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A sensory study on consumer valuation for plant-based meat alternatives: What is liked and disliked the most?

Giovanni Sogari [a,*], Vincenzina Caputo [b], Andrew Joshua Petterson [c], Cristina Mora [a], Fatma Boukid [d]

[a] Department of Food and Drug, University of Parma, Parma, Italy
[b] Department of Agricultural, Food, and Resource Economics, Michigan State University, East Lansing, MI, USA
[c] Charles H. Dyson School of Applied Economics and Management, Cornell University, Ithaca, NY, USA
[d] ClonBio Group Ltd., 6 Fitzwilliam Pl, D02 XE61 Dublin, Ireland

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ABSTRACT

The food sector has witnessed a surge in the production of plant-based meat alternatives that aim to mimic various attributes of traditional animal products. However, overall sensory appreciation remains low. This study employed open-ended questions, preference ranking, and an identification question to analyze sensory drivers and barriers to liking four burger patties, i.e., two plant-based (one referred to as pea protein burger and one referred to as animal-like protein burger), one hybrid meat-mushroom, and one 100 % beef burger. Untrained participants (n = 175) were randomly assigned to blind or informed conditions in a between-subject study. The main objective was to evaluate the impact of providing information about the animal/plant-based protein source/type, and to obtain product descriptors and liking/disliking levels from consumers. Results from the ranking tests for blind and informed treatments showed that the animal-like protein was the most preferred product, followed by the 100 % beef burger. Moreover, in the blind condition, there was no significant difference in preferences between the beef burger and the hybrid and pea protein burgers. In the blind tasting, people preferred the pea protein burger over the hybrid one, contrary to the results of the informed tasting, which implies the existence of affecting factors other than pure hedonistic enjoyment. In the identification question, although consumers correctly identified the beef burger under the blind condition, they still preferred the plant-based 'animal-like' burger.

1. Introduction

The world is currently experiencing an unparalleled increase in population, combined with rapid economic growth that has led to an increase in average individual income (Godfray et al., 2018). This has resulted in a significant rise in global demand for meat over the past few decades (Battaglia Richi et al., 2015; He et al., 2020). However, meat production, particularly red meat, is a major contributor to CO2 emissions (González et al., 2020), consumes one-third of the world's water supply, and 98% of animal feed used in agriculture (Godfray et al., 2018). Moreover, it is responsible for the conversion of vast areas of arable land, which in turn compromises biodiversity (Nijdam et al., 2012). Overconsumption of meat is also associated with several health concerns, such as cardiovascular diseases and hypertension (Battaglia Richi et al., 2015; Godfray et al., 2018), and animal welfare issues (Marescotti et al., 2020).

As a result, there has been a shift towards plant-based diets, which either reduce (i.e., flexitarians) or eliminate meat consumption (i.e., vegan and vegetarian) (Dagevos, 2021). The food industry is actively developing new meat alternatives to cater to this demand (Andreani et al., 2023), with plant-based meat alternatives (PBMAs), fungi-based, and culture-grown meat alternatives being the most extensively studied options (Onwezen et al., 2021; Van Loo et al., 2020). Among these alternatives, PBMAs currently dominate the market, likely due to consumer familiarity and the entry of popular brands (e.g., Beyond Meat Inc., Morningstar™, and Impossible Foods Inc.) into the mainstream market (Bohrer, 2019; Sha & Xiong, 2020). These products simulate animal sensory potentials and include a vast variety of products such as

* Corresponding author at: Department of Food and Drug, University of Parma, Parco Area delle Scienze 45, 43124 Parma, Italy.
E-mail addresses: giovanni.sogari@unipr.it (G. Sogari), vcaputo@msu.edu (V. Caputo), ajp264@cornell.edu (A. Joshua Petterson), cristina.mora@unipr.it (C. Mora), fboukid@clonbioeng.com (F. Boukid).

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burgers, sausages, meatballs, and bacon (Ahmad et al., 2022).

As sensory attributes are crucial in driving food purchases (Hung & Verbeke, 2018), companies have developed various PBMAs (e.g., burgers, sausages, meatballs, and bacon) that simulate animal sensory potentials (Ahmad et al., 2022). Technological advancements have enabled the production of low-moisture and high-moisture textured vegetable proteins with a meat-like texture, juiciness, and bite (Boukid, Rosell, Rosene, et al., 2021). The latest generation of PBMAs has made improvements in texture and color to enhance consumer acceptance of plant-based alternatives (Barone et al., 2021; Grasso et al., 2022). However, producing PBMAs with similar sensory attributes as animal-based meat products, such as appearance, flavor, odor, and texture (Fiorentini et al., 2020; Giacalone et al., 2022), while keeping prices low remains a significant challenge for producers. As a solution, hybrid meat products have emerged, which blend animal- and plant-based ingredients, preserving the sensory properties of meat products (Boukid & Castellari, 2021; Grasso & Jaworska, 2020) and facilitating the transition towards a semi-vegetarian diet (i.e., flexitarianism) (Grasso et al., 2022; Sogari et al., 2021; Spencer & Guinard, 2018). However, sensory studies evaluating consumer preferences for different meat alternatives remain limited.

Sensory studies are essential for improving product characteristics, understanding consumer expectations, and increasing consumer acceptance (Aschemann-Witzel et al., 2019). However, training assessor panels for descriptive analysis can be time-consuming and expensive. Furthermore, trained panelists may report attributes that are not relevant to consumers' perception (Fonseca et al., 2016; Varela & Ares, 2012). To overcome this issue, researchers have recently proposed new methods that rely on sensory terms generated by untrained individuals, such as consumers (Fonseca et al., 2016). For instance, open-ended questions that allow for free-text responses are considered user-friendly for consumer tests (ten Kleij & Musters, 2003). Nevertheless, researchers seldom conduct an extensive textual analysis of consumer feedback, as it can be laborious and time-consuming (Varela & Ares, 2012). Despite so, qualitative data is a valuable resource, and sensory descriptions in "consumer language" can aid in comprehending consumers' perceptions of a product from a sensory standpoint and why they prefer or dislike it (Fonseca et al., 2016; Seo et al., 2021). Many previous studies have evaluated the impact of information disclosure on sensory characteristics and provide insights for product marketing (Grasso et al., 2017, 2022; Martin et al., 2021). Therefore, using untrained individuals, such as consumers, to elicit sensory terms via open-ended questions and conducting an in-depth textual analysis of the responses can offer valuable insights for product development and marketing.

This study aims to investigate the impact of informing consumers about the composition of commercial burgers on their sensory perception. To achieve this goal, we employed blind and informed conditions to assess the effect of animal/plant-based protein sources on product preference ranking. We also considered various commercial brands of plant-based meat alternatives (PBMAs), hybrid meat alternatives, and traditional beef burgers, as suggested by recent studies (Falkeisen et al., 2022; Grasso et al., 2022; Moss et al., 2022; Samant & Seo, 2020; Varela & Ares, 2012). Untrained participants (n=175) were recruited for hedonic tests, as these tests typically require a sample of 75-150 consumers who are regular users of the product (Lawless & Heymann, 2010). Participants were asked to taste the products, describe them using consumer jargon, and rate their liking/disliking levels. We employed various sensory techniques, including open-ended questions (Symoneaux, Galmarini, & Mehinagic, 2012) and identification questions. Additionally, we used a ranking test to determine the most and least preferred alternatives for the different conditions (blind vs. informed) and explored whether the information (i.e., beef vs. hybrid meat-mushroom vs. pea protein patty vs. animal-like patty) influenced consumers' preferences and sensory descriptors.

The results of this study can inform product reformulation and marketing campaigns. They can also provide valuable insights to increase consumer acceptance of plant-based and hybrid meat substitutes. The findings could assist food producers in making more informed marketing decisions concerning the communication strategy of these products and promoting their consumption (Caputo et al., 2022; Grasso et al., 2022). Additionally, the results could be helpful to product developers of meat alternatives in meeting consumer expectations and, if desired, better resembling the benchmark product, i.e., the traditional beef patty.

2. Methods

2.1. Sample preparation and evaluation

In this study, we considered four burgers – namely, 100 % animal-based (beef), hybrid (≈75 % grass-fed beef and ≈25 % mushrooms), 100 % plant-based (made with pea proteins), and 100 % plant-based (made with soy proteins and soy leghemoglobin) – that are commercially available in most grocery stores and restaurants in the United States. The hybrid meat-mushroom burger (The Blend Burger™) and the plant-based burger with pea proteins (Beyond Burger®) were purchased from local supermarkets (Ithaca, NY, USA), whereas the 100 % beef and the plant-based burgers made with soy proteins and soy leghemoglobin (Impossible™ Burger) were directly purchased at the college (Cornell, NY, USA) dining center. The plant-based brands (Impossible™ Burger and Beyond Burger®) were selected as they were among the most sold in the US at the time of the data collection (Impossible Burger vs. Beyond Meat Burger: Taste, Ingredients and Availability, Compared, 2019). These two products differ in ingredients, especially in the protein source. Furthermore, these products were chosen as test samples as they exhibited variations in consumer responses in a previous study (Van Loo et al., 2020). Regarding the beef patty, the decision to select a product available at the university canteen was based on the idea of presenting something participants were familiar with.

Table A1 in the Appendix shows the ingredient list and the nutritional facts reported on the labeling of the meat alternatives. The burgers were stored in frozen conditions (−18 °C ± 2.0 °C) until they were used for the sensory experiments. Each type of burger was prepared according to the manufacturer's guidelines reported on the packaging. The samples were served within 30 min of cooking and kept warm in slow cookers (60 °C ± 4.0 °C – which is the common serving temperature of burgers) (Monego et al., 2018). Half a burger was presented to each participant and no buns were included with the patties. Serving sizes (65 g) were sufficient to allow 2–3 bites per sample. No dressing or condiments were added, except for a small pinch of salt.

The products were served in a white paper containers coded with a 3-digit random number and presented in a monadic and randomized sequence following a Williams Latin Square experimental design (Williams, 1949). To reduce sensory fatigue, filtered water and crackers were available to participants to cleanse their palates before tasting each sample. The sensory evaluation was carried out in an individual testing room of a college sensory laboratory designed according to ISO 8589 (ISO 2007), with adequate ventilation, temperature regulation, and protection from outside sounds.

2.2. Consumer panel product evaluation

Data from this study were collected using computers with the RedJade® Sensory Software Suite (RedJade Sensory Solutions LLC, California, USA)[1]. Participants were recruited from the Ithaca area (NY, US) and the university campus through invitations via e-mail, flyers, and social networks, and they included students, faculty, and staff members

[1] This study was deemed exempt by the Cornell University Institutional Review Board (Protocol ID # 1908009006).

as well as the general public. Selected participants were aged 18 or older, were primarily food shoppers, regular buyers, and consumers of meat burgers in the preceding six months (i.e., vegetarians and vegans were excluded). They also signed the informed consent and confirmed that they had no allergies or intolerances (e.g., wheat/gluten, tree nuts, or soy). During the recruitment process, participants were not informed about the nature of the study or the characteristics of the products, including the burger full list of ingredients and the brand names. The sensory testing took place at the Cornell Sensory Evaluation Center in September 2019, and each sensory experiment lasted about 30 min. At the end of the experiment, participants were given $5 as a participation fee.

Altogether, 178 participants were recruited; however, to obtain a homogeneous group, three retired individuals were removed for a final sample of 175 consumers, with an average age of 30.2 years (±13.4). Table 1 outlines the basic socio-demographics of the final sample: 37.1 % of participants were fully employed, 53.7 % were students, and the remaining 10 % were split into part-time employment and other arrangements. As for ethnicity, most participants (57.1 %) were white, followed by Asian or Pacific Island participants (29.7 %). Most consumers self-identified as omnivores, and 55 % of participants had not eaten a plant-based burger in the previous three months.

During the experiment, respondents were randomly assigned to one group, either the blind or the informed sensory group (see Fig. 1). In the blind treatment group, consumers were asked to taste the four burgers and then answer questions about their sensory experience without knowing what they had tasted. In the informed sensory group, consumers were made aware of the nature of the four burgers before they evaluated them, i.e., 100 % beef burger, hybrid meat-mushroom burger, plant-based 'pea protein', and plant-based 'animal-like protein'. "Animal-like protein" was used to label the plant-based Impossible™ burger made with soy proteins and soy leghemoglobin, in particular the heme protein (unique to the Impossible™ products) closely mimic the taste of animal meat (Fraser et al., 2018). The decision to use this term was consistent with a previous study by Van Loo et al. (2020) where a choice experiment was conducted using this label to identify such products.

No information about the brand (to avoid the "brand effect") and the nutritional facts (not in the scope of the study) of the products was provided to participants. After tasting each product, participants were asked to report what they liked/disliked about the burger using two open-ended questions (Step 1): "What, if anything, do you like about this burger?" and "What, if anything, do you dislike about this burger?".

After tasting all four burgers, participants were asked to rank the products from the most preferred to the least preferred (Step 2) and respond to two additional open-ended questions using free-text responses (Step 3), i.e., "Why did you choose the product ranked as first, and the one ranked as fourth?". Finally, participants in the blind tasting group were asked to identify which product they believed was the 100 % beef option (Step 4) and explain their choice (Step 5). We did not reveal whether the choice they made was correct.

Table 1
Socio-demographics information of the sample (n = 175).

	Treatment		
	Blind (85)	**Informed (90)**	**Total (175)**
Gender			
Male	31.8 %	33.3 %	32.5 %
Female	67.0 %	66.7 %	66.9 %
Other/No Response	1.2 %	0 %	0.6 %
Age (years)			
Mean	29.93	30.46	30.2
Standard Dev.	13.40	13.37	13.38
Race			
White	52.9 %	61.1 %	57.1 %
African American	2.4 %	3.3 %	2.9 %
Hispanic	3.5 %	6.7 %	5.1 %
Native American	0 %	1.1 %	0.6 %
Asian/Pacific Islander	31.8 %	27.8 %	29.7 %
Other	9.4 %	0 %	4.6 %
Employment			
Full-time	34.1 %	40.0 %	37.1 %
Part-time	5.9 %	7.8 %	6.9 %
Student	56.5 %	51.1 %	53.7 %
Other	3.5 %	1.1 %	2.3 %
Dietary Regimen			
Omnivore	87.1 %	94.5 %	90.8 %
Flexitarian	7.0 %	4.4 %	5.7 %
Other	5.9 %	1.1 %	3.5 %

Note: A chi-square test testing the null hypothesis of equality of frequencies of demographics across groups was performed and there were no significant differences between the two groups.

2.3. Data analysis

Four types of analysis were used to explore the data collected during the sensory experiment: a comment and correspondence analysis of the open questions, a ranking analysis of the preference for the four burgers, and finally the identification of the beef burger among the alternatives.

First, after a cleaning process, we started with the comment analysis to explore the open-ended questions collected in Steps 1 and 3 (see Fig. 1), as shown in Table A2 in the Appendix. The analysis was divided into two steps: a) the development of contingency tables, which were created by counting the number of respondents who used the same attributes within each product and question; b) a comment analysis on likes and dislikes (Section 3.1), as previously performed in prior studies by Symoneaux et al., (2012) and Ares et al., (2010). To increase the accuracy of data interpretation, contingency tables were analyzed using a global chi-square test and chi-square per cell test, which allowed the identification of significant differences in consumers' response frequencies among the products for each sensory attribute (Symoneaux & Galmarini, 2014).[2] The presentation of the results in response frequency is a common format used in previous studies (Symoneaux et al., 2012; Varela et al., 2014).

Second, we executed a correspondence analysis[3] (Section 3.2) to visualize the relationship between product samples and attributes, as suggested in previous research (Symoneaux et al., 2012; ten Kleij & Musters, 2003). Using this technique, row and column variables were spatially represented, which allowed a visual representation of the data (Greenacre, 1984; ten Kleij & Musters, 2003). We obtained 2-dimensional representations of the four samples and the sensory attributes.

The ranking analysis (Section 3.3) was conducted by applying a Friedman test within each treatment to determine the significant differences in the ranking of our samples. Each respondent was asked to rank the four burgers from 1 to 4, with 1 being the favorite and 4 being the least favorite. These rankings were averaged for each product to obtain a final rank for all the respondents. Thus, a lower mean represents that, on average, the burger was preferred in the rankings among respondents. Additionally, the two treatments were further disaggregated based on demographic information (i.e., gender) to analyze any potential for treatment differences. To compare the rankings between treatments and identify differences between individual preference rankings for the various products, a Mann-Whitney *U* test was performed (Barsics et al., 2017). Given the nature of the ranking scale employed, a negative rank difference indicates that the sample in the informed tasting group is more preferred than the sample in the blind tasting group, whereas a positive rank difference indicates the opposite effect.

Finally, the analysis of the question asking respondents which of the

[2] This statistical approach was performed using a Visual Basic macro developed by Symoneaux et al., (2012) as in other studies (Cadena et al., 2014; Fonseca et al., 2016; Sharma, Swaney-Stueve, Severns, & Talavera, 2019).

[3] Correspondence analysis is a descriptive/exploratory technique designed to analyze simple two-way contingency tables containing some correspondence between the rows and columns (Symoneaux et al., 2012).

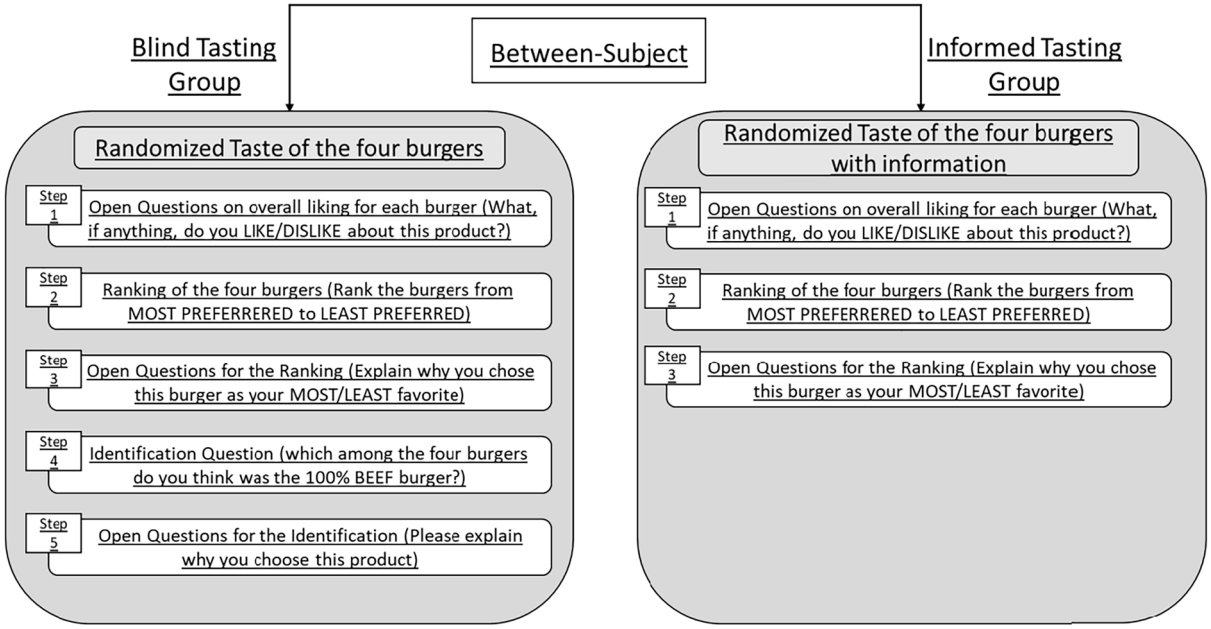

Fig. 1. The flow of the questions outlined in the sensory experiment.

four products they believed was the 100 % beef burger and *why* was conducted (Section 3.4). We used a binomial test to determine whether respondents perceived a difference between the beef sample and the other burgers, i.e., the accuracy of individuals in identifying the correct answer was higher than a random guess (Lawless & Heymann, 2010). We also cleaned the open-ended part (*why*), and then categorized the data into four senses, namely 'Taste', 'Texture', 'Smell', and 'Appearance'. This allowed us to determine which senses were relied on most heavily when trying to identify the 100 % beef sample. The software XLSTAT version 2020.5 (Addinsoft SARL, France) was used for data analysis.

3. Results

3.1. Comment analysis on likes and dislikes

Tables 2-5 show the results of the global chi-squares for the liking and disliking questions across the blind and informed groups. The tables also report the contribution of each cell (Attribute) to the global chi-square, which is indicated through a "(+)" or a "(−)" and shows whether the frequency observed is higher or lower than expected (Symoneaux et al., 2012; Symoneaux & Galmarini, 2014). For example, within the row "Meat-like", if a burger had more responses overall, then it would also have a higher expected value within that row than other burgers with fewer total data points.

Table 2
Frequency of terms provided by consumers for the Blind All Liked Open-response.

Attributes	100 % Beef	Hybrid meat-mushroom	Pea Protein	Animal-like Protein	Total
Appearance	7	4	4	10	**25**
Cooking	4	2	9(+)*	4	**19**
Juicy	4(−)**	34(+)***	10	12	**60**
Meat-like	43 (+)***	23	11(−)***	25	**101**
Seasoning	10	12	6	5	**33**
Smell	1	1	4	5	**11**
Smokey	3	1	3	5	**12**
Soft	0	3	2	5	**10**
Taste	17	29	26	38	**110**
Texture	11	16	26(+)**	20	**73**
Thickness	0	2	9(+)***	2	**13**
Total	**100**	**127**	**110**	**130**	**467**

The probability (p) value for the global chi-square test was < 0.0000. * (p <= 0.05), ** (p <= 0.01), *** (p <= 0.001); effect of the chi-square per cell. The significant contribution of each attribute to the global chi-square is between parentheses. Attributes marked with a (+) were reported more than expected and attributes marked with (−) less than expected.

Table 3
Frequency of terms provided by consumers for the Informed All Liked Open-response Results.

Attributes	100 % Beef	Hybrid meat-mushroom	Pea Protein	Animal-like Protein	Total
Appearance	2	3(−)*	12(+)**	10	**27**
Experience	4	3	4	1	**12**
Juicy	3(−)**	25(+)**	15	15	**58**
Meat-like	46 (+)***	34	17(−)***	37	**134**
Mushroom	0(−)*	18(+)***	0(−)*	0(−)**	**18**
Savory	3	2	5	3	**13**
Seasoning	8	4	7	11	**30**
Smell	3	3	2	4	**12**
Taste	21	29	28	40	**118**
Texture	14	23	26	29	**92**
Total	**104**	**144**	**116**	**150**	**514**

Notes: The probability (p) value for the global chi-square test was < 0.0000. * (p <= 0.05), ** (p <= 0.01), *** (p <= 0.001); effect of the chi-square per cell. The significant contribution of each attribute to the global chi-square is between parentheses. Attributes marked with a (+) were reported more than expected and attributes marked with (−) less than expected.

All global chi-square analyses returned significant results and provided many insights into what shaped consumers' preferences around the four product samples. The 100 % beef sample immediately stands out for being liked, since participants recognized its meat properties; however, being liked for juiciness was found to be less important than expected in both the blind (Table 2) and informed treatments (Table 3). Juiciness was a key positive attribute for the hybrid meat-mushroom burger under both conditions. In the informed condition, its mushroom attributes were also widely liked, whereas its appearance was reported as unsatisfactory.

In the blind treatment, many respondents reported liking the pea

Table 4
Frequency of terms provided by consumers for the Blind All Disliked Open-response.

Attributes	100 % Beef	Hybrid meat-mushroom	Pea Protein	Animal-like Protein	Total
Aftertaste	1(−)*	6	6	7	**20**
Appearance	4	4	6	3	**17**
Bland	17(+)**	9	5(−)*	2(−)*	**33**
Chewy	11	3	13	1(−)*	**28**
Color	6	4	8	3	**21**
Cooking	12(+)**	4	4	2	**22**
Dry	28 (+)***	3(−)**	8(−)*	8	**47**
Not Meat-like	2(−)***	10	15	16(+)**	**43**
Smell	6	8	12	8	**34**
Taste	5(−)***	17	20	17	**59**
Texture	24	18	28	11	**81**
Vegetable/ Legume	0(−)*	3	3	7(+)**	**13**
Total	**116**	**89**	**128**	**85**	**418**

Notes: The probability (p) value for the global chi-square test was < 0.0000. * (p <= 0.05), ** (p <= 0.01), *** (p <= 0.001); effect of the chi-square per cell. The significant contribution of each attribute to the global chi-square is between parentheses. Attributes marked with a (+) were reported more than expected and attributes marked with (−) less than expected.

Table 5
Frequency of terms provided by consumers for the Informed All Dislike Open-response.

Attributes	100 % Beef	Hybrid meat-mushroom	Pea Protein	Animal-like Protein	Total
Aftertaste	0(−)**	7	4	12(+)***	**23**
Appearance	4	4	9	3	**20**
Bland	7	11(+)***	3	0(−)**	**21**
Chewy	8	4	11	3	**26**
Color	4	6(+)*	2	1	**13**
Cooking	20 (+)***	5	1(−)**	1(−)*	**27**
Dry	35 (+)***	6(−)*	5(−)***	9	**55**
Greasy	3	4	2	5	**14**
Not Meat-like	2(−)**	6	15(+)*	12	**35**
Off Taste	0(−)*	2	2	9(+)***	**13**
Seasoning	12	5	6	7	**30**
Smell	2	6	2	10(+)**	**20**
Taste	5(−)**	10	24 (+)***	11	**50**
Texture	19	7(−)**	6(+)***	16	**78**
Vegetable/ Legume	0(−)**	13(+)***	4	6	**23**
Total	**121**	**96**	**126**	**105**	**448**

Notes: The probability (p) value for the global chi-square test was < 0.0000. * (p <= 0.05), ** (p <= 0.01), *** (p <= 0.001); effect of the chi-square per cell. The significant contribution of each attribute to the global chi-square is between parentheses. Attributes marked with a (+) were reported more than expected and attributes marked with (−) less than expected.

protein burger for its cooking, texture, and thickness attributes. In both the blind and informed groups, only a few respondents reported liking the pea protein burger for its meat-like attributes, whereas, in the informed condition, the same product was frequently reported as being liked for its appearance. Finally, the attributes of the animal-like protein burger were generally not liked.

Tables 4 and 5 indicate what respondents disliked about each burger in the blind and informed condition, respectively. In both conditions, the beef burger was mainly disliked, which could be due to the formulation and/or standard cooking conditions. These two attributes were listed more commonly than expected in both treatments. Another disliked attribute was blandness, particularly in the blind condition. However, in both treatments, the beef burger was rarely criticized for attributes such as taste, aftertaste, and off-taste. In the informed condition, respondents reported blandness, color, and vegetable/legume attributes as a reason for disliking the hybrid meat-mushroom burger more frequently than expected. In the blind condition, the pea protein burger was often disliked for its chewiness, while dryness and blandness were not a concern for most participants. In the informed condition, a significant portion of participants reported disliking the pea protein-based burger due to its taste, texture, and not-meat-like attributes. Finally, participants in the blind group reported not to like the animal-like protein sample for being not-meat-like and for its vegetable/legume attributes. The informed group also listed aftertaste, smell, and off-taste as significant contributors to disliking the animal-like product.

3.2. Correspondence analysis

Fig. 2 represents the analysis of the question "What did you like about this burger?", whereas Fig. 3 shows the analysis of the question "Why did you like this burger the least?". Percentages in Fig. 2A (87.01 %) and Fig. 2B (95.08 %) represent the explained variance of the two dimensions (F1 and F2). For the blind condition (Fig. 2A), all four burgers were distinct, which underlines that participants were able to detect significant differences between the burgers. We identified a clear difference between beef (positively associated with *meat-like*) and plant-based (made with pea protein) burgers, as they were localized on opposite sides of the first component (F1). The plant-based animal-like burger was located closer to the origin, meaning it is less differentiated than the other products. The hybrid meat-mushroom product was characterized by its *juiciness*.

A similar distribution was identified for the informed condition (Fig. 2B), with some differences. First, the discriminating attribute for the hybrid meat burger was the *mushroom flavor*; in addition, *appearance* was positively associated with the pea protein burger and negatively linked to the beef patty.

Fig. 3 represents the results for the question on *why* they choose the lowest ranked burger as their least favorite under blind and informed conditions. Percentages in Fig. 3A (87.60 %) and Fig. 3B (90.33 %) represent the explained variance of the two dimensions (F1 and F2). In the blind condition (Fig. 3A), the beef and hybrid burgers were discriminated from the rest, whereas the two plant-based burgers overlapped, indicating that they are less clearly differentiated. In the informed condition (Fig. 3B), the beef and animal-like protein burgers were discriminated against, while the hybrid meat-mushroom and the pea protein burgers were closely located. As a result, information plays a stronger role for some products than for others. For example, in both conditions, the 100 % beef sample was disliked for being *dry*, while in the informed condition, it was disliked for being *bland* and *overcooked*. Finally, in the informed condition, individuals reported disliking the animal-like protein burger because it was *processed* or had an unpleseant *smell*.

3.3. Ranking analysis

The results of the ranking tests for blind and informed conditions are reported in Table 6. In both conditions, the animal-like protein was the most preferred product, followed by the 100 % beef burger. In the blind condition, participants did not identify significant differences between the 100 % beef burger and the remaining alternatives. When considering gender, males did not identify significant differences among the three alternative burgers (two plant-based and one hybrid), while female participants reported significantly lower scores for the hybrid meat-mushroom and pea protein burgers compared to the animal-like protein burger.

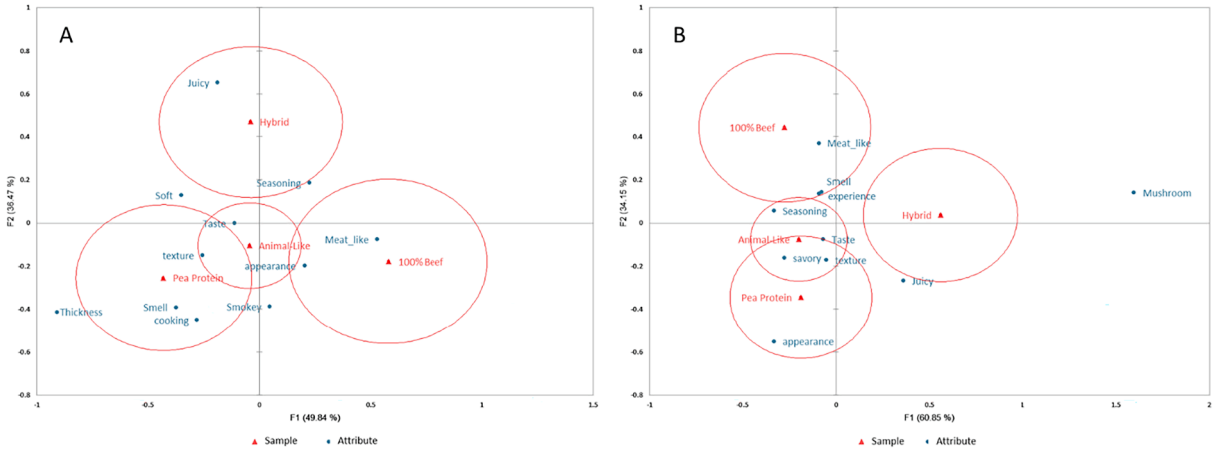

Fig. 2. Blind (Fig. 2A) and Informed (Fig. 2B): All Liking Correspondence Analysis. Note: Attributes are depicted in red, and product samples are depicted in blue. Attributes closer to a product sample were mentioned more frequently in relation to the sample than those located further away. The confidence ellipses around the samples show whether the products are perceived as significantly different from each other (Cadoret & Husson, 2013). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

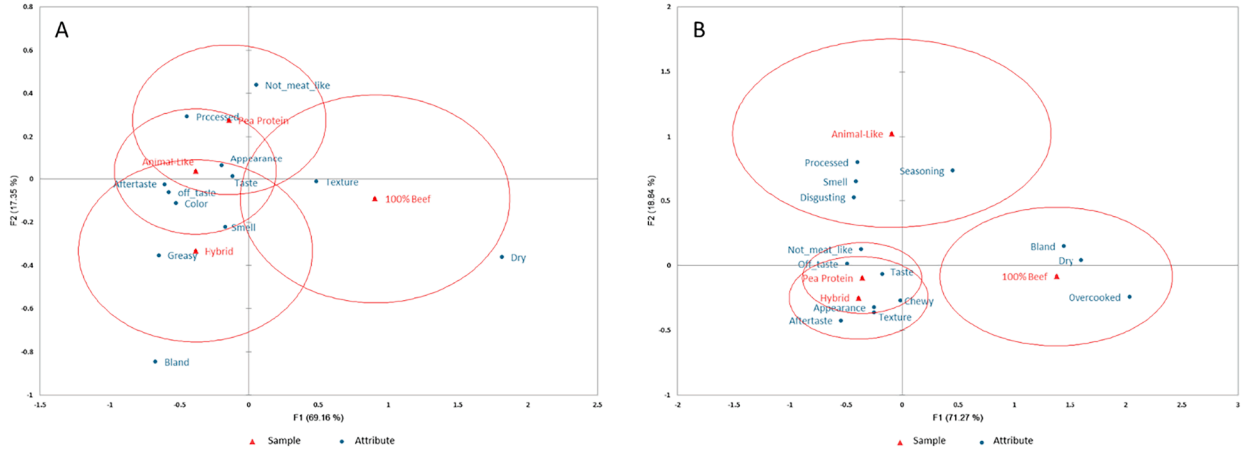

Fig. 3. Blind (Fig. 3A) and Informed (Fig. 3B) Least Liked Correspondence Analysis. Note: Attributes are depicted in red, and product samples are depicted in blue. Attributes closer to a product sample were mentioned more frequently in relation to the sample than those located further away. The confidence ellipses around the samples show whether the products are perceived as significantly different from each other (Cadoret & Husson, 2013). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 6
Results of the Ranking Test of the four burgers in informed and blind conditions.

	Friedman Test						Wilcoxon Test	
	Blind Condition			**Informed Condition**			**Results**	
Product Sample	All	Male	Female	All	Male	Female	Rank Difference	p-value
100 % Beef	2.47*ab* (2nd)	2.41*a*	2.50*ab*	2.30*a* (2nd)	2.20*a*	2.35*a*	−0.15	0.36
Hybrid meat-mushroom	2.77*b* (4th)	2.74*a*	2.78*b*	2.50*a* (3rd)	2.53*a*	2.48*ab*	−0.24	0.10
Pea Protein	2.69*b* (3rd)	2.48*a*	2.79*b*	3.13*b* (4th)	3.40*b*	3.00*b*	0.43	0.01**
Animal-like Protein	2.07*a* (1st)	2.37*a*	1.93*a*	2.07*a* (1st)	1.87*a*	2.17*a*	−0.03	0.78

Notes: In columns 2–7 of the table, we show the Friedman Rank test for the informed and blind condition, as well as within the male and female groups of participants. For the Friedman Test: a and b denote product samples with significant differences between them. The above analysis was conducted on a ranking scale from 1 to 4, with 1 being the favorite and 4 being the least favorite burger. The ranking of the samples for each treatment can be found in parentheses.
In the last two columns, we show the results of the Wilcoxon Rank Sum test which provides an analysis of the differences between treatments of the same product sample. For the Wilcoxon Test, the p-value of the rank difference represents the significance of the difference between the average ranking of a sample between the blind and informed condition. ** designates p-value <= 0.01.

In the informed condition, the pea protein burger was significantly different from the other three products. Among male participants, the same result was achieved, with the pea protein product sample being significantly different from the rest. Female respondents also identified the pea protein burger to be significantly different from the 100 % beef and animal-like samples, but not from the hybrid meat-mushroom burger.

The Wilcoxon Rank Sum Test was used to explore significant

differences in the rankings for the same product between the blind and informed condition. The informed group showed that the pea protein sample had a higher mean than the blind condition. As a result, in the average rankings, pea protein was ranked third – above the hybrid meat-mushroom patty – in the blind condition and last in the informed group.

After the ranking questions, participants were asked to explain their choice. The comments were tested using global Chi-square and Chi-square per-cell tests. All but one (Blind Most Liked) of the most and the least liked tests returned significant global Chi-square and Chi-square per-cell results. These results closely followed the same reasoning for liking and disliking seen in the general open-ended response section (Section 3.1). Therefore, it was decided not to report and comment on these tests in the manuscript, but to provide them in the Appendix (Tables A3 – A6).

3.4. Identification

Under blind conditions, respondents were asked to identify the 100 % beef burger among the four products. Table 7 shows that more than half of the participants recognized the beef burger correctly (54.11 %) with men showing a slightly higher accuracy level than women. The second most selected item was the hybrid meat-mushroom burger (28.24 %), which still contains beef, followed by the animal-like protein (16.47 %), and the pea protein (1.18 %) burgers.

Table 8 shows the reasons provided by participants for the identification test. For the 100 % beef burger, the taste was the most significant reason for individuals' guesses, garnering the highest number of responses (n = 29), followed by the texture (n = 23), and appearance (n = 14). The smell was the least significant sense (n = 7) relied upon in respondents' guesses.

4. Discussion

Heretofore, technological innovations of PBMAs have enabled the development of a wide variety of plant-based meat alternatives (Giacalone et al., 2022), and this sector is expected to gain increased industry, policy, and consumer attention in the years to come (Apostolidis & McLeay, 2016; Aschemann-Witzel et al., 2020). However, reproducing the complex sensory profile of animal meat products, especially the texture and flavor of muscle-like tissue, is technologically challenging (Sha & Xiong, 2020). Nevertheless, previous studies (Kerslake et al., 2022; Neville et al., 2017) have identified how taste, appearance, and texture are crucial factors for the acceptance or rejection of plant-based and hybrid products. In fact, in our study the main reason provided by participants for the identification test was the taste, followed by the texture, the appearance, and, to a lesser extent, the smell.

Our results also confirm some strong preferences and greater liking that consumers usually have towards familiar foods, such as beef burgers (Caparros Megido et al., 2016; Caputo et al., 2022; Grasso et al., 2022). In the informed group, the pea protein burger ranked as the least favorite and was perceived as significantly different from the other three products. One potential reason for this differentiation could be the peculiar organoleptic properties of peas, such as legume flavor, less fibrous structure, and meat-unlike mouthfeel (Boukid, Rosell, & Castellari, 2021). This result is consistent with earlier studies that found plant-based burgers (made with lentils) were the least preferred compared to beef burgers and beef blended with mealworms (Caparros Megido et al., 2016). However, in our blind tasting, people preferred the pea protein burger over the hybrid one. This outcome could be attributed to the texture and the smell of the pea protein burger, which were two attributes appreciated in the open responses. On the other hand, in the informed tasting, the pea protein burger was less liked than the hybrid burger, implying that label information impacted the perception of the product. This might be explained by the fact that peas may have negative connotation, and that people are not familiar with having legumes in highly processed products (Lemken et al., 2019).

Furthermore, in blind and informed tasting, people preferred the animal-like burger over the 100 % beef burger, implying that the order of preference depended mostly on hedonistic enjoyment. In fact, even though most participants accurately identified identified the beef burger in the blind condition, the animal-like burger was still ranked as the most preferred, indicating that hedonistic enjoyment was the primary factor in determining the preference. The animal-like protein burger was the plant-based patty that more closely mimicked conventional ground beef patties. This could be due to the use of soy leghemoglobin as a color/flavoring agent, as this ingredient is able to resemble the "bloody" appearance of meat heme proteins (hemoglobin and myoglobin) and to evoke the characteristic meat-like mouthfeel and taste (Fraser et al., 2018). Nevertheless, in the blind condition, even the animal-like protein burger showed some negative attributes of dislike, such as "not meat-like" and "vegetable". These terms might be connected to the beany smell of soy and soy-related products, as well as off-odors generated during processing (Zhang et al., 2021). However, in the informed condition, these attributes were not significantly different when compared to the other products. This could be due to the role of information that influences consumers' perceptions.

Our results also showed that the plant-based burgers made with pea protein were disliked for their lower sensory taste (off-taste, not meat-like) and appeal compared to meat. On the other hand, the external color (appearance) was appreciated by the participants in the informed condition. This positive attribute could be due to the use of beet juice or powder, which provides the traditional meat color (Giacalone et al., 2022).

Food developers continue to seek for innovative ingredients and processes to develop new plant-based alternative products that can replicate meat properties and, as a result, increase acceptance among meat lovers with stricter taste and appearance standards for meat-based dishes (Zhang et al., 2021). Currently, many major companies are investing and launching new flavoring agents to replicate meat and masking agents to attenuate the plant flavor. Moreover, since a single

Table 7
Identification of the 100 % beef burger in the blind group, in percentages (frequency).

Product Sample	All (n = 85)	Male (n = 27)	Female (n = 57)
100 % beef	54.11 %*** (46)	59.26 % (16)	52.63 %*** (30)
Hybrid meat-mushroom	28.24 % (24)	29.63 % (8)	26.32 % (15)
Pea protein	1.18 % (1)	3.70 % (1)	0.00 % (0)
Animal-like protein	16.47 % (14)	7.41 % (2)	21.05 % (12)

Note: One respondent did not disclose gender and chose the hybrid meat-mushroom, resulting in the Male and Female columns having a sum not equal to the All column. Respondents were asked: "Which of these do you think was the 100 % BEEF burger?" The count values of the respondents are represented in parentheses. *** designates a p-value < 0.001.

Table 8
Reasons provided by participants for the identification test, in frequency.

Product Sample	Guesses	Taste	Texture	Smell	Appearance
100 % beef	46	29	23	7	14
Hybrid meat-mushroom	24	14	10	3	11
Pea protein	1	1	0	0	1
Animal-like protein	14	5	5	1	4
Total	85	51	39	11	30

Notes: The Guesses column marks the number of individuals who thought each sample was the 100 % beef sample and the percentage of individuals is in parentheses. The following columns show the count for the number of justifications that mentioned those attributes. For example, if a respondent reported that the burger was 100 % beef with the justification that the burger "tastes the most like meat and feels the most like meat in my mouth, also looks like meat compared to the other burgers", then this was recorded as one count for each, 'Taste', 'Texture', and 'Appearance'.

product cannot fit all consumers' categories, the versatility of non-animal protein (i.e., cereals, vegetables, pulses, algae, and mushrooms) in terms of functional and structural properties provides a toolbox to food developers to create different blends that can meet different needs.

In addition to proteins and colorants, fats are an essential component of plant-based meat substitutes. Specifically, the solid fats extracted from tropical fruits, such as coconut oil and cocoa butter, are combined with liquid fats, such as soybean oil, corn oil, sunflower oil, canola oil, and others. Their primary goals are to improve the flavor, texture, and mouthfeel to revoke animal fat, and to mimic the marbling appearance of regular ground beef, i.e., small globules of white fat (Sha & Xiong, 2020).

One possible strategy to develop meat alternatives that do not compromise sensory appeal (e.g., taste, texture) that meat eaters are expecting is the replacement of part of the meat with alternative proteins, e.g., plant, algae, or mushroom proteins (Baune et al., 2023). In our study, the main positive attribute associated with the hybrid product made with mushrooms was moistness, which underlines the importance of formulating meat alternative products with improved juiciness to mimic meat products. This juiciness could be attributed to mushrooms' high percentage of dietary fiber and proteins, which enable higher water-holding capacity during cooking and, thus, result in a juicy product with a meat-like texture (Pérez-Montes et al., 2021). Moreover, mushrooms contain umami tastants glutamic acid, aspartic acid, and 50-ribonucleotides – which have flavor-enhancing properties (Guinard et al., 2016) – and are rich in sulfur-containing amino acids – which contribute to achieving a meaty flavor (He et al., 2020; Pérez-Montes et al., 2021). However, when consumers were asked to rank the four burgers based on their liking, the hybrid meat-mushroom burger ranked fourth (blind condition) and third (informed condition). This result could be linked to the negative attributes reported by participants for this product (i.e, appearance, texture, and off-taste).

As of now, analysis of open-ended comments has been employed in a limited number of studies (Varela & Ares, 2012); however, this approach could support product development – especially of new products – as gaining insight into the language used by consumers has important implications on the design of communication strategies. Our study showed the effect of plant- vs meat-sounding labeling (e.g., pea protein vs animal-like protein) on consumer preferences and comments. Another benefit of utilizing open-ended comments is that product developers and marketers can explore how the sensory attributes are stated in consumer language (ten Kleij & Musters, 2003). This work consolidates the role of consumers in developing, positioning, and communicating meat alternative products to replace traditional meat.

In the context of product innovation, a strong interdisciplinary collaboration between consumers and scientists from different disciplines (e.g., communication, linguistics, marketing, food, and sensory science) is necessary to advance product development and reduce the risk of market failure of protein alternatives. In addition, it is worth highlighting that, in our study, we consider both sensory and extrinsic attributes (e.g., tasting and product information) as these can contribute to better and more meaningfully predicting product performance (Giacalone, 2018; Sogari et al., 2019).

Regardless the treatment conditions, our results showed that the plant-based animal-like protein burger was the most preferred burger. On the other hand, providing information about the pea protein burger modified the ranking, from third to the last position. This suggests that disclosing the protein source could affect consumers' ranking preferences.

The question remain unanswered as to whether naming plant-based products with meat-sounding labeling emphasize the importance of the labeling system in shaping consumers' perceptions and their willingness to buy PBMA products. As suggested by Demartini, Vecchiato, Finos, Mattavelli, & Gaviglio, (2022), addressing the legal gap of PBMAs is urgently needed to regulate the sector, protect consumers, and satisfy the requests of both meat and PBMA producers, who support opposite policy interventions. Gleckel (2020) reported that using animal-associated words for plant-based meat alternatives does not confuse consumers and omitting words associated with animal products increases consumers' confusion about the taste and application of the product. In line with Gleckel et al (2019), our findings suggest that providing animal-sounding labels could inform consumers that the plant-based alternative aims to replicate the taste of beef. However, the number of new ingredients employed to revoke meat-like texture, juiciness, and flavor highlights the importance of clearly informing consumers of the nutritional profile of such products (Cutroneo et al., 2022).

Despite the abovementioned findings, our study has some limitations. First, the use of commercial products, which have different nutritional compositions and ingredients, can influence consumers' sensory perception; however, when comparing blind and informed conditions, this variable (i.e., the inter-variability among the burgers) is controlled. Second, the preparation procedure of the products, including cooking time and temperature, might influence the sensory perception of the final burger. To minimize this limitation, the preparation method for all four samples was consistent throughout the sensory test. Finally, during the transcription process, researchers faced the risk of information loss and bias. To reduce this risk, in the present study, three researchers independently conducted the data analysis.

5. Conclusions and future research

When investigating how consumers perceive new plant-based and hybrid-meat alternatives, companies should focus on the main attributes that influence liking, such as texture and flavor. This information is critical for developing efficient product and marketing strategies for new plant-based foods. Additionally, it can be used to reformulate existing products and find solutions to overcome disliked features and accentuate liked attributes. Therefore, including consumer qualitative sensory studies at the early stages of new meat analog development could provide key insights into whether product expectations are satisfactorily met (or exceeded), and thus, whether the recipe should be adjusted accordingly.

Furthermore, our research stresses the importance of implementing studies that combine the R&D stages of a new orreformulated food with marketing strategies (e.g., communication on the packaging) before launching it on the market; the expectations created by information given before tasting the products should be confirmed also after the sensory experience. This approach will allow the food industry to ensure greater product consistency and address consumers' most valued attributes.

A relevant topic to be considered by producers and that requires further investigation, is the high number of ingredients and additives employed to replicate meat-like characteristics. This aspect could be negatively perceived by consumers and become a barrier, especially for those interested in clean labels (i.e., a few ingredients) and nutrition-related issues. Finally, an additional area for future research to explore is whether consumer preferences for PBMAs have changed after the COVID-19 outbreak, given the increase in PBMA product launches in the market (Andreani et al., 2023).

CRediT authorship contribution statement

Giovanni Sogari: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Project administration, Funding acquisition. **Vincenzina Caputo:** Conceptualization, Methodology, Writing – review & editing. **Andrew Joshua Petterson:** Data curation, Formal analysis, Visualization, Writing – original draft. **Cristina Mora:** Conceptualization, Supervision, Writing – review & editing. **Fatma Boukid:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The brand names in this article are for product identification purposes only. No endorsement or criticism was intended, nor was endorsement or criticism implied of products not mentioned.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodres.2023.112813.

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