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Exploring the lack of liking for faba bean ingredients with different sensory profiles

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ABSTRACT

Faba bean ingredients offer a key role as protein source for wide-ranging food applications, including alternatives to meat and dairy products. However, consumer acceptance is crucial for their integration into people's diets. This study investigated consumer liking and willingness to use faba bean ingredients and identified the sensory properties that drive consumer preference. Our research involved 264 participants, each with diverse taste abilities, personal attitudes, food choice motives, dietary habits, and demographics. Participants evaluated four pastes made with faba bean ingredients and water in a sensory laboratory setting. Ratings for the liking of smell, taste, overall liking and willingness to use were collected. Additionally, participants evaluated various sensory attributes using Rate-All-That-Apply and Check-All-That-Apply methodologies. To explore the relationships between hedonics, sensory attributes, and participant characteristics, we performed L-PLS regression. Our study revealed that the liking of smell, taste, overall liking, and willingness to use were low for all ingredients, despite their distinct sensory properties. While L-PLS regression did not reveal a distinct pattern of liking, penalty-lift analysis indicated that bitterness was the primary driver of dislike. Moreover, our study identified distinct consumer groups with varying preferences for certain ingredient types. However, considering the overall low-liking scores, the practical relevance of consumer insights might be limited. Our study underscores the interplay between sensory attributes, consumer preferences, and attitudes towards faba bean ingredients. It suggests that addressing bitterness issues could be pivotal in enhancing the market prospects of faba bean ingredients and facilitating their broader acceptance as a protein source.

1. Introduction

The faba bean (*Vicia faba* L.) is gaining attention as a sustainable alternative to conventional animal- or soy-based protein sources (Augustin & Cole, 2022). While popular in the Mediterranean and West Asia in various forms (Pasqualone et al., 2020), Northern Europe, including Finland, has not widely embraced faba beans for human consumption, despite their adaptability to the region's climate (Bodner et al., 2018; Pasqualone et al., 2020; Singh et al., 2013). Given this context, food innovation becomes crucial for the widespread adoption of faba beans in regions where traditional consumption is limited (Sharan et al., 2021).

As the global food industry seeks to address the challenge of providing innovative, sustainable, affordable, and tasty food worldwide (Miller et al., 2021), integrating faba beans emerges as a plausible solution. Noteworthy for their nutritional and agroecological advantages (Karkanis et al., 2018; Köpke & Nemecek, 2010; Samaei et al., 2020; Siah et al., 2000), faba beans stands out as a versatile crop (Dhull & Kidwai, 2021). The beans can be processed into flour, protein concentrate, and protein isolate; these are ingredients suitable for diverse food applications, including bread, pasta, egg-free mayonnaise, protein shakes, porridge, and meat and dairy alternatives (Armaforte et al., 2021; Dhull & Kidwai, 2021; Giménez et al., 2012; Hamed et al., 2023; Kumar et al., 2022; Ouraji et al., 2020; Sharan et al., 2021). Such diverse

Abbreviations: BMI, Body Mass Index; CATA, Check-All-That-Apply; DSI, Domain-Specific Innovativeness; EFA, Exploratory Factor Analysis; FCQ, Food Choice Questionnaire; FPCa/FPCb, Faba bean protein concentrate; FPI, Faba bean protein isolate; FF, Faba bean flour; IQR, Interquartile range; L-PLS, Partial Least Squares regression for L-shaped data; NVA, Negative Vegetarian Attitude; RATA, Rate-All-That-Apply; SD, Standard deviation; SUS, Attitude toward sustainability based on the statement "*I think that sustainability is an important factor when making food choices.*"; SVD, Singular Value Decomposition; WTU, Willingness to use.

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range of options supports consumers in adopting healthy and sustainable diets (Multari et al., 2015; Verain et al., 2017) and replacing animal proteins (De Boer & Aiking, 2011). Despite the growing demand for faba bean products, the availability of commercially available materials meeting safety standards is low, especially when compared to other protein sources such as wheat, soy, and pea (Business Intelligence Consulting, 2023).

Understanding consumer attitudes and perceptions towards faba beans as an ingredient is crucial before investing in the development of retail-ready products. Research has primarily focused on characterizing these ingredients structurally and functionally (Chillo et al., 2008; Petitot & Micard, 2010; Sitohy & Osman, 2011), revealing their strong dependence on processing methods when incorporated into foods (Multari et al., 2015). Consequently, there is a notable gap in studies investigating faba bean ingredients in minimally processed forms, highlighting the need to understand their sensory and functional properties in their raw state for effective product development strategies. Moreover, faba bean ingredients exhibit versatility beyond serving as an added protein source; they can also function as standalone components. When faba bean ingredients were extruded solely with water in laboratory setups, they yielded products with a meat-like texture (Kantanen et al., 2022; Saldanha do Carmo et al., 2021). Despite these advancements, it remains a significant challenge for the food industry to effectively incorporate pulses into products or utilize them as protein powders in ways that align with consumer preferences and expectations (Hamed et al., 2023; Multari et al., 2015; Nezlek & Forestell, 2022; Saint-Eve et al., 2021).

Faba beans, among other pulses, are known for their off flavors (Wang et al., 2022). Challenging sensory attributes, including bitterness and astringency, have been described in faba bean ingredients and their resulting meat alternatives, indicating that off-flavors can persist even after high-moisture extrusion processing (Tuccillo, Kantanen, et al., 2022). While steps have been taken to understand the molecular causes of bitterness of faba bean gels at the varietal level (Karolkowski et al., 2022, 2023), several flavor modification strategies have also been explored (Akkad et al., 2021; Badjona et al., 2023; Ritter et al., 2022; Tuccillo et al., 2022b; Wang, et al., 2022). In this context, insights from consumers can guide decisions on whether technological improvements are needed at the crop level, ingredient production level, or solely during product development. Moreover, there has been limited exploration into consumer liking and willingness to use faba bean ingredients in their standalone form, such as pastes with different consistencies when mixed with water. Consequently, we lack understanding of which sensory attributes are associated with liking, and as far as our knowledge extends, no studies have been conducted to address this.

Food acceptance depends not only on product characteristics but also on consumer attributes and personal characteristics (Pohjanheimo & Sandell, 2009). In the context of sustainable eating, dietary choices are influenced by numerous factors, including cultural background, social norms, attitudes, motivations, taste preferences, and educational level (Henn et al., 2022; Jallinoja et al., 2016; Onwezen et al., 2021). Understanding consumer characteristics aids in promoting sustainable dietary choices and reducing environmental impacts (Didinger & Thompson, 2020). Nevertheless, as far as our knowledge extends, no sensory consumer study has investigated how consumer attributes influence the liking of different faba bean ingredients.

The main objective of this study was to investigate the relationship between overall liking and the sensory characteristics of faba bean flour, protein concentrate, and protein isolate when mixed with water, with a focus on identifying the sensory properties driving consumer preference. Additionally, the study aimed to explore the impact of the characteristics of Finnish consumers on overall liking. The hypothesis underlying this investigation was that specific consumer characteristics (e.g., a positive attitude towards vegetarianism) would significantly influence overall liking.

2. Materials and methods

2.1. Faba bean ingredients

This study used four faba bean ingredients: faba bean flour (FF), two faba bean protein concentrates differing for variety and origin (FPCa and FPCb), and faba bean protein isolate (FPI). FF and FPCb (cultivar Kontu) were manufactured by Suomen Viljava Oy© (Helsinki, Finland), while FPCa and FPI (cultivars Snowbird, Tabasco, Malik, FBP-4) were manufactured by AGT Food and Ingredients© (Regina, SK, Canada). The proximate composition, flavor-related compounds, and sensory profiles of these materials were reported in Tuccillo et al. (2022a), Kantanen, et al. (2022). With the risk of challenging flavors causing consumer fatigue, we opted for a limited sample selection accordingly. The chosen faba bean ingredients were selected to be representative of the diversity of varieties and forms available in the market, thereby ensuring relevance to real-world applications and chemical and microbiological safety for consumers. Before sample preparation, the ingredients were stored at −20 °C and then brought to room temperature. The faba bean ingredients were mixed with tap water in 1:3 (w/w) ratio using a metal spoon until all the lumps had dissolved. This resulted in pastes with varying consistencies, thinner in the case of the flour and concentrates, and thicker in the case of the isolate.

2.2. Study participants

Recruitment of participants was advertised on several email lists of the University of Helsinki. Additionally, participants were invited to the study via social media, Telegram and WhatsApp messages, brochures, and face-to-face advertisement on site. Participants were free to join the test at any time during working hours over a time span of eight days. No prerequisites were established as inclusion or exclusion criteria; however, participants were kindly asked not to eat, drink (other than water), or smoke for 30 min before the test. Participation was voluntary and withdrawing was allowed at any time throughout the test. Participants were informed about the aim of the study as stated in the brochure: *"By joining our study, you will help us understand the sensory characteristics of plant-based samples and consumers' attitudes towards them."* They were also informed about the duration of the session, the presence of allergens, and the data treatment policy. All participants signed an informed consent. The study was conducted in accordance with the Declaration of Helsinki and approved by The University of Helsinki Ethical Review Board in Humanities and Social and Behavioral Sciences (Statement 15/2020).

2.3. Study design

The study design is represented in Fig. 1. The research took place in the sensory laboratory conforming to ISO 8589, having controlled ventilation and white light conditions. Participants were evaluating in individual booths, where they found the digital questionnaire and the tray. Trays were prepared on each test day and included a bitter and astringent sample, faba bean samples, spoons, napkins, and corn snacks and water to neutralize participants' palate. After language selection (Finnish or English), subjects entered their participant code, which was affixed on the tray. The research consisted of a series of sensory evaluations alternated by breaks, which were incorporated to mitigate the impact of participant fatigue on the quality of the data. During these breaks, participants were able to cleanse their palates with water and corn snacks. Simultaneously, they were requested to complete several questionnaires encompassing their attitudes, food choice motives, dietary habits, and other pertinent information. Study design and data collection were conducted with RedJade© (RedJade Sensory Solutions LLC, Boulder, CO, USA).

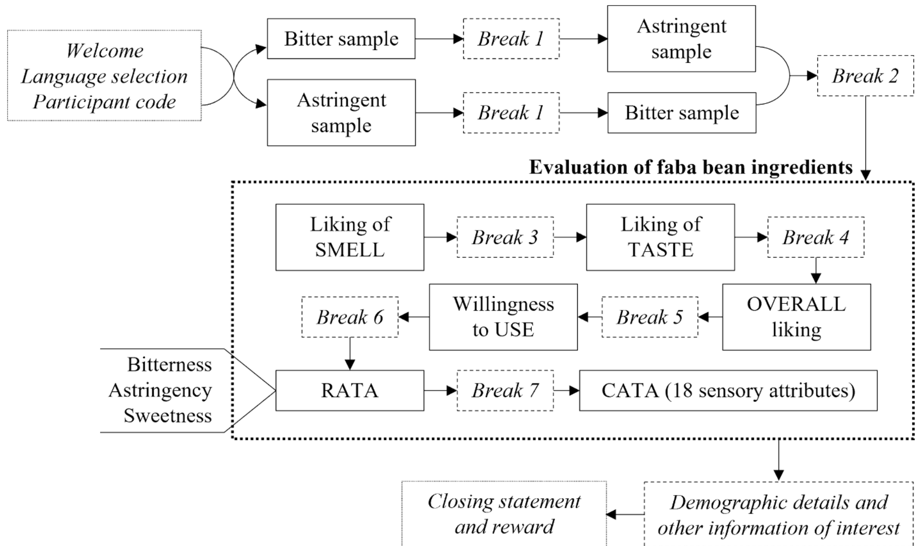

Fig. 1. Schematic representation of the study design. Note: Breaks 1–2 included questions from the Negative Vegetarian Attitude scale (NVA), Domain-Specific Innovativeness scale (DSI), and a question on sustainability (SUS). Breaks 3–6 included questions from the Food Choice Questionnaire (FCQ). Break 7 included questions on dietary habits and previous experience of consumption. Solid lines denote a sensory evaluation, dashed lines indicate breaks and questionnaires, and dotted lines encompass other types of information.

2.3.1. *Sensory evaluations*

First, participants evaluated a bitter and an astringent sample to determine if they tasted them as such, as water, or as something else. Both samples were prepared by dissolving the respective powders in tap water. The bitter sample used anhydrous caffeine powder (Honeywell Fluka™, Seelze, Germany), while the astringent sample used tannic acid powder (Honeywell Fluka™, Seelze, Germany) at concentrations 0.7 g/L and 0.5 g/L, respectively. The solutions were prepared in advance and stored in the refrigerator throughout the study. On each testing day, 5 ml of the solution was poured into coded plastic cups and allowed to reach room temperature before sensory evaluation. These samples were presented with a letter code in a randomized order across participants, following a monadic sequential presentation format. For both samples, participants were asked to describe the taste sensation. The response options included water, salty, sweet, sour, bitter, umami, and astringent. At this stage, if participants did not know the meaning of these terms they were advised to ask for clarification.

Next, participants evaluated the faba bean samples. The samples were placed into coded plastic cups and covered with a plastic lid to preserve their sensory properties. Each cup contained 10–15 g of the sample, which was presented with a 3-digit code in a randomized block design across participants. Samples were prepared every day throughout the study. Participants were not given any prior information about the products except that they were plant-based. Participants evaluated using 9-point hedonic scales with labels (1 = dislike extremely, 9 = like extremely) the liking of the smell, taste, and overall liking. After that, they were asked how willing they would be to use (WTU) the samples as a food or food ingredient on a 5-point hedonic scale (1 = not willing, 5 = very willing). Next, participants carried out a Rate-All-That-Apply (RATA) assessment (Greis et al., 2023). Participants were instructed to take a spoonful of the sample and indicate whether they perceived bitterness, astringency, and sweetness in the sample. If they perceived the attribute, they proceeded with rating its intensity (1 = very low, 2 = moderately strong, 3 = very strong). At this stage, definitions were provided before each attribute evaluation. Finally, participants tasted the samples again and selected all the sensory attributes that they perceived using Check-All-That-Apply (CATA) methodology (Greis et al., 2023). The listed sensory attributes were the following: beany, bitter, brothy, cheesy, cooked bean, earthy, fatty, floury, fruity, grassy, mushroom, musty, nutty, pea pod, potato, raw bean, sweet, and other. Attributes were selected with a small group of subjects having a strong experience in sensory profiling.

2.3.2. *Questionnaires*

Several questionnaires were employed to define participants' personal characteristics. Attitudes towards vegetarianism and veganism, plant-based protein products, and sustainability were investigated using sets of questions as previously reported in both Finnish and English (Greis et al., 2023). The Negative Vegetarian Attitude (NVA) and the Domain-Specific Innovativeness (DSI) scales, consisting of four and six items respectively, were employed. Additionally, participants were asked a question on the importance of sustainability (SUS) when making food choices. Participants evaluated the items on a 7-point categorical scale (1 = strongly disagree, 7 = strongly agree). To assess the attitudes, the sum of the ratings for NVA and DSI was computed separately. For DSI, the scores of three items were reversed. Being only one question, no data processing was needed for SUS. Lower NVA and DSI values indicated a positive attitude towards vegan and vegetarian lifestyles and towards plant-based protein products, respectively. Conversely, a lower SUS score indicated disagreement on the importance of sustainability when making food choices.

Furthermore, food choice motives were investigated using the 36 items of the Food Choice Questionnaire (FCQ) available in Finnish (Pohjanheimo et al., 2010) and in English (Steptoe et al., 1995). Each item belonged to one of the nine subscales composing the FCQ, which assessed the importance of a factor influencing food choice (health, mood, convenience, sensory appeal, natural content, price, weight control, familiarity, ethical concern). Participants evaluated each item on a 7-point categorical scale (1 = not at all important, 7 = extremely important). To assess the importance of each factor, the mean values were computed for the items of each subscale. In addition, information on diet type (omnivore, flexitarian, vegetarian, vegan, other) and frequency of consumption of pulses and meat alternatives was collected.

Finally, we asked questions on gender, age, nationality, education, employment, household, income, weigh, height, smoking habits, self-assessed taste ability, and pre-test consumption behavior. Self-reported weight and height values were used to calculated body mass indexes (BMI). The term "self-assessed taste ability" pertains to participants' personal evaluation as being good at tasting, whereas the concept of "pre-test consumption behavior" pertains to whether participants engaged in activities such as eating, drinking (excluding water), or smoking within the 30-minute window leading up to the test. Some questions and answer options were developed based on previous research (Monteleone et al., 2017; Torri et al., 2020; Tuccillo et al., 2020).

2.4. Statistical analysis

Data analyses were conducted using the following statistical software: SPSS® (Version 29, IBM® SPSS® Inc., Chicago, IL, USA), Microsoft® Excel® (Version 2302, Microsoft® Inc., Redmond, WA, United States), and The Unscrambler® X (Version 10.5, Aspen Technology® Inc, Bedford, MA, USA). The described statistical analyses align with the order of results presented, covering data treatment, reliability assessment, inferential tests, correlations, regression modeling, and validation methods.

2.4.1. Variable treatment

Participant variables were primarily categorical, except for NVA, DSI, SUS, and FCQ subscales treated as continuous. Samples-related variables (likings, WTU, RATA) were also treated as continuous. CATA variables were categorized using binary values. Normality of distribution was assessed with skewness and kurtosis (±1 threshold) and Kolmogorov-Smirnov and Shapiro-Wilk tests ($p < 0.001$). Due to the use of categorical scales as continuous and departure from normal distribution for several variables (Supplementary Table S1), non-parametric tests were employed for conducting inferential statistics.

2.4.2. Scale reliability and factor analysis

Internal consistency of the NVA and DSI scales was assessed by calculating Cronbach's alpha as previously reported (Greis et al., 2023; Huotilainen et al., 2006). For the FCQ, a different approach was adopted (Pohjanheimo et al., 2010; Steptoe et al., 1995). After calculating Cronbach's alphas, item-total correlations, and Cronbach's alphas if each item is deleted from the respective subscale, an Exploratory Factor Analysis (EFA) was conducted using the method of maximum likelihood with varimax rotation. Suitability of conducting EFA was assessed using Kaiser-Meyer-Olkin measure of sampling adequacy and Bartlett's test of sphericity.

2.4.3. Descriptive, inferential statistics, and correlations

On the whole sample, mean values and standard deviations (SD) were calculated for NVA, DSI, SUS, and for items and subscales of the FCQ. Moreover, correlations among NVA, DSI, SUS, and FCQ subscales were investigated using Spearman's correlation. Furthermore, based on their NVA, DSI, and SUS scores, participants were segmented into groups using a previously established approach involving percentile cut-off points (Laureati et al., 2018; Torri et al., 2020). The *low* group exhibited scores within the first quartile, the *medium* group fell between the second and third quartiles, the *high* group represented the fourth quartile. The score ranges for the *low*, *medium*, and *high* groups for NVA, DSI, and SUS were, respectively, as follows: 4, 5–9, 10–28 (NVA); 6–13, 14–23, 24–42 (DSI); 1–5, 6, 7 (SUS).

Results on liking (smell, taste, overall), WTU, and sensory attributes from RATA (bitterness, astringency, sweetness) were presented as median, interquartile range (IQR), mean, and SD. Differences among samples in liking, WTU, and RATA attributes were assessed using separate samples-independent Kruskal-Wallis tests and pairwise comparisons with Bonferroni correction for the totality of subject. To assess the effect of consumer's attitudes on liking and WTU, Kruskal-Wallis tests and pairwise comparisons with Bonferroni correction were conducted also for all consumer segments separately (*low*, *medium*, and *high* of NVA, DSI, and SUS). Results from CATA were presented as frequencies and differences among samples for all sensory attributes were assessed using Cochran's Q test and Dunńs pairwise comparison test with Bonferroni correction. For all tests, significance was set at alpha = 0.05.

2.4.4. Regression models

To investigate the potential patterns in overall liking data (*Y*-variables) that can be explained simultaneously by sensory (*X*-variables) and consumer (*Z*-variables) attributes, a Partial Least Squares regression for L-shaped data (L-PLS) was performed as a 1-step procedure based on external preference mapping (Asioli et al., 2022).

The initial *Model I* combined the following datasets: average intensity scores of RATA attributes and frequencies of CATA attributes for each faba bean sample across all consumers (X, n = 4 × 21), liking scores for each faba bean sample across all consumers (Y, n = 4 × 264), and all consumer-related variables (Z, n = 67 × 264). Categorical consumer-related variables were binary encoded, and all variables were weighted and mean-centered. The Singular Value Decomposition (SVD) algorithm was applied. To address the noise generated by the high number of *Z*-variables, additional L-PLS models with a limited number of *Z*-variables, but fixed *Y*-and *X*-variables, were constructed to explore the relationship between overall liking and (*II*) attitudes and food choice motives, (*III* and *IV*) bitter/astringent perception and tasting ability, (*V* and *VI*) dietary habits and related attitudes, and (*VII*) BMI and socio-demographic factors.

Model II included variables such as NVA, DSI, SUS, and food choice motives (Z, n = 12 × 264). *Model III* incorporated information on whether participants identified the bitter sample as bitter (Bit_Bit), astringent (Bit_Ast), water (Bit_water), or other taste modalities (Bit_other), as well as the identification of the astringent sample as astringent (Ast_Ast), bitter (Ast_Bit), water (Ast_water), or other taste modalities (Ast_other) (Z, n = 8 × 264). *Model IV* included the variables from *Model III*, along with self-assessed taste ability, smoking habits, and the abstinence from eating or drinking within 30 min before the test (Z, n = 17 × 264). *Model V* included variables related to diet type and the frequency of consuming pulses and meat alternatives (Z, n = 11 × 264). *Model VI* included the same variables as *Model V*, with the addition of NVA, DSI, and SUS (Z, n = 14 × 264). *Model VII* incorporated information on BMI, gender, age, income, occupation, household, nationality, and education (Z, n = 27 × 264).

2.4.5. Validation and interpretation of the regression model

To verify the main interpretations derived from L-PLS related to the samples, we employed several approaches. Firstly, we assessed the validity of the interpretation of the *X*-loadings from *Model I* by comparing the sensory characteristics of the faba bean samples. We generated scatter plots for all sample pairs (n = 6) using mean-centered and scaled sensory descriptors. By examining the regression line and the position of the sensory descriptors in the plot, we identified both similarities and differences among the samples.

Secondly, we examined the validity of the interpretation of the *Y*-loadings by analyzing the correlation between the overall liking of all sample pairs using scatter plots.

Thirdly, we sought to confirm which sensory descriptors influenced liking the most. To achieve this, we performed penalty-lift analysis as described by Meyners et al. (2013). This analysis was conducted for each attribute separately. The penalty-lift score was calculated as the average liking score across samples and participants when the attribute is checked (1), minus the average liking score when the attribute is not checked (0). A positive difference indicates that the attribute is a driver of liking, while a negative difference indicates the opposite. The magnitude of the value signifies the attribute's importance.

3. Results

3.1. General description of the participants

This study involved 264 participants from Finland, comprising 34 % males (n = 89) and 64 % females (n = 169). Supplementary Table S2 presents information about gender, age, nationality, education, employment, household, income, self-reported BMI, smoking habits, self-assessed taste ability, pre-test consumption behavior, diet, and frequency of consumption of pulses and meat alternatives. Participants' ages were distributed as follows: 19–25 years (23 %), 24–27 years (26 %), 28–35 years (25 %), and over 36 years (26 %). The highest percentage of participants had advanced education (81 %), had Finnish nationality (74 %), had normal weight (60 %), and considered themselves good at tasting (67 %). Additionally, 96 % of participants declared that they did not eat, smoke, or drink within 30 min before starting the test.

3.2. Reliability of the scales and segmentation of the participants

Reliability of the NVA and DSI scales was confirmed, with Cronbach́s alpha of 0.71 and 0.89, respectively, indicating good internal consistency (>0.70) (Cortina, 1993; Greis et al., 2023). Cronbach's alpha of FCQ subscales, ranged from 0.69 to 0.93, whereas Cronbach's alphas for deleted items ranged from 0.53 to 0.92 (Table 1). The other metrics of reliability related to the FCQ, including item-total correlation coefficients and outcomes of exploratory factor analysis, are reported in Table 1, and explained in the Supplementary Material (Supplementary Text S1).

Regarding participant's attitudes, the mean (±SD) NVA value was 7.55 ± 3.66 (range = 4.00–23.00), reflecting a positive attitude towards vegan and vegetarian lifestyles. The mean (±SD) DSI value was 18.91 ± 8.63 (range = 6.00–42.00), indicating openness to innovative plant-based protein products. The mean SUS value was 5.58 ± 1.60 (range = 1.00–7.00), displaying a moderate endorsement of sustainability in food choices. In terms of food choice motives, attributes such as *"Keeps me healthy," "Is nutritious," "Makes me feel good," "Tastes good,"* and *"Is good value for money"* carried higher importance (mean values > 6.00), while qualities *like "Contains no additives," "Is low in calories," "Is low in fat," "Is familiar,"* and *"Resembles childhood food"* held relatively lower importance (mean values < 4.00) in shaping participants' dietary preferences.

Moreover, participants were clustered into *low*, *medium*, and *high* groups based on their attitudes. For NVA, the *low* (mean value ± SD = 4.00 ± 0), *medium* (6.63 ± 1.44), and *high* (12.46 ± 2.91) groups encompassed 25 % (n = 66), 48 % (n = 127), and 27 % (n = 71) of the sample, respectively. For DSI, the *low* (mean ± SD = 9.72 ± 2.29), *medium* (18.12 ± 2.85), and *high* (29.2 ± 5.09) groups encompassed 33 % (n = 86), 36 % (n = 94), and 32 % (n = 84) of the sample, respectively. For SUS, the *low* (mean ± SD = 3.70 ± 1.48), *medium* (6.00 ± 0), and *high* (7.00 ± 0) groups encompassed 32 % (n = 85), 36 % (n = 95), and 32 % (n = 84) of the sample, respectively.

3.3. Correlations of attitudes and food choice motives

Spearman's correlation was conducted to examine the interrelationships among attitudes and food choice motives (Fig. 2). A negative attitude towards vegetarianism (NVA) was strongly and positively correlated with a positive attitude towards sustainability when making food choices (SUS) (r = 0.70, $p < 0.001$) and a negative attitude towards innovative plant-based products (DSI) (r = 0.45, $p < 0.001$). SUS and DSI where also correlated to each other (r = 0.41, $p < 0.001$). Several food choice domains were found to be correlated to each other, with the highest correlations (r > 0.30, $p < 0.001$) observed between the following pairs: health and natural content (r = 0.40, $p < 0.001$), health and mood (r = 0.37, $p < 0.001$), natural content and weight control (r = 0.34, $p < 0.001$), mood and sensory appeal (r = 0.33, $p < 0.001$), and price and convenience (r = 0.31, $p < 0.001$).

3.4. Liking and willingness to use of faba bean ingredients

Results for the liking and willingness to use (WTU) of faba bean

Table 1
Food Choice Questionnaire (FCQ) items, subscales, mean scores, standard deviations (SD), item-total correlation coefficients, Cronbach's alphas (α) of subscales and items if deleted, and outcomes of Exploratory Factor Analysis (EFA) using maximum likelihood with varimax rotation. Note: Only the highest factor loadings are reported.

Subscale (α) Items	Mean	SD	Item-Total	α if deleted	Factor loading (factor)
Health (0.79)	**5.61**	**0.73**			
Contains a lot of vitamins and minerals	5.50	1.07	0.68	0.73	0.72 (1)
Keeps me healthy	6.11	0.86	0.67	0.74	0.83 (1)
Is nutritious	6.20	0.70	0.58	0.76	0.69 (1)
Is high in protein	5.35	1.13	0.46	0.78	0.50 (1)
Is good for my skin/teeth/hair/nails etc.	4.98	1.32	0.48	0.79	0.44 (1)
Is high in fiber and roughage	5.51	1.06	0.52	0.76	0.47 (1)
Mood (0.80)	**5.33**	**0.86**			
Helps me cope with stress	4.73	1.46	0.61	0.75	0.74 (3)
Helps me to cope with life	5.48	1.34	0.61	0.75	0.75 (3)
Helps me relax	5.12	1.29	0.56	0.76	0.63 (3)
Keeps me awake/alert	5.16	1.26	0.47	0.78	0.39 (3)
Cheers me up	5.36	1.10	0.61	0.75	0.51 (3)
Makes me feel good	6.14	0.78	0.49	0.78	0.43 (1); 0.41 (3)
Convenience (0.83)	**5.36**	**1.01**			
Is easy to prepare	5.56	1.15	0.72	0.77	0.83 (4)
Can be cooked extremely simply	5.14	1.35	0.73	0.76	0.92 (4)
Takes no time to prepare	4.62	1.53	0.61	0.80	0.74 (4)
Can be bought in shops close to where I live or work	5.61	1.36	0.54	0.81	0.75 (10)
Is easily available in shops and supermarkets	5.85	1.18	0.53	0.81	0.96 (10)
Sensory appeal (0.69)	**5.69**	**0.74**			
Smells nice	5.81	1.00	0.49	0.61	0.51 (8)
Looks nice	4.84	1.31	0.60	0.54	0.73 (8)
Has a pleasant texture	5.74	1.03	0.53	0.58	0.65 (8)
Tastes good	6.35	0.66	0.33	0.70	0.38 (8)
Natural content (0.93)	**4.17**	**1.58**			
Contains no additives	3.77	1.75	0.85	0.91	0.84 (2)
Contains natural ingredients	4.62	1.58	0.83	0.92	0.81 (2)
Contains no artificial ingredients	4.12	1.72	0.90	0.87	0.91 (2)
Price (0.82)	**5.48**	**1.01**			
Is not expensive	5.40	1.21	0.76	0.65	0.85 (7)
Is cheap	5.01	1.35	0.77	0.64	0.87 (7)
Is good value for money	6.03	0.95	0.53	0.88	0.56 (7)
Weight control (0.85)	**3.87**	**1.39**			
Is low in calories	3.50	1.56	0.77	0.74	0.87 (5)
Helps me control my weight	4.22	1.60	0.68	0.82	0.73 (5)
Is low in fat	3.88	1.60	0.70	0.81	0.73 (5)
Familiarity (0.82)	**3.57**	**1.24**			
Is what I usually eat	4.14	1.47	0.65	0.77	0.73 (6)
Is familiar	3.82	1.46	0.77	0.64	0.91 (6)
Is like the food I ate when I was a child	2.75	1.41	0.59	0.82	0.67 (6)
Ethical concern (0.76)	**4.87**	**1.23**			
Comes from countries I approve of politically	4.31	1.68	0.60	0.66	0.67 (9)
Has the country of origin clearly marked	5.14	1.57	0.70	0.53	0.89 (9)
Is packaged in an environmentally friendly way	5.17	1.21	0.49	0.78	0.52 (9)

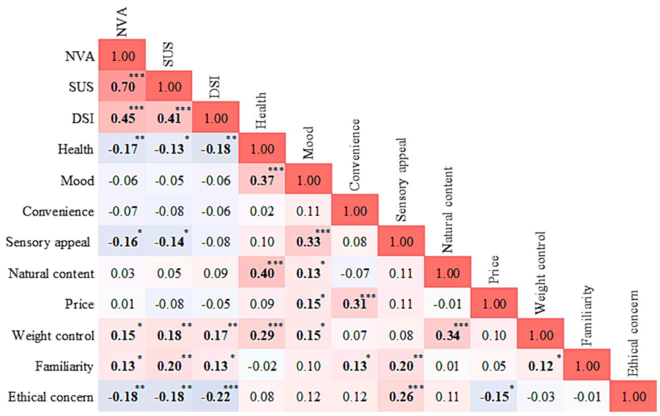

Fig. 2. Correlation heatmap of attitudes, including Negative Vegetarian Attitude (NVA), Sustainability (SUS), and Domain-Specific Innovativeness (DSI), along with the food choice motives domains derived from the Food Choice Questionnaire. Note: Positive Spearman's Rho values are depicted in red, indicating a positive relationship, while negative values are shown in blue, indicating a negative relationship. Statistical significance levels are denoted as follows: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ingredients are presented in Table 2. The median liking scores for smell ranged from 4 to 5, indicating slight dislike to neither liking nor disliking. In contrast, liking scores for taste and overall liking ranged from 2.5 to 4, showing moderate to slight dislike. This suggested a relatively neutral response to the smell, white taste and overall liking were less preferred. Median WTU scores ranged from 1 to 2, indicating very low to no willingness among participants to use the samples as food or food ingredients. Significant differences were observed among the samples. FPI received the lowest liking scores for smell, whereas FPCa and FPCb received the highest scores. On the other hand, FPCa and FPCb received lower scores for taste, overall liking, and WTU compared to FF and FPI.

Results within the three NVA groups were consistent with the totality of the subjects (Supplementary Fig. S1). However, within the *high* group, no differences among the samples were observed in liking of smell, nor between FPCb and FPI for liking of taste, overall liking, and WTU. Within the DSI groups (Supplementary Fig. S2), there were no differences in the liking of smell in the *low* group for all the samples, and between FPCa and FPI for the *medium* and *high* groups. For the *medium* group, liking of taste and overall liking was the highest for FF. Similarly, the *low* SUS group showed no difference in liking of smell among the samples (Supplementary Fig. S3). Moreover, the *medium* group found no differences between FPCa, FPCb, and FPI in terms of liking of smell, whereas the *low* group found no differences between FPCb and FPI for overall liking and WTU.

3.5. Sensory properties of faba bean ingredients

Table 2 also displays the perceived intensity of bitterness, astringency, and sweetness measured using RATA. The median scores ranged for bitterness from 1 to 2 and for sweetness from 0 to 1. Median scores for astringency were 1 across all samples. Statistically significant differences were observed for the three attributes. FPCa and FPCb were more bitter and astringent than FF, whereas FPI was the least bitter and as astringent as FF. FF was the sweetest among the ingredients.

The other sensory descriptors evaluated through the CATA approach are presented in Fig. 3. Among these descriptors, the most prominent attributes (with frequencies, n > 300) included raw bean, bitter, beany, pea pod, floury, musty, and earthy. Attributes such as beany, earthy, brothy, and cheesy did not exhibit statistically significant differences across the various samples. Notably, there were no significant distinctions between FPCa and FPCb for any of the sensory attributes. Conversely, both FPCa and FPCb differed significantly from FF and FPI, particularly in terms of being perceived as the most bitter. Additionally, FPCa and FPCb stood out in comparison to FPI but not FF for being associated with the raw bean and grassy flavors, but not with the floury, nutty, cooked bean, and potato flavors. FPI was the mustiest sample, followed by FPCa/FPCb, and by FF. FF was identified as the sweetest among all the samples.

3.6. Overview of the factors affecting overall liking (Model I)

To explore the relationships between overall liking (Y) and sensory properties (X) of faba bean ingredients, as well as consumer characteristics (Z), a series of L-PLS models were employed. Table 3 presents the variance explained in *Models I-VII*, each constructed with different sets of *Z*-variables while maintaining the same *X*- and *Y*-variables. Overall, a significant portion of the variance was explained by Factor 1, which was primarily influenced by sensory and consumer attributes. This suggests that differences among the samples were primarily attributed to variations in sensory perception, followed by consumer differences. In contrast, the variance explained by overall liking was relatively low, indicating that distinct preferences in terms of liking were not observed among the samples. Therefore, the model inadequately captures the weak relationship between the independent variables (X and Z) and the dependent variable (Y). In such cases, the predictive power of the L-PLS model for Y may be limited. Notably, the variance explained by the *Z*-variables varied across the different models, and a detailed discussion of these variations is provided in this section for *Model I* and in sections 3.7 to 3.10 for *Models II-VII*.

In *Model I*, where all the *Z*-variables of this study were considered together, the variance explained by Factor 1 was 89 % for X, 1 % for Y, and 71 % for Z. For Factor 2, the variance explained was 10 % for X, 2 % for Y, and 4 % for Z. Fig. 4 illustrates the scores and *X*-, *Y*-, *Z*-loadings plots of *Model I*, which can be observed simultaneously in the correlation plot in Supplementary Material Fig. S4. The insights gained from the

Table 2
Liking, willingness to use, and sensory proprieties measured with RATA of faba bean flour (FF), faba bean protein concentrates (FPCa/FPCb), and faba bean protein isolate (FPI).

Variable	Range	FF		FPCa		FPCb		FPI			
		Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	H (df)	*p*-value
Liking of smell	1–9	5 (2)[b]	5.1 (1.4)	5 (2)[a]	4.7 (1.6)	5 (2)[ab]	4.9 (1.4)	4 (2)[c]	4.3 (1.5)	38.6 (3)	***
Liking of taste	1–9	4 (2)[a]	4 (1.6)	2.5 (2)[b]	2.8 (1.5)	3 (1)[b]	2.8 (1.5)	4 (2)[a]	3.7 (1.6)	127.2 (3)	***
Overall liking	1–9	4 (2)[a]	4.1 (1.7)	3 (2)[b]	2.9 (1.5)	3 (2)[b]	3 (1.5)	4 (3)[a]	3.7 (1.7)	89.0 (3)	***
Willingness to use	1–5	1 (1)[a]	1.8 (1)	1 (0)[b]	1.3 (0.6)	1 (1)[b]	1.4 (0.7)	2 (1)[a]	1.8 (1)	87.2 (3)	***
Bitterness	0–3	1 (1)[b]	1.2 (0.9)	2 (2)[a]	1.8 (1)	2 (2)[a]	1.9 (0.9)	1 (1)[c]	0.7 (0.8)	226.9 (3)	***
Astringency	0–3	1 (1)[b]	0.9 (0.8)	1 (1)[a]	1.3 (1)	1 (1)[a]	1.4 (1)	1 (2)[b]	0.9 (0.9)	59.5 (3)	***
Sweetness	0–3	1 (1)[a]	0.8 (0.7)	0 (1)[b]	0.5 (0.6)	0 (1)[b]	0.5 (0.6)	0 (1)[b]	0.4 (0.6)	38.4 (3)	***

IQR, interquartile range; SD, standard deviation; H, Kruskal-Wallis' test statistic; df, degrees of freedom; ***, *p*-value < 0.001
Different superscript letters indicate a significant difference among samples.

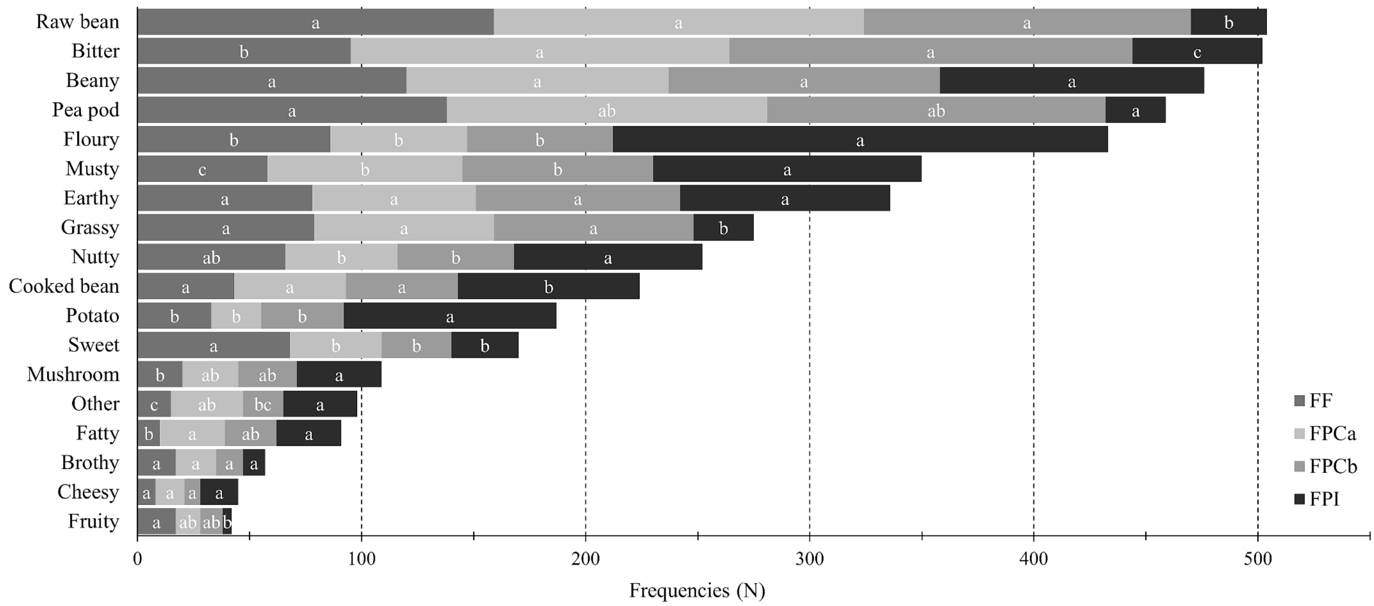

Fig. 3. Frequencies (N) of sensed flavors in faba bean flour (FF), faba bean protein concentrate (FPCa/FPCb), and faba bean protein isolate (FPI) using Check-All-That-Apply (CATA). Note: Different letters indicate statistical difference ($p < 0.05$) according to samples-independent Kruskal-Wallis tests and pairwise comparisons with Bonferroni correction.

Table 3
X-, *Y*-, and *Z*-variance (%) explained by Factor 1 and Factor 2 in *Models I-VII* built with Partial Least Squares regression for L-shaped data (L-PLS). Note: NVA, Negative Vegetarian Attitude; DSI, Domain-Specific Innovativeness; SUS, Attitude toward sustainability; BMI, Body Mass Index.

L-PLS model	*Z*-variables	X-variance (%)		Y-variance (%)		*Z*-variance (%)	
		Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
I	All	89.3	9.6	1.2	2.3	70.7	3.9
II	Attitudes and food choice motives	89.3	9.6	1.2	1.8	76.4	4.6
III	Bitter/Astringent perception	88.3	10.5	0.8	1.3	23.5	20.8
IV	Same as III, but also taste ability, smoking habits, and abstinence from eating or drinking	89.6	9.2	1.5	1.4	19.3	15.9
V	dietary habits	89.2	9.6	0.4	0.6	32.1	14.3
VI	Same as V, but also NVA, DSI, SUS	89.2	9.5	1.1	1.0	84.4	10.7
VII	BMI, gender, age, income, occupation, household, nationality, and education	89.7	9.1	1.9	1.5	8.8	10.8

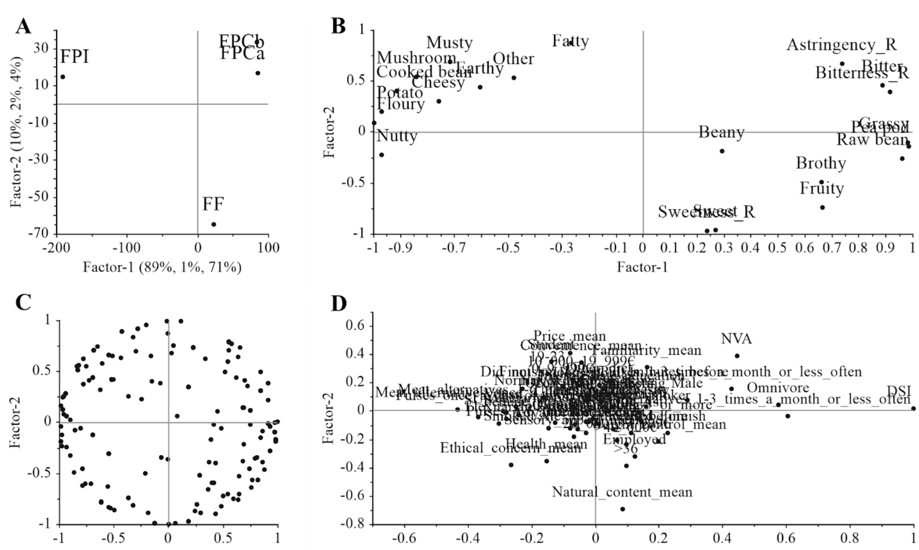

Fig. 4. Scores (A) and loadings plots of *X*-variables (B), *Y*-Variables (C), and *Z*-Variables (D) from Partial Least Squares regression for L-shaped data (L-PLS) of *Model I*. Note: FF, Faba bean flour; FPCa/FPCb, Faba bean protein concentrate; FPI, Faba bean protein isolate,_R, attribute measured using RATA; NVA, Negative Vegetarian Attitude; DSI, Domain-Specific Innovativeness.

scores and *X*- and *Y*-loadings plots can be extended to Models II-VII, as they were built on the same *X*- and *Y*-dataset.

Distinct patterns emerged when examining the samples. FPI was located on the negative side along Factor 1, while FF, FPCa, and FPCb were located on the positive side. Notably, FF stood apart from the other samples by being positioned on the negative side along Factor 2. Furthermore, FPCa and FPCb exhibited proximity, primarily explained by the loadings of the sensory attributes. Specifically, FPI was characterized by consumers as having nutty, floury, potato, cooked bean, mushroom, musty, cheesy, earthy, and fatty flavors. Consumers also identified other undefined flavors not included in the CATA questionnaire. On the other hand, FPCa and FPCb were described as bitter and astringent, with grassy, raw bean, and pea pod flavors. FF, in contrast, was perceived as sweet and fruity. Despite clear sensory property differences, overall liking scores remained consistently low for all samples, without discernible patterns. However, consumer attributes played a role in defining the differences among the samples. Individuals who consumed pulses and meat alternatives more frequently exhibited a higher liking for FPI and a lower liking for FPCa and FPCb. Conversely, individuals who consumed fewer meat alternatives and pulses, primarily followed an omnivorous diet, and held negative attitudes towards food innovation and vegetarianism seemed to prefer FPCa/FPCb over FPI. However, this finding can also be interpreted as the difference in liking between these two sample types being more pronounced among frequent consumers of pulses and meat alternatives, while less familiar consumers showed less differentiation between the two sample types. As *Model I* included all consumer-related variables of this study, it seemed that dietary habits and related attitudes were the most influential ones.

3.7. Effect of attitudes and food choice motives (Model II)

With *Model II*, a closer investigation on attitudes and food choice motives was conducted. The variance explained for these *Z*-variables was 76 % and 5 % by Factor 1 and Factor 2, respectively. According to the *Z*-loadings plot (Fig. 5), attitudes were described by Factor 1, whereas food choice motives were described by Factor 2. SUS was located on the negative side along Factor 1, whereas DSI and NVA were located on the positive side. This indicated a positive correlation between NVA and DSI, but a negative correlation with SUS when considering all these variables simultaneously. Ethical concern was closest to SUS along Factor 1, suggesting that individuals who consider sustainability an important factor in their food choices are primarily driven by ethical concerns (e.g., political approve and labeling of country's food origin, environmentally friendly packaging). Familiarity was located close to NVA, indicating that people exhibiting negative attitudes toward veganism and vegetarianism find familiarity of food an important factor when making food choices. In relation to the faba bean ingredients, it appears that positive attitudes towards food innovation, vegetarianism, veganism, and sustainability when making food choices were linked to higher overall liking of FPI.

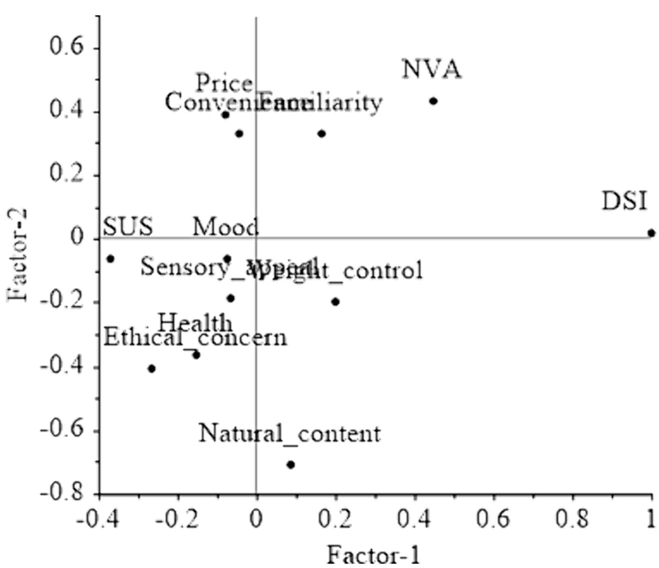

Fig. 5. Loadings plot of *Z*-Variables from Partial Least Squares regression for L-shaped data (L-PLS) of *Model II*. Note: NVA, Negative Vegetarian Attitude; DSI, Domain-Specific Innovativeness; SUS, Attitude toward sustainability.

3.8. Effect of bitter/astringent perception and tasting ability (Models III and IV)

With *Models III and IV*, we closely examined participants' ability to identify bitterness and astringency, as well as other variables related to tasting ability (Fig. 6). The variance explained in Model III was 24 % and 21 % by Factor 1 and Factor 2, respectively, while in Model IV it was 19 % and 16 % by Factor 1 and Factor 2, respectively. In both models, participants who correctly identified the bitter samples as bitter (Bit_Bit) and the astringent sample as astringent (Ast_Ast) were located on the negative side along Factor 1. These two types of participants were situated on opposite sides of Factor 2 in *Model III*, but on the negative side in *Model IV*. Conversely, individuals who perceived these samples as water (Bit_water, Ast_water) were located on the positive side along both Factors in both models. Participants who identified the samples as sensations other than their correct attributes (Bit_Ast, Bit_other, Ast_Bit, Ast_other) were positioned on the positive side of Factor 1 or closer to the origin in both models.

Regarding the faba bean samples, these findings suggest that individuals who correctly identified the bitter and astringent samples expressed lower liking for FPCa and FPCb, which were described as the most bitter and astringent. On the other hand, individuals who could not identify bitterness and astringency in the reference samples found FPCa and FPCb more likable. Participants with high self-assessed tasting ability were positioned on the negative side along Factor 1, while those with low self-assessed tasting ability were positioned on the positive side. Similarly, participants who had never tried smoking were positioned on the negative side along Factor 1, whereas those with smoking experience (ranging from trying it once to regular smoking) were located on the positive side. These results suggest a positive relationship between self-assessed good tasting ability and no smoking experience with higher levels of dislike for FPCa and FPCb and higher liking for FPI.

3.9. Effect of dietary habits and attitudes related (Models V and VI)

With *Models V* and *VI*, we closely examined participants' diet types, frequency of consumption of pulses and meat alternatives, as well as their NVA, DSI, and SUS scores (Fig. 7). In *Model V*, Factor 1 accounted for 32 % of the variance, while Factor 2 accounted for 14 %. In *Model VI*, Factor 1 explained 84 % of the variance, and Factor 2 explained 11 %. In both models, frequent consumption was positively associated with a flexitarian, vegan, and vegetarian diet, positioned on the negative side of Factor 1. Conversely, low frequency of consumption was positively associated with an omnivore diet, positioned on the positive side of Factor 1. These variables were positively correlated with NVA and DSI, but negatively correlated with SUS. Thus, we observed a cluster of consumers who frequently consume meat alternatives and pulses, primarily follow a flexitarian, vegetarian, or vegan diet, and hold positive attitudes towards vegetarianism and food innovation. They also consider sustainability an important factor in their food choices. These participants tended to express higher liking for FPI and lower for FPCa and FPCb.

3.10. Effect of BMI and sociodemographic variables (Model VII)

With *Model VII*, we explored the influence of BMI and various

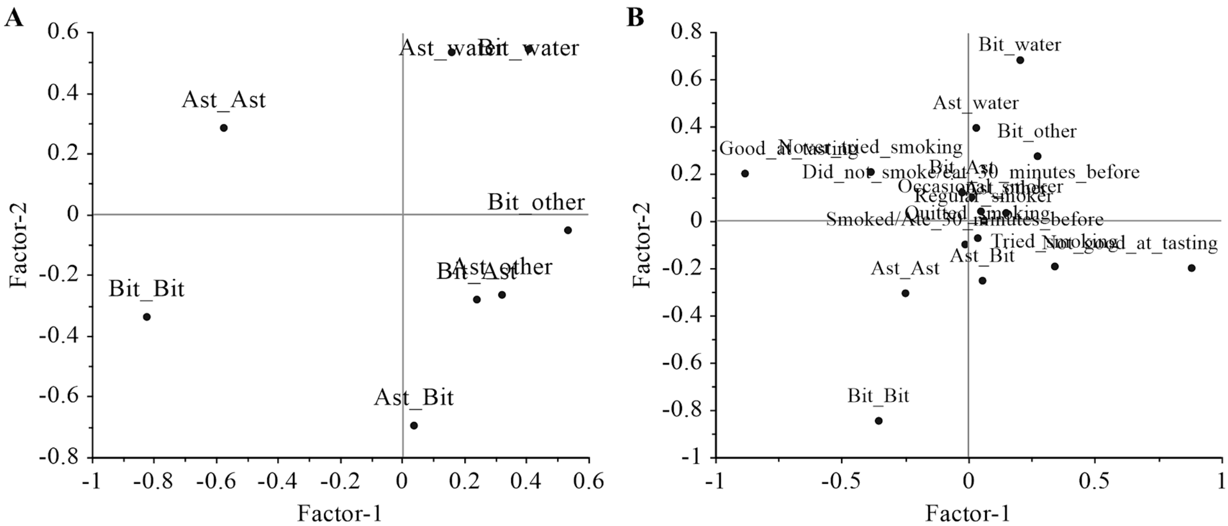

Fig. 6. Loadings plot of *Z*-Variables from Partial Least Squares regression for L-shaped data (L-PLS) of *Model III* (A) and *Model IV* (B). Note: Bit_Bit, Participants' identification of the bitter sample as bitter; Bit_Ast, Participants' identification of the bitter sample as astringent; Bit_water, Participants' identification of the bitter sample as water; Bit_other, Participants' identification of the bitter sample as other taste modalities; Ast_Ast, Participants' identification of the astringent sample as astringent; Ast_Bit, Participants' identification of the astringent sample as bitter; Ast_water, Participants' identification of the astringent sample as water; Ast_other, Participants' identification of the astringent sample as other taste modalities.

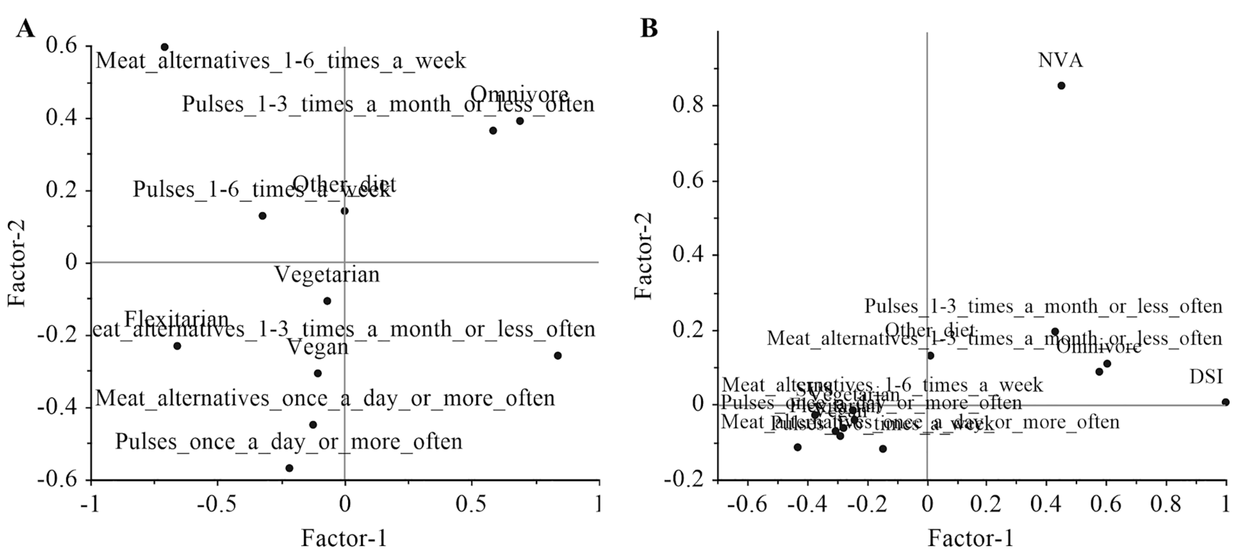

Fig. 7. Loadings plot of *Z*-Variables from Partial Least Squares regression for L-shaped data (L-PLS) of *Model V* (A) and *Model VI* (B). Note: NVA, Negative Vegetarian Attitude; DSI, Domain-Specific Innovativeness; SUS, Attitude toward sustainability.

sociodemographic factors (Fig. 8). Factor 1 accounted for 9 % of the variance and Factor 2 for 11 %. Factor 1 primarily captured gender, nationality, education level, and BMI. Non-Finnish females with normal weight and advanced education leaned towards the negative side, whereas Finnish overweight males with intermediate education leaned towards the positive side. Factor 2 reflected occupation, income, and age. Older, employed individuals with higher income were positioned on the negative side, while young students with lower income were on the positive side. These findings indicate that non-Finnish females favored FPI more and had lower preferences for FPCa and FPCb. Additionally, participants aged over 36, employed, and with incomes between 20,000–39,000€ exhibited the strongest preference for FF.

3.11. Verification of the sample-related interpretations

To ensure the reliability of the interpretations of the *X*-variables from the L-PLS regression, we examined sensory descriptor scatter plots for each sample pair (Supplementary Fig. S5). These plots aligned with the findings described in Section 3.6, showing similar patterns. Correlation coefficients indicated stronger differences between FPI and FF (−0.60), FPCa (−0.53), and FPCb (−0.53), compared to FF and FPCa (−0.11) and FPCb (−0.09), as well as FPCa and FPCb (0.10). These scatter plots mirrored our understanding that FPI differed from the others, which were sweet and fruity (FF) or bitter and astringent (FPCa and FPCb).

For *Y*-variable interpretation, we generated scatter plots of the overall liking for each sample pair (Supplementary Fig. S6), which revealed positive correlations in the liking data across all sample pairs, with correlation coefficients ranging from 0.16 to 0.50. These findings support our earlier conclusion that, despite variations in sensory profiles, there is no discernible liking pattern.

To address the missing information on liking drivers in the L-PLS models, we conducted penalty-lift analysis, considering all samples but one attribute at a time. The results (Fig. 9) highlighted key liking drivers (coefficient > 0.5), such as musty, sweet, cheesy, and fruity, while bitter

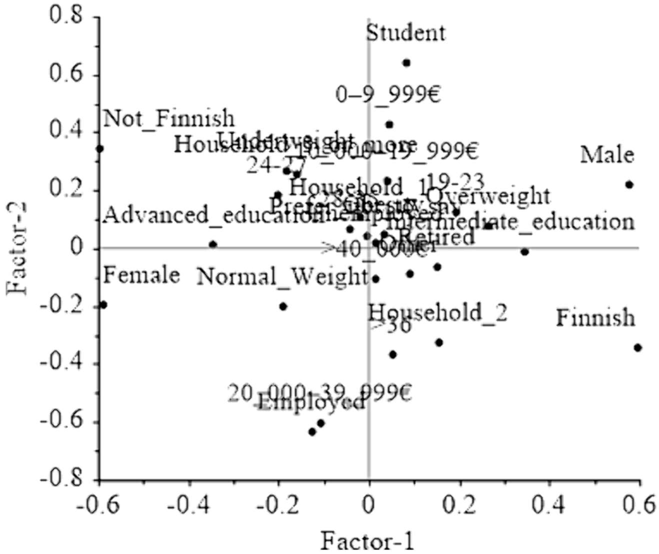

Fig. 8. Loadings plot of Z-Variables from Partial Least Squares regression for L-shaped data (L-PLS) of *Model VII.*

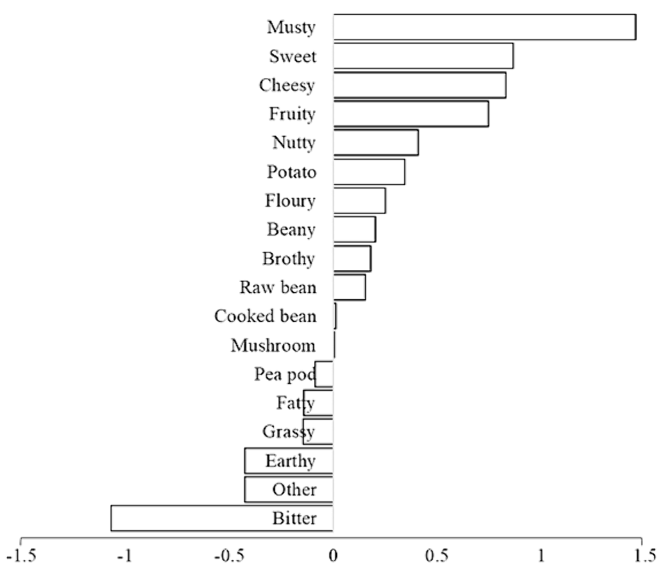

Fig. 9. Bar chart derived from penalty-lift analysis, indicating differences in overall liking for each CATA attribute when checked compared to when the attribute was not checked.

(coefficient < -1) emerged as the primary driver of dislike.

4. Discussion

In relation to faba bean ingredients, this study revealed the relationship between sensory attributes, liking, and consumer characteristics. Specifically, we observed that faba bean ingredients, despite having clearly different sensory characteristics, were not liked, and consumers were unwilling to use them. Although we did not observe clear liking patterns, we found that several consumer attributes influenced preferences for certain ingredient types. The following subchapters discuss (1) the flavor challenges associated with faba bean ingredients, including sensory characteristics, off-flavors, and potential technological solutions to enhance their acceptability; (2) consumer attributes and preferences, shedding light on how personal attitudes, dietary habits, and taste ability influence the liking of faba bean ingredients; and (3) research limitations and considerations.

4.1. *Flavor issues*

When it comes to pulses, taste is not only a motivating factor (De Boer et al., 2013), but also a potential barrier to acceptance (Melendrez-Ruiz et al., 2019). Challenging sensory attributes, including bitterness, astringency, and pungency, have been observed in food applications where all or some of these ingredients were used, including meat alternatives (Saldanha do Carmo et al., 2021; Tuccillo, Kantanen, et al., 2022) and pasta (Rizzello et al., 2017). As flavor issues in pulses, including faba bean, are becoming well known (Wang et al., 2022), this study revealed that these off-flavors might be so overpowering that individual differences among consumers may not play a significant role in overcoming them.

Our consumer insights revealed that technological improvements might be needed at both the crop and ingredient production levels, as low liking was observed across all studied varieties and ingredient types. Indeed, protein-rich fractions of faba bean ingredients can vary based on their manufacturing process (Vogelsang-O'Dwyer et al., 2020), variety (Akkad et al., 2021), environmental factors, and interactions with macromolecules (Multari et al., 2015). In faba bean-based gels, flavors such as potato, cereal, and haricot bean were described as drivers of liking, whilst green, bitter, metallic, and rancid flavors were identified as drivers of dislike (Karolkowski et al., 2022). In our study, attributes such as musty, sweet, cheesy, and fruity were found to be drivers of liking, whereas bitter and earthy were drivers of dislike in all ingredients. These conclusions were captured by penalty-lift analysis, but not from L-PLS based on external preference mapping. Compared to the sensory profiling with consumers, the sensory profiles of the trained panel lacked descriptors. (Tuccillo, Kantanen, et al., 2022). However, both panels could distinguish between the types of ingredients based on their most prominent sensory characteristics. For example, the multifaceted profile of FPI was described by panelists as having a cereal-like odor and flavor, as well as off-notes in both odor and flavor, and an umami taste (Tuccillo, Kantanen, et al., 2022). On the other hand, FF was characterized as sweet, while the two FPC variations were noted as bitter, causing mouth-drying sensations, with pea-like odors and flavors, along with a high-intensity taste and aftertaste (Tuccillo, Kantanen, et al., 2022). While the debate on the superiority of trained versus consumer panels in analytical tests remains, the line is becoming blurred (Ares & Varela, 2017), as both panels could achieve comparable results (Worch et al., 2010).

4.2. *Consumer perspective*

This study also investigated the role of several consumer characteristics in the liking of faba bean ingredients while also providing insights into the relationships among consumer variables (personal attitudes, food choice motives, dietary habits, sociodemographic) as such. Regarding the latter, our study showed that a negative attitude towards vegetarianism was positively correlated with a positive attitude towards sustainability in food choice-making. This may mean that for Finnish consumers sustainability is something else than being vegan or vegetarian. Indeed, consumer understanding of sustainability is multifaced, and while some countries (e.g., China) find the concepts of sustainability and vegetarianism to be strictly linked, other countries (e.g., Spain and USA) have a more neutral attitude towards this association (Sánchez-Bravo et al., 2021). Regarding the former, the *Z*-loading plots of the L-PLS models displayed that clusters of consumers preferred certain ingredient types. For example, we identified a group of consumers who gave greater liking scores to FPI and lower scores to FPCa and FPCb, and that was characterized by regular consumption of pulses and meat alternatives within a primarily vegetarian, vegan, and flexitarian diet, and by a positive attitude towards vegetarianism, food innovation, and sustainability. On the other hand, subjects with opposite characteristics showed an apparent preference for FPCa and FPCb compared to FPI. We believe that this finding is to be interpreted as such: the first group, being more experienced and prone towards pulses, was able to appreciate FPI more, as it was less bitter and astringent. On the other hand, the second group, less experienced and with a more negative attitude, considered all samples to be similar, showing fewer differential preferences. Similarly, participants who correctly identified the bitter sample as bitter and the astringent sample as astringent tended to show a stronger preference for FPI compared to the bitter and astringent FPCa and FPCb samples. Conversely, individuals who perceived the bitter and astringent samples as having a different taste profile, such as water or other taste modalities, had difficulty distinguishing among the samples and tended to favor FPCa and FPCb. Studies on taste perception have shown that individuals with lower responsiveness to bitterness tend to have a higher liking for bitter-tasting samples, in contrast to those with higher responsiveness (Pagliarini et al., 2021; Shen et al., 2016). This theory is consistent with the evolutionary perspective that suggests the rejection of bitter tastes as an adaptive human behavior (Breslin, 2013). Furthermore, there appears to be a correlation between low consumption of pulses, inability to identify the bitter sample, and higher liking towards the most bitter samples. In this regard, Pagliarini et al.(2021) suggested that increased choice of bitter foods was linked to lower responsiveness to bitter taste, and higher liking towards for phenol-rich plant-based products (such as bitter faba bean ingredients and similar pulses). This finding adds another layer of insight into the complex interplay between consumer preferences, taste ability, and sensory attributes in the context of faba bean ingredients and similar plant-based products.

4.3. Research limitations and considerations

Despite having an adequate sample size to characterize clusters of consumers, this study mainly involved highly educated Finnish subjects. Therefore, the results may not be applicable to typically underrepresented populations. Nevertheless, compared to the general population data of Finland, the higher percentage of females and individuals with Finnish citizenship and advanced education is justified; however, the study sample mainly consists of young participants (age $<$ 36 years) (Statistics Finland, 2023).

Moreover, the prevalence of low liking scores among participants for all faba bean samples posed challenges in establishing clear patterns between participant characteristics and liking. As a result, the limited variability in liking scores led to low *Y*-variance explained in the regression models used to identify predictors that could account for the variability in liking. Therefore, it is important to interpret the results regarding the influence of participant variables on overall liking as exploratory rather than predictive. However, the high variance explained by the *X*- and *Z*-variables still yielded meaningful insights into their underlying dynamics. Therefore, the study could still provide valuable insights into the relationships and patterns within X and Z, even though the predictive power for Y might be limited in this specific context.

Additionally, it should be noted that the low variance explained can be partly attributed to the low number of samples for multivariate analysis (n = 4). However, this limitation was a deliberate choice due to the challenging sensory characteristics of the samples. Including additional samples could have led to consumer fatigue. Moreover, the use of four samples in multivariate analysis yielded successful results in explaining the variance of sensory attributes. Furthermore, the conclusions about the sensory properties of the ingredients were similar to those found by a trained panel, despite its smaller descriptive vocabulary (Tuccillo, Kantanen, et al., 2022). Unfortunately, due to limited availability, we were unable to find a mild-flavored control sample, except for wheat gluten, which is also commonly used in extrusion technology. However, preparing wheat gluten in water would have resulted in a dough-like sample, potentially presenting textural issues for consumers. Having such a different sample could have caused distortions in the models, potentially grouping all the faba bean samples together and not allowing for the observation of differences.

The low liking could also be explained by the unfamiliarity of the subjects with the sample types. While FPI resembled a thick puree, the other samples had a slurry-like appearance. Different textures can not only influence flavor release (Weel et al., 2002) but also affect consumer perception of sensory attributes and liking. Indeed, it can be challenging for consumers to distinguish texture from taste and liking. The influence of texture in the sensory evaluations might explain the fact that "musty" was considered a driver of liking instead of disliking. The "musty" attribute mainly characterized the FPI, which was the most diverse sample texturally. Nevertheless, despite the samples' unfamiliarity to consumers, it is noteworthy that the samples exhibited evident sensory issues such as bitterness, astringency, and earthy flavors, which are typical in pulse ingredients (Wang et al., 2022). Future research could aim to discern whether familiarity or taste exerts a greater influence on the liking of minimally processed pulse ingredients.

Our research primarily aimed to assess these ingredients from a sensory standpoint, rather than concentrating on their potential applications in food. This approach builds upon earlier studies that delved into their flavor chemistry. In those studies, we concluded that presenting these ingredients as slurries reveals the flavor problems inherent in extrudates (meat alternatives) produced with the same ingredient-water ratio (Tuccillo et al., 2022b; Kantanen, et al., 2022). This choice aligns with our use of commercially available ingredients that the industry commonly exploits to create meat and dairy alternatives. By examining these ingredients from a consumer perspective, we encourage stakeholders not to resort to quick fixes like masking flavor problems in faba bean-based products with salt, acids, and flavorings (Roland et al., 2017). Instead, we advocate for future research to focus on sustainable approaches to address flavor issues in minimally processed faba bean ingredients.

5. Conclusions

Our research on consumer perceptions of faba bean ingredients has provided valuable insights into the intricate relationship between liking, sensory attributes, and consumer characteristics. Despite the unique sensory profiles of these ingredients, our study has revealed that they received low levels of appreciation from consumers, with limited willingness to use them. One of the prominent challenges we identified in our research was the presence of sensory issues such as bitterness, astringency, and earthy flavors in faba bean ingredients, which are common barriers to consumer acceptance in plant-based products. These findings underscore the critical need for addressing these flavor challenges through technological advancements at both the crop cultivation and ingredient production stages.

Our research has also shed light on the significant role played by consumer characteristics, including attitudes towards sustainability, vegetarianism, food innovation, dietary habits, and taste abilities, in shaping preferences for specific ingredient types. However, due to the sensory challenges associated with these ingredients, we did not discern a clear pattern of liking among consumers. While these findings hold important implications for the food industry and policy, they also underscore the pressing need for further exploration of the sensory dimension in pulse innovation and the development of sustainable plant-based food products.

By proactively addressing these flavor challenges and customizing products to align with consumer preferences, the food industry can better integrate faba bean ingredients into the market, thus contributing to the broader objective of promoting sustainable and nutritious dietary choices.

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CRediT authorship contribution statement

Fabio Tuccillo: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Anna-Maija Lampi:** Conceptualization, Supervision. **Kati Katina:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing. **Mari Sandell:** Conceptualization, Methodology, Supervision, 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

Data might be available on a trusted data repository

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2024.105198.

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