Food Quality and Preference 116 (2024) 105134

Contents lists available at ScienceDirect

Food Quality and Preference

journal homepage: www.elsevier.com/locate/foodqual

Consumers' attachment to meat: Association between sensory properties and preferences for plant-based meat alternatives

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ARTICLE INFO

Keywords:
Meat attachment
Meat alternatives
Consumers
Liking
Rate all that apply (RATA)
Penalty analysis

ABSTRACT

For the sake of both the environment and human health, it is necessary to reduce meat consumption. However, increased consumer adoption of plant-based meat alternatives (PBMAs) will only occur when such products are attractive. PBMAs with meat-like sensory attributes and those that can be cooked similarly to meat are known to be preferred, but the preference for meat-likeness varies depending on the consumer's attitude towards meat. This study determined the relationship between consumers' level of meat attachment (MA) on their sensory perceptions of and preference for commercial PBMAs, and their drivers of liking. MA was measured by the Meat Attachment Questionnaire (MAQ); consumers with either low or high MA (LMA and HMA, respectively) were invited to participate in the study ($n = 99$). The sensory characteristics of seven PBMAs were evaluated using a rate-all-that-apply (RATA) questionnaire, along with an ideal profile and product hedonics. Consumers with LMA had significantly higher overall, aroma, and taste liking, compared with consumers with HMA. Both LMA and HMA consumers similarly discriminated among the sensory properties of PBMAs and the ideal profile. Nevertheless, a further adapted penalty analysis showed subtle differences in consumers' penalisation of sensory attributes depending on MA level. These findings could be used for future research and the development of PBMAs based on consumers' MA; they could also be extended for application in a meal context where the PBMAs are consumed.

1. Introduction

Meat has traditionally held significance in the human diet due to its nutritional value, and the inclusion of meat in meals has been widely regarded as part of a balanced diet (Biesalski, 2005; Pereira & Vicente, 2013). However, given the pressing need to address environmental and human health issues, an expedited shift to a sustainable diet is imperative (Hallström et al., 2015; Willett et al., 2019). A promising approach for achieving a sustainable dietary shift involves reducing the consumption of animal-based food whilst concurrently increasing plant-based food consumption. Although an increasing number of people are adopting meat-free diets, such as vegetarian and vegan diets, or limiting meat consumption, as in a flexitarian diet, for various reasons (e.g., health, animal welfare, and environmental concerns) (Alcorta et al., 2021; Leitzmann, 2014; Ruby, 2012), global meat consumption is still projected to increase (Michele, 2021). Total meat consumption per capita in Sweden has decreased by around 8 kg from 2016 to 2021 (Swedish Board of Agriculture, 2022). Despite this and that many consumers are aware of the environmental impact of meat, it is still perceived as more popular, suitable in diet, and tastier (Röös et al., 2022).

Individuals' food choices are not simple, and altering one's eating habits is challenging (Fischler, 1998); thus, both the food industry and researchers have actively sought out viable product options that can effectively replace conventional animal-based counterparts. One of the emerging strategies is alternative protein sources, including cultured meat, insect-based products, and fungi-based products, of which plant-based meat alternatives (PBMAs) have gained prominence as a mainstream option (He et al., 2020). Plant-based products high in protein such as tofu, tempeh, and seitan have existed for centuries in Asia (He et al., 2020), however, those products have hardly been adopted in Western society (Dekkers et al., 2018; Giacalone et al., 2022). As PBMAs that have meat-like sensory attributes and those that can be cooked similarly to meat are known to be preferred (Elzerman et al., 2011; Fiorentini et al., 2020; Hoek et al., 2011; Röös et al., 2022), PBMAs have been developed to mimic meat-like sensory attributes to meet a wider

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https://doi.org/10.1016/j.foodqual.2024.105134
Received 31 August 2023; Received in revised form 5 February 2024; Accepted 5 February 2024
Available online 8 February 2024

consumer demand (Boukid, 2021; Giacalone et al., 2022; He et al., 2020). Despite growing consumer demand and significant technological advances, PBMAs still lack taste and texture and are still unfamiliar to and inconvenient for many consumers (Aschemann-Witzel et al., 2020; Collier et al., 2021; Röös et al., 2022; Szenderák et al., 2022). Among other barriers, the palatability of PBMAs requires further improvement to shift consumers' consumption patterns (Fiorentini et al., 2020; Röös et al., 2022), however, exactly the right level of sensory properties at which consumers find PBMAs palatable remains significant challenging. In fact, the preference for meat resemblance in meat alternatives varies from consumer to consumer. Vegan and vegetarian consumers are open to PBMAs that do not resemble meat, whereas omnivore and flexitarian consumers favour PBMAs that closely resemble meat (Kerslake et al., 2022; Michel et al., 2021). In addition, consumers who seldom use meat substitutes desire sensory characteristics that resemble meat far more than those who are heavy users (Hoek et al., 2011). Naturally, a low consumption of meat substitutes and a lack of familiarity with them go hand in hand, and this unfamiliarity can result in uncertainty and even scepticism regarding the acceptance of PBMAs (Collier et al., 2021).

Another major aspect that plays an important role in food choices is an individual's cognitive factors related to food - knowledge and skills, attitude, liking and preference, anticipated consequences, and personal identity (Chen & Antonelli, 2020). Previous studies have shown that people's willingness to reduce meat consumption while increasing their PBMA consumption is suggested to be associated with their meat attachment (MA) (Circus & Robison, 2019; Graça et al., 2015a; Graça et al., 2015b; Lentz et al., 2018). MA refers to a positive bond towards the consumption of meat. To measure the MA, Graça et al. (2015a) developed the Meat Attachment Questionnaire (MAQ), which comprises four dimensions: *hedonism* (viewing meat as a source of pleasure), *affinity* (affinity towards meat consumption), *entitlement* (feeling entitled to meat consumption) and *dependence* (feeling dependent on meat consumption). The interplay of these dimensions shapes an individual's degree of bonding with meat consumption, therefore, consumers who are highly attached to meat are likely to consume more meat and to view the intention to follow a plant-based diet negatively (Graça et al., 2015a). Using the MAQ, similar trends have been observed in other studies; in New Zealand, Lentz et al. (2018) reported that MA is one of the strongest predictors of individuals' willingness and intention to reduce their meat consumption. The degree of MA also influences consumers' attitudes towards alternative protein sources, including cultured meat, edible insects, and PBMAs. Consumers with higher MA scores who predominantly followed a meat-eating diet displayed greater willingness to consume cultured meat and PBMAs; in comparison, consumers with lower MA scores who primarily adhered to meat-excluding diets showed greater willingness to consume PBMAs, with only a limited number expressing willingness to consume cultured meat or edible insects (Circus & Robison, 2019). Consumers, particularly those who adhere to meat-eating diets, have lower sensory expectations for PBMAs compared to conventional meat (Michel et al., 2021; Slade, 2018; Vural et al., 2023), which can be seen in consumer preferences during tasting (Cordelle et al., 2022; Elzerman et al., 2011; Grasso et al., 2022; Hoek et al., 2013). Whereas those who follow meat-free diets tend to rate higher liking on plant-based alternative products than meat-eaters, and there was also a different tendency to select sensory attributes and rate intensities based on the consumer's dietary orientation (Pointke et al., 2022). Yet, recent studies have demonstrated partial consumer acceptance of meat alternatives to conventional meat products, with PBMA occasionally performing better than meat (Cordelle et al., 2022; Niimi et al., 2022; Sogari et al., 2023). Therefore, there may be another factor that makes the difference in hedonic preference for PBMAs, rather than demographic factors (e.g. dietary orientation).

Previous studies have mainly focused on the relationship between consumers' MA and their intention to reduce their meat consumption and increase their consumption of alternative proteins (Circus & Robison, 2019; Erhardt & Olsen, 2021; Graça et al., 2015a; Graça et al., 2015b; Lentz et al., 2018), but not on how MA might affect consumers' perception of the sensory properties of PBMAs and the hedonic value of such foods. Furthermore, it is unknown how consumers' MA affects their conceptualisation of PBMAs with ideal sensory properties. Examining this area may fill a gap in the knowledge of why some consumers perceive PBMAs to be unpalatable. Therefore, utilising MA as a tool for consumer segmentation, the present study aimed to investigate the relationship between consumers' level of MA, their sensory perception of and preference for PBMAs from various sources of plant-based protein, and what they consider the ideal sensory properties of PBMAs to be. More specifically, this study tested the following hypotheses:

1) Depending on their MA, consumers will prefer each PBMA differently.
2) Consumers with a high attachment to meat will prefer PBMAs with more meat-related sensory attributes over products with less meat-related sensory attributes, and vice versa.
3) Consumers will have different ideal product profiles based on their MA levels.

2. Materials and methods

2.1. Samples and sample preparation

A total of seven commercial PBMAs in the form of mince were selected from varying sources of protein: two soy-based products (soy-23 and soy-26), two pea-based products (pea-23 and pea-25), two grey pea-based products (greypea-1 and greypea-2) and one oat-based product (oat-21). The samples were selected based on the greatest variety of the main plant-based raw materials and samples that could demonstrate a wide range of sensory properties. The current study belongs to a project which is part of a larger research centre, PAN Sweden. All products were pre-seasoned by the manufacturers; both the soy- and the pea-based products were seasoned with flavours and spices, while greypea-2 was seasoned with black pepper and yellow onion, and greypea-1 and oat-21 were only seasoned with salt (more details on the samples are provided

Table 1
Description of samples and their ingredients as provided by the manufacturers.

Protein	Sample name	Status	Raw materials
Soy	Soy-23	Frozen	Water, **SOY PROTEIN (23 %),** rapeseed oil, methylcellulose (E461), salt, onion powder, tomato powder, caramelised sugar, garlic powder, black pepper
	Soy-26	Frozen	Water, **SOY PROTEIN (26 %),** rapeseed oil, onions, salt, spices, natural flavours, sugar (caramelised)
Pea	Pea-23	Frozen	Water, **PEA PROTEIN (23 %),** rapeseed oil, apple extract, natural flavours, salt, methylcellulose (E461)
	Pea-25	Fresh	Water, **PEA PROTEIN (25 %),** vegetable oil (rapeseed), thickener (E461), natural aroma, spices, spice extract, salt, vinegar, beetroot powder, aroma.
Grey Pea*	Greypea-1	Fresh	**SWEET LUPINE, GRAY PEA, FIELD BEAN,** rapeseed oil, water, rapeseed cake, a little salt
	Greypea-2	Frozen	**GREY PEA**, water, rapeseed oil, yellow onion, modified potato starch, salt, black pepper
Oat	Oat-21	Frozen	Water, **OAT (21 %) (oat protein, oat bran, whole grain oat flour), PEA PROTEIN (21 %), FABA PEA PROTEIN (11 %),** rapeseed oil, iodised salt.

*Percentage of grey pea not provided by manufacturers.

in Table 1).

Prior to cooking, the frozen products were thawed overnight in the refrigerator at 4 °C. All samples were cooked before being packed for serving. Samples (600 g) were stir-fried for 8 min on medium heat with vegetable oil (30 g). The cooked samples were cooled to room temperature (21 °C) before being portioned out into servings of approximately 20 g each in transparent plastic containers (60 ml) with lids. Each sample was blind labelled with a unique three-digit code. The samples were packaged in a transparent resealable plastic bag as a tasting package with serviettes, cutlery, plain crackers, printed lists of attributes with definitions, and instructions on tasting protocols, with a QR code link to access the questionnaire. The packages were stored in the refrigerator (4 °C) until being handed out to consumers.

2.2. Attribute generation

To generate attributes for sensory profiling, six experienced sensory panellists participated in attribute generation. All panellists were female, and the median age was 60. The panellists were previously screened using International Organisation for Standardisation (ISO) standards, and each had more than 4 years of experience in sensory evaluation.

During the first 30 min of the 3-hour session, the panelists tasted the samples individually and generated a list of sensory attributes. The remainder of the session was devoted to refining the attribute list by defining each sensory attribute through consensus and setting scale anchors for each attribute. A total of 39 attributes covered the sensory modalities of appearance (AP: 7 attributes), aroma (AR: 8 attributes), taste (TA: 14 attributes), texture (TEX: 8 attributes) and after-taste/texture (after TA/TEX: 2 attributes) of the plant-based mince samples (Table S1).

2.3. Consumer study – Recruitment and testing

Consumers were initially recruited through an online pre-screening questionnaire consisting of two parts. The first part included demographic questions such as gender, age, education, household situation (i.e. number of adults and children at home), food allergies and dietary orientation (omnivore, flexitarian, pescatarian, vegetarian, vegan or other); the second part was the MAQ that indicate an individual's bond towards meat consumption (Graça et al., 2015a). The MAQ is a validated questionnaire consisting of 16 items (e.g., "I love meals with meat") on a 5-point Likert scale ranging from 0 (strongly disagree) to 4 (strongly agree). The original questionnaire was translated into Swedish and back-translated into English to confirm the translation accuracy (Johnson, 1998), and the translated Swedish scale can be found in the supplementary materials (Table S2). Furthermore, the validity of the MAQ in Sweden was evaluated through additional surveys in both English (n = 268) and Swedish (n = 262) (Table S3). Exploratory factor analysis (EFA) was performed and showed that the items consisted of four dimensions, as suggested by the original study. Cronbach's alpha was calculated for internal consistency for each dimension in both versions; English (hedonism: 0.93; affinity: 0.88; entitlement: 0.81; dependence: 0.86) and Swedish (hedonism: 0.93; affinity: 0.89; entitlement: 0.86; dependence: 0.93). Multiple factor analysis (MFA) was used to compare the factor loadings of EFA to each other, the MAQ collected during screening of the consumer study, and against the original MAQ (Graça et al., 2015a). The RV coefficients (≥0.94) indicated a high degree of similarity between the languages of the questionnaire and across different participant samples tested in Swedish (Table S4 and Fig. S1).

Initially, 213 consumers completed the pre-screening questionnaire. After the further exclusion of consumers who were unable to participate in the tasting and those who responded to the survey twice, complete questionnaires were obtained from 208 participants. Based on the MA scoring (theoretical possible scores: 0–64), the 208 participants were split into three equal groups of low (scored ≤ 20), medium (21 < score < 30) and high (scored > 31) levels, and only the low and high MA groups (LMA and HMA, respectively, n = 140) were invited to participate in a further consumer test. Product evaluations were conducted under home-use test (HUT) conditions, due to COVID-19 pandemic restrictions at the time of testing (February 2022). The invited consumers collected the tasting package (described in Section 2.1) from a designated location in Gothenburg, Sweden. They were instructed to keep the package in the refrigerator until 30 min before the evaluation and to evaluate within 24 h of collection. A total of 100 consumers received the tasting package, and 99 completed the evaluation (54 LMA and 45 HMA) (Table 2).

The consumers were instructed to use their smartphones to access the questionnaires online. Data were collected using RedJade® Sensory Solutions (Silicon Valley, CA, USA). Each consumer tasted and evaluated the seven samples in a randomised order. For each given sample, the consumers first evaluated the product's hedonic value (appearance, aroma, taste, texture, and overall) on a 9-point hedonic scale (1 = extremely dislike, 5 = neither dislike nor like and 9 = extremely like) and then scored the intensity of the product's sensory attributes using a 5-point intensity rate-all-that-apply (RATA) scale (1 = very low, 3 = moderate, and 5 = very high) (Ares et al., 2014a). After evaluating all the samples, the consumers indicated the intensities of attributes that would signify their ideal PBMA product (i.e. evaluated hypothetically) using the same attribute list and scales in the sample evaluation. Lastly, consumers answered questions on their frequency of consumption of meat and PBMAs.

The consumers were informed that they would evaluate PBMAs. All consumers gave their informed consent and were compensated with 250 SEK as a gift card for their participation after completing the evaluation. The study was conducted in compliance with the Declaration of Helsinki (2013) and was assessed for compliance with national research requirements by an internal process at RISE Research Institutes of Sweden. The study was approved by the Department of Material and Surface Design, and personal data was collected and handled in compliance with the General Data Protection Regulation (GDPR) (EU) 2016/679.

Table 2
Demographic information of consumers participating in the consumer test.

	Total	Low MA	High MA
N (%)	99 (100 %)	54 (54.5 %)	45 (45.5 %)
MA score (0–64):		≤20	≥31
mean (SD)		11.7 (±6)	38.5 (±5.8)
Gender			
Female	66 (66.7 %)	42 (77.8 %)	24 (53.3 %)
Male	33 (33.3 %)	12 (22.2 %)	21 (46.7 %)
Age: mean (SD)	38.0 (±12.0)	35.3 (±10.9)	41.2 (±12.5)
Dietary orientation			
Omnivore	55 (55.5 %)	12 (22.2 %)	43 (95.6 %)
Flexitarian	10 (10.1 %)	8 (14.8 %)	2 (4.4 %)
Pescatarian	8 (8.1 %)	8 (14.8 %)	0 (0.0 %)
Vegetarian	17 (17.2 %)	17 (31.5 %)	0 (0.0 %)
Vegan	9 (9.1 %)	9 (16.7 %)	0 (0.0 %)
Consumption frequency			
Red meat			
Never	33 (33.3 %)	33 (61.1 %)	0 (0.0 %)
Less than once a month	11 (11.1 %)	7 (12.9 %)	4 (8.9 %)
Less than once a week	16 (16.2 %)	5 (9.3 %)	11 (24.4 %)
Once or twice a week	26 (26.3 %)	8 (14.8 %)	18 (40.0 %)
Three or four times a week	10 (10.1 %)	1 (1.9 %)	9 (20.0 %)
Five or more times a week	3 (3.0 %)	0 (0.0 %)	3 (6.7 %)
Meat alternatives			
Never	3 (3.0 %)	0 (0.0 %)	3 (6.7 %)
Tried it once	17 (17.2 %)	2 (3.7 %)	15 (33.3 %)
Less than once a month	24 (24.2 %)	10 (18.5 %)	14 (31.1 %)
Less than once a week	28 (28.3 %)	19 (35.2 %)	9 (20.0 %)
Once or twice a week	16 (16.2 %)	16 (29.6 %)	0 (0.0 %)
Three or four times a week	7 (7.1 %)	6 (11.1 %)	1 (2.2 %)
Five or more times a week	4 (4.0 %)	1 (1.9 %)	3 (6.7 %)

2.4. Data analysis

The internal consistency of the MAQ was computed using Cronbach's alpha for the MAQ dimensions (Hedonism: 0.93; Affinity: 0.87; Entitlement: 0.77; Dependence: 0.86). Total scores from the MAQ were calculated for each consumer (also accounting for reverse-scored items), and the consumer sample was divided into three equal groups based on these scores. The factorial validation of the additional surveys for the English and Swedish versions of the MAQ, as well as the MAQ used in the screening to the consumer study, was verified through EFA with oblimin rotation. The similarities between factor loadings obtained from the original MAQ (Graça et al., 2015a) and the MAQs conducted in Sweden (Swedish version from the screening to the consumer study and additional surveys conducted in both English and Swedish) were compared using MFA and the RV coefficient.

The normality of the hedonic data from the consumers was checked using the Shapiro-Wilk test. As the analysis showed that the data was not normal, non-parametric tests were used for further analysis of the hedonic data. To analyse the differences in hedonics by MA levels and by samples, Mann-Whitney and Kruskal-Wallis tests were respectively performed. Multiple pairwise comparisons were performed using the Dunn-Bonferroni *post-hoc* test for a further investigation of the significant effects of the Kruskal-Wallis test. Effect sizes were calculated according to the method suggested by Lenhard & Lenhard (2022). Sensory profiling data were also checked for normality, as with the hedonics, and the data also showed non-normality. Therefore, the Mann-Whitney test was conducted to analyse the difference between MA levels for each sensory attribute. In addition, the Mann-Whitney test was used to compare the difference between MA groups in terms of their ideal sensory profile.

Principal component analysis (PCA) was separately performed for each MA group on the mean attribute intensities from RATA in order to visualise the sensory space and the projection of the samples in relation to the sensory space. The hedonic attributes and the ideal product were considered as supplementary data in the analysis. For a further comparison of the relationship between the perception of the two MA groups of the samples, based on the consumers' ratings of the samples' attributes in the RATA questions, MFA was conducted. In this analysis, the ideal product was considered as a sample. In addition, the RV coefficient between both groups was calculated. Agglomerative hierarchical clustering (AHC) was used to explore the clustering patterns of the attributes based on their intensities, with the aim of identifying the consumers' perception of sensory attributes for their ideal product, while also discerning any differences based on the MA levels. The analysis followed Euclidean distance and Ward's method to investigate attribute clusters based on the raw data.

Lastly, a modified penalty analysis was performed separately for each MA group to identify the attributes associated with the mean drop in overall liking based on a deviation between the consumers' responses for each attribute from the RATA question for each sample. The data were transformed to pseudo-just-about-right (JAR) scores by assuming that the attribute intensities in the ideal profiles of each consumer were JAR for every attribute. The data were transformed by calculating deviations between the ideal attribute intensity and the perceived intensity of the matching attribute measured in each sample for everyone. The calculated deviations were transformed further as pseudo-JAR scores with 'too little', 'ideal', and 'too much' as negative, zero, and positive, respectively. The mean drop was calculated by comparing the mean liking for the ideal level minus the 'too much' or 'too little' levels, which provided insights into the decrease in liking that occurred when a product deviated from the desired intensity level. All statistical analyses were performed using XLstat (Addinsoft, New York, USA).

3. Results

3.1. Consumer dietary characteristics

The consumers exhibited different dietary orientations according to their MA levels (Table 2). The LMA group displayed a broader range of self-reported meat-excluding dietary orientations including flexitarian (15 %), pescatarian (15 %), vegetarian (32 %) and vegan (17 %), in contrast to the HMA group, in which most consumers identified themselves as omnivores (96 %). As expected, these two consumer groups also differed in their frequency of consumption of PBMAs and meat. The majority of the LMA consumers never consumed meat (61 %), and 43 % consumed PBMAs at least once a week. In contrast, 67 % of HMA consumers consumed meat at least once a week, and most (91 %) seldom consumed PBMAs.

3.2. PBMA hedonics and MA

The hedonics of all the modalities significantly differed across the samples (p <.0001, See TableS5) with a large Cohen's d effect size (d > 0.8) in both MA groups (Fig. 1). Samples based on soy (soy-23 and soy-26) and pea (pea-23 and pea-25) were generally more liked than samples based on grey pea (greypea-1 and greypea-2) and oat (oat-21) in both MA groups. Interestingly, greypea-2 was rated lowest in liking of appearance, yet the aroma and taste modalities were rated close to the most liked samples (soy-26, pes-23 and pea-26). The hedonic scores of the consumer groups based on the consumers' MA were analysed (Table S6). The consumers with HMA had significantly lower mean scores than those with LMA in terms of overall liking (mean difference = |0.4|, p =.011), aroma (mean difference = |0.4|, p =.011) and taste (mean difference = |0.4|, p =.006). However, the effect size for each variable, as measured by Cohen's d, was relatively small (d = 0.2). There were no significant differences in liking for appearance (mean difference = |0.2|, p =.15) and texture (mean difference = |0.3|, p =.15) between the MA groups, with very small effects (d = 0.1). In general, the HMA group scored each hedonic modality in each sample lower than LMA group, except for soy-23 (aroma), greypea-1 (overall and appearance), and oat-21 (taste). Overall, however, the LMA and HMA groups similarly liked soy- and pea-based products more than grey pea- and oat-based products.

3.3. Sensory characteristics of PBMAs and the consumers' ideal product

All sensory attributes except 'Legumes_AR', differed significantly (p <.05) across samples. Notably, 'Homogeneous colour_AP (d = 1.6)', 'Red colour_AP (d = 1.5)', 'Moist_AP (d = 1.5)', 'Juicy_TEX (d = 1.5)', 'Brown colour_AP (d = 1.0)' and 'Meaty_TA (d = 1.0)' exhibited large effect sizes, suggesting substantial differences in these characteristics among the samples. On the other hand, attributes such as 'Burnt_AR (d = 0.2)', 'Herbs_AR (d = 0.3)', and 'Sour_AR (d = 0.3)' had comparatively smaller effect sizes, indicating less pronounced differences. When comparing the sensory attributes between the MA groups, 13 attributes significantly differed (p <.05) with small effect sizes (d < 0.3) in intensity scores, all of which were scored higher by the LMA group than the HMA group (Fig. 2A). In terms of differences in the ideal profiles between the MA groups, six attributes significantly differed, where the scores were again higher for the LMA consumers compared with the HMA consumers: 'Smoky_AR (p =.005)' and 'Smoky_TA (p =.004)' had medium effect sizes (d = 0.6), 'Bitter_TA (p =.042)', 'Umami_TA (p =.024)', 'Peppery_TA (p =.036)' and 'Rubbery_TEX (p =.031)' showed small effects (d < 0.4) (Fig. 2B).

The RATA scores from each MA group were analysed with PCA separately to determine the sample projections of the sensory attributes (Fig. 3). The first two components explained 74 % and 73 % of the variance of the data for the LMA and HMA groups, respectively. Samples were discriminated into two main groups on PC 1 and were similar for

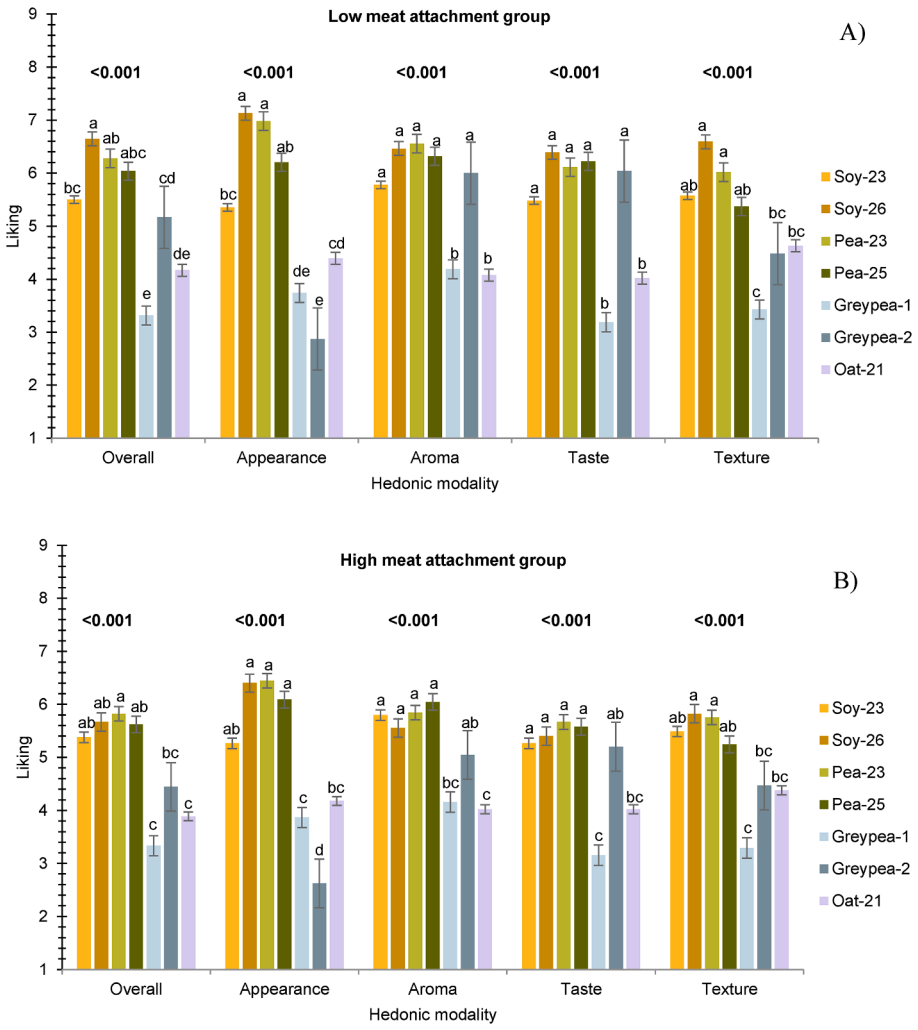

Fig. 1. Mean liking scores by samples (mean ± standard error, SE). Graphs are shown for A) the LMA group and B) the HMA group. *Note:* The different superscript letters indicate significant differences according to Kruskal-Wallis and *post-hoc* Dunn-Bonferroni tests ($p > 0.05$).

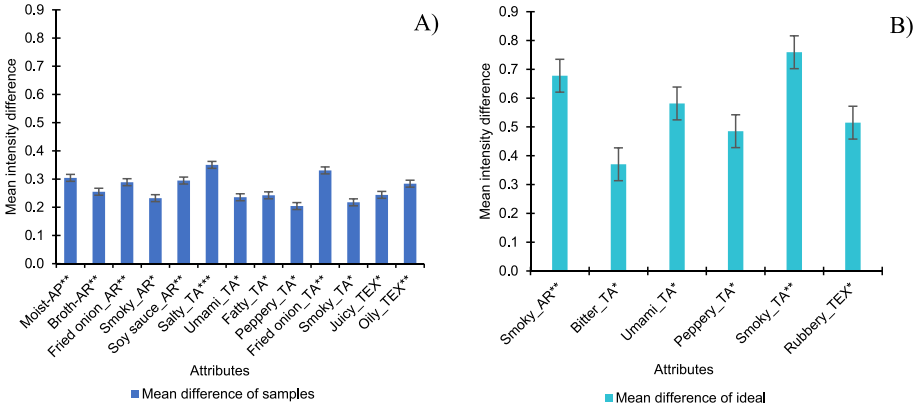

Fig. 2. Mean differences in attribute intensities between LMA and HMA groups. Differences are calculated from LMA - HMA, whereby, positive values indicate higher mean intensities for the LMA group. Graphs are shown for A) plant-based mince products and B) consumers' ideal product. *Note:* AP = appearance; AR = aroma; TA = taste; TEX = texture.

both MA groups. Soy-23, soy-26, pea-23, pea-25 and greypea-2 were characterised by attributes such as 'Homogeneous colour_AP', 'Moist_AP', 'Soy sauce_AR', 'Broth_AR/TA', 'Fried onion_AR/TA', 'Smoky_AR/TA', 'Salty_TA', 'Sweet_TA', 'Fatty_TA', 'Umami_TA', 'Meaty_TA', 'Juicy_TEX' and 'Oily_TEX' along the positive axis of PC 1. Many of these attributes demonstrated a positive correlation with hedonic attributes, implying a favourable perception by participants. In contrast, oat-21 and greypea-1 were located on the negative axis of PC 1, being described as 'Bitter_TA', 'Cereal_TA', 'Bitter after_TA', 'Grainy_TEX', 'Mealy_TEX' and 'Remaining-after_TEX', which correlated negatively with hedonics for

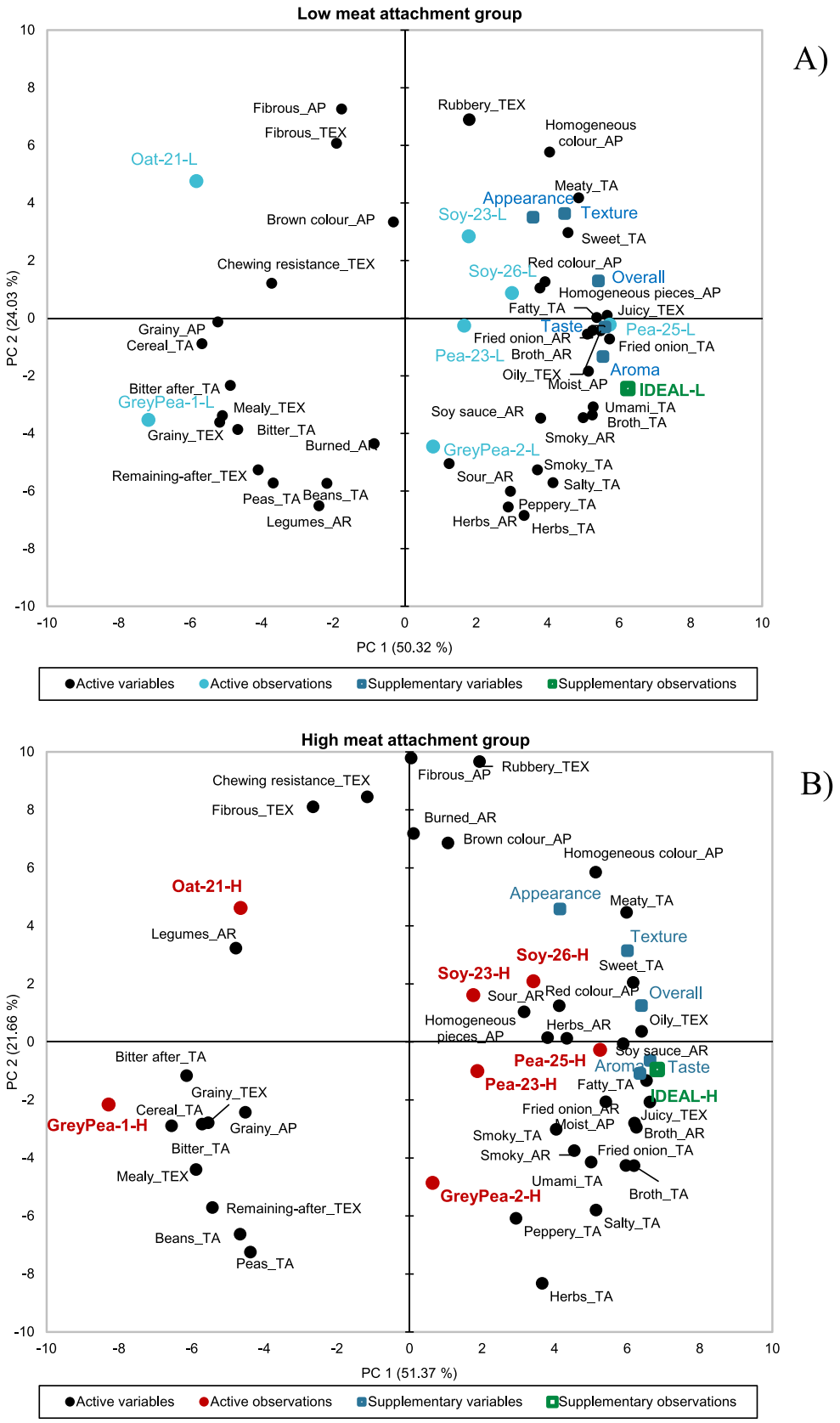

Fig. 3. PCA biplot of attributes and PBMAs. Biplots are shown for A) the LMA group and B) the HMA group. *Note:* L = the LMA group; H = the HMA group; AP = appearance; AR = aroma; TA = taste; TEX = texture; Supplementary variables = hedonic attributes; Supplementary observation = ideal product.

both MA groups. However, some attributes were differently projected on PC 1 and PC 2. For example, 'Legumes_AR' was projected on the negative axis of PC 1 in the HMA group, whereas it was projected on the negative axis of PC 2 in the LMA group. Again, 'Chewing resistance_TEX' was projected on the positive axis of PC 2 in the HMA group, while it was projected on the negative axis of PC1 in the LMA group. Despite slight variations in the attribute mapping projected through PCA for the LMA and HMA groups, the overall configuration of the samples and the ideal product demonstrated a high degree of closeness, as indicated by the MFA result (RV coefficient = 0.98) (Fig. S2). The RV coefficient of 0.98 indicated a high degree of similarity on the attribute matrices of the samples and the ideal product based on consumers' MA level.

3.3.1. Cluster analysis on ideal product profiles

To better understand whether attributes tend to cluster differently across MA groups, and if so, how each group ideally would like the same attribute to be differently intense, AHC was conducted separately for each MA level using the raw RATA data. Three distinct attribute clusters were found for each MA level (Table 3). Cluster 1 comprised attributes that were ideal at relatively high intensities, with mean intensity ranges of 3.7–3.2 and 3.7–3.1 for the LMA and HMA groups, respectively. Cluster 2 consisted of attributes that were ideal at relatively moderate intensities, with mean intensity ranges of 3.3–2.7 and 3.0–2.3 for the LMA and HMA groups, respectively. Lastly, Cluster 3 included attributes that were ideal at relatively low intensities, with mean intensity ranges of 2.7–1.5 and 2.3–1.4 for the LMA and HMA groups, respectively. These results indicate a notable difference in attribute clustering patterns between the LMA and HMA groups. More specifically, the consumers in the LMA group showed a strong preference for a high intensity of 'Umami_TA' in their ideal product, whereas the consumers in the HMA group expressed a preference for a moderate intensity of this attribute in their ideal product. Moreover, LMA consumers showed a tendency to cluster attributes such as 'Fibrous_AP/TEX', 'Grainy_AP/TEX' and 'Red colour_AP' in Cluster 3, indicating a perception of relatively low intensity, whereas HMA consumers tended to associate these attributes with Cluster 2, indicating a moderate intensity perception. It is worth noting that, despite these differences in clustering, the mean values of these attributes were similarly scored in both groups.

Despite the observed differences between the LMA and HMA groups, there were similarities in the clustering of sensory attributes for the consumers' ideal intensities in their ideal product. Attributes related to meat, including 'Brown colour_AP', 'Moist_AP', 'Meaty_TA', 'Juicy_TEX' and 'Chewing resistance_TEX' were clustered together as relatively high intensity, whereas attributes related to off-odours and tastes such as 'Legumes_AR', 'Sour_AR', 'Burnt_AR', 'Beans_TA', 'Peas_TA', 'Cereal_TA','Bitter_TA' and 'Bitter after_TA' were clustered together as relatively low intensity. In addition, attributes that significantly differed in the ideal product across the MA groups (Fig. 2B) were grouped together in Cluster 2 ('Smoky_AR/TA' and 'Peppery_TA') and Cluster 3 ('Rubbery_TEX' and 'Bitter_TA') for both MA groups. These findings suggest that individuals' MA levels may influence their perception and desired intensity of specific attributes; yet, there are common attributes that are considered highly (un)desirable, which play an important role in shaping consumers' perception of the ideal product for both MA levels.

Table 3
Clusters of sensory attributes scored for the ideal product by the low and high MA groups.

Cluster	Cluster 1 (Relatively high intensity)		Cluster 2 (Relatively moderate intensity)		Cluster 3 (Relatively low intensity)	
	Attribute	Mean (SD)	Attribute	Mean (SD)	Attribute	Mean (SD)
Low MA	Homogeneous colour_AP	3.8 (1.2)	Fried onion_TA	3.3 (1.2)	**Fibrous_TEX**	2.7 (1.2)
	Juicy_TEX	3.7 (1.3)	Smoky_TA	3.1 (1.3)	Fatty_TA	2.5 (1.1)
	Brown colour_AP	3.7 (1.1)	Fried onion_AR	3.1 (1.2)	**Grainy_AP**	2.5 (1.2)
	Chewing resistance_TEX	3.7 (0.7)	Herbs_AR	3.1 (1.4)	**Fibrous_AP**	2.4 (1.2)
	Moist_AP	3.5 (1.0)	Smoky_AR	3.1 (1.0)	Oily_TEX	2.3 (1.0)
	Homogeneous pieces_AP	3.4 (1.0)	Broth_TA	3.0 (1.2)	Rubbery_TEX	2.3 (1.1)
	Meaty_TA	3.2 (1.5)	Peppery_TA	3.0 (1.3)	**Red colour_AP**	2.3 (1.2)
	Umami_TA	3.2 (1.3)	Broth_AR	3.0 (1.1)	Beans_TA	2.1 (1.1)
			Herbs_TA	2.9 (1.3)	**Grainy_TEX**	2.1 (1.2)
			Soy sauce_AR	2.9 (1.1)	Peas_TA	2.1 (1.1)
			Salty_TA	2.7 (1.0)	Sour_AR	2.1 (1.1)
					Legumes_AR	2.1 (1.2)
					Sweet_TA	2.1 (0.7)
					Remaining-after_TEX	2.0 (1.0)
					Cereal_TA	2.0 (1.2)
					Burnt_AR	1.9 (1.2)
					Bitter_TA	1.8 (1.0)
					Mealy_TEX	1.5 (0.9)
					Bitter after_TA	1.5 (0.8)
High MA	Brown colour_AP	3.7 (1.2)	Fried onion_TA	3.0 (1.2)	Fatty_TA	2.3 (1.2)
	Homogeneous colour_AP	3.7 (1.3)	Fried onion_AR	3.0 (1.3)	Oily_TEX	2.2 (1.3)
	Meaty_TA	3.6 (1.2)	**Grainy_AP**	2.9 (1.3)	Remaining-after_TEX	2.0 (1.3)
	Juicy_TEX	3.6 (1.1)	Broth_AR	2.8 (1.2)	Beans_TA	1.9 (1.2)
	Chewing resistance_TEX	3.4 (1.0)	Broth_TA	2.8 (1.2)	Legumes_AR	1.9 (1.1)
	Moist_AP	3.4 (1.1)	Herbs_AR	2.7 (1.3)	Sour_AR	1.8 (1.0)
	Homogeneous pieces_AP	3.1 (1.3)	Salty_TA	2.7 (1.1)	Sweet_TA	1.8 (1.0)
			Herbs_TA	2.7 (1.2)	Rubbery_TEX	1.8 (1.2)
			Umami_TA	2.6 (1.1)	Peas_TA	1.7 (1.1)
			Soy sauce_AR	2.6 (1.3)	Cereal_TA	1.7 (1.1)
			Fibrous_TEX	2.6 (1.4)	Burnt_AR	1.6 (0.9)
			Grainy_TEX	2.6 (1.4)	Mealy_TEX	1.6 (1.0)
			Peppery_TA	2.5 (1.2)	Bitter after_TA	1.5 (1.1)
			Smoky_AR	2.4 (1.2)	Bitter_TA	1.4 (1.0)
			Fibrous_AP	2.4 (1.2)		
			Red colour_AP	2.3 (1.2)		
			Smoky_TA	2.3 (1.3)		

Note: Attributes clustered differently between LMA and HMA groups are marked in **bold**.

3.3.2. Penalty analysis

To understand how deviation of sensory properties could impact the overall liking of the samples, a modified penalty analysis was conducted separately for each MA group, expressed as mean drops in overall liking. Here, only two samples are shown for brevity (see Fig. S3 for other samples), soy-26 (Fig. 4A and B) and greypea-1 (Fig. 4C and D), which were overall the most liked and disliked, respectively. Differences in attributes were seen that led to penalties for the same samples across different MA groups. The LMA group penalised soy-26 (Fig. 4A) for not being moist enough (35 % of consumers), having too little aroma and too little taste of fried onions (39 % and 44 % of consumers respectively), and having pieces that were not homogeneous enough (31 % of consumers). The impact of herbs aroma on overall liking scores was also observed, but the direction of the impact, whether it was 'too much' or 'too little', was not found to be statistically significant. In the HMA group (Fig. 4B), soy-26 was penalised when the texture was too grainy, as indicated by 40 % of consumers. Although 'too much' pea and umami taste also led to a decrease in overall liking, both attributes were present in the threshold of 20 % of consumers. Furthermore, 'Fatty_TA' was above the threshold, yet the mean drop was not significant when the attribute was too much or too little. Notably, greypea-1 was penalised very strongly for having too much grainy texture, as indicated by 83 % of consumers in the LMA group (Fig. 4C). On the other hand, the HMA group (Fig. 4D) penalised greypea-1 for not being moist enough (89 % of consumers), not being meaty or salty enough (87 % and 62 % of consumers, respectively), having too much of a peas or beans taste (56 % and 60 % of consumers, respectively), having a burnt aroma (36 % of consumers) and having a grainy appearance (69 % of consumers).

4. Discussion

4.1. Consumer characteristics by MA level

This study used the MAQ to explore the influence of MA on consumers' preferences, sensory perception and ideal product regarding PBMAs. The findings revealed distinct consumption patterns and dietary orientations between the two MA groups. The LMA group consisted of younger consumers with a greater proportion of females who exhibited more diverse meat-excluding dietary orientations, while most of the consumers in the HMA group followed meat-eating dietary patterns, either as omnivores or flexitarians. These findings validated the ability of the MAQ to illustrate meaningful consumer segments. These

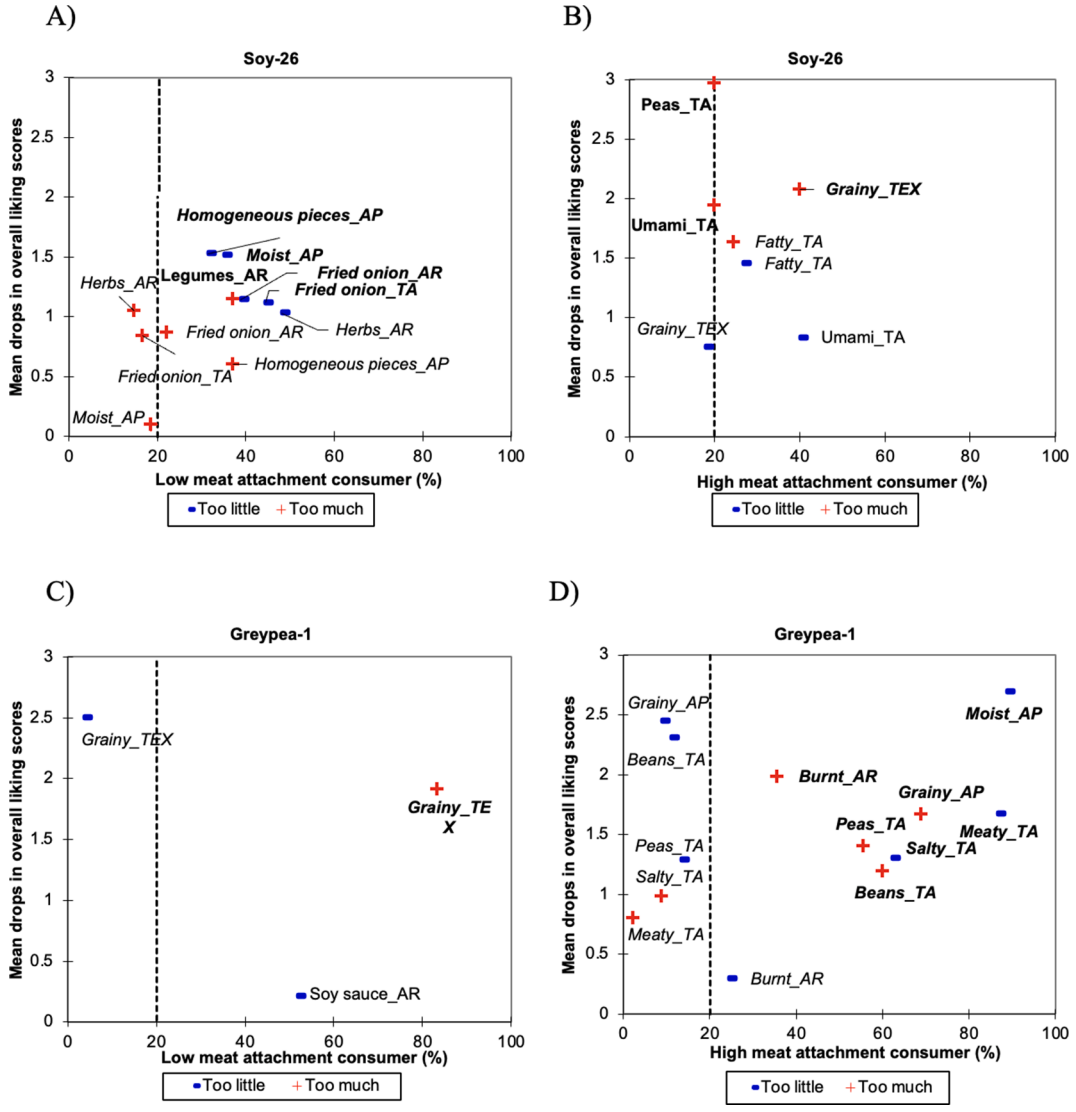

Fig. 4. Penalty analysis on soy-26 and greypea-1, based on the ideal product profile. Penalties for soy-26 are shown for A) the LMA group and B) the HMA group, while penalties for greypea-1 are shown for C) the LMA group and D) the HMA group. *Note:* **Bold** = significant in mean drop; *italics* = significant in penalty. Dashed line = 20 % of consumers. AP = appearance; AR = aroma; TA = taste; TEX = texture.

consumption patterns align with the broader trends observed in Sweden, where more than half of the Swedish population never or seldom consumes PBMAs, while the remaining 40 % of the Swedish population consumes PBMAs at least once a month and about 20 % consumes PBMA weekly (Röös et al., 2022). Furthermore, the MA groups demonstrated variations in sociodemographic characteristics that are in line with previous studies investigating MA (Circus & Robison, 2019; Erhardt & Olsen, 2021; Graça et al., 2015; Lentz et al., 2018).

4.2. Relationship between consumers' MA level and preference for PBMAs

The findings of this study showed that consumers with HMA had significantly lower mean scores on hedonic attributes (overall, aroma and taste) than consumers with LMA. These results align with a previous study that reported PBMAs having low sensory appeal to consumers who viewed meat positively and rarely used PBMAs (Hoek et al., 2011). The current study also indicated that consumer preferences varied based on the raw ingredients of the PBMAs. Consumers generally liked PBMAs made from soy and pea more than those made from grey pea and oat. Indeed, studies have shown that soy-based PBMAs often tend to perform well in terms of hedonics compared with other plant-based protein sources and, in some cases, even outperform their meat counterparts, for example in applications such as Bolognese sauces (Niimi et al., 2022) and burger patties (Sogari et al., 2023). This could be due to the known desirable functional properties of soy proteins, such as gelation and fibre-forming abilities, which play a crucial role in the development of textures and structures in PBMAs (Zhang et al., 2021). In addition, both the soy- and pea-based products were seasoned with flavour and spice agents, which can mask undesirable sensory properties whilst enhancing desirable ones (Fiorentini et al., 2020). On the other hand, grey pea and oat are relatively new protein sources in the PBMAs market (Singh et al., 2021; Westling et al., 2021; Yang et al., 2023), and it is worth noting that greypea-1 and oat-21 were seasoned solely with salt. This minimal seasoning may have contributed to their placement in the negative PC 1, which is associated with sensory attributes such as bitterness, cereal tastes and bitter after-taste. These sensory characteristics are known to negatively affect hedonics (Drewnowski, 1997), which could potentially explain the lower hedonic scores observed for these samples.

Although the consumers were able to discriminate among the samples based on their sensory perception of the raw ingredients of the products, the discrimination among products was similar across MA groups. The ability to discriminate among the sensory properties of PBMAs might not be strongly related to psychographic cues. Niimi et al. (2022) investigated whether consumers with different levels of cooking ability projected the sensory properties of Bolognese made with meat and PBMAs differently; their results showed that consumers similarly discriminated among the samples in terms of their cooking abilities.

The results of this study confirmed that the consumers preferred products that mask raw ingredients and resemble meat, thereby providing support for the hypothesis that consumers with HMA prefer PBMAs with meat-related attributes. However, the hypotheses concerning LMA consumers, who were expected to favour PBMAs without meat-related attributes, and whose perception of PBMA sensory characteristics were also expected to differ from that of the HMA consumer group, were not substantiated by the study findings. This may be related to the nature of the LMA group in the present study, which were more diverse in dietary orientation than the HMA group. Among the LMA group, 37 % of consumers identified themselves as omnivores or flexitarians. These consumers may be more likely to choose PBMA as an alternative to meat or reduce their meat consumption than consumers with the same dietary orientation in the HMA group, yet they may want PBMA to be similar to meat. Furthermore, unlike other traditional alternatives such as tofu and tempeh, PBMAs may also be perceived as a treat by vegans and vegetarians, who are primarily classified as LMA consumers (Kerslake et al., 2022).

4.3. Ideal product profiles based on MA levels and influence of MA extent on PBMA preferences

Consumers with HMA showed significantly lower intensity scores on 'Umami_TA', 'Smoky_AR/TA', and 'Peppery_TA' than the LMA consumers, in the attributes not only of samples but also of their ideal product. The initial expectation was that HMA consumers would give higher scores to attributes that are related to meat, particularly for their ideal product, since smokiness and umami have been used to recreate a meaty flavour and mask off-flavour in plant-based products (Fiorentini et al., 2020). However, it was observed that the HMA group generally gave lower scores on both the intensity RATA question and the hedonic scale, in comparison with the LMA group. This finding might be related to the consumers' familiarity with these types of products, as previous research suggests that product familiarity is associated with consumers' extent of usage, acceptance and perception of the appropriateness of the product (Giacalone & Jaeger, 2016). Moreover, frequent exposure to and experience with such products may contribute to familiarity and hence form the foundation of sensory expectations, through an improved ability to identify sensory attributes (Bitnes et al., 2007; Rabin & Cain, 1986). Most consumers within the HMA group never or seldom used PBMAs, and these consumers might have more negative attitudes and taste expectations towards these products than regular users (Hoek et al., 2011).

Although both MA groups demonstrated similar ideal profiles as identified by the MFA results, further analysis through AHC and penalty analysis revealed that the perception of certain sensory attributes and the desired intensity might be influenced by the level of MA. The AHC results revealed the groups of attributes with their range of ideal intensities that would shape the most desirable ideal product for both MA groups. Consumers expressed a clear preference for their ideal PBMAs to closely resemble meat in terms of sensory characteristics, including meat taste and texture (e.g. juiciness and chewing resistance), while exhibiting low levels of characteristics associated with legumes and some textural attributes. Although these preferences were observed in both the LMA and HMA groups, certain attributes, such as 'Umami_TA', exhibited distinct clustering patterns between the two groups. These results partially confirm that consumers have different ideal product profiles based on their MA levels.

The penalty analysis conducted in this study also showed that specific attributes have varying impacts on the overall liking of each product, depending on the MA levels of consumers. For example, the HMA consumers identified too much pea or bean taste and too little meat-like taste as attributes causing greypea-1 – which was ranked as the sample furthest from the meat-like attribute characteristic – to be least liked. This was the expected result, as the HMA consumers consistently showed their preference for meat-likeness in PBMAs. Interestingly, on the other hand, the LMA consumers – who projected their ideal product and each sample similarly to HMA consumers – cited the presence of a grainy texture, which was categorised into the relatively low-intensity cluster based on the AHC analysis, as the attribute with the most pronounced negative impact on their overall liking of greypea-1.

This study reaffirms the importance of sensory properties that closely resemble meat in determining consumers' preference for PBMAs (Elzerman et al., 2013). However, it also reveals that the perceptions and recognition of specific sensory attributes vary depending on the consumer's MA level, and that the impact of different sensory attributes on consumers' overall liking of PBMAs varies across low and high MA groups.

4.4. Methodological considerations and future research

This study employed the MAQ (Graça et al., 2015a), a well-validated instrument, to segment consumers based on their MA levels. In addition, this study included a diverse range of PBMAs available in the Swedish

market and compared consumer preferences among these alternatives, rather than directly comparing the PBMAs to meat. This approach allowed for a deeper understanding of the sensory space of PBMAs within different consumer segments, particularly among individuals following plant-based diets who are likely to be actual consumers of PBMAs.

Moreover, this study aimed to explore the sensory attributes that influence consumer preferences for PBMAs based on their level of MA. The evaluation of samples incorporated a combination of the hedonic scale, sample profiling through RATA and the ideal product sensory profile. The RATA method has demonstrated a discriminative ability comparable to that of other sensory evaluation methods, such as check all that apply (CATA) (Vidal et al., 2018) and descriptive sensory analysis (Oppermann et al., 2017), enabling effective differentiation of samples by consumers. Furthermore, directly asking consumers about their ideal product makes it possible to garner the sensory properties that strongly influence liking (Ares et al., 2014b). To profile the sensory space and assess discrimination ability across the MA levels, PCA and MFA were conducted based on the mean intensity of attributes. The analyses revealed similar trends among the consumer groups; additional analyses were then performed using AHC and a pseudo-penalty analysis based on raw intensity data to identify salient attributes with notable differences between the two groups.

Given that RATA is a variant of CATA and can measure the intensity of products, an approach was taken that combined the penalty analysis approach with RATA data for both the samples and the ideal product. Traditionally, the application of a penalty analysis utilises JAR data to evaluate the impact of specific attributes on overall liking by quantifying penalties associated with deviations from the optimal attribute levels (Meullenet et al., 2007; Plaehn, 2013). However, when utilising JAR data for penalty analysis, it is important to consider the limitations of such data, such as ignorance of correlations among attributes (Meullenet et al., 2007) and the potential influence of the JAR task on consumers' hedonic perception (Ares et al., 2014b; Popper et al., 2004). In addition, although the JAR scale helps identify the sensory attributes that are considered optimal for a specific product, it may not necessarily align with consumers' ideal product profile (van Trijp et al., 2007). To overcome these limitations, researchers have proposed alternative methods, one of which is the utilisation of CATA data for conducting penalty analysis (Ares et al., 2014b; Plaehn, 2012). Ares and colleagues (2014b) employed a combined approach of CATA data and ideal data based on CATA in their penalty analysis, which enabled them to identify the sensory attributes that significantly impacted liking based on consumer perceptions of the products. Nevertheless, it is important to note that this method does not capture information on attribute intensity or the extent of divergence between the products and the ideal for each individual consumer (Ares et al., 2014b). In this context, the use of pseudo-JAR data, derived from each consumer's profiling data, could provide valuable insights for a more targeted approach to product formulation and optimisation, in particular when evaluating novel products where it is not known exactly what the consumer's ideal product is. This approach could guide the direction of adjustments in attribute level indicating whether reductions or enhancements of intensity are necessary to align with consumers' preferences, unlike MFA, which describes products by weighted multiple sets of variables (Pagès, 2004). Furthermore, the utilisation of the RATA scale, as demonstrated by Vidal et al. (2018), offers an increase in the selection of attribute terms in comparison with the use of CATA questions. This expanded range of terms can facilitate the identification of implicit attributes that might influence consumers' overall liking. However, the reliability and validity of penalty analysis utilising pseudo-JAR, which was derived by applying RATA methodology together with ideal profiling with RATA, requires additional investigation.

The pseudo-JAR approach may lead to a loss of information and amplify differences between data characteristics, as RATA data, which are ordinal, are treated as JAR data, which are nominal. However, this can be considered a minor problem as JAR data can be considered ordinal in nature (Meullenet et al., 2007). Furthermore, the data analysis approach of the pseudo-JAR differs from that of traditional penalty analysis. The approach taken in this study is to posit the existence of an optimal ideal product as desired by consumers *after* they have evaluated all the samples and investigate how the hedonics of a product is affected by sensory attributes that fall short of this ideal product level. This is in contrast to the traditional penalty analysis approach from JAR, which may indicate if sensory attributes measured are optimal, but is not necessarily a proxy for the consumer's ideal product characteristic. In addition, RATA allows for a wider range of attributes to be measured than traditional JAR, which is limited to a few simple attributes (Lawless & Heymann, 2010). Yet, further research is needed, including comparisons between penalty analysis using pseudo-JAR and JAR, as well as other techniques such as CATA-penalty analysis, to assess their effectiveness and applicability in accurately evaluating consumer preferences.

4.5. Limitations

Several limitations are worth noting with regards to the current study. The sample selection exclusively being PBMA and the general information for consumer recruitment including mention of PMBA broadly, may nevertheless have influenced participants' responses, in particular, HMA individuals since they may have a predisposition towards favouring conventional meat over PBMAs. At the same time, there may be a potential skewed effect since participants who voluntarily engage in the study on PBMAs may possess a higher curiosity or interest in such products, regardless of their level of MA. Another limitation point is that the present study did not account for other factors (i.e. familiarity) that could influence liking and perception of sensory attributes. Nevertheless, PBMAs are commonly found in supermarkets in Sweden, implying that consumers in Sweden may already have existing knowledge of the product or product type in general. Thus, using MA as a tool to understand consumer perception of PBMA, along with prior knowledge of such products, may help to reflect what actual/potential consumers want for such products. Finally, while this study deliberately categorised consumers into low and high MA groups and excluded those with medium MA, the data is also possible to handle continuously rather than categorically, which could uncover other information that may have been missed in this study. Future research would warrant handling MA continuously and investigate how MA correlates with consumer responses and other psychographical measures.

5. Conclusions

This study sought to explore consumers' perception of the sensory properties of and preferences for PBMAs according to the consumers' level of MA. Level of MA affected consumers' hedonic ratings and perception of the sensory properties of PBMAs. The consumers were able to discriminate among PBMAs based on the main protein sources and project their ideal product. Despite similarities in consumers' perception of the sensory characteristics of each sample and their identification of the ideal product, differences in the penalisation of sensory attributes emerged based on the consumers' MA level. Overall, the penalty analysis provided valuable insights for optimising product acceptability and gaining a better understanding of the needs and preferences of target consumer groups with differences in MA. This result sheds light on the fact that the sensory characteristics desired by consumers differ depending on product and consumer psychographics (i.e. MA). These findings could be used for the future research and development of PBMAs based on consumers' MA and could be extended to apply in a meal context where the PBMAs are consumed.

Ethical statement

The study was conducted in compliance with the Declaration of Helsinki (2013) and was assessed for compliance with national research requirements by an internal process at RISE Research Institutes of Sweden. The study was approved by the Department of Material and Surface Design, and personal data was collected and handled in compliance with the General Data Protection Regulation (GDPR) (EU) 2016/679. All consumers gave their informed consent and were compensated with 250 SEK as a gift card for their participation after completing the evaluation.

CRediT authorship contribution statement

Ansung Kim: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Åsa Öström:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Mihaela Mihnea:** Writing – review & editing, Conceptualization. **Jun Niimi:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition, Conceptualization.

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 will be made available on request.

Acknowledgements

This work was supported by FORMAS, the Swedish government research council for the environment, agricultural sciences, and spatial planning (reference no. 2020-02843). The authors would like to thank Victoria Sörensen and Lisa-Maria Oberrauter for assisting in attribute generation and data collection. The authors would like to thank Peter Blomgren at Paulig AB and Jan-Åke Frykholm at Delmat AB for supplying one of the samples for testing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2024.105134.

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