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Beyond sugar: Exploring the influence of health and naturalness framing on attitudes towards products with sweet proteins in Europe

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ABSTRACT

Amidst rising obesity rates in the EU and the significant public health impact of excessive sugar consumption, the debate on reducing sugar through reformulation with sweet proteins derived from precision fermentation gains prominence, presenting a viable alternative to traditional sugars and conventional sweeteners. We conducted two studies to investigate the effects of health (emphasizing sugar reduction) versus naturalness (highlighting sweet proteins as alternatives to artificial sweeteners) message framing on the acceptance of products reformulated with sweet proteins. Study 1 (N = 296, Denmark) evaluated the impact of health and naturalness message framing on attitudes towards such reformulations. Study 2, in a cross-cultural sample (N = 3,000 Denmark, Germany, and Poland), tested the mediating role of health perceptions and the moderating effects of BMI and guilt (Study 2a), as well as naturalness perceptions, sweetener use, and pleasure (Study 2b) on product attitudes. Results of Study 1 indicated that healthiness perceptions had a more persuasive influence than naturalness perceptions. The cross-cultural findings of Studies 2a and 2b revealed that BMI, sweetener usage frequency, anticipatory guilt, and pleasure can modulate these effects. These insights suggest that while both perceived healthiness and naturalness shape attitudes towards sweet protein-enriched products, the significance of health perceptions prevails, with anticipatory emotions of guilt enhancing this influence, particularly when sweet proteins substitute added sugar. Such evidence holds substantial implications for strategies aimed at reducing sugar consumption and fostering the acceptance of products containing alternative sweeteners.

1. Introduction

The increase in obesity rates among the EU population (EUROSTAT, 2023), the effects of excessive sugar consumption on public health (EC, 2020), and the need for rethinking sugar reduction are currently active areas of scientific and policy debate (Deliza et al., 2021; Freeman et al., 2018; WHO/EURO, 2022). European Union legislation distinguishes between two major categories: 'sugars' and 'sweeteners' (EC, 2021). It includes under 'sugars' all monosaccharides (such as glucose, fructose, galactose) and disaccharides (such as sucrose, lactose, and maltose) found in food, while excluding polyols (low-calorie sweeteners or alcohols containing more than two hydroxyl groups) (EC, 2008, 2011, 2021). Sugars are further differentiated between 'intrinsic sugars' (such as fructose and lactose), and 'free sugars' that include 'added sugars' (monosaccharides and disaccharides added to foods and beverages) (WHO, 2015). 'Sweeteners' are defined as 'food additives' used to provide a sweet taste to foods or act as the table-top sweeteners to replace sugar in production of foods with no added sugars and/or extend the shelf life of foods (EC, 2008, 2011). Sweeteners fall into two categories under EU legislation: 'high-intensity sweeteners' (substances with intense sweet taste and no energy value) and 'low-calorie sweeteners' (polyols) that may also serve other technological functions in food aside from sweetening (EC, 2021; EFSA, 2011). High-intensity sweeteners can be either 'natural sweeteners' such as stevia (stevioside) and sweet protein (thaumatin), or 'artificial sweeteners' as aspartame and sucralose (Debras et al., 2022; EP, 2022; Yebra-Biurrun, 2013).

In the European Union (EU27), the average consumption of sugar (raw equivalent) is approximately 34 kg per capita a year, while the consumption of sweeteners is 7 kg per capita a year, and honey is about 0.7 kg per capita a year (FAOSTAT, 2023). Therefore, the consumption of sugar is more than three times higher than the conditional recommendations of the WHO of<10 kg per capita a year (or approximately 5% of total daily energy intake) (WHO, 2015). The European Food Safety Authority (EFSA) has also highlighted that the intake of added

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sugars in some EU countries exceeds WHO recommended threshold, particularly in children (EC, 2021). Possible recommended strategies for reducing added sugar intake include the introduction of taxes on sugary foods and sugar-sweetened-beverages (SSBs), reducing portion size (or shifting purchasing patterns towards lower/no added sugar products), implementing nutrition labelling (Di Monaco et al., 2018; Hawkes et al., 2015; Séveno, 2021), using sweeteners as substitutes for added sugar (EC, 2021) and implementing marketing regulations to minimize the impact of unhealthy food and beverage marketing on children (WHO, 2013, 2015).

However, despite the introduction of taxes in only 10 out of 53 European countries as of 2020 (WHO/EURO, 2022), mandatory nutritional labelling requirements (EC, 2016), and the adoption of rules in some countries to restrict the marketing of unhealthy foods to children (WHO, 2022), these strategies have not effectively curbed the purchases and consumption of sugary foods and sugar-sweetened-beverages (SSBs) (Azaïs-Braesco et al., 2017; Biltoft-Jensen et al., 2021). As a result, there is a growing recognition that product reformulations, coupled with marketing regulations, hold potential for curbing sugar consumption (Deliza et al., 2021).

Recently, advancements in precision fermentation technology have enabled the reformulations of products using sweet proteins as a substitute for sugar (Banovic & Grunert, 2023; Banovic, 2023). Sweet proteins, such as thaumatin, are classified as natural high-intensity sweeteners (Yebra-Biurrun, 2013). In the EU, thaumatin is authorised as a food additive in fifteen food categories, such as chocolate and chocolate products (EC, 2008), and is considered by EFSA as a digestible protein, which is non-allergenic, and safe for human consumption (Younes et al., 2021). As thaumatin, sweet proteins are digestible ultra-sweet proteins inspired by proteins found in fruits and are produced through precision fermentation using yeasts to express the protein (Joseph et al., 2019). In comparison to commonly used artificial sweeteners like aspartame and sucralose, often associated to synthetic ingredients and health risks (Debras et al., 2022; Hovhannisyan & Bastian, 2022), sweet proteins offer significant potential for product reformulations and applications in the food industry. For instance, they possess low-caloric properties and show great potential as novel sugar substitutes (Joseph et al., 2019; Watson, 2022). However, despite these promising attributes, there have been no studies examining consumer acceptance of sweet proteins or the optimal communication strategies necessary to ensure successful adoption of products reformulated with sweet proteins to reduce sugar consumption.

Previous research has highlighted the significance of message framing as an important communication strategy in the context of new product reformulations involving alternative proteins (e.g., Banovic & Otterbring, 2021; Onwezen et al., 2021). Given that reformulations are often aimed at promoting health, it is logical to frame such products as healthy options that can contribute to reducing sugar consumption. This framing approach could be particularly instrumental among individuals with higher body mass index (BMI) levels, as they are often more motivated to modify their behavior due to experiences of overt or implicit discrimination (Rosenblatt et al., 2019; Schwartz et al., 2006). Additionally, the presence of anticipatory guilt associated with the consumption of sugary foods may have a predictive impact on the desired behavioural outcome (Conradt et al., 2007).

However, it is important to note that previous research (Lähteenmäki et al., 2010) has shown that consumers may reject health messages if they perceive that the health-related reformulation compromises the naturalness of the product. An alternative framing approach, therefore, could involve describing the product as the result of a natural process. Naturalness is a strongly positive associate of food intake, as most people in western countries prefer natural foods (Roman et al., 2017; Scott & Rozin, 2020). Further, natural framing has been shown to increase product acceptance, even for more complex products (Aschemann-Witzel & Grunert, 2017). Precision fermentation can be described as an extension of a natural fermentation process (Banovic & Grunert, 2023). This framing effect may be further enhanced among individuals who already have experience with high-intensity sweeteners, both natural and artificial, as sugar alternatives would be more familiar to them. The perception of naturalness is expected to have a positive impact on attitudes towards the product, and this effect could be reinforced by anticipatory pleasure associated with consuming the product (Goldsmith et al., 2012). Indeed, anticipatory pleasure is a fundamental component of any hedonic experience (Rozin et al., 2003), and it has the potential to enhance attitudes towards reformulated products and motivate individuals to follow recommended courses of action (Verma et al., 2016).

Based on this background, the main objectives of the present study were as follows: i) to investigate the influence of message framing (healthy *vs.* natural) on attitudes towards products reformulated with sweet protein, a high-intensity sweetener (Study 1); ii) to examine whether the relationship between message framing and attitudes is mediated by perceived health benefits, and moderated by Body Mass Index (BMI) and anticipatory guilt, in the case of the health framing; and iii) to examine whether the relationship between message framing and attitudes is mediated by perceived naturalness, and moderated by high-intensity sweetener consumption and anticipatory pleasure, in the case of naturalness framing. Study 2 investigates objectives ii) and iii) in a cross-cultural context, Fig. 1 summarizes our conceptual framework.

2. Method

We tested our hypotheses on how differently framed messages on sweet proteins would lead to the product acceptance, and whether such presumed effect would be mediated by perceptions of health benefits and naturalness, and moderated by individual BMI level, anticipated guilt, anticipated pleasure, and sweetener usage (Fig. 1). We investigated this assumption across two studies. In Study 1, focus was on the main experimental condition, to demonstrate how message framing influences attitudes toward product reformulations with sweet protein. In Study 2, for the case of health framing, the effect of health perceptions as a mediator, and BMI levels and anticipated guilt as moderators, on attitudes were assessed (Study 2a). Further, for the case of naturalness framing, the effect of naturalness perceptions as a mediator, and high-intensity sweetener use and anticipated pleasure as moderators on product attitudes were tested (Study 2b). Study 2 has been undertaken in a cross-cultural context.

2.1. Experimental design, framing, procedure and measures

This research has obtained ethical approval from the Research Ethics Committee at Aarhus University. Participants were fully informed about the purpose of the study and provided with an explanation of the background and objectives of the research project. They were also given detailed information about the precision fermentation technology and sweet proteins. Informed consent was obtained from all participants before their participation. To ensure participants had the necessary knowledge and context, a section was included providing background information about precision fermentation technology. Previous research has shown that the information about novel technologies, especially in the context of food products, can significantly affect attitudes and subsequent acceptance of these products (Siegrist & Hartmann, 2020). The provided information focused on highlighting the similarities and differences between precision fermentation and traditional fermentation processes used in the food industry for products like beer, yoghurt, and alcoholic beverages. Participants were specifically informed that, in precision fermentation, only the desired ingredient, sweet protein, is produced, setting it apart from traditional fermentation. This information aimed to provide participants with a baseline understanding of precision fermentation technology and the products created using this process.

Subsequently, participants were assigned to one of the two

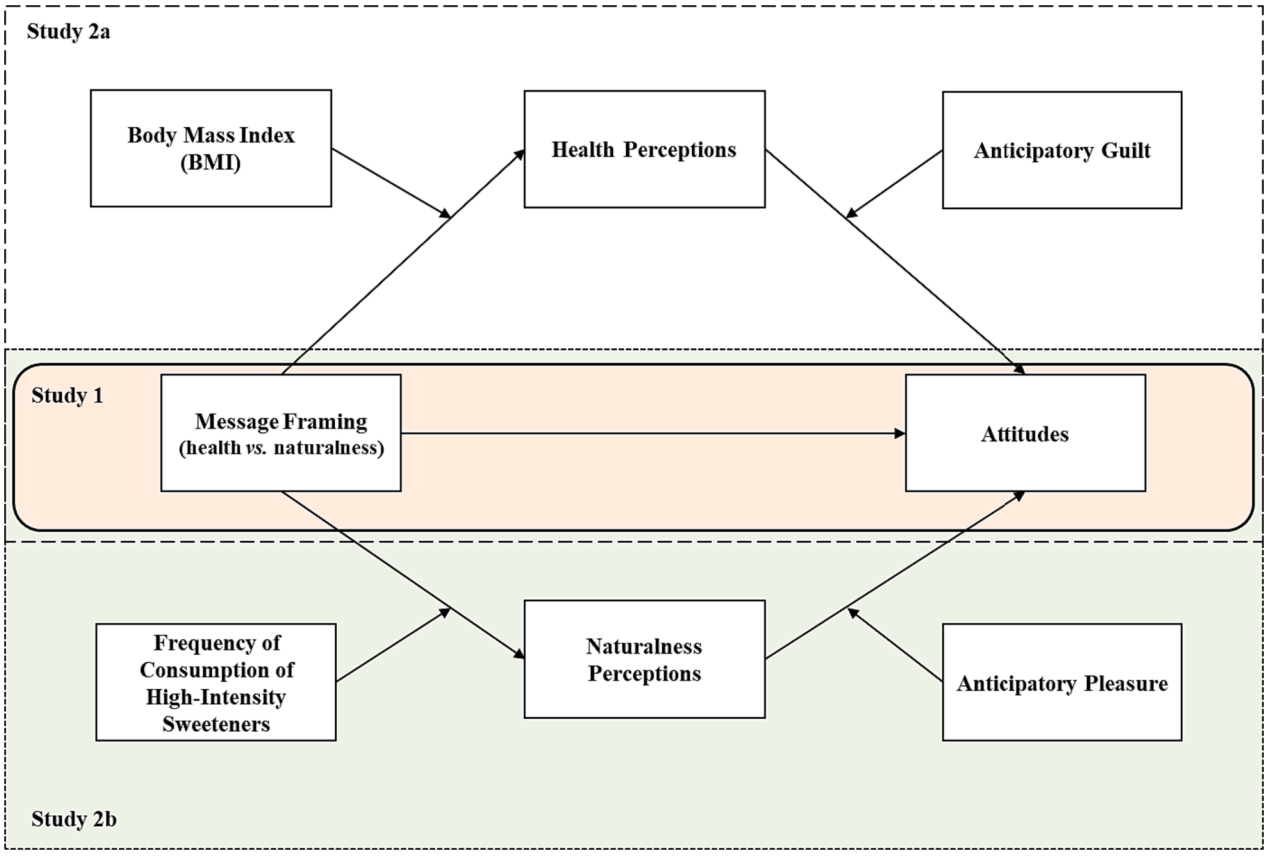

Fig. 1. Conceptual Model.

experimental conditions: the health frame or the naturalness frame. Both frames included the same introduction defining the sweet proteins:

> *"Novel sweet proteins have been produced through precision fermentation inspired by proteins found in fruits along the equatorial belt. Sweet protein is up to 10,000 times sweeter than sugar. One teaspoon of sweet protein is equivalent to about 40 Kg of sugar. Very small amounts of sweet protein are required to sweeten products."*.

After reading the introduction on sweet proteins, participants were presented with the health (*vs.* naturalness) frame, respectively:

> *Health Frame: "Sugar overconsumption is a major risk for obesity, diabetes and more. Food industry uses new alternatives to reduce sugar consumption. Consumers are concerned about the amount of sugar they consume. Sweet proteins are 100% proteins that can enable significant reduction of the amount of sugar consumed."*.
> *Naturalness Frame: "Sugar overconsumption is a major risk for obesity, diabetes and more. Food industry uses artificial sweeteners to reduce sugar consumption. Consumers are concerned about the consequences of eating sweeteners. Sweet proteins are 100% proteins that are a genuine alternative to the existing sweeteners."*.

The two messages presented in the study differed in their description of sweet proteins. One message framed sweet proteins as an alternative to sugar, emphasizing health benefits, while the other message framed sweet protein as an alternative to existing artificial sweeteners, highlighting the naturalness benefits.

In Study 1, attitudes towards reformulated products with sweet protein were assessed. Participants rated their attitudes using a bipolar scale, consisting of three items: 1= "Negative" and 7 = "Positive"; 1= "Unfavourable" and 7 = "Favourable", and 1= "Bad" and 7 = "Good" (Banovic & Otterbring, 2021). The reliability of the scale was assessed using Cronbach's alpha ($\alpha = 0.94$). In Study 2, in addition to attitudes ($\alpha = 0.95$) several other measures (as depicted in Fig. 1) were included and are described below.

Perceptions of healthiness were assessed using 2 items adapted from the weight control factor, Food Choice Questionnaire (FCQ) (Steptoe et al., 1995), which measured participants' perception of sweet protein having low calorie content and slimming properties. Participants rated these items on a 7-point Likert scale (1 = "Strongly disagree" and 7 = "Strongly agree") ($\alpha = 0.86$). Perceived low (*vs.* high) calorie content is the most important factor that individuals associate with healthy food (Foroni et al., 2022), and it is accompanied by a health halo effect (Sundar & Kardes, 2015). Furthermore, research has shown that consumers institutively associate light (slimming) food with healthiness, perceiving food with fewer calories to be healthier (Li et al., 2022). In addition, the weight control factor derived from FCQ has been found to induce higher arousal levels among health-conscious consumers and exert a more pronounced effect on product attitudes compared to the health factor from the FCQ (Banovic & Otterbring, 2021). In the present study, participants' BMI levels serve as the main moderator between experimental conditions and health perceptions (see Fig. 1), underlining that the aforementioned items a suitable choice for assessing health perceptions.

Perceptions of naturalness was measured using 2 items that evaluated participants' perceptions of sweet protein as a "natural" or "artificial" ingredient. Participants rated these items on a 7-point Likert scale (1 = "Strongly disagree" and 7 = "Strongly agree") ($\alpha = 0.80$), to understand if they perceived sweet proteins as a natural (or artificial) ingredient.

BMI levels for each individual were calculated based on the reported height and weight of the participants using a standardized formula (WHO, 2010), and used as a continuous variable in the data analysis. The frequency of consumption of high-intensity sweeteners was assessed on a 9-point categorical scale ranging from 0 – never to 8 – everyday.

Anticipatory guilt was measured using 3 items adapted from the guilt subscale of the Weight- and Body-Related Shame and Guilt (WEB-SG) scale (Conradt et al., 2007). These items assessed the degree of guilt, responsibility, and accountability that participants would feel in specific situation (i.e., "When I have eaten more than I want, I experience feelings of guilt."; "When I eat fattening food (e.g., tarts), I get distressed by the feeling that I did something wrong"; and "I blame myself when I break a good resolution concerning my eating."). Each item were administered using a 7-point Likert scale (1 = "Strongly disagree" and 7 = "Strongly agree") ($\alpha = 0.90$).

Anticipated pleasure with the reformulated product was measured using 4 items (i.e., "excited", "thrilled", "pleasurable", "tempting)" that assessed participants' excitement, thrill, pleasure and temptation associated with consuming the product (Verma et al., 2016). Participants rated these items on a 7-point Likert scale (1 = "Strongly disagree" and 7 = "Strongly agree") ($\alpha = 0.91$).

Lastly, we surveyed sociodemographic characteristics, which apart from the quota measures on age, gender, and region, also included education level, and household composition (i.e., marital status and number of children).

2.2. Pretest of experimental stimuli

A pretest of the two messages, health (sweet protein as an alternative to sugar) versus naturalness (sweet protein as an alternative to artificial sweeteners) was conducted to determine if treatment could be successfully implemented in the subsequent studies. Eighty-two Danish students participated in the framing pre-test ($N_{naturalness} = 40$; $N_{health} = 42$; $M_{age} = 25$, $SD_{age} = 2.99$, range: 22–38; 57% females). They were randomly assigned to one of the two experimental conditions (health *vs.* naturalness framing) and exposed first to a recognition test where they were asked to recognize which words they remember seeing in the message, namely, "alternative to sweeteners"; "alternative to sugar"; "fiber", and "fat". Eight students were further eliminated from the study, as they scored incorrect words. Subsequently, in the second manipulation check students rated naturalness *vs.* health motivational focus of the message on a 7-point scale, ranging from 1 = "Sweet protein as alternative to sweeteners" to 7 = "Sweet protein as alternative to sugar". The results from the second manipulation check in the pre-test showed that message framing was successful and that students scored lower when being exposed to naturalness ($M = 3.08$, $SD = 1.11$) *vs.* health message content ($M = 5.52$ $SD = 1.27$; t (80) = 6.38, $p < 0.001$).

2.3. Participants

Data for Study 1 were collected through an online survey in Denmark with a sample of 296 participants ($N_{naturalness} = 147$; $N_{health} = 149$). There were no significant differences between the two experimental conditions in terms of gender ($\chi^2 = 0.600$, $p = 0.741$) and age ($t = 0.012$, $p = 0.990$). The final sample consisted of 50% male participants with average age of 27 years ($SD = 14.34$).

Data for Study 2 were collected in three European countries, namely Denmark, Germany, and Poland. The three selected countries were considered as appropriate as the individual interest in products with no added sugar in the last five years increased in all three countries, that is, in Denmark by 23%, Germany by 46% and especially in Poland by 164%. On the other hand, the demand for high/added protein products increased in Denmark by 15%, in Germany by 71%, and in Poland by 147% (Mintel, 2022). All the study procedures were approved by the ethical committee of the University where the study was conducted. Eligibility criteria included individuals being between 20 and 70 years of age and being main decision makers or sharing the responsibility for household food purchases. Quotas on age, gender and region were applied to allow for a more representative sample of each country. Participants were recruited through an ESOMAR certified market research agency. Eligible participants, after consenting to participate in the study, completed an online survey. The total sample size was 3000 with 1000 participants per country and approximately 500 participants per experimental condition (age $M = 45.59$ years, $SD = 14.15$; 48.0% of males), Table 1. 160 participants were excluded because they had completed less than 50% of the study or they took more than 15 min to complete the study.

2.4. Data analysis

To estimate the effect of the message framing (healthy *vs.* natural) on attitudes towards products reformulated with sweet protein, considering two mediators (health perceptions and naturalness perceptions) and four moderators (BMI, anticipatory guilt, high-intensity sweetener consumption, and anticipatory pleasure) as depicted in Fig. 1, we used SPSS v28.0 (IBM, 2021) and PROCESS v4.0 (Hayes, 2022b) software. These tools allow for implementation of mediation, moderation, and conditional process analysis. To assess scale reliability, we calculated Cronbach's alpha (α) to test the internal consistency of each of measurement scale used, including health perceptions, naturalness perceptions, anticipatory guilt and pleasure, and attitudes. The average score for each scale was then used in the analysis. Further, in Study 1 we employed analysis of covariance (ANCOVA) to analyse the effects of the independent variable (message framing: healthy *vs.* natural), on the dependent variable (product attitudes) (IBM, 2021). In Study 2, we conducted two separate analyses in PROCESS, using Model 21. This model employs ordinary least squares (OLS) regression-based path analysis (Hayes, 2022a). In the first analysis (Study 2a), a moderated moderated mediation analysis was performed to assess the conditional

Table 1
Sociodemographic characteristics of the participants, Study 2.

	Total N = 3000	Denmark N = 1000	Germany N = 1000	Poland N = 1000
Gender (%)				
- Male	48.0	47.5	48.6	47.9
Age (mean, range 20–70 years old)	45.6	46.6	46.1	44.1
Main household decision maker (%)				
- Individual responsibility	45.7	43.4	55.2	38.5
- Shared responsibility	52.5	54.2	43.1	60.2
- Someone else	1.8	2.4	1.7	1.3
Education (%)				
- Primary school	5.4	8.6	5.2	2.3
- Secondary school	34.7	15.6	50	38.3
- Higher education	20.4	28.9	21.1	11.2
- Bachelor	16.0	24.4	11.4	12.5
- Master/PhD	23.5	22.5	12.3	35.7
Marital status (%)				
- Married/Co-habiting	62.1	62.5	56.9	67.2
- Single	34	33.2	40.6	27.9
- Other (i.e., widowed, divorced)	3.9	4.3	2.5	4.9
Children (%)				
- Have children	60.8	62.8	51.3	68.1
BMI category levels (%)				
<18.5 = Underweight	2.7	2.7	3.1	2.2
- 18.5–24.9 = Normal weight	42.8	38.5	44.8	45.0
- 25.0–29.9 = Pre-obesity	32.8	31.7	31.7	35.0
- 30.0–34.9 = Obesity class I	10.9	13.9	9.4	9.4
- 35.0–39.9 = Obesity class II	3.8	4.3	3.2	4.0
>40 = Obesity class III	7.0	8.9	7.8	4.4
Frequency of consumption of high-intensity sweeteners (%)				
- Never	23.40	25.70	19.80	24.80
- Less than once a month	28.90	38.00	22.50	26.30
- Once a month	12.70	12.50	14.20	11.50
- 2–3 times a month	10.90	7.50	12.60	12.50
– once a week	12.00	9.30	14.10	12.50
– twice a week	5.50	3.70	7.70	5.00
– 3–4 times a week	4.00	1.90	5.80	4.20
– 5–6 times a week	1.60	0.60	2.10	2.10
– Everyday	1.00	0.80	1.20	1.10

indirect effect of the antecedent (message framing: naturalness *vs.* health) on the outcome variable (product attitudes) through health perceptions as the mediator, moderated by BMI as the first moderator, and anticipated guilt as the second moderator. Country was included as a covariate. In the subsequent analysis (Study 2b) PROCESS v.4.0 with Model 21 was used to estimate the effect of message framing (naturalness *vs.* health) as antecedent on product attitudes through naturalness perceptions as the mediator, moderated by frequency of consumption of high-intensity sweetener as the first moderator, and anticipated pleasure as the second moderator. Country was again used as a covariate. All the variables in both analyses were treated as continuous except for the experimental condition, frequency of consumption of high-intensity sweetener, and country, which were treated as categorical variables.

3. Results

3.1. Study 1: Effect of health vs. Naturalness message framing on product attitudes

We first assessed the manipulation check for the message framing. It showed that the framing was effective and those participants exposed to the naturalness message scored lower on a 7-point bipolar scale (1 = "Sweet protein as alternative to sweeteners" to 7 = "Sweet protein as alternative to sugar") ($M = 1.90$, $SD = 0.83$) than those exposed to the health message ($M = 5.34$, $SD = 1.24$; t (294) = 28.09, $p < 0.001$). A second manipulation check was performed also for the message framing to assess how participants perceived the sweet proteins mentioned in the message. They were asked to rate their perception on a 7-point bipolar scale, ranging from 1-healthy ingredient to 7-natural ingredient. The results of the manipulation check showed that participants in the naturalness condition perceived the sweet protein as a natural ingredient ($M = 5.20$, $SD = 1.36$), while those in the health condition perceived it as healthy ($M = 3.17$, $SD = 1.44$; t (294) = 12.48, $p < 0.001$).

An independent samples t-test showed significant differences in attitudes towards products reformulated with sweet proteins between the two experimental conditions ($t(294) = 4.04$, $p < 0.001$), with participants in the healthiness condition exhibiting more favourable attitudes ($M = 5.07$, $SD = 1.52$) than those in the naturalness condition ($M = 4.34$, $SD = 1.62$). Additionally, ANCOVA analysis confirmed these results and also revealed a significant positive effect of the health framing condition on product attitudes ($F(1, 292) = 16.31$, $p < 0.001$), as depicted in Fig. 2 where participants reported significantly more favourable attitudes towards products with sweet protein when exposed to health framing.

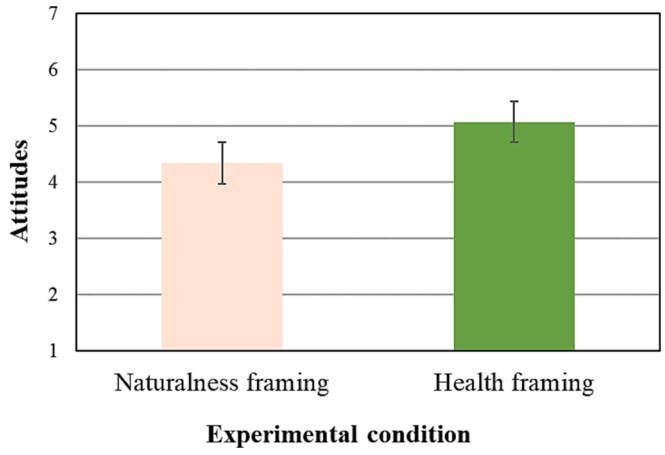

Fig. 2. Effect of experimental condition on attitude towards product reformulated with sweet proteins (N = 300, Denmark). Attitude measured on a 7-point bipolar scale with 3-items (1-negative, 7-positive; 1-bad, 7-good; 1-unfavourable, 7-favourable). The bars display standard errors.

Furthermore, one-sample t-tests showed that, on average, product attitudes were significantly more positive compared to the measurement scale midpoint (of 4) for those participants in the health framed condition ($t(148) = 8.60$, $p < 0.001$). No significant differences in product attitudes were found concerning gender ($t(291) = 0.568$, $p = 0.570$), and there were no correlation between age and product attitudes ($p = 0.083$).

3.2. Study 2: Mediators and moderators of framing effects on product attitudes

In order to analyse the role of mediators and moderators (see Fig. 1), two separate analyses were carried out for the two mediators: health perceptions (Study 2a) and naturalness perceptions (Study 2b), as previously described in the data analysis section. Therefore, two separate moderated moderated mediation analyses were performed (PROCESS v.4.0; Model 21; Hayes, 2022) with message framing as the predictor and attitudes as the outcome variable.

3.2.1. Conditional effect of message framing on attitudes mediated by health perceptions

Before the first analysis on the role of mediators and moderators (Fig. 1), an independent sample t-test of the experimental conditions revealed significant differences in both health perceptions ($t(3000) = 3.93$, $p < 0.001$) and attitudes ($t(3000) = 2.40$, $p = 0.016$). In both cases, participants in the health experimental condition exhibited more favourable health perceptions ($M = 4.53$, $SD = 1.19$) and attitudes ($M = 4.73$, $SD = 1.33$) compared to those in the naturalness condition (for health perceptions: $M = 4.33$, $SD = 1.22$) for attitudes: $M = 4.50$, $SD = 1.17$), respectively. This effect was holding across all three countries (all $ps < 0.05$ for both health perceptions and attitude).

Following above, in the first analysis (Fig. 1, Study 2a) we examined the effect of message framing (health *vs.* naturalness) on attitudes, with participants' health perceptions as the mediator. BMI served as the first moderator, and anticipated guilt served as the second moderator (Table 2). Country was included as a covariate. We found a significant positive effect of the experimental condition on health perceptions ($b = 0.17$, $t = 3.89$, $p < 0.001$). Participants in the health condition reported higher health perceptions ($M = 4.55$, $SE = 0.05$) than participants in the naturalness condition ($M = 4.28$, $SE = 0.05$). Furthermore, we found a marginally significant negative direct effect of BMI on health perceptions ($b = -0.008$, $t = -1.98$, $p = 0.048$), indicating that participants with higher BMI levels generally reported higher health perceptions than those with lower BMI levels. Importantly, we found a significant positive interaction effect between BMI and framing condition ($b = 0.012$, $t = 2.06$, $p = 0.039$).

To examine the moderation effect of BMI, we employed a bootstrapping procedure ($N = 5{,}000$) and 95% confidence intervals (CI) that estimated three distinct points for BMI: low = 19.70, medium = 27.20, and high = 34.70 (Fig. 3). The results showed that the conditional effect of experimental condition on health perceptions was not significant for participants with lower BMI levels (95% CI = [-0.04, 0.20]) or for those with underweight (<18.5) and normal weight (18.5–24.9) BMI levels (Fig. 3). However, it was significant for participants with medium and higher BMI levels (95% CI = [0.14, 0.39]), specifically for those with preobese (25.0 – 29.9) and obese (>30) BMI levels. This indicated that the health (*vs.* natural) message framing increased (*vs.* decreased) health perceptions among individuals with high (but not low) BMI levels. The effect for the natural framing was in fact negative and greater than that of the health framing. Indeed, while the effect of the health framing was positive mainly among individuals with high BMI levels, the effect of natural framing was producing greater negative effect among those individuals with high BMI levels.

Country, included as a covariate, yielded significant effect ($b = 0.10$, $t = 3.78$, $p < 0.001$), as shown in Table 2. Further examination using planned contrast tests revealed that health perceptions were

Table 2
Results from the OLS regression-based path analysis, Study 2.

	Consequent								
	Health perceptions			Naturalness Perceptions			Attitudes		
	Coeff.	*SE*	*p*	*Coeff.*	*SE*	*p*	*Coeff.*	*SE*	*p*
Antecedent									
Study 2a									
Message framing (MF)[a]	0.170	0.044	<0.001	–	–	–	–	–	–
Body Mass Index (BMI)	−0.008	0.004	0.048	–	–	–	–	–	–
MF × BMI	0.012	0.001	0.039	–	–	–	–	–	–
Country	0.102	0.027	0.002	–	–	–	–	–	–
MF[b]	–	–	–	–	–	–	0.110	0.058	<0.001
Health perceptions (HP)	–	–	–	–	–	–	0.854	0.051	<0.001
Anticipatory guilt (AG)	–	–	–	–	–	–	0.554	0.053	<0.001
HP × AG	–	–	–	–	–	–	−0.072	0.011	<0.001
Country	–	–	–	–	–	–	0.231	0.032	<0.001
Study 2b									
MF[c]	–	–	–	0.129	0.092	0.159			
Freq. of consumption of high-intensity sweeteners (FCHIS)	–	–	–	0.143	0.018	<0.001			
MF × FCHIS	–	–	–	−0.049	0.026	0.056			
Country	–	–	–	0.289	0.039	<0.001			
MF[d]	–	–	–	–	–	–	0.123	0.042	0.003
Naturalness perceptions (NP)	–	–	–	–	–	–	0.416	0.033	<0.001
Anticipatory pleasure (AP)	–	–	–	–	–	–	0.812	0.032	<0.001
NP × AP	–	–	–	–	–	–	−0.047	0.007	<0.001
Country	–	–	–	–	–	–	−0.094	0.026	0.003

[a] $R^2 = 0.107$, $F(4, 2995) = 8.60$, $p < 0.001$; [b]$R^2 = 0.496$, $F(5, 2994) = 194.83$, $p < 0.001$.
[c] $R^2 = 0.229$, $F(4, 2995) = 41.25$, $p < 0.001$; [d]$R^2 = 0.532$, $F(5, 2994) = 681.22$, $p < 0.001$.

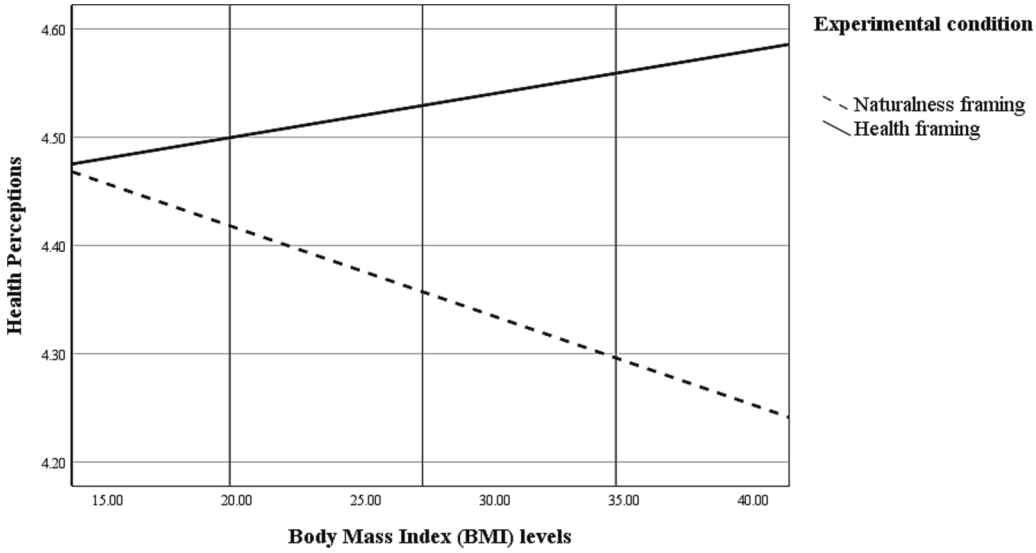

Fig. 3. The conditional effect of experimental condition on health perceptions as moderated by BMI. Data provided by PROCESS v4.0, Model 21, for visualizing the conditional effect of the focal predictor. Health perceptions measured on a 7-point Likert scale. Body Mass Index (BMI) levels measured on a continuous scale and estimated, plotted points are: low = 19.70, medium = 27.20, and high = 34.70. This corresponds to standardized BMI levels: 18.5–24.9 = Normal weight; 25.0–29.9 = Pre-obesity, and 30.0–34.9 = Obesity class I.

significantly higher in Denmark ($p < 0.001$, 95% *CI* [0.10, 0.31]) and Germany ($p < 0.001$, 95% CI [0.10, 0.31]) compared to Poland. However, no significant differences in health perceptions were found between Danish and German participants ($p = 0.969$, 95% *CI* [-0.11, 0.11].

Consistent with the above one-country findings in Study 1, the results in Study 2 revealed a significant effect of the experimental condition on participants' product attitudes ($b = 0.11$, $t = 2.12$, $p = 0.034$). Participants in the health framed condition reported higher product attitudes than participants in the naturalness framed condition, as shown in Table 2. The direct effects of health perceptions on product attitudes ($b = 0.85$, $t = 16.84$, $p < 0.001$) and anticipatory guilt ($b = 0.55$, $t = 10.35$, $p < 0.001$) were also significant. As assumed in our model (Fig. 1), there was a significant interaction between health perceptions and anticipatory guilt, influencing participant's attitudes towards products reformulated with sweet protein ($b = -0.07$, $t = -6.45$, $p < 0.001$). A bootstrapping procedure showed that the conditional effect of health perceptions on attitudes differed from zero for participants scoring both one standard deviation below the mean on anticipatory guilt (95% *CI* = [0.64, 0.76]), and for those scoring one standard deviation above the mean on anticipatory guilt (95% CI = [0.40, 0.51]). This moderated effect further demonstrated that participants with higher health perceptions and increased levels of anticipatory guilt are generally more receptive to the idea of products reformulated with sweet proteins, as depicted in Fig. 4. Lastly, the index of moderated

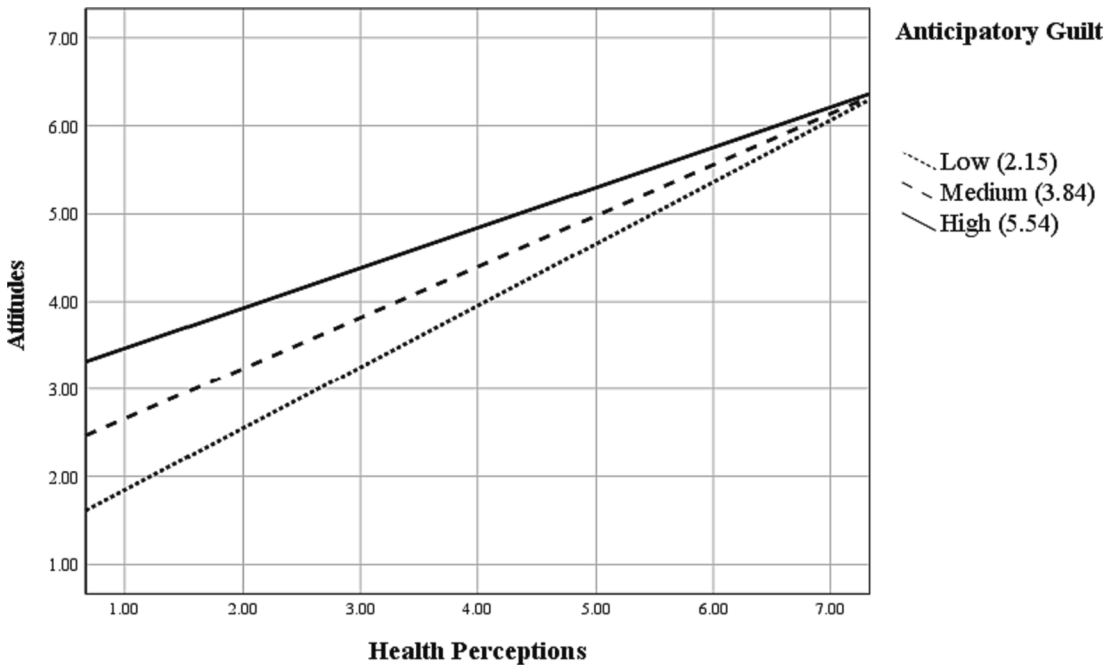

Fig. 4. The conditional effect of health perceptions on attitudes as moderated by anticipatory guilt. Data provided by PROCESS v4.0, Model 21, for visualizing the conditional effect of the focal predictor. Indicated low, medium and high values represent 16th, 50th, and 84th percentiles of the distribution. Health perceptions and anticipatory guilt measured on a 7-point Likert scale.

moderated mediation was significant (Index: −0.01, 95% *CI* = [-0.039, −0.001]).

Country as a covariate remained significant ($p < 0.001$), Table 2. Interestingly, planned contrast test showed that attitudes towards products reformulated with sweet protein were in this instance higher in Poland compared to Denmark ($p < 0.001$, 95% CI [-0.60, −0.34]) and Germany ($p < 0.001$, 95% *CI* [-0.60, −0.34). However, no significant differences in attitudes were found between Danish and German participants ($p = 0.998$, 95% *CI* [-0.13, 0.13].

3.2.2. Conditional effect of message framing on attitudes mediated by naturalness perceptions

In the second analysis (Fig. 1, Study 2b), naturalness perceptions (i.e., sweet protein perceived as natural) served as the mediator, the frequency of consumption of high-intensity sweeteners was the first moderator, anticipated pleasure was the second moderator, and product attitudes were the outcome variable. Country was included as a covariate. Before this analysis an independent sample *t*-test of experimental conditions demonstrated no significance difference for naturalness

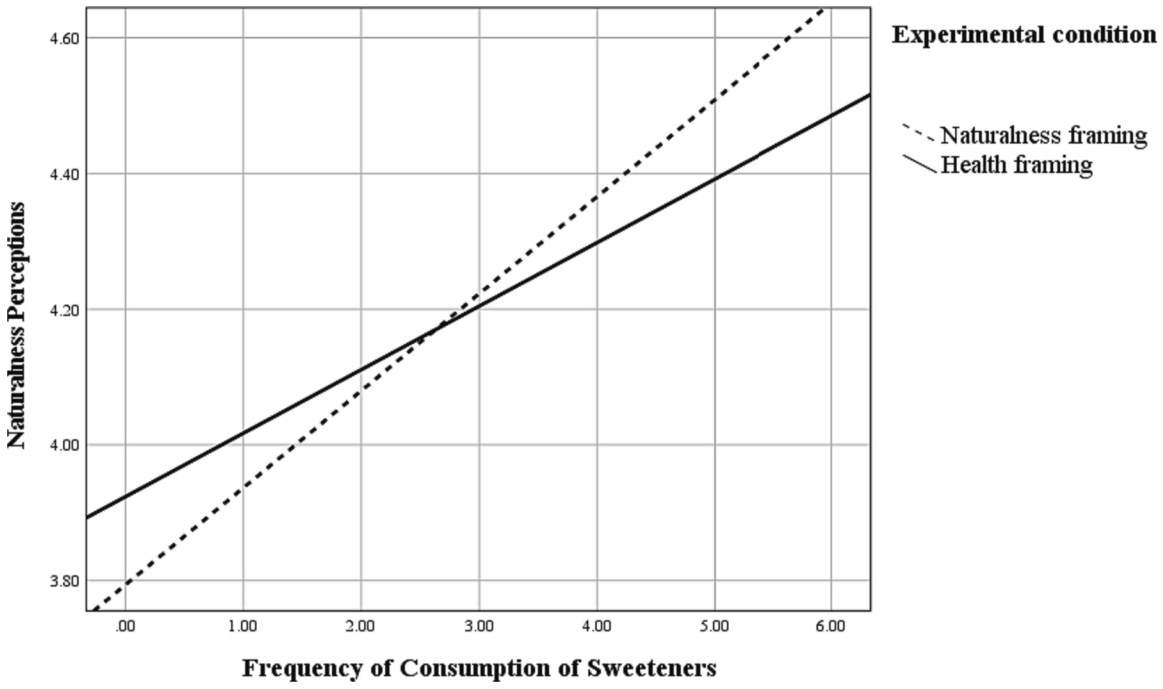

Fig. 5. The conditional effect of experimental condition on naturalness perceptions as moderated by frequency of consumption of sweeteners. Data provided by PROCESS v4.0, Model 21, for visualizing the conditional effect of the focal predictor. Naturalness perceptions measured on a 7-point Likert scale.

perceptions ($t(3000) = 0.795$, $p = 0.427$), with effect holding across the investigated countries (all $ps > 0.05$). Similarly, in the subsequent analysis (in PROCESS, Model 21) we find that the direct effect of experimental condition on naturalness perceptions was not significant ($b = 0.13$, $t = 1.41$, $p = 0.159$), further indicating that naturalness condition did not convey well the naturalness of sweet protein. However, the interaction effect between experimental condition and the frequency of consumption of sweeteners on naturalness perceptions was marginally significant ($b = -0.05$, $t = -1.91$, $p = 0.056$). This finding further suggested that participants with higher frequency of consumption of sweeteners generally reported higher naturalness perceptions in the naturalness condition compared to those in the health condition (Fig. 5).

Country as a covariate was significant ($b = 0.29$, $t = 7.46$, $p < 0.001$), Table 2. Planned contrast test revealed significant differences in naturalness perceptions among three countries. Naturalness perceptions were significantly higher in Poland ($p < 0.001$, 95% *CI* [0.53, 0.84]) and Germany ($p < 0.001$, 95% *CI* [0.24, 0.55]) compared to Denmark. Additionally, significant differences in naturalness perceptions were also found between German and Polish participants ($p < 0.001$, 95% *CI* [-0.44, −0.13], in favour of the latter.

Consistent with the previous findings, there was significant direct effect of experimental condition on attitudes ($b = 0.12$, $t = 2.97$, $p = 0.003$). The direct effect of naturalness perceptions on attitudes was positive and significant ($b = 0.42$, $t = 12.68$, $p < 0.001$), as well as of the anticipatory pleasure ($b = 0.81$, $t = 25.70$, $p < 0.001$).

It is important to notice, from Table 2, that the effect of health perceptions (in Study 2a) on attitudes was two times higher ($b = 0.85$) than the effect of the naturalness perceptions ($b = 0.42$) (Study 2b). Also, the direct effect of anticipatory pleasure on attitudes was positive and greater ($b = 0.81$) (Study 2b) when compared to that of anticipatory guilt ($b = 0.55$) (Study 2a).

As presumed in Fig. 1 (Study 2b), naturalness perceptions and anticipatory pleasure further interacted and affected participant's attitudes towards products with sweet protein ($b = -0.05$, $t = -6.93$, $p < 0.001$). Moreover, a bootstrapping procedure demonstrated that the conditional effect of naturalness perceptions on attitudes was significant for both participants scoring one standard deviation below the mean (95% *CI* = [0.25, 0.32]), as well as for those scoring one standard deviation above the mean (95% *CI* = [0.11, 0.18]) for anticipatory pleasure. The moderated effect of anticipatory pleasure showed that participants with higher naturalness perceptions and higher levels of anticipatory pleasure were generally more receptive to products with sweet proteins, as shown in Fig. 6. However, due to the weak effect of the naturalness condition, the postulated full moderated moderated mediation was not significant (Index: 0.002, 95% CI = [-0.0002, 0.005]).

Finally, similarly to our first analysis, the effect of country was significant ($b = -0.09$, $t = -3.62$, $p < 0.001$). In this instance, a planned contrast test showed that attitudes towards products reformulated with sweet protein were higher in Poland when compared to Denmark ($p < 0.001$, 95% *CI* [0.27, 0.56]) and Germany ($p < 0.001$, 95% *CI* [-0.56, −0.28). No significant differences on attitudes were found between Danish and German participants ($p = 0.928$, 95% *CI* [-0.15, 0.14].

3.2.3. Robustness check

To check the robustness of our findings on product attitudes, we tested whether the effects of the experimental conditions (health *vs.* naturalness) would persist with a different dependent variable, in this case, the intention to buy products reformulated with sweet protein. Participants' intentions to buy were measured using three items on a 7-point bipolar scale (1 – unlikely to 7 – likely; 1 – improbable to 7 – probable; and 1 – definitely no to 7 – definitely yes; $\alpha = 0.96$). There was a significant correlation between the intention to buy and product attitudes ($r = 0.79$, $p < 0.001$). The results closely mirrored those for product attitudes, with the health (*vs.* naturalness) framing eliciting a more positive intention to buy sweet protein-reformulated products ($t(3000) = 3.93$, $p < 0.001$; health framing: $M = 4.77$, $SD = 1.16$; naturalness framing: $M = 4.29$, $SD = 1.15$). We also found a significant main effect of the experimental conditions on the intention to buy (Study 2a: Process, Model 21; $b = 0.27$, $t = 4.90$, $p < 0.001$), with health perceptions mediating and anticipatory guilt moderating this effect (interaction effect: $b = -0.15$, $t = -3.21$, $p = 0.001$). The moderated mediation

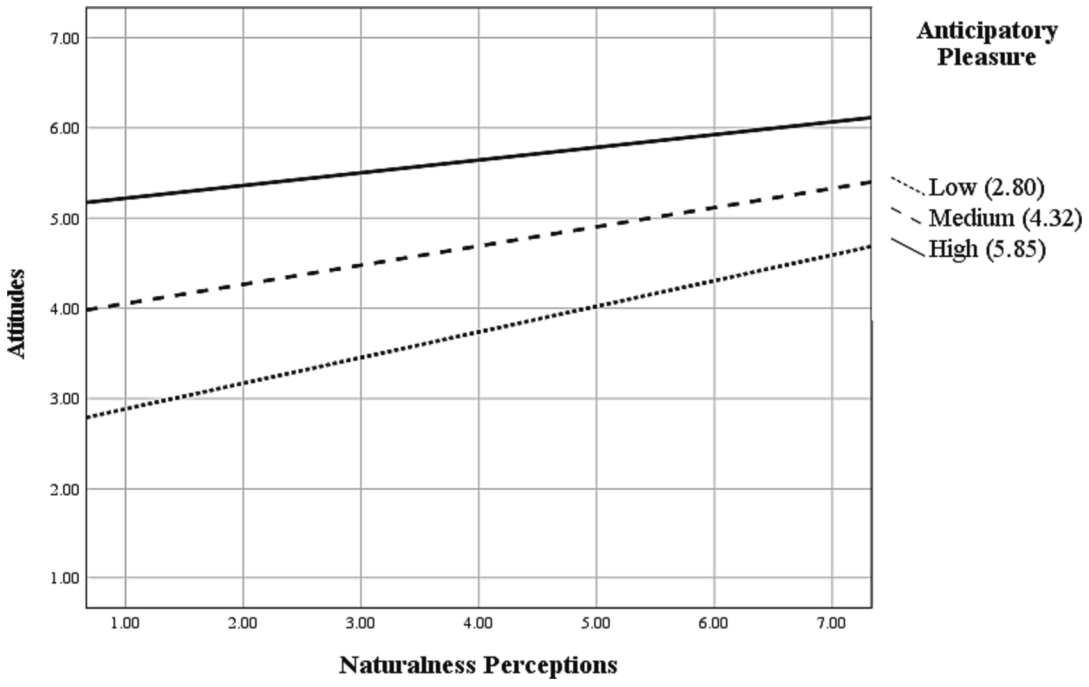

Fig. 6. The conditional effect of naturalness perceptions on attitudes as moderated by anticipatory pleasure. Data provided by PROCESS v4.0, Model 21, for visualizing the conditional effect of the focal predictor. Indicated low, medium and high values represent 16th, 50th, and 84th percentiles of the distribution. Naturalness perceptions and anticipatory pleasure measured on a 7-point Likert scale.

was again significant (Index: −0.01, 95% *CI* = [-0.04, −0.001]).

4. Discussion

Previous research has demonstrated that product reformulations with the aim to improve healthiness may by perceived by consumers as less natural, preventing adoption of these products (Lähteenmäki et al., 2010). In our study, attitudes towards products reformulated with sweet proteins (i.e., high intensity natural sweeteners) were affected by both perceived healthiness and perceived naturalness. However, the effect of perceived healthiness was two times greater than the effect of perceived naturalness, suggesting that consumers' attitudes are significantly more influenced by their perception of the healthiness of these reformulated products compared to their perception of naturalness. This highlights the importance of health-related considerations in shaping consumer attitudes towards such reformulated products (Banovic & Otterbring, 2021). In addition, both effects were moderated. The effect of perceived healthiness on product attitude was stronger the more people anticipated guilt linked to sugar consumption. The effect of perceived naturalness on product attitude was stronger the more people felt anticipated pleasure of consuming these products.

We tested two different framings of the message introducing sweet proteins. One message emphasised how sweet proteins can replace sugar and led to improved perception of healthiness, especially for people with a higher BMI. The second message emphasised how proteins can replace artificial and natural sweeteners, aiming to enhance the perception of naturalness. However, we observed a weak effect in terms of naturalness perception, which was only significant for individuals with a high consumption of natural and artificial sweeteners. This might be attributed to the fact that we did not distinguish between natural and artificial sweeteners in our framing condition, and one could expect that this effect would be stronger if only artificial sweeteners were taken into account. Exploring this aspect in the future research would be valuable. Nonetheless, taken together, the results show that the attitudes towards products reformulated with sweet proteins are primarily influenced by the perception of their healthiness and the guilt associated with consuming sugary products, while the perception of naturalness plays only an auxiliary role.

The present research has several implications. First, the findings highlight the significance of anticipatory guilt and, to a lesser-extent, anticipated pleasure in influencing participants' product attitudes. Marketers can leverage this understanding to develop effective communication strategies when positioning alternative natural sweeteners against sugar-based products. Instead of solely emphasizing the pleasurable aspects of product consumption, marketers of hedonic alternatives like sweet protein reformulated products can benefit from highlighting the guilt associated with traditional sugary products. Such communication could be more persuasive and could help overcome possible scepticism towards sweet proteins or precision fermentation technology (Banovic & Grunert, 2023), while avoiding the perception of manipulative appeals (Goldsmith et al., 2012). Secondly, these implications extend to policymakers involved in planning communication strategies aimed at reducing consumer interest in sugar. Here, policymakers face the challenge of encouraging consumers to shift towards new product alternatives where added sugar has been replaced with natural sweeteners such as sweet proteins. Previous research showed that anticipatory guilt can have a self-regulatory mechanism and discourage consumers from certain behaviours (Ahn et al., 2014). In our study, we demonstrated that associating guilt with the consumption experience of sweet protein could have a productive effect at encouraging healthy behaviours, particularly when it increases the pleasure derived from consumption. Our findings align with previous research showing that ingredient claims influence the accessibility of health and pleasure goals, and thereby also the role of anticipatory pleasure and guilt (Belei et al., 2012). Further research could try to compliment the present measures and test the limits of the above effects when it comes to healthy behaviours. For instance, it would be particularly interesting to explore and isolate this effect through a sensory based study among those consumers that are interested in consuming high-intensity natural sweeteners, as sweet proteins. This would further our understanding of separate factors and provide a more nuanced picture of our underlining results.

Improving the nutritional value of foods by substituting added sugars with alternative sweeteners, such as sweet proteins, which reduce caloric intake and the glycemic index (GI), is found to be correlated with obesity management (Johnson et al., 2022). A large randomized trial involving adults across the full Body Mass Index (BMI) levels spectrum (from underweight to class III obesity) revealed that conventional sugar-sweetened beverages (SSBs) contribute to weight gain, in contrast to artificially sweetened or unsweetened alternatives (Ebbeling et al., 2020). Additionally, population-based modelling studies have shown that a reduction in SSBs consumption could lead to a decrease in obesity prevalence (Duffey & Poti, 2016). This evidence supports the recommendations for reducing added sugar and replacing it with low or zero GI alternatives like sweet proteins, as an important strategy for weight and obesity management.

Nevertheless, it is important to emphasise that if a potent sweetener, as sweet protein, is used to substitute added sugar, other filling material is needed, as sugar also acts as a bulking agent. Here, the choice of these substitute fillers in reformulated products is crucial as they can significantly influence the product's overall health profile (O'Donnell & Kearsley, 2012). When sweet proteins are used to reduce sugar content, they are typically needed in much smaller quantities due to their higher sweetening power. Consequently, other ingredients must be introduced to maintain the product's volume and texture. These bulking agents, which range from dietary fibers to maltodextrin, can vary in their nutritional value and health implications. For instance, while dietary fibers can have beneficial effects on digestion and satiety, other fillers like maltodextrin may not offer the same health benefits and thus could impact blood sugar levels and GI values (O'Donnell & Kearsley, 2012). Therefore, the healthiness of the product is not solely determined by the reduction of sugar but also by the nutritional quality of the bulking agents used.

Our study is based on large representative samples from three European countries, providing a solid base for our conclusions. However, it is important to note that our study deals only with high-intensity natural sweetener, specifically sweet protein, and therefore, our conclusions about the relative role of healthiness and naturalness may not be generalizable to other reformulations with similar health objectives. Additionally, the study is limited by the specific formulations in the two framing conditions. Exploring different types of framing and their effect on the adoption of reformulated products containing high-intensity sweeteners, such as sweet protein, is an important area for future research. Furthermore, it is crucial to acknowledge that while attitudes can facilitate the acceptance of new products, they do not always translate into actual behaviour. It is important to note that our study did not collect any behavioural data, and therefore future research is needed to investigate the link between attitude and actual consumer behaviour.

Despite its limitations, the present study also has several important strengths. First, it tests the relationships between perceptions of healthiness and naturalness, BMI, frequency of consumption of high-intensity sweeteners, anticipatory guilt and pleasure in a cross-cultural context, demonstrating the robustness of the findings. Second, BMI levels are used as a continuous variable in the analysis, allowing for a more comprehensive understanding of the results, and the distribution of BMI levels within sample is well-balanced, with a substantial proportion of the individuals falling within the preobese/obese range (on average 54%, Table 1). This aligns with the EU's overweight and obesity BMI statistics of 53% of the adult (aged 18 and over) EU's population being overweight in 2019 (EUROSTAT, 2023). Therefore, the study findings can be reasonably generalized across different BMI categories. Moreover, this study is among the first to suggest that communication

efforts combining the effects of anticipatory guilt and pleasure may be more persuasive and can be employed as a protective strategy to help curb sugar intake. In connection to the previous, the experimental nature of our study further implies a causal link between framing messages (healthiness *vs*. naturalness) and the dependent variables (attitudes and intention to buy), enhancing our study's internal validity. Additionally, the observed effect's consistency across diverse cultural contexts not only bolsters our results but also suggests that these findings may be generalizable to other settings, indicating a wider cultural relevance.

5. Conclusion

Our results show that attitude to products reformulated with sweet proteins (i.e., high-intensity natural sweeteners) depends on the effect of perceived healthiness, and perceived naturalness of these products. However, when comparing the two factors, the effect of perceived healthiness is more pronounced than the effect of perceived naturalness. The presence of anticipated guilt and pleasure can further amplify the effect of perceived healthiness and naturalness on product attitudes, particularly in the context of products where added sugar has been substituted by sweet proteins.

Compliance with ethical standards

Ethical approval

The present research has obtained ethical approval from the Research Ethics Committee at Aarhus University under the number Journal no.: 2021-0288596, Approval number: 2021-87. Participants were fully informed about the purpose of the study, and provided with an explanation of the background and objectives of the research project. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee as outlined in the Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent

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

CRediT authorship contribution statement

Marija Banovic: Conceptualization, Methodology, Investigation, Funding acquisition, Project administration, Writing – review & editing. **Klaus G. Grunert:** Conceptualization, Methodology, Writing – review & editing.

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.

Data availability

The data that has been used is confidential.

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