophilic often had a positive perception of technology (Cluster 1), whereas consumers who were neophobic had a negative attitude towards it (Cluster 2). Usually, unfamiliarity is correlated with a higher perceived risk, such as in the study of Fischer and Frewer (2009), which showed that unfamiliarity with the food increased risk perception. However in our study, this correlation was not found, and there was no difference between the familiarity with the technologies between the two groups, as previously revealed by Slovic (1988).

When applying the regression analysis for both clusters, the factors that affect perceived risk for both groups can be seen (Table 8). First of all, it can be seen the similarities, there is a positive correlation between PRS and less Hygienic. Both clusters presented neophobia as factor (FNS for cluster 1 and FTNS for cluster 2).

For the first cluster PRS, FTNS, Unhygienic, SE and Pleasant Taste are positive while Trust, natural, Environment Friendly and Good are negatively correlated to risk perception.

For the second cluster all the present factors (PRS, low quality, FNS, Unhygienic, Modern and Familiarity) are positively correlated to the perceived risk. Familiarity has a positive correlation to perceived risk, which is different from what is normally found in the literature, where the risk perception increases when familiarity is lower (Fischer & Frewer, 2009; Slovic, 1988).

When comparing the factors which influence risk perception in both clusters with the ones that influence the countries (Tables 6 and 8) we can see that cluster 1 (Trusting and positive consumers) has seven factors in common with Portugal (FTNS, PRS, Unpleasant Taste × Pleasant Taste, Hygienic × Unhygienic, Artificial × Natural, Do Not Respect The Environment × Environment-Friendly and Trust); three factors in common with the UK (FTNS, PRS and Trust) and four factors in common with Germany (FTNS, PRS, Do Not Respect the Environment × Environment Friendly, and Trust). While cluster 2 (risk and negative) has three factors similar to PT (PRS, Hygienic × Unhygienic and Familiarity inverse); two with the UK (PRS and Traditional × Modern) and DE (PRS and High Quality × Low Quality). Cluster 1 has a large representation of Portuguese consumers, demonstrating this similarity with the factors that affect risk perception, and that cluster 1 has the same factors in common with all countries (PRS, FNS and Trust).

Regarding the identification of the predicting factors which significantly influence the risk perception towards the technologies, for each of the consumers' clusters (Tables 8, S3, S4 and S5), some similarities were found. Within cluster 1, one may identify as predicting factors:

- FTNS – for all technologies except HPP (UK, DE) and PEF (DE);
- Trust – for HPP (PT DE), NTP (UK), PEF (PT, DE);
- Attitudinal variable "Bad × Good" – for HPP (PT);
- PRS – for HPP (UK, DE), PEF (PT, DE), US (PT, UK, DE);
- SE – for HPP (UK), PEF (DE), US (UK);
- Attitudinal variable "Do Not Respect The Environment × Environment Friendly" – for NTP (PT, UK), PEF (DE), US (UK);
- Hygienic × Unhygienic - PEF (PT), US (PT).

Within cluster 2, the following patterns were unveiled:

- PRS – for HPP (UK DE), PEF (PT, DE), US (PT, UK, DE),
- Attitudinal variable "Traditional × Modern" – for HPP (UK), NTP (UK), PEF (UK);
- Attitudinal variable "High Quality × Low Quality" – for HPP (DE), NTP (PT, UK), US (DE);
- Attitudinal variable "Hygienic × Unhygienic" – for PEF (PT), US (PT).

In general, it is possible to identify that the predicting factors for risk perception vary from country to country, and between technologies within each country. This can also be seen in the socio-demographic characteristics of the clusters, with significant differences across technologies and countries (Table S6).

4. Conclusion

British consumers demonstrated the highest familiarity with all four non-thermal technologies (HPP, NTP, PEF, and US) compared to Portuguese and German consumers, but still had a relatively low value, suggesting that while consumers may have some awareness of these technologies, they do not deeply understand their applications and implications.

Despite lower familiarity, Portuguese consumers reported the highest levels of trust in science and public health entities regarding non-thermal technologies compared to their German and British counterparts. This increased trust could contribute to a greater willingness to accept these technologies among Portuguese consumers, as endorsements from trusted sources can significantly shape consumer

Table 8
Summary of the multiple linear regression analysis for the variables predicting consumers' perceived risk for each non-thermal technologies for both clusters.

Dependent Variable: Perceived Risk				
Cluster 1 - Trusting and positive (n = 738)	Adjusted R Square: 0.360			
Predictors:	Unstandardised Coefficients		Standardised Coefficients	Sig.
	B	Std. Error		
(Constant)	2.126	0.299		<0.001
FTNS	0.282	0.030	0.284	<0.001
PRS	0.258	0.029	0.276	<0.001
Unpleasant taste × Pleasant taste	0.134	0.038	0.138	<0.001
Hygienic × Unhygienic	0.126	0.025	0.170	<0.001
SE	0.077	0.026	0.095	0.003
Artificial × Natural	-0.071	0.024	-0.097	0.003
Do not respect the environment × Environment friendly	-0.084	0.032	-0.098	0.009
Bad × Good	-0.103	0.041	-0.107	0.011
Trust	-0.170	0.030	-0.193	<0.001
Cluster 2 - Risk and negative (n = 507)	Adjusted R Square: 0.599			
Predictors:	**Unstandardised Coefficients**		**Standardised Coefficients**	**Sig.**
	B	**Std. Error**		
(Constant)	0.419	0.286		0.144
PRS	0.381	0.037	0.405	<0.001
FNS	0.116	0.038	0.118	0.002
Hygienic × Unhygienic	0.115	0.034	0.138	0.001
High quality × Low quality	0.110	0.040	0.114	0.007
Traditional × Modern	0.108	0.030	0.141	<0.001
Familiarity	0.093	0.036	0.100	0.010

perceptions. Additionally, Portuguese consumers exhibited the highest levels of self-efficacy across all technologies, meaning they felt more confident in finding and purchasing products processed with these methods.

In contrast, German consumers reported the lowest benefits perception associated with HPP and PEF, suggesting that they may need reliable information regarding the specific advantages of these technologies to mitigate potential uncertainties and promote acceptance. Furthermore, German consumers revealed less susceptibility to social influence (subjective norm) concerning PEF-processed foods. This can suggest that strategies like social reinforcements or peer influence might be less effective in promoting PEF products among German consumers.

It has been shown that risk perception is a key factor that affects consumers' acceptance of novel food technologies and therefore, it is important to know the factors which affect such risk perception. The results of this research show that the development and production of new products with novel technologies should take into account the consumers' perception in each country and for the specific technologies that will be launched. It was found that perceived risk associated with non-thermal technologies varied depending on the technology and the cultural context. For instance, British consumers had a higher perceived risk across technologies than German consumers, except for NTP. This highlights the importance of tailoring communication and marketing strategies to address specific cultural group's concerns and needs.

It was possible to separate the consumers into two groups. Even though they had a few similarities in terms of sociodemographic characteristics, they were completely different in terms of values and opinions regarding new food technologies, one being more neophobic and with negative attitudes, while the other more neophilic and with more positive attitudes towards the non-thermal technologies. The study concluded that opinions and perceptions are influenced by cultural differences, and this needs to be taken into account in the product development phase.

CRediT authorship contribution statement

Aline Silva: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Célia Rocha:** Conceptualization, Investigation, Formal analysis, Methodology, Resources, Writing – review & editing. **José Carlos Ribeiro:** Writing – review & editing. **Kemal Aganovic:** Conceptualization, Investigation. **Rui C. Lima:** Project administration, Funding acquisition, Resources, Supervision. **Lisa Methven:** Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing. **Luís M. Cunha:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no conflicts of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ifset.2024.103772.

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