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FLINT, Megan <http://orcid.org/0000-0002-2484-1627>, LEROY, Fiona, BOWLES, Simon <http://orcid.org/0000-0001-5935-8187>, LYNN, Tony and PAXMAN, Jenny <http://orcid.org/0000-0003-3596-489X>

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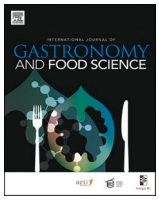

'Meating' consumer expectations: More work required to improve acceptability of plant-based meat alternative products

Megan Flint [a,*], Fiona Leroy [b], Simon Bowles [a], Anthony Lynn [a], Jenny R. Paxman [a]

[a] Food and Nutrition Subject Group, Sheffield Hallam University, Sheffield, S1 1WB, UK
[b] Institute Agro Dijon, 26 Bd Dr Petitjean, 21079, Dijon, France

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ABSTRACT

Plant-based meat alternatives (PBMA) offer a steppingstone towards healthier, more sustainable food systems. However, product acceptability is pivotal to successful consumer adoption and PBMAs must deliver a positive sensory experience. This study reports consumer acceptability and sensorial characterisation of five commercially available PBMA categories versus meat-based equivalents, stratified by exposure to product information (closed/open condition) and participants familiarity with PBMAs (habitual/habitual non-consumer). Naïve assessors were recruited to participate in sensory evaluation of plant-based burgers ($n = 96$), meatballs ($n = 53$), breaded 'chicken' ($n = 62$), plain 'chicken' ($n = 47$), and sausages ($n = 23$) versus meat-based equivalents. Acceptability was measured on a nine-point hedonic scale and sensorial characterisation was determined via check-all-that-apply questioning. In all cases but one, PBMAs were significantly less acceptable versus meat-based equivalents ($p < .05$). Overall burger acceptability was significantly higher in the closed versus open label condition ($p = .046$) and in habitual versus habitual non-consumers ($p = .047$). Condition and familiarity did not influence other PBMA categories. PBMA products were more frequently associated with off-flavours alongside a dry appearance and texture. Alternately, meat-based products were associated with meaty and umami flavours and a juicy texture. This study generates preliminary findings which indicate the need for evidence-based product development to improve PBMA acceptability, accelerate consumer adoption, and promote individual and planetary health.

1. Introduction

Overconsumption of meat, particularly red and processed meat, has been shown to be detrimental to both human health and planetary sustainability (Rust et al., 2020; Szenderák et al., 2022; Tso and Forde, 2021; Zahari et al., 2022). Meanwhile extensive evidence suggests that plant-based diets are associated with a wide range of health benefits including the prevention and/or management of non-communicable diseases (Dinu et al., 2017; Haghighatdoost et al., 2023; Harland and Garton, 2016; Naghshi et al., 2020). There is therefore a collective sense of urgency across a range of stakeholders to reimagine our current food system to address this by facilitating a reduction in meat consumption whilst concomitantly increasing our reliance on plant-based foods (Caputo et al., 2023; Neville et al., 2017; Kwasny et al., 2022; Rust et al., 2020; Willett et al., 2019). Plant-based meat alternatives (PBMA) may offer a steppingstone to accelerate this dietary shift to meet public health and climate change targets (Alae-Carew et al., 2022; Department for Environment Food & Rural Affairs, 2022; Kwasny et al., 2022; Pastorino et al., 2023).

Consumer concern for animal welfare, environmental sustainability and personal health are widely cited as drivers towards increased plant-based consumption (Onwezen et al., 2021; Rizzo et al., 2023; Szejda et al., 2020). However, consumer engagement and acceptance of PBMA products is dependent on a wider range of complex factors (Jahn et al., 2021; Szenderák et al., 2022; Tyndall et al., 2024). Previous authors have purported that level of familiarity with a product can act as both a driver and barrier to engagement with novel food products (Barrena and Sánchez, 2013; Beacom et al., 2021; Coucke et al., 2023; Rini et al., 2024). Thus, novel PBMAs may both appeal to individuals keen to try new foods, and deter neophobic consumers (Gonera et al., 2021; Jahn et al., 2021). Prior familiarity has been noted to have a positive influence upon consumers PBMA purchase and consumption behaviour (Bryant et al., 2019; Hoek et al., 2013). In addition, increased awareness of PBMA-related information may promote consumer familiarity with

* Corresponding author.
E-mail address: m.flint@shu.ac.uk (M. Flint).

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these products (Ai et al., 2023).

Product packaging, ingredients, nutritional information, nutritional claims and any health claims associated with their consumption have been shown to influence sensory evaluation and willingness to purchase PBMAs (Ang et al., 2023; Baptista and Schifferstein, 2023; Estell et al., 2021; Martin et al., 2021). Chang and colleagues (2012) reported the negative impact on purchasing intent for PBMAs that listed soy as an ingredient. Conversely, statements of sensory likeness to meat ("tastes like meat", for example) positively influenced consumer perceptions (Fiorentini et al., 2020). However, a key barrier to consumer adoption for omnivorous consumers is their inability to effectively mimic the desirable sensorial attributes of their meat-based equivalents (Alcorta et al., 2021; Beacom et al., 2021; Hoek et al., 2011; International Food Information Council, 2020; Jahn et al., 2021; Michel et al., 2021; Szenderák et al., 2022; Tyndall et al., 2024; Van Loo et al., 2017; Weinrich, 2019).

Replication of desirable meat-associated sensory characteristics in novel PBMAs poses a significant challenge to food manufacturers. The ingredients used in PBMAs can both limit desirable taste and texture, attributable to the higher fat content of meat-based equivalents and can generate undesirable beany off-flavours and a gritty mouthfeel, where legumes are included as a protein source (Asgar et al., 2010; Boukid, 2021; Fiorentini et al., 2020; Giacalone et al., 2022; Sha and Xiong, 2020). Thus, PBMAs are often perceived inferior to their meat-based counterparts in terms of overall acceptability. Consumers associated meat-based products with the term 'delicious' whilst PBMAs were associated with 'disgust' (Michel et al., 2021) and preferred meat-versus plant-based burgers despite being informed that all burgers tasted the same (Slade, 2018). However, *actual* (as opposed to *perceived*) acceptance offers a more accurate insight (Caputo et al., 2023; Slade, 2018).

Previous sensory studies with untrained consumer panels have consistently reported a general preference for meat-based products versus their PBMA although these have been largely limited to a single product category (Caputo et al., 2023; Grasso et al., 2022; Schouteten et al., 2016; Sogari et al., 2023, 2024) and limited consideration of chicken (Ettinger et al., 2022; Godschalk-Broers et al., 2022), sausage (Neville et al., 2017; Nguyen et al., 2023) and meatball alternatives (Giezenaar et al., 2024). There is a paucity of evidence regarding the impact of prior familiarity (habitual consumption/habitual non-consumption) with PBMA products, where only burger and sausage products have been considered (Neville et al., 2017).

Therefore, there is a need for further studies to address these limitations and investigate a wider range of emerging and underrepresented PBMA product categories. Consideration must also be given to the influence of prior level of familiarity and impact of product information upon acceptability and sensorial characterisation. Thus, the current study had three objectives: 1) to determine consumer acceptability and to sensorily characterise commercially available plant-based burgers versus meat-based equivalents under closed/open label conditions; 2) to segment naïve assessors into habitual consumers/habitual non consumer of PBMA products; 3) to replicate this for a further four underrepresented PBMA product categories. Herein, we report, for the first time, the acceptability and sensorial characterisation of five PBMA categories under closed versus open label conditions between habitual consumers and habitual non-consumers of PBMA products. These novel findings will increase knowledge regarding consumer perceptions of a range of PBMA categories, including those which are currently underrepresented in the research field. Such knowledge has the potential to influence new product development and marketing strategies to accelerate adoption of PBMAs which may promote sustainable outcomes for both future individual and planetary health.

2. Materials and methods

2.1. Plant- versus meat-based burger products

2.1.1. Sample Selection

A comprehensive online search of dominant UK supermarkets and food suppliers (Tesco, Sainsbury's, ASDA, Morrisons's, Waitrose, Aldi, The Co-op, M&S, Iceland and Ocado) was conducted between May 2022 and May 2023 to identify PBMA burgers and equivalent meat burgers available for purchase. Contemporary price-point data were recorded between September and October 2023 from supermarket websites. Nutritional information (per 100 g) and price (per 1 kg) data for eligible plant-and meat-based burger products (Table S1) were used to generate a nutritional composition 'heatmap'. While PBMA products are designed to mimic the nutritional profile of their meat-based equivalents, previous studies have demonstrated significant compositional differences both within and between product categories (Alessandrini et al., 2021; Curtain and Grafenauer, 2019). Such variation in nutritional composition has previously been noted to influence sensorial experience (Cutroneo et al., 2022; Forde and de Graaf, 2022); a fundamental limitation of previous studies within the research field (Sogari et al., 2023). In light of this, Schouteten and colleagues (2016) called for studies where, apart from main protein source, products have a similar composition. A key aim of this study was to minimise the influence of variation in nutritional composition. Therefore, plant-versus meat-based burger pairs ($n = 3$, respectively) were selected with the least variation across nutritional categories (per 100 g energy [kcal]; total fat; carbohydrate and protein), with a maximum tolerance limit of 20% applied to at least three nutritional categories within the heatmap (Table 1; Table 2) (Flint et al., 2024).

2.1.2. Participants

Ninety-six naïve assessors were recruited via convenience sampling methods which included physical and electronic posters, social media, email communication, virtual learning environment messaging to students at Sheffield Hallam University and word-of-mouth. Individuals who expressed an interest in the study completed a pre-screen questionnaire, deployed via Qualtrics (Qualtrics, Provo, UT). Questions regarding age, gender, dietary pattern, and any allergy/intolerance were asked to assess eligibility against strict inclusion criteria: 18–60 years old, willing to consume meat and no allergy/intolerance to study products. Individuals aged 60 and over were excluded due to the purported decline in sensory function in adults at this age (Cavazzana et al., 2018; Kondo et al., 2020). The pre-screen questionnaire also required individuals to report their frequency of consumption of any PBMA products (informed by Knaapila et al., 2022) to determine segmentation into habitual consumers and habitual non-consumers ($n = 46$; $n = 50$, respectively). Since no participant selected 'prefer not to say' when reporting their gender, data were presented as male or female. Thus the resultant panel consisted of 54 female and 42 male assessors with a mean age of 32.4 (SD 12.0) years.

2.1.3. Sensory evaluation

All testing took place at Sheffield Hallam University's industry standard sensory facilities in which assessors were separated in individual booths with controlled lighting, temperature and air flow (BS EN ISO 8589, 2014). Each booth was equipped with a cup of still tap water, unsalted cracker (*Carr's Table Water, Carr's of Carlisle Ltd, England)*, napkin, and metal knife and fork. All responses were recorded on paper by participants. A welcome sheet provided instructions and also informed participants that part 1 involved a blind tasting of plant- and meat-based samples whilst in part 2 samples would be presented with product information to read. Written instructions were reinforced verbally throughout the session. All participants gave their written informed consent to participate. This study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics

Table 1
Mean energy density (kcal/100 g) and macronutrient content (g/100 g) ± SD of 6 burger products (3 plant-based, 3 meat-based, respectively).

Burgers	Energy Mean ± SD (kcal/100 g)	Total Fat Mean ± SD (g/100 g)	Carbohydrate Mean ± SD (g/100 g)	Protein Mean ± SD (g/100 g)
Meat-Based	245.67 ± 13.65	17.47 ± 2.59	3.67 ± 0.64	18.13 ± 2.40
Plant-Based	235.67 ± 17.6	16.73 ± 2.41	3.83 ± 0.31	15.93 ± 1.68

Table 2
Burger product pairs.

Product Pair	PB Burgers	PB Cooking Method	PB Product Cost (per 1 kg)	MB Burgers	MB Cooking Method	MB Product Cost (per 1 kg)
1	16 % pea protein	Grill	£22.50	82 % beef	Oven	£7.71
2	60 % pea protein	Oven	£15.00	93 % beef	Grill	£15.44
3	18 % pea protein	Grill	£13.22	86 % beef	Oven	£7.71

Committee of Sheffield Hallam University (Date 11/05/22; Reference ER42087634).

Burger samples were prepared following manufacturer guidance 45-min before a panel ensuring standardised sample preparation and presentation and kept warm using hot plates (*Buffalo Appliances, Bristol*).

Adopting a 6-block randomised, cross-over design, assessors tasted the burgers, coded with 3-digit codes using a monadic approach, firstly under closed-label conditions then open-label, where products were presented alongside brand, packaging, ingredients and nutritional information. Under the 3-digit code for each burger, photographs of product packaging were provided on a paper handout alongside a clear copy of the ingredients and nutritional information. Assessors were instructed to read the information prior to recording their responses.

Overall product acceptability was rated on a nine-point hedonic scale (1 = dislike extremely to 9 = like extremely). Sensory attributes, informed by Neville and colleagues (2017) (Table 3), were presented and assessors were instructed to Check-All-That-Apply (CATA) for each sample.

Table 3
List of sensorial attributes for evaluation of plant- and meat-based burger products.

	Burgers (Neville et al., 2017)
Texture	Juicy
	Dry
	Granular
	Greasy
	Easy to cut
	Difficult to cut
	Hard
	Soft
Flavour	Sweet
	Peppery
	Smokey/Grill
	Off-flavor
	Meaty
	Wheaty
Appearance	Dark brown colour
	Light brown colour
	Dry
	Oily
	Processed
	Uneven colour

2.2. Additional PBMA product categories

The method outlined in section 2.1 was redeployed for four further product categories (meatballs, breaded 'chicken', plain 'chicken' and sausages). The effect of variation in product composition on sensory evaluation was minimised using similar methods as described for burgers to select 'best fit' PBMA and meat comparators (Table 4).

2.2.1. Participants

The sampling methods described in section 2.1.2 were used to recruit sensory panels of naïve assessors (Table 5).

2.2.2. Sensory evaluation

The only variation in method of sensory analysis from that described in 2.1.3 was the sensory attributes list presented in each CATA which were adjusted for suitability by product category informed by current literature (Barros et al., 2019; Ettinger et al., 2022; Neville et al., 2017; Park et al., 2022; Sow and Grongnet, 2010) (Table 6).

2.3. Data analysis

Visual inspection of QQ plots indicated the data were sufficiently normally distributed for statistical analysis using parametric methods. Mixed model ANOVAs were conducted to compare overall acceptability between products, conditions (open/closed label) and familiarity (habitual/habitual non-consumers of PBMAs). Products (6 levels) and condition (2 levels) were within-subject factors and familiarity (2 levels) was a between-subject factor. Where ANOVA findings were significant, post-hoc Bonferroni tests were performed to compare mean differences and adjust for multiple comparisons. CATA data were analysed using Pearson Chi-squared tests to identify whether any sensorial attributes were more likely to be assigned to plant-versus meat-based products. The data are displayed as radar charts with significant associations highlighted using triangles ($p < .005$) and diamonds ($p < .001$).

IBM SPSS Statistics, version 26 (SPSS Inc, Chicago) was used to conduct all statistical analyses. Statistical significance was set at $P < .05$.

3. Results

3.1. Plant- versus meat-based burger products

3.1.1. Product acceptability

A mixed model ANOVA with a Greenhouse-Geisser correction showed that there was a significant main effect of burger product on mean acceptability ratings, ($F(3.896, 327.271) = 31.435$, $p = <0.001$). Post hoc tests using the Bonferroni correction revealed some significant differences both within the plant-based burgers products and between the plant-versus meat-based burger products (Fig. 1A). Plant-based burger 3 was perceived significantly less acceptable than all other burger samples (all $p < .001$). Plant-based burger 2 was significantly less acceptable than all three meat-based burgers. Plant-based burger 1 was perceived to be the most favourable plant-based burger with acceptability ratings not significantly different to meat-based burger 1 and 3 ($p = 1.000$, $p = .087$, respectively). However, acceptability of meat-based burger 2 was significantly greater than all three plant-based samples ($p < .05$).

There was a significant interaction effect between participant's prior level of familiarity with PBMAs and burger acceptability ratings ($p =$

Table 4
Mean energy density (kcal/100 g) and macronutrient content (g/100 g) ± SD of 6 plant-versus meat-based products (3 plant-based, 3 meat-based products, respectively).

	Energy Mean ± SD (kcal/100 g)	Total Fat Mean ± SD (g/100 g)	Carbohydrate Mean ± SD (g/100 g)	Protein Mean ± SD (g/100 g)
Meatballs	226.83 ± 45.04 (110.0–325.0)	14.40 ± 5.40 (2.4–25.2)	4.30 ± 2.46 (1.1–11.0)	19.96 ± 3.30 (12.0–25.3)
Plant-Based Meatballs	248.67 ± 14.50 (234.0–263.0)	17.30 ± 2.72 (14.3–19.6)	7.17 ± 2.97 (4.4–10.3)	14.20 ± 2.23 (11.7–16.0)
Breaded Chicken	239.22 ± 27.57 (142.0–288.0)	12.09 ± 2.85 (2.4–25.2)	17.38 ± 3.43 (10.0–23.0)	14.49 ± 2.66 (4.6–21.0)
Plant-Based 'Breaded Chicken'	269.67 ± 30.62 (251.0–305.0)	13.50 ± 2.18 (12.0–16.0)	21.93 ± 2.69 (20.0–25.0)	12.73 ± 1.10 (12.0–14.0)
Plain Chicken	131.16 ± 17.29 (106.0–168.0)	3.09 ± 2.15 (1.1–10.0)	0.64 ± 0.46 (0.0–2.4)	25.25 ± 3.05 (19.0–32.2)
Plant-Based 'Plain Chicken'	148.67 ± 16.07 (137.0–167.0)	3.73 ± 1.01 (2.8–4.8)	2.13 ± 1.69 (0.2–3.3)	22.53 ± 1.36 (21.0–23.6)
Sausages	257.71 ± 48.58 (117.0–336.0)	18.77 ± 6.30 (2.8–32.0)	7.42 ± 4.59 (0.6–18.0)	14.30 ± 2.80 (2.8–32.0)
Plant-Based Sausages	234.00 ± 18.33 (214.0–250.0)	13.77 ± 2.04 (12.0–16.0)	8.90 ± 5.35 (5.0–15.0)	14.20 ± 3.02 (11.0–17.0)

Table 5
Meatball, breaded chicken, plain chicken and sausage products evaluated.

Product Pair	PBMA Products	PB Cooking Method	PB Product Cost (per 1 kg)	MB Equivalents	MB Cooking Method	MB Product Cost (per 1 kg)
Meatballs n = 53 assessors (26 male and 27 female; mean age = 27.9, SD 6.5 years; n = 34 habitual PBMA consumers and 19 habitual non-consumers)						
1	22 % pea protein	Oven	£11.11	80 % beef	Oven	£5.83
2	14 % pea protein	Oven	£20.00	87 % beef	Oven	£10.60
3	8.1 % soya protein	Oven	£13.30	55 % pork; 15 % beef	Oven	£6.00
Breaded 'Chicken' n = 62 assessors (32 male and 30 female; mean age = 27.1, SD 5.8 years; n = 39 habitual PBMA consumers and 23 habitual non-consumers)						
1	12 % soya protein	Oven	£10.20	50 % chicken breast	Oven	£8.79
2	36 % soya protein	Oven	£6.25	45 % chicken breast	Oven	£3.44
3	29 % pea protein	Oven	£12.00	51 % chicken breast	Oven	£7.19
Plain 'Chicken' n = 47 assessors (21 male and 26 female; mean age = 27.2, SD 7.3 years; n = 26 habitual PBMA consumers and 21 habitual non-consumers)						
1	Unspecified amount soy protein	Pan Fry	£10.94	96 % chicken breast	Pan Fry	£6.32
2	88 % soy protein	Pan Fry	£19.69	100 % chicken breast	Pan Fry	£7.88
3	30 % soy protein	Pan Fry	£19.41	100 % chicken breast	Pan Fry	£9.39
Sausages n = 23 assessors (7 male and 16 female; mean age = 33.5, SD 12.6 years; n = 10 habitual PBMA consumers and 13 habitual non-consumers)						
1	16 % pea protein	Pan Fry	£20.00	1: 72 % pork	Grill	£9.38
2	1 % soy protein	Pan Fry	£14.00	2: 77 % pork	Grill	£1.65
3	23 % pea protein	Oven	£9.55	3: 42 % pork	Grill	£5.07

.047). Habitual PBMA consumers rated plant-based burgers more acceptable versus habitual non-consumers (Fig. 1B). There was also a significant main effect of tasting condition (closed/open label) on burger product acceptability ($F(1, 84) = 4.096$, $p = .046$) (Fig. 1C). However, this influence was no longer significant when participant's prior level of familiarity was controlled for ($p = .263$).

3.1.2. Sensory check-all-that-apply

3.1.2.1. Plant-versus meat-based burgers. Fig. 2 illustrates the frequency with which naïve assessors checked sensory attributes to describe plant- and meat-based burgers. Nineteen out of twenty sensory attributes were significantly differently assigned by assessors between plant-and meat-based burger products (Table S2).

The meat-based burgers were more frequently associated with the attributes "meaty", "juicy", "easy-to-cut", "oily", "greasy", "soft", "light brown colour" and "peppery". These products received low counts for the attributes "wheaty" and "off-flavour". Conversely, plant-based burgers received higher counts for these attributes as well as "dry", "granular", "dry appearance", "processed", "dark brown colour", "sweet", "hard", "difficult-to-cut" and "uneven colour".

3.1.2.2. Closed versus open label condition. There were also significant differences in the sensory attributes of plant and meat-based burgers under closed versus open label conditions (Table S2). The attributes "hard", "dark brown colour" and "processed" received higher counts for plant-versus meat-based burgers in the closed label condition only. Plant-based burgers were also more frequently associated with "difficult-to-cut" and "sweet" versus meat-based burgers within the open label condition only. Although "light brown colour" was more associated with meat-based burgers in the closed condition, this attribute was more frequently assigned to plant-based in the open label condition. Under both conditions, plant-based burgers were more associated with the terms "dry", "granular", "off-flavour", "wheaty", "dry appearance" and "uneven colour". Conversely, meat-based burgers were more associated with "juicy", "greasy", "easy-to-cut", "soft", "peppery", "meaty" and "oily". "Smokey/grill" was the only attribute assigned similarly to plant-and meat-based burgers under both closed and open label conditions.

3.1.2.3. Habitual consumer versus habitual non-consumer. The sensorial characterisation of plant-and meat-based burgers also significantly differed between habitual consumers and habitual non-consumers of PBMA (Table S2). Habitual PBMA consumers associated plant-based burgers more with "sweet", "smokey/grill" and "dark brown colour" and meat-based burgers with "light brown colour". In contrast, habitual non-consumers of PBMAs perceived plant-based burgers to be "difficult-to-cut", "hard" and "processed" whereas they perceived meat-based burgers to be "soft". Between both habitual consumers and habitual non-consumers, the attributes "dry texture", "granular", "off-flavour", "wheaty", "dry appearance" and "uneven colour" were more frequently assigned to plant-versus meat-based burgers. Conversely, meat-based burgers were more "juicy", "greasy", "easy-to-cut", "peppery", "meaty" and "oily" for both habitual consumers and habitual non-consumers.

3.2. Additional PBMA product categories

3.2.1. Product acceptability

The significant main effect of product type found for burgers was

Table 6
List of sensorial attributes for evaluation of plant- and meat-based products.

	Meatballs (Neville et al., 2017)	Breaded 'Chicken' (Barros et al., 2019; Ettinger et al., 2022)	Plain 'Chicken' (Park et al., 2022; Sow and Grongnet, 2010)	Sausages (Neville et al., 2017)
Texture	Juicy	Crunchy	Chewy	Dry
	Dry	Hard	Juicy	Fibrous
	Granular	Soft	Firm	Soft
	Greasy	Juicy	Tender	Hard
	Easy to cut	Crisp	Smooth	Easy to cut
	Difficult to cut	Moist	Springy	Difficult to cut
	Hard	Cardboard	Hard	Greasy
	Soft	Dry	Fibrous	Poor mouthfeel
		Rubbery		Moist
		Chewy		
		Gummy		
		Fibrous		
Flavour	Sweet	Sweet	Sweet	Meaty
	Peppery	Salty	Bitter	Wheaty
	Smokey/ Grill	Bitter	Astringent	Herby
	Off-flavour	Sour	Salty	Peppery
	Meaty	Savoury	Umami	Off-flavour/ unpleasant aftertaste
	Wheaty	Beany		
		Fatty		
		Nutty		
		Off-flavour Chicken		
		Aftertaste		
		No aftertaste		
		Meaty		
Appearance	Dark brown colour	Bright internal appearance	Brown	Dry
	Light brown colour	Dark internal appearance	Yellow	Coarse
	Dry	Fatty	White	Visible herbs
	Oily	Low fatty		Pale colour
	Processed			Fatty
	Uneven colour			

replicated within the four further product subcategories; meatballs ($F(3.142, 94.260) = 4.915$, $p = .003$), breaded 'chicken' ($F(3.533, 134.256) = 22.828$, $p = <0.001$); plain 'chicken' ($F(3.124, 112.462) = 21.171$, $p < .001$) and sausages ($F(3.444, 61.996) = 3.009$, $p = .031$) as illustrated in Fig. 3. Similarly, post-hoc tests using the Bonferroni correction revealed significant differences both within plant-based products and between the plant-versus meat-based products for meatballs, breaded 'chicken' and plain 'chicken'. While the overall test revealed a significant main effect of sausage product on mean acceptability ratings, post-hoc tests did not demonstrate significant differences between individual products.

Plant-based meatballs 1 and 3 were rated significantly less acceptable than meat-based meatball 3 ($p = .006$ and $p = .015$, respectively; Fig. 3A). Plant-based breaded 'chicken' 2 was rated significantly less acceptable than all other breaded chicken samples (all $p < .05$; Fig. 3B). While acceptance of meat-based breaded chicken 2 was not significantly different to plant-based breaded 'chicken' 1 and 3 (both $p = 1.000$), acceptability ratings for meat-based breaded chicken 1 and 3 were significantly greater compared to all plant-based samples ($p < .05$). The three plant-based plain 'chicken' products were perceived significantly less acceptable compared to the three meat-based samples (all $p < .05$; Fig. 3C). The analysis also revealed variability within the meat-based plain chicken products: meat-based plain chicken 1 was significantly more acceptable than meat-based plain chicken products 2 and 3 ($p = .030$, $p = .003$, respectively).

3.2.2. *Sensory check-all-that-apply*

Fig. 4 illustrates the frequency with which naïve assessors assigned CATA terms for plant-and meat-based meatballs, breaded 'chicken', plain 'chicken' and sausage products. Assessors associated plant-based meatballs with the attributes "dry", "off-flavour", "wheaty", "light brown colour" and "dry appearance". In contrast, "juicy", "meaty", "greasy", "dark brown colour", "oily" and "uneven colour" were more frequently assigned to the meat-based equivalents. For breaded 'chicken', the plant-based products received a higher count for "soft", "bitter", "beany" "nutty", "off-flavour", "wheaty", and "dark internal appearance" compared to meat-based products which were associated with "crunchy", "crisp", "chicken", "meaty", and "fatty appearance". Within the plain 'chicken' category, plant-based products were more frequently assigned to the attributes "smooth", "bitter", "astringent", "salty" and "brown". In contrast, meat-based chicken was associated with "tender texture", "umami" and "white". For sausage products, plant-based products received a higher count for "dry", "fibrous", "poor mouthfeel", "unpleasant aftertaste/off flavor", "wheaty", "coarse" and "dry appearance". In contrast meat-based sausages were more frequently described as "moist", "easy to cut", "soft", "meaty", "fatty", "pale", and "visible herbs".

Sensory attributes used to describe plant-and meat-based products within these subcategories also varied according to tasting condition and assessors' level of familiarity with PBMAs (see Table S3 for more details). For example, the attribute "nutty" was more associated with plant-based breaded chicken within the open label condition and by habitual PBMA consumers (Table S3).

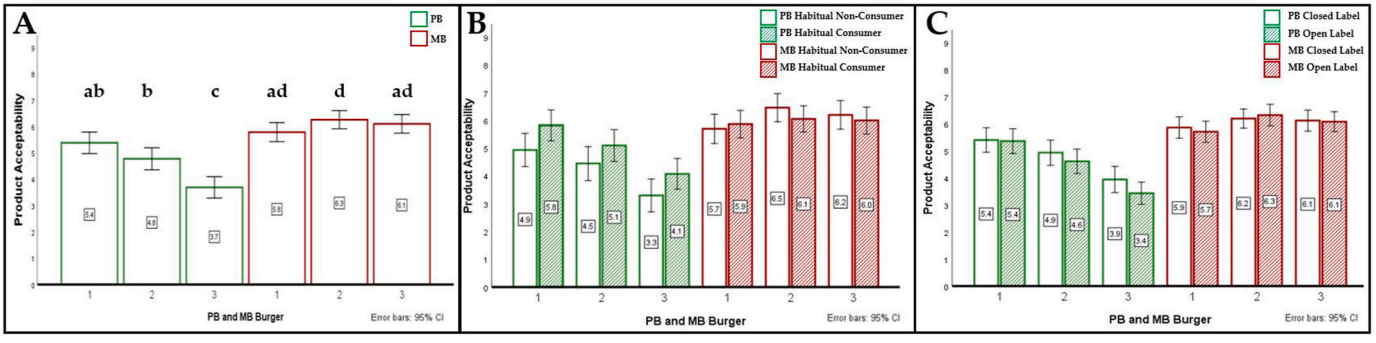

Fig. 1. Acceptability rating of six burger products (3 plant-based, 3 meat-based, respectively). A, plant-based versus meat-based evaluated by naive assessors (n = 96) B, plant-based versus meat-based evaluated by a naïve panel of habitual consumers and habitual non-consumers of PBMA (n = 50 and n = 46, respectively) C, plant-based versus meat-based under closed and open label tasting conditions evaluated by naive assessors (n = 96). Data are presented as mean and 95% confidence intervals and different letters represent statistically significant differences in product type acceptability ($p \leq .05$).

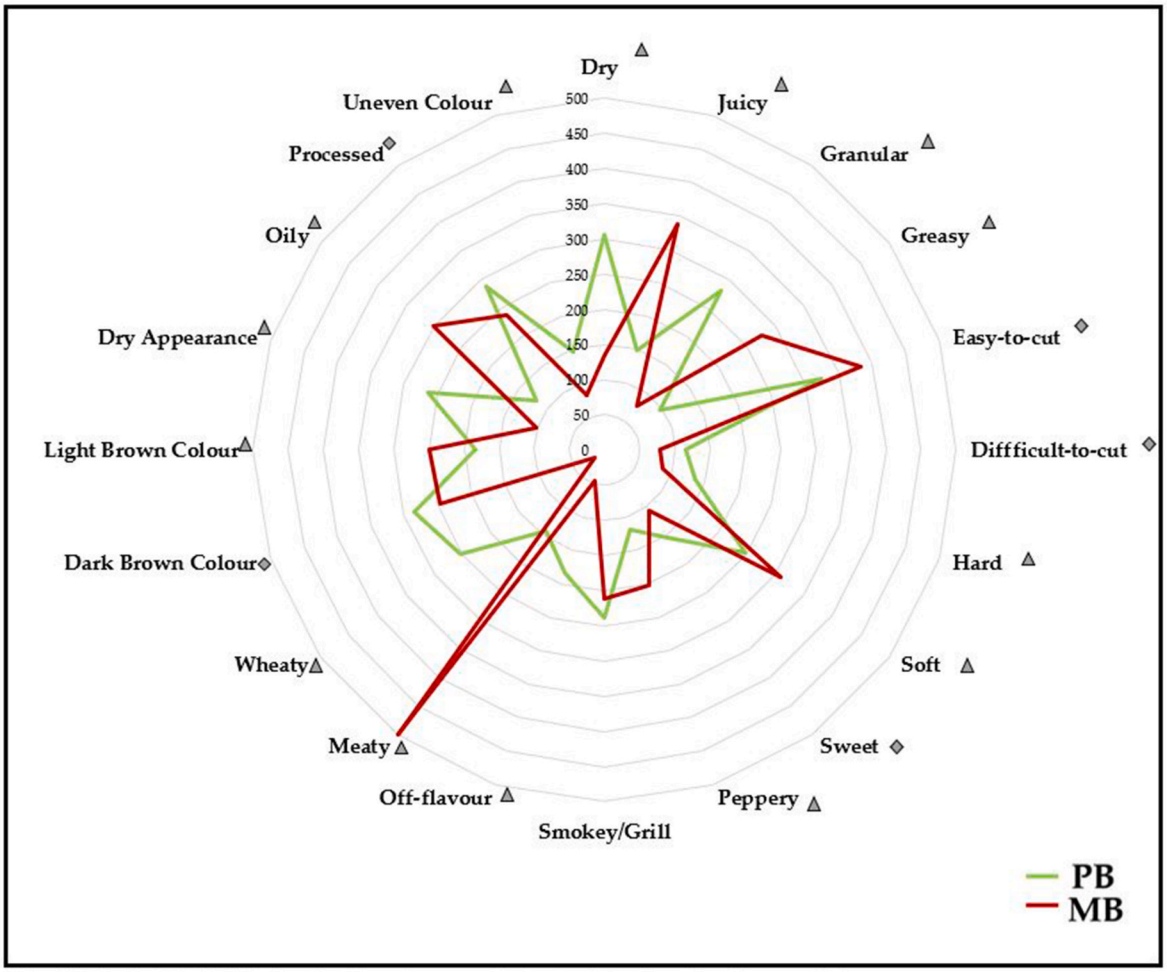

Fig. 2. Radar chart of CATA attributes assigned by naïve assessors to describe plant-and meat-based burger product. △p < .05, ◇p < .001.

4. Discussion

Herein we present the acceptability data and sensorial attributes of five commercially available PBMA product categories versus meat-based equivalents in closed versus open label conditions for both habitual and habitual non-consumers of PBMA products. PBMA products were consistently rated as less acceptable by naïve assessors than meat comparator products across different product categories though this was affected both by how informed assessors were when tasting and the degree of prior familiarity with the product type.

Our findings add to the existing body of evidence (Ettinger et al., 2022; Godschalk-Broers et al., 2022; Neville et al., 2017; Sogari et al., 2023) highlighting plant-based burgers do not currently offer an acceptable and sensorially comparable alternative to meat-based equivalents. We have also reported variation between plant-based burger products whereby plant-based burger 3 was significantly less acceptable versus other plant-based burgers in addition to meat burgers. Conversely, plant-based burger 1 was rated similar to meat-based burger 1 and 3. The composition and technologies employed to develop plant-based products are highly variable. Plant-based burgers 1 and 3 both utilised pea protein as a key ingredient, though plant-based burger 1 had a higher fat content compared to plant-based burger 3 which may have improved texture, mouthfeel and thus overall acceptability (Asgar et al., 2010; Starowicz et al., 2022).

Assessors generally expressed greater acceptability of burgers in closed versus open label conditions, contradicting previous work which found plant-based burgers were rated significantly more acceptable in an open versus closed label condition (Caputo et al., 2023; Grasso et al., 2022; Sogari et al., 2023). Furthermore, it is well documented that information signalling credence can influence an individual's perceptions and acceptance of a food product (Fernqvist and Ekelund, 2014). For example, on-pack information regarding associated health benefits have been noted to increase willingness to purchase PBMAs (Estell et al., 2021). However, Chang and colleagues (2012) argued that product information can also have a negative impact on consumer perception of PBMA (e.g., knowledge of soy ingredient); a possible explanation for the findings reported here. The complexity of PBMA ingredients employed to simulate meat-based equivalents may also contribute to lower acceptability as this compromises the current trend for minimally processed, clean label (containing ≤5 natural ingredients) (Asioli et al., 2017; Boukid, 2021; Flint et al., 2023). Variance in research findings reported here and in prior published work may be further explained by exploring the product familiarity effect. We found that a significant effect of condition (closed/open label) failed to hold true once product familiarity was accounted for. We found a significant interaction effect between participants prior level of familiarity and burger acceptability, with habitual PBMA consumers demonstrating greater acceptance of PBMA burgers than habitual non-consumers. This finding supports the body of evidence associating increased familiarity with improved attitude towards and acceptance of PBMA (Andreani et al., 2023; Beacom et al., 2021; Giacalone et al., 2022; Heijnk et al., 2023; Hoek et al., 2011).

Previous work by Neville and colleagues (2017) identified a greater preference for both meat-and plant-based burgers among PBMA consumers versus non-consumers reinforcing the importance of fostering an understanding of the needs and barriers of the specific target consumer

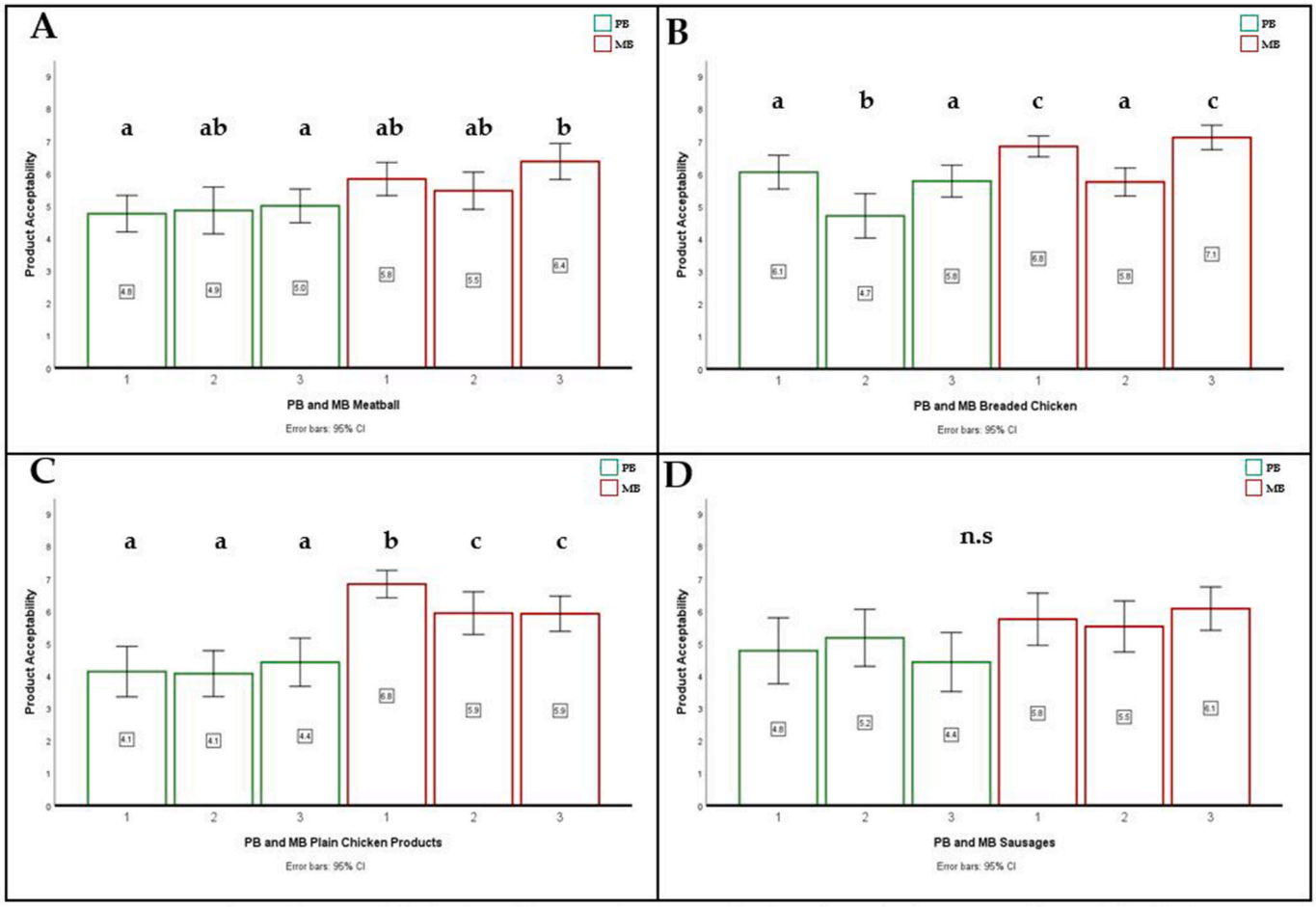

Fig. 3. Naïve assessor assigned acceptability ratings of plant-based meat alternative products versus meat-based equivalent products (n = 3, respectively) A, meatball products (n = 53 assessors) B, breaded chicken products (n = 62 assessors) C, plain chicken products (n = 47 assessors) D, sausage products (n = 23 assessors). Data are presented as mean and 95% confidence intervals and different letters represent statistically significant differences in product type acceptability ($p \leq .05$).

segment for developers, manufacturers and retailers (Flint et al., 2023). Such knowledge may inform the development of tailored marketing and educational campaigns to increase familiarity with, and thus acceptance of PBMA products (Andreani et al., 2023; He et al., 2020; Safdar et al., 2022). Strategies should adopt a whole-systems approach and incorporate a range of stakeholders. For example, early education in young individuals may help to transform social and cultural norms regarding plant-based eating (Abe-Inge et al., 2024; d'Angelo et al., 2020). Nudging strategies such as repositioning of PBMA products within supermarkets may also increase visibility (Coucke et al., 2022; Safdar et al., 2022) while media channels may increase awareness of the benefits associated with PBMA adoption (Abe-Inge et al., 2024; d'Angelo et al., 2020; Szejda and Parry, 2020). For example, Ai and colleagues (2023) noted that dissemination of product-related information via certain channels (e.g., newspaper, television and internet resources) may promote familiarity across various consumer subgroups.

Delivering positive sensorial experience is critical to promote and encourage repeated consumption (Appiani et al., 2023). Many PBMA marketing campaigns promote their similarity to meat, drawing on notions of extant familiarity. However, slogans such as "tastes like meat" require that products deliver on this expectation if they are to be successful in a crowded marketplace (Appiani et al., 2023; Fiorentini et al., 2020). In cases where consumer expectation does not align with the actual experience, disconfirmation occurs. There are four theoretical frameworks which illustrate the different outcomes of such disconfirmation; assimilation, contrast, generalised negativity and assimilation-contrast (Anderson, 1973; Piqueras-Fiszman and Spence, 2015). Anderson (1973) highlighted that within each framework, provision of product information influenced consumers product rating in contrast to the blind condition where no information was provided.

The sensorial characterisation of plant-versus meat-based burgers reported here concur with previously published work in which meat-based burgers are associated with attributes such as meaty and juicy and plant-based burgers are characterised as dry in texture and appearance, with perceived wheaty and off-flavours (Godschalk-Broers et al., 2022; Grasso et al., 2022; Neville et al., 2017; Schouteten et al., 2016). Some of these attributes have been noted to negatively impact consumer acceptability of burger products (Neville et al., 2017).

Dry appearance and texture may be the result of poor water-binding capacity and/or fat content, both of which are crucial in the successful replication of desirable mouthfeel and perceived juiciness (Boukid, 2021; Moss et al., 2023). Quantity of plant-based protein can further influence mouthfeel (Moss et al., 2023). Yuliarti and colleagues (2021) reported increased pea protein produced lower acceptance of textural properties. Furthermore, legume protein has been associated with off-flavouring and an unpleasant mouthfeel (Moss et al., 2023). Salt, spices and other flavourings are often added to mask these off-flavours (Asgar et al., 2010; Giacalone et al., 2022; Sha and Xiong, 2020). Likewise colourants can assist replication of meat-based visual cues such as a 'red colouring' (Boukid, 2021). However, both temperature and pH can lead to colour degradation and the attribution of "uneven colour" to plant-based burger products has previously been described (Kyriakopoulou et al., 2019).

In this study, assessors perceived plant-based burgers as "processed"

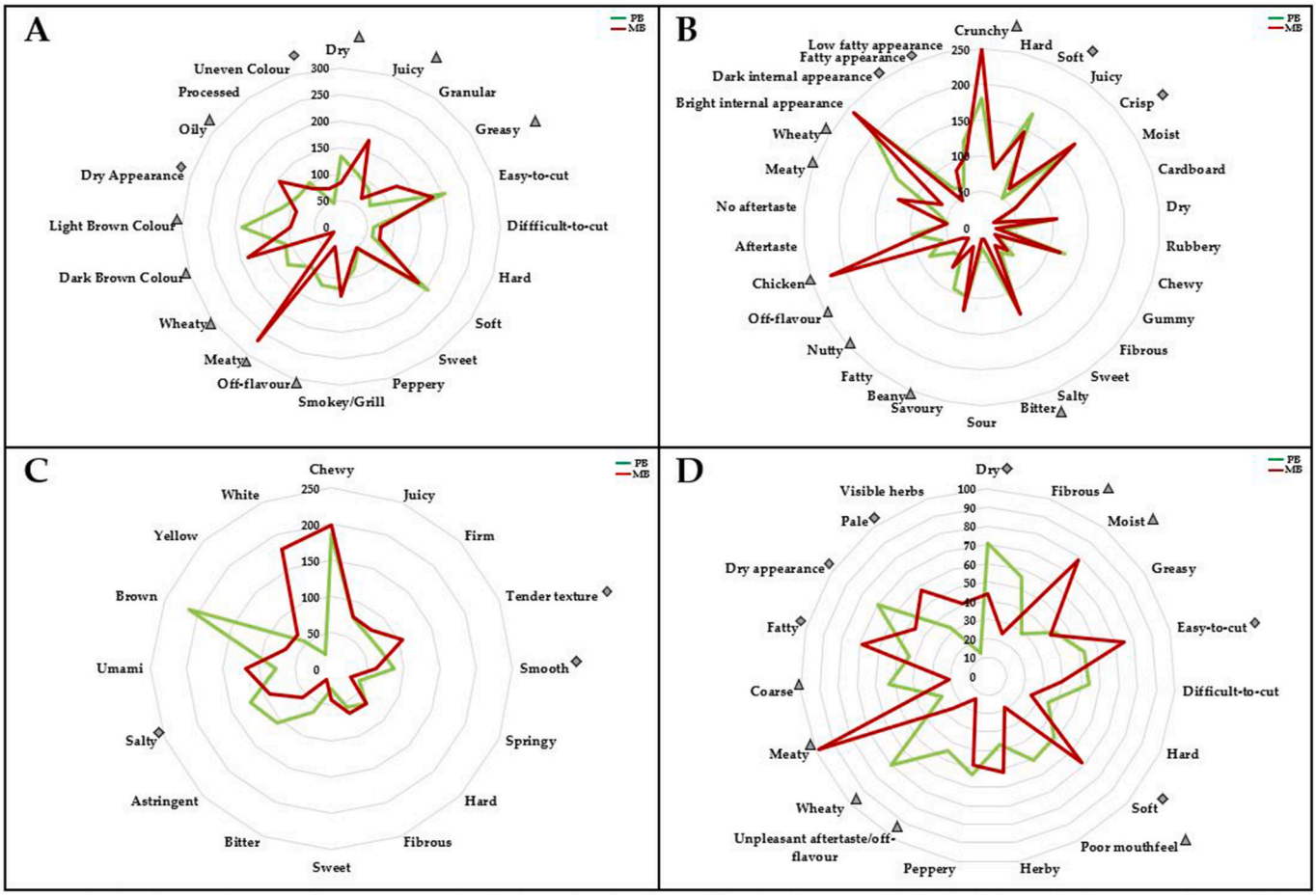

Fig. 4. Radar chart of CATA attributes assigned by naïve assessors to describe plant-and meat-based A, meatball products (n = 53 assessors) B, breaded 'chicken' products (n = 62 assessors) C, plain 'chicken' products (n = 47 assessors) D, sausage products (n = 23 assessors). $\triangle p < .05$ $\diamond p < .001$.

in the closed label condition, though this did not hold true for open label. Ineffective replication of meat burgers, despite considerable commercial product development, may have led to an 'unnatural' and confusing appearance in closed label conditions. When assessors subsequently received product information a so-called 'halo effect' may have led assessors to perceive these as healthier for human and/or planetary health diluting scepticism regarding degree of processing (Ang et al., 2023; MacDiarmid, 2021; Sucapane et al., 2021).

Meatiness and juiciness have been reported to be key desirable attributes driving acceptance of burger products (Godschalk-Broers et al., 2022; Neville et al., 2017). Godschalk-Broers and colleagues (2022) cited these attributes to contribute to 47% of the liking of plant-based burgers. However, many plant-based burgers currently lack these qualities and dryness, bland and off-flavouring are key barriers to consumer acceptance (Grasso et al., 2022; Neville et al., 2017). This reinforces the crucial need to address these sensorial challenges to increase consumer adoption of such products.

Increased diversity in the PBMA industry has emphasised the need to consider emerging PBMA categories to improve understanding regarding the evolving market (Li et al., 2023). The current study also investigated meatballs, breaded 'chicken', plain 'chicken' and sausage plant-versus meat products, categories currently underrepresented in this field (Andreani et al., 2023).

Our findings show that the PBMA subcategories face similar challenges to burgers with significant variation existing both within and between plant-versus meat-based products. Typically, PBMA were perceived less acceptable than their meat-based counterparts (with the exception of plant-based breaded 'chicken' 1; Fig. 3B).

The variation within the plant-based breaded 'chicken' category could be attributable to factors such as protein source. For example, plant-based product 1 contained wheat protein and demonstrated significantly higher acceptability in contrast to plant-based product 2 (soy-based). Previous work on nuggets also found consumers demonstrated greater acceptability for wheat-based nuggets though the authors highlighted notable variation in acceptability for soy-based nuggets suggesting different processing methods are linked to varying degrees of acceptability (Ettinger et al., 2022).

Plain 'chicken' was the least acceptable product category: all plant-based products were rated less acceptable versus their meat-based equivalents (Fig. 3C). Whole muscle products, such as chicken breasts, are more challenging to replicate compared to processed meat products due to their complex structure (Jahn et al., 2021; McClements and Grossmann, 2021). Godschalk-Broers and colleagues (2022) found 12 of 13 plant-based 'chicken' alternatives were significantly less liked compared to the single control meat-based product. The authors reported the one plant-based product demonstrating similar acceptability to the meat-based control contained 76% milk, an animal-derived ingredient noted to resemble meaty flavours (Zhu and Xiao, 2017). Alternately, all three plain 'chicken' alternatives used in our present study were soy-based. Godschalk-Broers and colleague's (2022) study was not conducted in a controlled environment and while the setting of participants homes may offer a more accurate tasting context, their findings may have been influenced by confounding variables (e.g., variation in cooking time).

Plant-based samples in subcategories other than burgers were frequently described, in the current study, to have off-flavours such as

"wheaty", "beany", "bitter", "astringent" and "nutty". Additionally, dry texture and appearance were also associated with meatball and sausage products in line with previous research (Ettinger et al., 2022; Godschalk-Broers et al., 2022; Neville et al., 2017). Ettinger and colleagues (2022) stated that attributes associated with plant-based nuggets were linked to lower acceptability. Aforementioned factors such as product composition, water-retention efficacy and the type and quantity of protein and fat may contribute to these perceptions (Boukid, 2021; Fiorentini et al., 2020; Giacalone et al., 2022; Moss et al., 2023). The association between plant-based plain 'chicken' and a "salty" flavour may simply be the result of a typically higher salt content with plant-versus meat-based chicken products, a common characteristic of most PBMA products (Alessandrini et al., 2021; Curtain and Grafenauer, 2019; SafeFood, 2020; Tonheim et al., 2022).

Unsurprisingly the meat-based samples were more associated with the flavours such as "meaty", "chicken", "umami" and textural attributes such as "tender," "juicy" and "easy-to-cut". Previous research has identified these characteristics as desirable and drivers of product acceptability (Ettinger et al., 2022; Godschalk-Broers et al., 2022; Neville et al., 2017). Similarly, the qualities "crispy" and "crunchy" have also been deemed pleasant characteristics associated with nugget products (Ettinger et al., 2022).

In contrast to burgers, the lack of influence of condition and familiarity upon product acceptability may be related to the novelty of the smaller subcategories limiting consumer familiarity. For example, while plant-based burger products are well-established in the market, consumer familiarity in relation to emerging entrants such as plain 'chicken' and meatballs may be limited (He et al., 2020). It is possible though that the lack of influence of condition and familiarity in the subcategories work was because it was undertaken with fewer assessors compared to the burger category work. Throughout the work, and indicative of the rapidly changing product landscape for PBMAs, supply chain challenges impacted product availability, reformulation and nutritional composition. For example, on product arrival, the final sausage product pair 3 only fell within the 20% tolerance limit across two of the nutritional categories within the heatmap. Future research should also consider the challenge of product availability. For example, Ettinger and colleagues (2022) recognised and accounted for such variation by selecting products which were consistently available over a period of store visits.

Throughout this work, it is likely that the restricted sample size limits the generalisability of the findings to the wider population, particularly for some subcategories of products. Segmentation upon analysis may have further compounded this issue. Our findings may therefore be considered preliminary, and further studies, with larger sample sizes of habitual consumers and habitual non-consumers of PBMAs, are warranted to corroborate our novel findings with regard to the acceptability of emerging or more unusual PBMA product categories. The study aimed to minimise variation in nutritional composition to address the limitation of previous studies. Further work would benefit from continued efforts to control for the influence of variation in product composition, which remains exceptionally challenging when testing commercially available products. It should also be noted that while the controlled nature of the laboratory environment promotes internal validity in the current study, the artificial nature of the consumption setting limits the representability. Thus caution should be applied when extrapolating these preliminary findings to real world consumption contexts.

5. Conclusion

This study reports consumer acceptability and sensorial characterisation of plant-based burgers and four additional underrepresented PBMA product categories versus meat-based equivalents, stratified by exposure to product information and by prior level of familiarity with PBMAs. There was a significant main effect of product type on acceptability rating across all product categories whereby the majority of PBMAs were perceived to be less acceptable compared to their meat-based equivalent. This emphasises the significant challenge product developers need to address to facilitate production of desirable PBMAs for retail. However, due to the sample size and context of the test, which was conducted in a laboratory environment, our findings should be interpreted as preliminary and need to be confirmed in larger studies undertaken in a real-world consumption context.

Our preliminary findings emphasise the need for manufacturers to place particular attention on removing characteristics such as wheaty off-flavours and increasing desirable attributes such as juicy texture to successfully mimic meat-based equivalents. Thus, future research is warranted to increase understanding regarding the influence of specific protein source/quantity and innovative processing methods are required to improve consumer acceptability. The possible influence of product information also warrants further investigation to evaluate specific types of messaging and how this can be appropriately applied to increase familiarity and facilitate effective educational and marketing strategies within prescribed constraints. Such knowledge may support evidence based PBMA development and manufacturing practice. Furthermore, identifying the needs and barriers within specific consumer subgroups will enable manufactures to tailor PBMA products to meet consumer demand which may accelerate sustained consumer adoption of PBMAs across the consumer population. This has the potential to facilitate the required dietary transition to reduce meat and increase plant-based consumption which may contribute to enhanced individual and planetary health.

Implications for gastronomy

Food manufacturers need to strike a careful balance between creating a desirable gastronomic experience whilst ensuring the sustained delivery of nutritious food. Shifting dietary patterns at a population level to reduce meat and increase plant-based food consumption are inhibited by the challenge of creating an equivalent organoleptic experience. While plant-based meat alternatives may offer a stepping-stone to accelerate the transition towards healthier, more sustainable food systems, our study articulates that sensorial barriers remain. In particular, the plant-based industry needs to focus on eradicating undesirable characteristics associated with plant-based meat alternatives. A deeper understanding of consumers' perceptions of plant-based meat alternative products that influence purchasing behaviour is required to support optimal recipe development and appropriate marketing strategies for future wholescale adoption.

CRediT authorship contribution statement

Megan Flint: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Fiona Leroy:** Writing – review & editing, Project administration, Investigation, Data curation, Conceptualization. **Simon Bowles:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Anthony Lynn:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Jenny R. Paxman:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Ethical statement

Ethical approval for the involvement of human subjects in this study was granted by Sheffield Hallam University Research Ethics Committee (ER42087634, 11.05.22).

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Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijgfs.2025.101102.

Data availability

Data will be made available on request.

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