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RESEARCH ARTICLE

REVISED Development of the lexicon, trained panel validation and sensory profiling of new ready-to-eat plant-based "*meatballs*" in tomato sauce

[version 3; peer review: 2 approved]

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Abstract

Background

Providing educational content for children and parents can promote healthy nutritional habits. During the TITAN project, a pilot digital contest where participants have to developed ready-to-eat meatballs in sauce, using only plant-based ingredients, will be tested. The objective of this study was to develop the lexicon needed to objectively assess the sensory profile of this product.

Methods

Eight judges were recruited and trained. Thirteen 1-hour sessions took place over three months. The steps followed were the selection of commercial reference, generation of descriptors, training of the panel, validation of the trained panel and product characterisation. The judges chose one commercial reference (using simple hedonic evaluation) to serve as a reference. The accepted intensity scale for the generated descriptors was from 0 (low intensity) to 9 (very intense). To test the first versions of the game, food product developers involved in the project, acted as participants, and used a mix of lentils, quinoa, and oats to enhance the commercial version. R-project software was used to analyse the performance of the panel and the sensory profiles.

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Any reports and responses or comments on the article can be found at the end of the article.

Results

A glossary with 14 descriptors was generated. The discriminatory capacity of the panel was confirmed by examining the significance of the product effect ($p < 0.05$). The product–judge interaction was not significant ($p > 0.05$) for most of the evaluated attributes, indicating a good degree of panel agreement. Overall, the panel was considered reproducible after 9 sessions. Although the appearance, firmness, fragility and chewiness were considered similar to the reference, juiciness and taste (understood as meaty flavour) of the new product were deemed improved.

Conclusions

According to the panel, two of the most appreciated attributes associated with meat analogues, juiciness and taste, were improved compared to the commercial reference. Therefore, the first approach for further development of the contest/game was validated.

Plain language summary

Don't you think it's important for a child to experiment with food from a very young age? Do they know where the food comes from? How do the products arrive to the supermarket? If the answer is yes and if your kids believe that meatballs can only be made with meat, this game is for them, and for you. "Imagine a future generation of children who, from a young age, have learned that vegetables are not just an alternative to meat, but a wholesome choice for nutrition and health".

This is study is part of the TITAN project, where different gaming options using artificial intelligence will be tested to promote healthy nutritional habits in scholars aged 6–12 years. One of these games is being designed as a contest were students have to develop a ready-to-eat meal, similar to “meatballs in sauce” but using only plant-based ingredients. They will have to improve the sensory properties of a commercial reference. But, to establish a common criterion for assessing the results, it is necessary to develop a common lexicon with descriptors that a trained panel can use to assess the improved prototypes. In this study, 8 judges (4 men and 4 women) were recruited and trained to develop a sensory profile for this type of products. To test the first versions of the game, food product developers involved in the project, acted as participants, and used a mix of lentils, quinoa, and oats to enhance a commercial version. The panel of trained experts validated the results.

Keywords

healthy nutritional habits, sensory analysis, trained panel, ready-to-eat meals, plant-based, meat analogues

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REVISED **Amendments from Version 2**

In this revised version of our article, significant enhancements have been made to address the insightful feedback from our reviewers:

- The revised version incorporates significant enhancements aligned with the international standards set by ISO 8586:2012, ISO 8586:2023, and ISO 5492:2008, particularly focusing on the training and performance evaluation of sensory assessors.

- We have elaborated on the methodology used in the ingredient selection step and in the sensory evaluation, particularly in the training of the panel and handling of outliers and deviations. This information improved the reproducibility and reliability of the study to better guide future research in sensory evaluation.

- The conclusions section has been revised. It now better reflects the significance of the study in the context of sensory analysis and the development of plant-based food products.

- References to supplementary materials have been added, providing readers with access to detailed data and statistical analyses that support our findings.

Any further responses from the reviewers can be found at the end of the article

Introduction

Healthy nutritional habits start by educating children and their families. Providing educational content of interest to children and their parents using gaming technologies is a promising tool that needs further development. For example, competitive-cooperative games where improving the nutritional profile a particular meal is the challenge to be solved, can influence peer pressure[1]. During the TITAN project, a particular challenge related to improving the nutritional and sensory profile of ready-to-eat meals is being tested before developing a gaming tool for kids and parents. The challenge will be presented as follows.

The large-scale production of animal proteins is considered a strong driver of the loss of biodiversity, global climate change and shortage of water[2]. With the increasing world population and growing concern for animal welfare and environmental properties, the demand for the transition from an animal-based to a plant-based diet is rising.

One of the many possible solutions to the current and future health and environmental challenges is to lower meat consumption and promote plant-based foods[3]. Substituting animal products with alternative proteins could be a viable strategy. However, introducing plant based meat alternatives faces many difficulties despite the known health and environmental issues associated with meat production[4]. The aversion of consumers to these dietary changes, often associated with the sensory and nutritional appeal of meat-based foods and simple access to such products, are of prime concern[5,6].

The plant-based meat analogues have attracted much attention thanks to their established health claims and functionality. Moreover, the required nutritional value can be achieved by modifying the physical properties of these products and, at the same time, promoting their sustainability over sensory descriptors[7].

Many companies have begun to explore the replacement of animal meat-based ingredients with alternative proteins. Some plant-based products are already accessible on the market, such as chunks, strips, patties, sausages, chicken-like blocks, nuggets, ground beef-like products, meatballs and steaks[8].

The biggest challenge facing the developers of meat analogues is obtaining meat-like texture and flavour[9]. The difficulties in recreating these sensory properties using plant protein sources are usually caused by strong flavours of legumes and decreased tenderness and succulence caused by reduced saturated fat content. However, protein blends can create synergies to overcome these technical issues[10,11].

Soy protein has been the most common base ingredient, but the use of other ingredients like pea and proteins from a range of grains and legumes are expected to increase[12]. Protein sources such as quinoa, lentils and oats have been reported as sustainable protein sources[13] with potential beneficial effects for human health[14]. However, even though most of them are already on the market, they are rarely used in everyday foods.

The psychochemical, functional and sensory characteristics of meat analogues can be manipulated to resemble those of meat-based products by changing their texture, flavour, appearance, mouthfeel, digestibility and bioavailability of the nutrients[15]. Testing the sensory properties of such novel products and their optimisation based on customer driven evaluation plays a decisive role in their development and commercialisation[16].

Several studies have reviewed consumer acceptance of alternative proteins, innovative food and novel food technologies[17] and meat consumption[18]. A review of consumer research on meat replacements and specific alternatives, such as cultured meat and insect and plant-based substitutes, is also available[19].

Recently, many alternative protein sources (e.g., plants, insects or fungi) have been explored as replacements for animal-derived proteins[20,21]. However, a lack of familiarity with novel foods affects expectations and can negatively impact sensory perception and overall liking[22]. It is important to remember that the opinion of the consumer can also be affected by personal factors, not just the sensory properties of the product.

The texture of meat has been widely studied. Many mechanical methods, analytical techniques and sensory evaluations are established for meat and fish products; however, it is unclear whether these methods are adequate for characterising the plant-based matrices[23]. Very little information is available on the flavour profiles of products with high content of plant proteins in comparison with meat such as beef, chicken or pork. Almost all available analytical methods deal with technical aspects and are not directly linked to sensory descriptors. In contrast, the sensory methods can provide both

quantitative and qualitative data on flavour, taste, texture and appearance[8].

The techniques used in sensory evaluations offer data beyond the oral perceptions of food. It is important to note which characteristics contribute to the acceptance of the product itself and which differences are associated with personal factors. Descriptive analysis is the most accurate method; it delivers both qualitative and quantitative data on the sensory profiles supplied by a trained panel. Such panels can provide the description of sensory characteristics and differences between the products, the qualification of intensities and recognition of descriptors[8]. A panel is considered expert when all the panellists can determine differences, reproduce the results, and are consistent with the rest of the panel. This technique improves the efficiency of the development of analogous meat products.

The plant-based meat analogues have some common flaws, e.g., lack of tenderness and characteristic juicy mouthfeel of meat. Some changes in processing technology and formulation of meat analogues are essential to overcome these shortcomings. There are some reports on the formulation of hybrid[24] or fully plant-based meatballs[25–27], but the processes described do not include sterilisation to obtain a shelf-stable precooked meal. The methods used in these studies use a cooking process on a laboratory scale. The current study employs processing methods on a pilot scale.

Here, the lexicon appropriate for the analysis of the studied products was developed, and an expert panel trained to the required standards. This panel conducted the validation and sensory profiling of newly formulated product (ready-to-eat plant-based meatballs in tomato sauce, containing a blend of lentils, quinoa and oats).

Methods

Preparation of the ready-to-eat plant-based meatballs in tomato sauce

Ingredients: The formulation of the plant-based meatballs was carefully designed based on (i) their nutritional compositions, contributing to the overall balance of macronutrients (protein, carbohydrates, and fat) as well as the presence of key micronutrients in the plant-based meatball formulation, and (ii) to mimic the sensory properties of meat while using only plant-based ingredients. The primary ingredients chosen were a blend of red lentil flour, quinoa, and oat flour. Red lentil flour (25% protein, source of dietary fiber, folate, iron, potassium and zinc) was selected for their high protein content and texture that closely resembles meat when cooked. Quinoa (15% protein, source of, dietary fiber, iron, magnesium, and phosphorus) was included for its nutritional value, particularly its high protein content and essential amino acids profile. Oat flour (10% protein, source of dietary fiber, beta-glucan, magnesium, phosphorus, and antioxidants) was used for their ability to improve the texture and to bind the ingredients together, contributing to the meatball's firmness and chewiness.

The proportions of these ingredients were determined through a series of preliminary sensory evaluations and trials. The aim was to create a product that not only resembled meat in terms of texture and flavour but also improved upon certain sensory attributes such as juiciness and taste. The final formulation consisted of water (17.0%), textured soy protein (17.0%), quinoa (5.0%), red lentil flour (5.0%), oat flour (1.0%), breadcrumbs (2.0%), soy sauce (1.0%), olive oil (1.5%), garlic powder (0.2%), salt (0.1%), parsley (0.1%), black pepper (0.1%) and tomato sauce (50%; consisting of water, tomatoes, sunflower oil, onion, sugar, salt and citric acid). All the ingredients were bought in a local supermarket (Makro, Erandio, Spain) except for the red lentil flour made at AZTI's pilot plant (Derio, Spain) using the lentils bought at the same supermarket. An ultracentrifuge mill (ZM 100, Retsch, Haan, Germany) with a sieve of 500 μm was used for producing the flour.

Production process: The ingredients were weighed and mixed in the Kenwood food processor at minimum speed. Once mixed, the mass was manually formed into balls. The balls weighed between 9 and 11 g. Afterwards, 6 balls were packed in aluminium vacuum bags (160 × 270 × 52 mm; Bolsaplast, Barcelona, Spain) and covered with tomato sauce. The bags were sealed under a vacuum of 750 mbar (Multivac C 200, Multivac, Wolfertschwenden, Germany).

The sterilisation process was performed in a pilot retort (Model APR-95, Surdry, Vizcaya, Spain) programmed to achieve 110°C in 15 min, hold this temperature for 60 min and cool to 30°C in 13 min. The pressure was programmed to the maximum of 0.8 bar. The temperatures were recorded employing a TrackSense Pro Mini Wireless Data Logger Serial No. 84633 (Ellab, Hillerød, Denmark) using the ELLAB software ValSuite Basic 3.1.3.10v (Ellab, Hillerød, Denmark). Data acquisition was performed at intervals of 1 min. In each batch, 1 "meatball" was punctured with the data logger before sealing the bag. The temperature at the core of the product was maintained at 105—108°C for 34 min, achieving an F_0 of 3. Then, the samples were stored at ambient temperature.

Sensory analysis

Sensory tests were carried out in a standard tasting room[28] with ten individual taste booths separated by screens to isolate the different judges. Samples were served at room temperature (about 20°C) on white plates. The sensory rooms were equipped with full-spectrum daylight LED lighting, which ensures consistent illumination across evaluations.

The ethical approval was conducted according to quality standards of the ISO 8586:2012 certified by AENOR, the Spanish Association for Standardization and Certification.

Recruitment of judges and basic training

The recruitment process was carried out to attract and train sensory assessors who were also consumers of meat analogues. Non-consumers were excluded to focus on feedback

from potential regular consumers of plant-based products. An email was sent to all AZTI employees (> 290) explaining the objective of the study and the profile required (female or male consumers of plant-based meat analogues). Those who expressed interest in joining the study were informed of the methods and the time needed to participate. Screening tests to evaluate the sensory abilities of the participants were carried out (a basic taste test, a smell recognition test and a scale management test)[29]. No remuneration was offered. Participants signed an informed consent prior to participating in the study.

Demographic characteristics

Eight participants were enlisted, 4 men and 4 women, aged from 27 to 40, all with middle income, employed, and consumers of this type of product at least once a week. Gender balance was aimed to gather a wide range of sensory feedback, reflecting a varied trained sensory assessor base. Eight assessors were chosen based on the availability and resources, acknowledging the deviation from ISO 8586:2023's recommendation of a minimum of 12.

Generation of descriptors and training of judges

The specific judge training was performed according to international standards[25]. Thirteen 1 hour sessions took place over three months. The subjects covered were the selection of commercial reference (1 session), generation of descriptors (2 sessions), training of the panel (7 sessions), validation of the trained panel and product characterisation (3 sessions).

A combination of methodologies was used for generating the descriptors. The first qualitative study (face-to-face focus group) was conducted to choose the reference product. The trained sensory assessors were presented with three commercially available types of ready-to-eat plant-based meatballs in tomato sauce (Figure 1). The focus was on developing a distinct plant-based product rather than directly imitating meat-based meatballs. The selection of these reference products was based on a thorough market search conducted in five local supermarkets (Bilbao, Spain) and three online platforms where these products were readily available for shopping in Spain. This comprehensive approach allowed us to capture a diverse range of shelf-stable plant-based meatballs in tomato sauce options, present in both physical and online retail spaces. The participants tasted the products and supplied a simple hedonic evaluation ("which one do you like most?" and "what is the sample most similar to its analogue?"). On the basis of the results, the trained sensory assessors decided which product would serve as the reference in the subsequent sessions. A standardised procedure for sensory analysis was used, following ISO 11035:1994[30].

The ingredients for each product are listed below.

PRODUCT 1:
Sauces (tomato, onion, carrot, extra virgin olive oil, cane sugar, garlic (citric acid), salt); artificial meatballs (soybean pulp, soybean curd (water, soybeans, magnesium chloride)); sunflower oil, soy, wheat flour, brown rice, cassava starch, oat flakes, parsley, salt, garlic; vegetable broth (onion, carrot, leek, garlic, celery, rice flour, salt, sunflower oil, extracts of yeast, onion powder, carob).

PRODUCT 2:
Filtered water, textured soy protein, isolated soy protein, hydrolysed soy protein, wheat gluten, canola seed oil, tomato juice, modified starch, salt, onion, garlic, vegetable seasonings, and spices.

PRODUCT 3:
Sauce (71%): tomato (40%), water, onion, green pepper, extra virgin olive oil, panela, garlic, pink Himalayan salt and tapioca starch. Meatballs (29%): natural tofu (water, soybeans and magnesium chloride (nigari)), quinoa (20%), textured soy protein, gelling agents: agar–agar and carrageenan, soy sauce (water, soya in variable proportions, 33–46%, sea salt and koji), yeast and Himalayan pink salt.

The methodology for reaching consensus on the final organoleptic attributes in the study involved a structured and participative approach. We conducted a series of training sessions (S1-S6) with the trained sensory assessor to develop a comprehensive sensory lexicon for the selected commercial



Figure 1. Images of the three commercial plant-based "meatballs" used in the focus group.

product, which served as the reference (Figure 2). To facilitate the process, each trained sensory assessor individually wrote down the descriptors on post-it notes, capturing their sensory perceptions. These descriptors were then collectively pasted onto a common panel, allowing for group discussion and consensus-building. This collaborative approach encouraged active participation and ensured that a comprehensive set of descriptors was generated to capture the sensory attributes of the reference product accurately.

The subsequent training sessions (S3, S4, S5, and S6) built upon this foundation to refine these descriptors further, utilising the agreed-upon descriptors to evaluate the sensory characteristics of the plant-based meatballs.

A structured scale of nine points 24 was used; the descriptors were awarded scores between 1 ("I dislike it extremely") and 9 ("I like it very much"). Each judge was given 2 identical meatballs without tomato sauce to focus on the meatball taste. In the sensory analysis of plant-based meatballs, a critical step involved the removal of the sauce to focus solely on the meatball's inherent sensory properties. This was achieved through a careful and standardized process using a napkin. Each meatball, initially prepared with sauce, was gently lifted from its sauce. Then, using a napkin, the surface of the meatball was dabbed to absorb the sauce. This dabbing was performed with enough care to ensure that the sauce was absorbed without exerting pressure that might alter the texture of the meatball. The goal was to remove any visible traces of the sauce, effectively isolating the meatball from external flavor influences. This method ensured that each meatball was treated uniformly, allowing for an accurate and focused assessment of its intrinsic sensory characteristics. Through iterative sessions and discussions, the trained sensory assessor achieved a consensus on the intensity of each descriptor for the reference product after seven sessions. The final organoleptic attributes were standardized through a consensus-based approach among the participants.

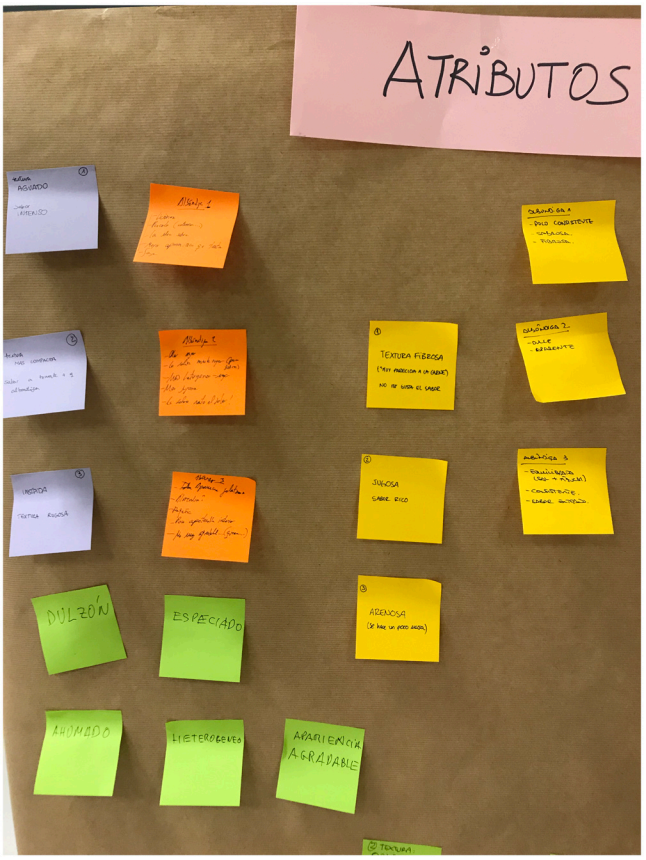


Figure 2. Generation of descriptors for the product selected as the reference.

This rigorous training process ensured the panel's ability to evaluate and discriminate the sensory characteristics of the plant-based meatballs accurately.

Performance of the panel and sensory profile development

The panel validation was based on ISO 11132:2021 (Guidelines for the measurement of the performance of a quantitative descriptive sensory panel)[31]. For each descriptor, the consistency of the panel between sessions was measured. After each tasting session, all responses were pooled to identify the descriptors and judges whose standard deviation was ≥ 1. The difference between sessions should not be significant at the 0.05 level; otherwise, it would mean that the scores of the individual tasters were inconsistent. The participants also scrutinised the descriptors that might be irrelevant or difficult to measure and discussed the potential harmonisation of sensoryevaluation for the product. After 7 sessions, the consensuson the intensity of each descriptor of the benchmark commercial product was reached (agreed QDA).

Once the panel performance was deemed repeatable and reproducible, and an adequate capacity of discrimination was determined, the sensory evaluation of the ready-to-eat plant-based meatballs in tomato sauce was conducted. Each assessor was provided with the 2 samples, the reference and the improved prototype (2 pre-heated meatballs per product without tomato sauce on a plate), coded with a 3-digit random number. Sample evaluations were performed at room temperature under normal lighting conditions. All samples were assessed in random order in three sessions (P1, P2 and P3). The trained sensory assessors scored the intensities of the generated descriptors. The results were analysed to determine whether there were significant differences between the samples and which descriptors made them different. The results were also examined for any resemblance to the QDA of the commercial product.

Statistical analyses

The data analysis was carried out using R-project software (v 4.1.2). The packages used were "readxl", "rapportools", "tidyverse", "ggplot" and "spiderchart". A one-way ANOVA was conducted (per trained sensory assessor) at the end of each session to see if there were any statistically significant differences ($p < 0.05$) between the assessors, and a three-way ANOVA to analyse statistical significance ($p < 0.05$) of the trained sensory assessor, descriptor and session.

Results and discussion

Glossary of descriptors for plant-based meatballs

Results were obtained and examined in 4 steps. First, the focus group results showed that the most preferred sample was "product 3", voted as the favourite by all trained sensory assessors. In the second step, two sessions of open discussion (S1 and S2) were organised to generate the list of descriptors and the procedure for evaluating their intensity (Table 1).

In the second stage, the panel was trained to assess the intensity of each descriptor during four sessions (S3, S4, S5 and S6). The product tested was the commercial reference. The results of these first four sessions are shown in Table 2 and Figure 3. The ANOVA carried out to examine descriptor scores assigned in different sessions showed very significant differences ($p < 0.01$) for cohesiveness and juiciness and significant differences ($p < 0.05$) for taste. In fact, the standard deviation for these descriptors per trained sensory assessor was > 1. To confirm the repeatability of a trained sensory assessor in different sessions for the same descriptor, the standard deviation should be < 1.

Three more sessions were needed to reduce the variability between the judges. Table 3 shows the results of the two-way ANOVA test for each judge and session; after the three additional sessions, the panel was consistent. The variability of each judge was reduced, and the standard deviation per descriptor and per judge was < 1.

Figure 2 also depicts the reduced variability, illustrated by the size of the boxplots. The black dots represent the

Table 1. Descriptors and definitions used to evaluate the commercial ready-to-eat plant-based "meatballs" in tomato sauce.

Descriptors	Definition and procedure used for their evaluation
Visual	
Outer colour	1, raw meat colour; 5, medium meat colour; 9, light brown
Brightness	1, low brightness; 9, high brightness
Elasticity	The middle of the meatball will be pressed with a thumb, slightly indenting the sample (pressing down to between 1/4 and 1/5 of the thickness). The recovery of the initial shape of the meatball will be assessed. The sample is considered very elastic and will be assigned a high score if it recovers quickly.
Inner colour	1, raw meat colour; 5, medium meat colour; 9, light brown
Compactness	The internal appearance of the meat: 1, loose-consistency meat and 9, very compact meat.
Odour	
Characteristic odour	The higher the intensity, the higher the score assigned (within the scale).
Texture	
Firmness	Force required to break the sample with the first bite. Bite the meatball in half with your incisors and assess the force exerted; 1, little force (like biting through a croquette) and 9, much force needed (for example, like biting through an almost raw chop).
Cohesiveness/Fragility	The ease with which the sample can be broken: 1, a very hard meatball, difficult to break; 9, a meatball that breaks easily without applying much force.
Juiciness	The sensation of moisture in the mouth during chewing. The greater the sensation of juiciness, the higher the score.
Chewiness	The number of chews necessary to swallow the meatball (1, very chewy, e.g., like black pudding; 9, not very chewy, e.g., tough meat).
Adherence	Force required to detach the product from the palate (1, not very adherent; 9, very adherent).
Graininess	Detection of granules or small particles
Pastiness	The effort required to swallow the product (1, a little; 9, very doughy)
Fat perception	The sensation of fatty coating in the mouth, warm sensation: 1, weak fat perception (e.g., chicken breast); 9, strong fat perception (e.g., bacon).
Taste	
Characteristic taste	Meaty flavour
Aftertaste	The higher the persistence, the higher the score assigned (within the scale).

Table 2. Sensory results per judge and descriptor in Step 1 (4 sessions).

Descriptor	Coefficients							Statistics		
	Judge 1	Judge 2	Judge 3	Judge 4	Judge 5	Judge 6	Judge 7	Judge 8	p-value	Mean panel ± SD
Brightness	5.75±0.50	5.75±0.50	6.50±0.58	6.00±0.00	5.50±0.58	5.75±0.50	5.75±0.50	5.75±0.50	0.545	5.84±0.51
Elasticity	1.75±0.50	2.25±0.50	3.00±0.82	2.25±0.50	3.00±0.82	2.50±0.58	2.50±0.58	2.50±1.00	0.082	2.47±0.72
Compactness	5.00±0.82	5.00±0.00	5.25±0.50	5.50±0.58	6.00±0.82	5.25±0.50	5.25±0.50	5.75±0.50	0.102	5.38±0.61
Characteristic odour	0.25±0.50	0.00±0.00	0.50±1.00	0.50±1.00	0.50±1.00	1.50±0.58	2.50±1.29	0.00±0.00	0.4707	0.72±1.08
Firmness	2.00±0.00	1.50±0.58	1.63±0.48	2.00±0.00	2.00±0.82	1.75±0.50	2.00±0.00	1.38±0.95	0.582	1.78±0.54
Cohesiveness	6.00±2.94	5.75±1.50	7.25±1.50	4.00±2.45	7.00±1.41	6.00±2.45	5.75±2.87	7.50±1.29	0.008**	6.16±2.17
Juiciness	2.50±1.73	3.25±1.71	2.75±1.50	2.25±1.89	4.25±2.87	4.25±2.87	3.25±2.06	3.25±2.06	0.001**	3.22±2.01
Chewiness	3.00±1.41	3.00±0.00	2.88±0.63	3.13±0.48	3.00±0.00	4.00±0.00	3.00±0.82	2.75±0.50	0.334	3.09±0.69
Adherence	2.25±0.50	2.75±0.96	2.00±0.00	2.50±0.58	2.75±0.50	2.50±1.00	2.00±0.00	2.00±0.00	0.083	2.34±0.60
Graininess	1.25±0.50	0.25±0.50	1.50±0.58	1.25±0.50	1.75±0.50	1.00±0.00	1.67±0.58	2.00±0.82	0.795	1.32±0.70
Pastiness	5.75±0.50	5.50±0.58	6.25±0.50	7.00±0.82	6.50±0.58	6.50±0.58	6.25±0.50	7.00±0.82	0.244	6.34±0.75
Fat perception	2.50±0.58	2.00±0.00	2.63±0.48	2.25±0.50	2.13±0.25	3.00±0.00	2.50±0.58	2.50±0.58	0.1939	2.44±0.49
Taste	2.50±1.29	3.25±2.75	1.50±1.91	2.25±1.26	0.75±1.50	2.25±1.26	3.50±1.00	1.50±1.91	0.020 *	2.19±1.73
Aftertaste	1.75±0.50	1.50±0.58	1.00±0.82	0.75±0.50	1.00±0.00	0.75±0.50	1.00±0.00	0.75±0.50	1	1.06±0.56

Significance codes for p-value: **, (0.001 < p-value < 0.01); *, (0.01 < p-value < 0.05), (0.05 < p-value < 1).

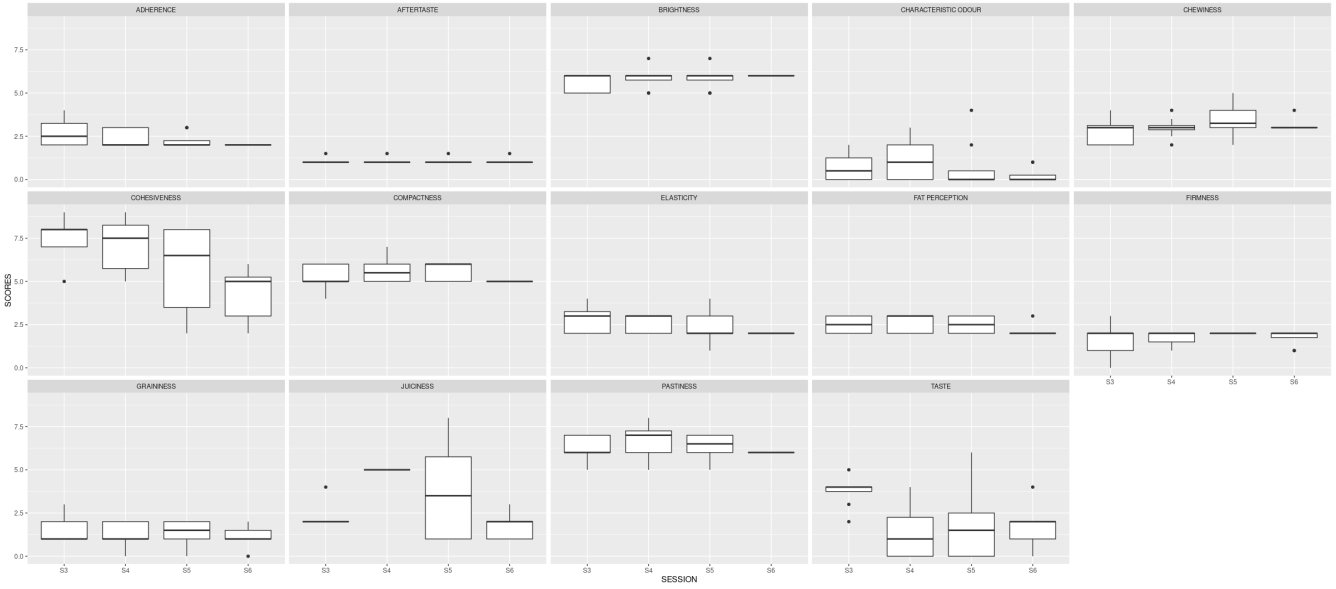


Figure 3. Boxplots showing the sensory results per judge and descriptor in Step1 (4 sessions).

outliers, the solid lines show the median value of the descriptor, and the whiskers represent the minimum and maximum values.

The three descriptors with high variability in the first analysis (cohesiveness, juiciness and taste) were more homogeneously assessed by the 8 judges during the subsequent 3 sessions.

Table 3. Evolution of descriptors defined during the qualitative descriptive analysis of the benchmarked product (7 sessions).

STEP 1	STEP 2	
S3, S4, S5, S6	**S7, S8, S9**	**AGREED QDA**
Brightness	~~Brightness~~	+Inner colour
		+Outer colour
Elasticity	Elasticity	Elasticity
Compactness	~~Compactness~~	
Odour	Odour	Odour
Firmness	Firmness	Firmness
Cohesiveness	Cohesiveness	+Fragility
Juiciness	Juiciness	Juiciness
Chewability	Chewability	Chewability
Adherence	Adherence	Adherence
Graininess	Graininess	Graininess
Pastiness	Pastiness	Pastiness
Fat perception	Fat perception	Fat perception
Flavour	Flavour	Taste
Aftertaste	Aftertaste	Aftertaste

The additional three sessions (S7, S8 and S9) were conducted to re-train the trained sensory assessors for the chosen descriptors. A particular emphasis was placed on the definition and the intensity of these descriptors. Table 3 shows the changes in the descriptors generated in Step 1 (retained, renamed or deleted).

The panel had difficulties evaluating brightness because the tomato sauce was removed from the meatballs during the tasting session (to reduce the effect of the sauce on the taste). The participants found it easier to assess the external and internal colour of the product (the latter was not affected by the sauce).

Another attribute that was difficult to assess was compactness as the panel did not understand the difference between compactness and cohesiveness or firmness. Therefore, the term "firmness" was retained, and "compactness" was removed. Following the same trend, cohesiveness was removed to avoid confusion, and "fragility" was included as the opposite of compactness/cohesiveness.

Finally, the flavour was deemed an overly complex attribute to assess; it was agreed to replace it with taste (understood as a meaty flavour in English).

In English, the terms "taste" and "flavor" have distinct meanings, which can lead to confusion in translation, especially into Spanish.

Taste: This refers to the sensation produced when a substance in the mouth reacts chemically with taste receptor cells located on taste buds. Taste is limited to five basic qualities: sweet, sour, salty, bitter, and umami. These basic tastes are perceived through the tongue.

Flavour: It is a broader concept that includes not only the basic tastes but also the aromas and other sensations (like spiciness or temperature) perceived through the olfactory receptors in the nose. Flavour is the overall perception of a food or drink, combining taste, smell, and other sensory attributes.

When translating these terms into Spanish, the distinction can become blurred:

"Taste" is translated to "gusto" or "sabor." "Gusto" aligns more with the English "taste," referring to the basic taste sensations. However, "sabor" can be interpreted as both "taste" and "flavour," encompassing the broader sensory experience.

"Flavour" is often translated as "sabor," but this doesn't fully capture the complexity of the term as understood in English, which includes aroma and other sensory experiences beyond just taste.

The confusion arises because "sabor" in Spanish can mean both the basic tastes perceived by the tongue and the overall flavour experience, which includes aroma and other factors. This overlap in meaning can make it challenging to convey the distinct concepts of "taste" and "flavour" from English into Spanish accurately.

In the context of this study conducted in Spain, the term "taste" (or "gusto" in Spanish) can often be understood to encompass what is referred to as "overall flavour" in English. This broader interpretation in the Spanish context arises from linguistic and cultural nuances in how sensory experiences are described. Therefore, in this study, when the term "taste" is used, especially given its Spanish context, it is aligned more with the English concept of "overall flavour." This encompasses a more holistic sensory assessment rather than just the basic taste sensations. Such linguistic and cultural differences are important to consider in sensory studies, as they can influence how sensory data is described, interpreted, and communicated.

A second ANOVA analysis was carried out to examine the statistical differences and the robustness of the panel after 9 sessions. The results are shown in Table 4. Cohesiveness, juiciness and taste have reduced their variability after the second training. All the standard deviations were below 1. Figure 4 depicts the boxplots for each descriptor per session. The red

Table 4. Sensory results per judge and descriptor in Step 2 (3 sessions).

Descriptors	Coefficients							Statistics		
	Judge 1	Judge 2	Judge 3	Judge 4	Judge 5	Judge 6	Judge 7	Judge 8	p-value	Mean for the panel ± SD
Outer colour	7.31±0.32	7.71±0.35	7.32±0.29	7.33±0.34	7.52±0.02	7.74±0.35	7.73±0.34	7.23±0.35	0.633	7.46±0.21
Inner colour	8.34±0.28	8.74±0.33	8.34±0.34	8.70±0.30	8.73±0.34	8.22±0.28	8.80±0.32	7.24±0.34	0.914	8.36±0.53
Elasticity	1.67±0.58	2.33±0.58	3.33±0.58	2.33±0.58	3.33±0.58	2.67±0.58	2.67±0.58	2.67±1.15	0.449	2.63±0.77
Characteristic odour	0.33±0.58	0.00±0.00	0.67±1.15	0.67±1.15	0.67±1.15	1.67±0.58	3.00±1.00	0.00±0.00	0.783	0.88±1.19
Firmness	2.00±0.00	1.33±0.58	1.50±0.50	2.00±0.00	2.33±0.58	2.00±0.00	2.00±0.00	1.17±1.04	0.425	1.79±0.57
Fragility	7.67±0.58	7.33±0.58	8.00±0.00	7.33±0.58	7.33±0.58	7.67±0.58	8.00±1.00	7.67±0.58	0.705	7.63±0.58
Juiciness	1.67±0.58	1.67±0.58	2.00±0.00	1.67±0.58	1.00±0.00	1.67±0.58	2.00±0.00	2.00±0.00	0.482	1.71±0.46
Chewiness	3.00±1.73	3.00±0.00	2.83±0.76	3.17±0.58	3.00±0.00	4.00±0.00	3.00±1.00	2.67±0.58	0.264	3.08±0.78
Taste	2.00±0.00	2.17±0.29	2.00±0.00	2.00±0.00	2.00±0.00	2.00±0.00	2.33±0.58	1.33±0.58	0.616	1.98±0.38
Aftertaste	2.00±0.00	1.67±0.58	1.33±0.58	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00	1.000	1.25±0.44
Adherence	2.33±0.58	3.00±1.00	2.00±0.00	2.67±0.58	3.00±0.00	2.67±1.15	2.00±0.00	2.00±0.00	0.298	2.46±0.66
Graininess	1.33±0.58	0.33±0.58	1.67±0.58	1.33±0.58	1.67±0.58	1.00±0.00	1.67±0.58	2.00±1.00	0.796	1.38±0.71
Pastiness	5.67±0.58	5.33±0.58	6.33±0.58	7.33±0.58	6.67±0.58	6.67±0.58	6.33±0.58	7.33±0.58	0.478	6.46±0.83
Fat perception	2.67±0.58	2.00±0.00	2.83±0.29	2.33±0.58	2.14±0.29	3.00±0.00	2.67±0.58	2.67±0.58	0.850	2.54±0.49

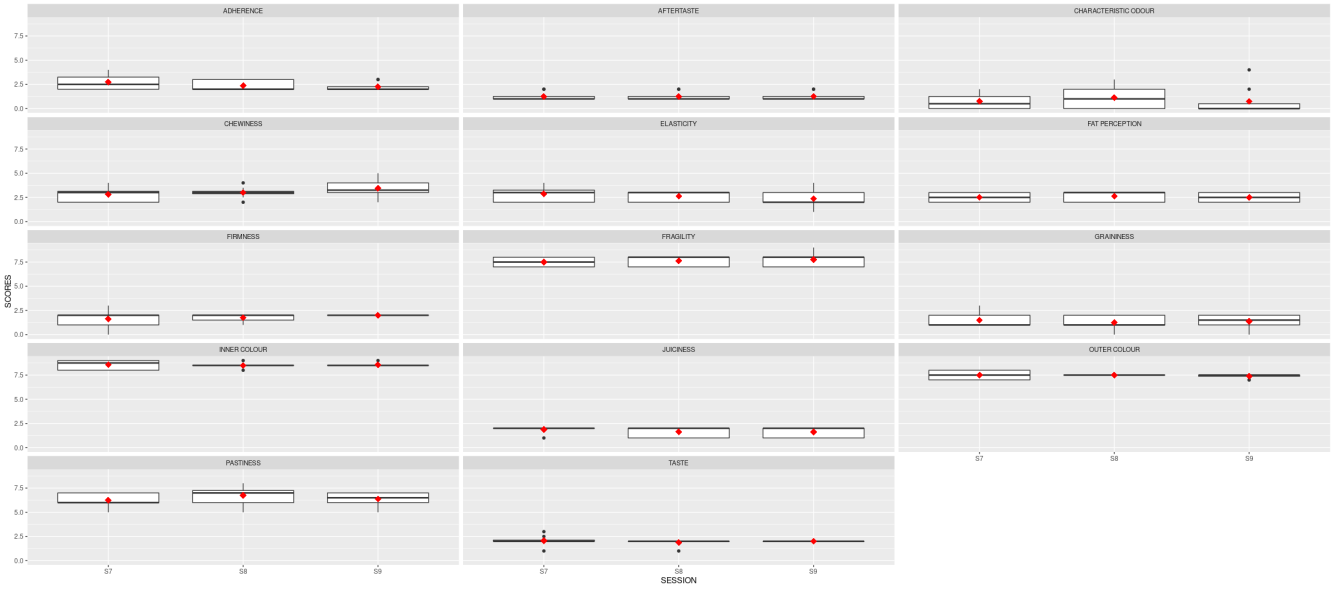


Figure 4. Boxplots showing the sensory results per judge and descriptor in Stage 2 (3 sessions). S7, S8 and S9 are the session names. Red squares show the averages; black dots represent the outliers.

squares indicate the averages for the panel, and the black dots show the outliers. Noticeably, the red symbols are now aligned, with slight variability per session.

A review published by Djekic *et al.*[32] has reported that the average number of sessions necessary to train a panel can be as high as 10 (in 22.9% of the searched articles) or even higher (in 5% of the cases). However, no data have been provided in 72.1% of the cases. This is a relevant issue as training a panel can take up to 3 months. Reporting the number of sessions or the time necessary for training is essential as it has a bearing on the robustness of the panel and, thus, can affect the conclusions of the sensory analysis.

Once the standard deviations per descriptor and judge were reduced to less than 1, the panel was scrutinised for its robustness, reproducibility, and repeatability (Table 5).

Panel performance

Discriminatory capacity

A significant product effect means that the judges can discriminate between the products. The p-values (Table 5, F-values in three-way ANOVA, column 1) indicated that the panel was capable of such discrimination based on most of the descriptors, except for the outer or inner colour, firmness, fragility, chewiness and graininess. Overall, the results confirmed that the panel could distinguish between the products.

The judge effect was not significant ($p > 0.05$) for any of the descriptors (Table 5, column 2), which implies that the assessors did not differ in evaluating the products. However, there were significant differences ($p < 0.05$) between scores given for the outer colour (Table 5, column 3); i.e., the outer colour varied between the sessions, and it was not repeatable. This might have happened because the procedure for removing tomato sauce differed from session to session.

Panel agreement

The product–judge interactions (Table 5, column 5) were not significant ($p > 0.05$) for most of the evaluated attributes, which indicated a good degree of agreement within the panel. Significant interactions were only observed for 3 descriptors (elasticity, pastiness and fat perception), and overall, good repeatability was achieved. A significant product–judge interaction would imply a lack of consensus for the given variable. Moreover, it is necessary to take into account the product effect; thus, when this effect is also significant, an adequate panel agreement is presumed.

Panel reproducibility

The product–session and judge–session interactions were analysed to examine the panel reproducibility. Non-significant product–session interactions mean that each product was assessed in the same way in each session. Reproducibility between the different sessions was considered very good for the panel as a whole; significant differences were found only for one descriptor, the pastiness (Table 2, column 5). This descriptor was scored differently in different sessions. The judge–session interaction (Table 5, column 6) was only significant for elasticity and fat perception. This implies that some judges did

Table 5. F-values in three-way ANOVA (8 judges, 3 products, 3 sessions) for all descriptors.

Descriptors	Product	Judge	Session	Product–Judge	Product–Session	Judge–Session
Outer colour	13.46	3.18	3.00***	0.82	0.34	0.32
Inner colour	73.65	0.87	0.90	0.83	1.12	1.60
Elasticity	62.02**	0.51	0.87	3.26*	2.18	2.90*
Characteristic odour	263.28***	0.60	1.00	5.02	0.21	1.64
Firmness	3.33	0.21	0.03	2.94	3.28	0.75
Fragility	27.81	1.16	0.36	0.57	1.77	1.34
Juiciness	448.00*	43.00	0.28	0.26	3.10	0.80
Chewiness	126.44	0.41	2.54	1.07	0.40	1.37
Taste	780.34***	0.54	0.36	2.07	2.54	1.44
Aftertaste	3642.03*	1.83	0.47	1.06	0.54	1.61
Adherence	42.00*	2.27	1.93	1.42	0.80	1.08
Graininess	1292.85	1.35	26.60	1.41	0.06	0.98
Pastiness	172.50***	0.72	0.02	5.75**	6.24*	2.15
Fat perception	29.56*	0.33	0.00	5.71**	1.00	4.29**

Significant effects: *p-value < 0.05, ** p-value < 0.01, ***p-value < 0.0001.

not assign the same scores for those descriptors to all the samples in the two replicates. Overall, the panel reproducibility was very good.

Since the panel response was repeatable and reproducible, and their discrimination capacity was adequate, the judges were considered sufficiently trained, and the sensory evaluation stage could begin.

Sensory profile of ready-to-eat plant-based "meatballs"

The mean results obtained for the two samples analysed are depicted in Figure 5. The red line represents the average value for the reference sample; the dark grey stripe shows an area of ± 1 standard deviation from the agreed QDA for the reference sample. The red squares indicate the mean values for the improved prototype in each session, and the black symbols represent the outliers. Solid lines in the boxes mark the median values of the descriptor, and the whiskers represent the minimum and maximum values. The prototype sample values fell within the reference QDA area for firmness, fragility, inner colour, outer colour, and chewiness.

The ANOVA results for product variability presented in Table 5 (column 1) show significant differences between the prototype and reference samples (p-value < 0.05) for aftertaste (6.5 vs 1.2), adherence (1.4 v 2.4), fat perception (1.4 vs 2.5) and juiciness (5.7 vs 1.7). The values for elasticity (7.6 vs 8.5; p-value < 0.0001), characteristic odour (6.9 vs 0.8), taste (6.8 vs 2.0) and pastiness (1.4 vs 6.4) also differed significantly between these products.

Aftertaste, juiciness, characteristic odour and taste were rated higher for the new prototype samples, i.e., the intensities assigned to these descriptors were stronger for the prototype formulation than for the reference. In contrast, the intensities for adherence, fat perception, elasticity and pastiness were reduced in the prototype; the improved formulation lowered the sensory perception of these attributes.

Appearance-related descriptors (the outer and inner colour) and texture-related descriptors (firmness, fragility, graininess and chewiness) did not differ between the samples.

The sensory profiles for the two products are plotted in Figure 6. The statistical significance (p-value) of the difference between the two samples is shown in Table 5. The main difference between the formulations is the use of gelling agents. The commercial reference product contains agar–agar and carrageenan, whereas the new prototype plant-based "meatballs" were made without any gelling agents. This could explain the lower scores assigned to the texture-related descriptors such as adherence, elasticity and pastiness in the prototype samples compared to the reference. The hydrocolloids employed as thickening agents in foods increase the intensity of attributes such as adhesiveness and elasticity[33]. Carrageenan, used in gel formation, is associated with a perception of pastiness during oral breakdown[34]. These are some of the undesirable sensory attributes of meat analogues[35,36]. The taste-related descriptors of new prototype samples, the aftertaste, juiciness and taste, obtained higher scores than the reference product descriptors. In a study by Godschalk-Broers, Sala[37], taste and juiciness were highly correlated with consumer liking. In another recent study by Starowicz, Kubara Poznar[38], juiciness and meaty taste have been reported among the main sensory attributes determining the acceptance of meat alternatives.

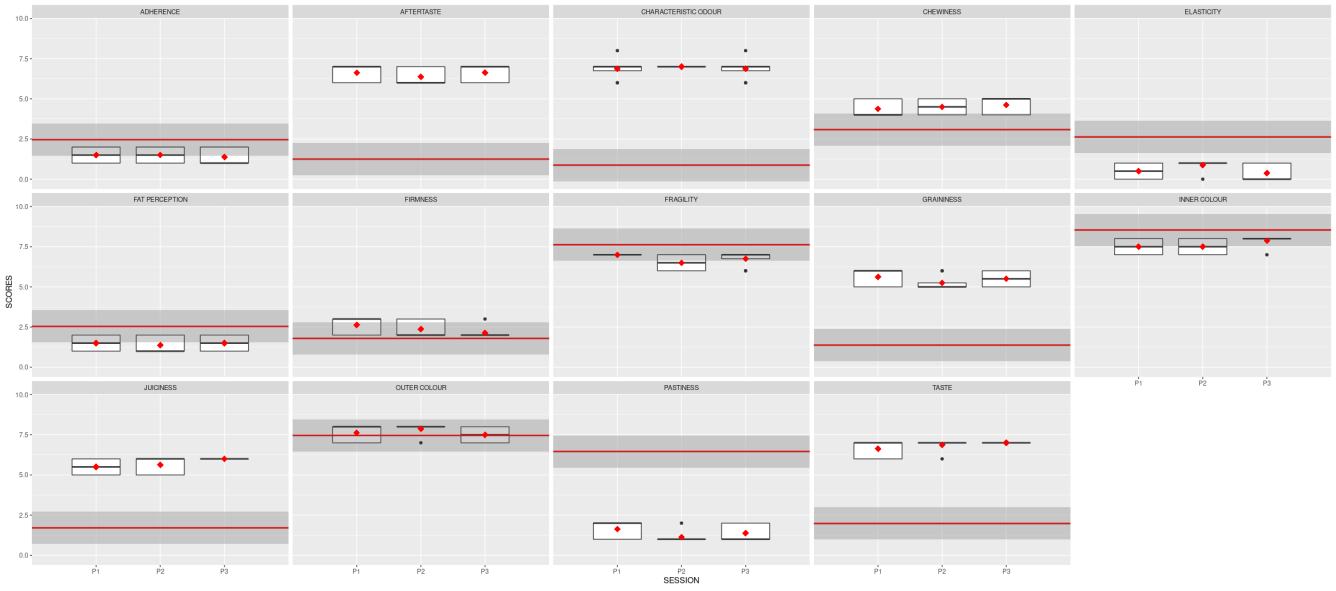
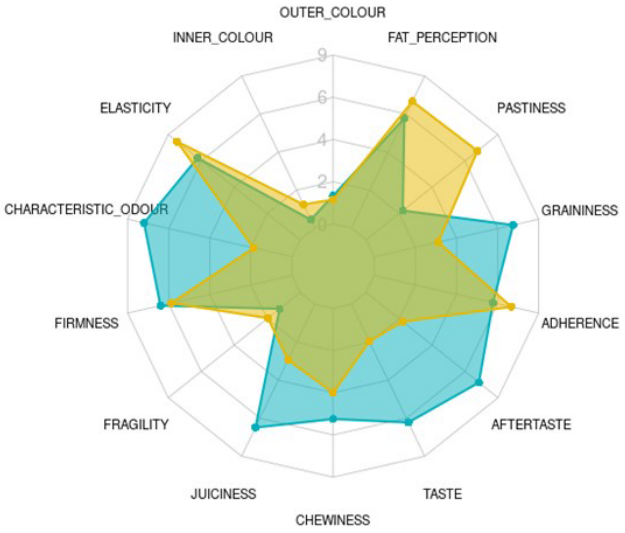


Figure 5. Boxplots showing the sensory results for each judge and descriptor in Step 3 (3 sessions).



	REFERENCE	PROTOTYPE
INNER COLOUR	8.5	7.6
ELASTICITY	2.6	0.6
FRAGILITY	7.6	6.8
ADHERENCE	2.5	1.5
PASTINESS	6.5	1.4
FAT PERCEPTION	2.5	1.5
CHARACTERISTIC ODOUR	0.9	6.9
FIRMNESS	1.8	2.4
TASTE	2.0	6.8
GRAININESS	1.4	5.5
OUTER COLOUR	7.5	7.7
JUICINESS	1.7	5.7
CHEWINESS	3.1	4.5
AFTERTASTE	1.3	6.5

Figure 6. Spider chart showing sensory profiling of the reference meatballs (REFERENCE) and the improved prototype (PROTOTYPE); n = 3 sessions. Mean values are shown in the attached table.

The fat perception was stronger in the commercial sample than in the new product. Godschalk-Broers, Sala[37] also report that large fat globules or pools of oil are associated with stronger fat perception. Although their study focused on chicken-analogue pieces, similar behaviour can be expected when tasting "meatball" analogue pieces elaborated with texturised protein ingredients.

Conclusion

The study focuses on creating a lexicon to objectively assess the sensory profile of plant-based meatballs. The research involved training eight judges over thirteen 1-hour sessions across three months. The panel was able to develop 14 descriptors for sensory evaluation, with a significant product effect observed for most descriptors, indicating the panel's ability to discriminate between products. The study found that attributes like juiciness and flavour, crucial for meat analogues, were improved in the plant-based product compared to a commercial reference. The sensory profile demonstrated that the developed plant-based product had enhanced attributes like juiciness and taste without compromising other characteristics like appearance and texture. The study emphasizes the critical role of a trained panel in sensory evaluation and presents a robust methodology that can be applied to a broader range of plant-based foods. It lays a foundation for future research aimed at expanding sensory evaluation across diverse food categories and developing specific lexicons for each, thereby contributing significantly to sensory analysis and innovation in the plant-based food sector.

Data availability

Underlying data

Zenodo: Fundacion-AZTI/TITAN: Development of the lexicon, trained panel validation and sensory profiling of new ready-to-eat plant-based "meatballs" in tomato sauce. Extended data. http://doi.org/10.5281/zenodo.7452100[39].

This project contains the following underlying data:

- Quali_sessions_panel.xlsx
- Panel_3steps.xlsx
- R Sensory panel meatballs.R

The qualitative data is in Spanish, however, readers should contact the corresponding author for any queries on the qualitative data.

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

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No comments.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Food development and Sensory analysis. (Meat and fish science and technology).

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 16 February 2024

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✔ **Kaiser Younis**
Department of Food Technology, Islamic University of Science and Technology, Pulwama, Jammu and Kashmir, India

I have no further comments to make.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My area of expertise is food product development.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 2

Reviewer Report 22 January 2024

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Juan B. Calanche M
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This article offers a compelling exploration into the intricacies of constructing a semantic lexicon for the sensory characterization of plant-based meat substitute products. The comprehensive methodology employed encompasses diverse approaches, including focus groups, hedonic testing, descriptor identification and selection, quantitative descriptive analysis, and performance evaluation. While the study's breadth and ambition are noteworthy, its substantial findings make a significant contribution to the research landscape in this domain. However, to enhance the scientific rigour of the work, certain sections may benefit from refinement, clarification, or the incorporation of additional information. The ensuing breakdown provides a detailed analysis of specific comments aimed at optimizing the scientific quality of the manuscript.

1) **Plain language summary:** The phrase "but rather their salvation" is questioned for its appropriateness, as the concept of salvation lacks clarity. Further clarification is needed to convey a more precise message to consumers.

2) **Methods (Ingredient):** Elaboration on the rationale behind ingredient selection and a clarification of the criteria governing proportion choices in the formulations would enhance methodological transparency.

3) **Article:** Provide an early explanation of the acronym "AZTI" within the article for reader comprehension.

4) **Methods (Demographic characteristics):** Clarify the purpose of the demographic characteristics section, particularly regarding the necessity of gender balance among sensory panel members. Additionally, justify the predetermined characteristics of the selected sample, considering its relatively small size.

5) **Methods. Sensory analysis:** Identify the entity endorsing the ethical certification of the experiment following ISO 8586:2012, specifying the relevant paragraph or section.

6) **Methods. Recruitment of judges and basic training:** Provide the rationale for excluding non-consumers of plant-based products and elucidate the criteria used to establish these selection criteria.

7) **Methods. Recruitment of judge:** Justify the choice of 8 assessors and address the discrepancy with ISO 8586:2023 (4.2.5 Number of persons to be selected), which recommends a minimum of 12 trained assessors for a sensory panel.

8) **Methods:** Explain the omission of an independent hedonic analysis to determine the product with the highest acceptability. Additionally, clarify the rationale behind using the same candidates for both hedonic and quantitative descriptive tests.

9) **Methods. Generation of descriptors and training of judges:** Specify how the sauce's impact on sensory perception was accounted for during the selection of organoleptic attributes for the vegan meatball. Clarify the considerations given to the sauce-meat sausage interaction.

10) **Methods. Generation of descriptors and training of judges:** Justify the choice of not using typical meatballs as reference products for imitation when substituting a meat product with a plant-based alternative. Discuss the potential insights gained from comparing the profiles of the original food with its various analogues.

11) **Methods. T Generation of descriptors and training of judges:** Provide details on the process of sharing, selecting, and standardizing the final organoleptic attributes after obtaining general descriptors from participants during training. Clarify the methodology employed in evaluating the plant-based product.

12) **Methods. T Generation of descriptors and training of judges:** Consider replacing the term "panellist" with sensory, screened, or trained sensory assessor, as deemed appropriate, to align with the evolution of assessors during training, as per ISO 8586:2023 standards.

13) **Results and discussion.** Glossary of descriptors for plant-based meatballs: Address the conceptual inconsistency in defining "characteristic taste" as the flavour of meat, given the distinct sensory receptors for taste and flavour. According to ISO 5492:2008 the term “taste” only corresponds to the basic ones (acid, salty, sweet, bitter and umami) and can include alkaline and metallic. For that reason, must clarify the definitions of "flavour" and "taste" to enhance understanding, particularly concerning the perceived difficulty in assessing this organoleptic property.

14) **Results and discussion.** Sensory profile of ready-to-eat plant-based “meatballs” Fig. 6: Clearly state whether the observed differences between the attributes of the two types of burgers are statistically significant, providing additional information on the statistical analysis employed.

15) **Results and discussion:** Provide insights into how outliers and deviations were addressed during training, including specific actions taken in response to individual tasters' performance. This information is crucial for enhancing the robustness of future research or training endeavours.

16) **Conclusions:** The conclusions of this study should be revisited and refined in consideration

of the aforementioned observations. Incorporating these insights will contribute to a more robust and nuanced interpretation of the findings, ensuring the overall integrity and scientific merit of the article.

References

1. Ardila P, Honrado A, Marquina P, Beltrán JA, et al.: Innovative Plant-Based Burger Enriched with Tenebrio molitor Meal: Characterization and Shelf-Life.*Foods*. 2023; **12** (18). PubMed Abstract | Publisher Full Text

Is the work clearly and accurately presented and does it engage with the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

Are all the source data and materials underlying the results available?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Food development and Sensory analysis. (Meat and fish science and technology).

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 24 Jan 2024

Clara Talens

In response to the insightful feedback received from the reviewers, we have systematically addressed each comment to ensure that our study on the sensory is presented with greater precision and depth: 1) Plain language summary: The phrase "but rather their salvation" is questioned for its appropriateness, as the concept of salvation lacks clarity. Further clarification is needed to convey a more precise message to consumers. The phrase "but rather their salvation" has been modified to provide more clarity: "Imagine a future generation of children who, from a young age, have learned that vegetables are not just an

alternative to meat, but a wholesome choice for nutrition and health." 2) Methods (Ingredient): Elaboration on the rationale behind ingredient selection and a clarification of the criteria governing proportion choices in the formulations would enhance methodological transparency. We agree that providing criteria for ingredient selection is important. In our study, the choice of lentils, quinoa, and oats was based on their nutritional properties, availability, and compatibility with the target product's sensory attributes. We aimed to create a plant-based meatball that is both nutritionally balanced and appealing to consumers. However, we acknowledge the need for detailed information on the nutritional aspects of the chosen ingredients to prevent any deficiencies. We have included a paragraph in the Materials and methods section. 3) Article: Provide an early explanation of the acronym "AZTI" within the article for reader comprehension. AZTI is not an acronym but the name of the institution where the flour was processed, location is included. AZTI is one of the affiliations of the manuscript. 4) Methods (Demographic characteristics): Clarify the purpose of the demographic characteristics section, particularly regarding the necessity of gender balance among sensory panel members. Additionally, justify the predetermined characteristics of the selected sample, considering its relatively small size. The necessity of gender balance among sensory panel members is crucial for ensuring diverse sensory perceptions. To clarify, we can add: "Gender balance was aimed to gather a wide range of sensory feedback, reflecting a varied panellist base." 5) Methods. Sensory analysis: Identify the entity endorsing the ethical certification of the experiment following ISO 8586:2012, specifying the relevant paragraph or section. This was already specified in the sentence: “The ethical approval was conducted according to quality standards of the ISO 8586:2012 certified by AENOR, the Spanish Association for Standardization and Certification.” 6) Methods. Recruitment of judges and basic training: Provide the rationale for excluding non-consumers of plant-based products and elucidate the criteria used to establish these selection criteria. The rationale for excluding non-consumers of plant-based products is based on targeting a specific consumer group. We can clarify by stating: "Non-consumers were excluded to focus on feedback from potential regular consumers of plant-based products." 7) Methods. Recruitment of judge: Justify the choice of 8 assessors and address the discrepancy with ISO 8586:2023 (4.2.5 Number of persons to be selected), which recommends a minimum of 12 trained assessors for a sensory panel. The following sentence was added: Eight assessors were chosen based on the availability and resources, acknowledging the deviation from ISO 8586:2023's recommendation of a minimum of 12. 8) Methods: Explain the omission of an independent hedonic analysis to determine the product with the highest acceptability. Additionally, clarify the rationale behind using the same candidates for both hedonic and quantitative descriptive tests. The main objective of the study was to train judges for sensory analysis, rather than conducting hedonic tests. Throughout these sessions, a combination of methodologies was employed to generate descriptors, and a structured approach was followed to train the judges. The training encompassed discussions and consensus-building exercises to ensure a shared understanding of the sensory characteristics of the plant-based meatballs. 9) Methods. Generation of descriptors and training of judges: Specify how the sauce's impact on sensory perception was accounted for during the selection of organoleptic attributes for the vegan meatball. Clarify the considerations given to the sauce-meat sausage interaction. We added the following paragraph: “In the sensory analysis of plant-based meatballs, a critical step involved the removal of the sauce to focus solely on the meatball's inherent sensory properties. This was

achieved through a careful and standardized process using a napkin. Each meatball, initially prepared with sauce, was gently lifted from its sauce. Then, using a napkin, the surface of the meatball was dabbed to absorb the sauce. This dabbing was performed with enough care to ensure that the sauce was absorbed without exerting pressure that might alter the texture of the meatball. The goal was to remove any visible traces of the sauce, effectively isolating the meatball from external flavor influences. This method ensured that each meatball was treated uniformly, allowing for an accurate and focused assessment of its intrinsic sensory characteristics." 10) Methods. Generation of descriptors and training of judges: Justify the choice of not using typical meatballs as reference products for imitation when substituting a meat product with a plant-based alternative. Discuss the potential insights gained from comparing the profiles of the original food with its various analogues. We added the following sentence: "The focus was on developing a distinct plant-based product rather than directly imitating meat-based meatballs." 11) Methods. T Generation of descriptors and training of judges: Provide details on the process of sharing, selecting, and standardizing the final organoleptic attributes after obtaining general descriptors from participants during training. Clarify the methodology employed in evaluating the plant-based product. Regarding the process of sharing, selecting, and standardizing the final organoleptic attributes, we would like to clarify that the details of this methodology have been comprehensively provided in the manuscript. However, acknowledging the importance of ease of understanding for the reader, we have incorporated additional connectors and transitional phrases within the text. 12) Methods. T Generation of descriptors and training of judges: Consider replacing the term "panellist" with sensory, screened, or trained sensory assessor, as deemed appropriate, to align with the evolution of assessors during training, as per ISO 8586:2023 standards. Agree. The term 'panellist' has been replaced with 'trained sensory assessor' to better reflect their role. 13) Results and discussion. Glossary of descriptors for plant-based meatballs: Address the conceptual inconsistency in defining "characteristic taste" as the flavour of meat, given the distinct sensory receptors for taste and flavour. According to ISO 5492:2008 the term "taste" only corresponds to the basic ones (acid, salty, sweet, bitter and umami) and can include alkaline and metallic. For that reason, must clarify the definitions of "flavour" and "taste" to enhance understanding, particularly concerning the perceived difficulty in assessing this organoleptic property. We sincerely appreciate the reviewer's insightful observation on this matter, as it significantly enhances the depth and clarity of our study. The term 'taste' is clarified to represent the basic taste sensations, and 'flavour' is used to describe the overall sensory experience. We have included the following explanation. *In English, the terms "taste" and "flavor" have distinct meanings, which can lead to confusion in translation, especially into Spanish. Taste: This refers to the sensation produced when a substance in the mouth reacts chemically with taste receptor cells located on taste buds. Taste is limited to five basic qualities: sweet, sour, salty, bitter, and umami. These basic tastes are perceived through the tongue. Flavour: It is a broader concept that includes not only the basic tastes but also the aromas and other sensations (like spiciness or temperature) perceived through the olfactory receptors in the nose. Flavour is the overall perception of a food or drink, combining taste, smell, and other sensory attributes. When translating these terms into Spanish, the distinction can become blurred: "Taste" is translated to "gusto" or "sabor." "Gusto" aligns more with the English "taste," referring to the basic taste sensations. However, "sabor" can be interpreted as both "taste" and "flavour," encompassing the broader sensory experience. "Flavour" is often translated as "sabor," but this doesn't fully capture the complexity of the term*

as understood in English, which includes aroma and other sensory experiences beyond just taste. The confusion arises because “sabor” in Spanish can mean both the basic tastes perceived by the tongue and the overall flavour experience, which includes aroma and other factors. This overlap in meaning can make it challenging to convey the distinct concepts of "taste" and "flavour" from English into Spanish accurately. In the context of this study conducted in Spain, the term "taste" (or "gusto" in Spanish) can often be understood to encompass what is referred to as "overall flavour" in English. This broader interpretation in the Spanish context arises from linguistic and cultural nuances in how sensory experiences are described. Therefore, in this study, when the term "taste" is used, especially given its Spanish context, it is aligned more with the English concept of "overall flavour." This encompasses a more holistic sensory assessment rather than just the basic taste sensations. Such linguistic and cultural differences are important to consider in sensory studies, as they can influence how sensory data is described, interpreted, and communicated. 14) Results and discussion. Sensory profile of ready-to-eat plant-based “meatballs” Fig. 6: Clearly state whether the observed differences between the attributes of the two types of burgers are statistically significant, providing additional information on the statistical analysis employed. The statistical significance (p value) of the difference between the two samples is shown in Table 5. We have included additional information near the description of Figure 6 to clarify the statistical analysis and findings, enhancing the reader's understanding of the presented data. 15) Results and discussion: Provide insights into how outliers and deviations were addressed during training, including specific actions taken in response to individual tasters' performance. This information is crucial for enhancing the robustness of future research or training endeavours. In response to the reviewer's comment about addressing outliers and deviations during training, as well as actions taken in response to individual tasters' performance, the study does provide detailed information on these aspects. The training of judges was performed in compliance with international standards, involving thirteen 1-hour sessions over three months, covering the selection of commercial reference, generation of descriptors, training of the panel, and validation of the trained panel and product characterization. Specific actions taken in response to individual tasters' performance included scrutinizing the descriptors and judges whose standard deviation was ≥ 1 after each tasting session. It was ensured that the difference between sessions was not significant at the 0.05 level, otherwise, it indicated that the scores of individual tasters were inconsistent. Additional three sessions were conducted to re-train the tasters for descriptors with high variability. A particular emphasis was placed on the definition and intensity of these descriptors. The study illustrates a rigorous approach to ensuring the consistency and reliability of the panel's evaluations. The panel's performance was deemed repeatable and reproducible, and an adequate capacity for discrimination was determined before commencing the sensory evaluation. The study also reports the statistical analyses employed, including a one-way ANOVA conducted per taster at the end of each session to identify statistically significant differences, and a three-way ANOVA to analyse the significance of the taster, descriptor, and session. It is important to note that further details on the analysis conducted can be found in the “Underlying data” section of the study. 16) Conclusions: The conclusions of this study should be revisited and refined in consideration of the aforementioned observations. Incorporating these insights will contribute to a more robust and nuanced interpretation of the findings, ensuring the overall integrity and scientific merit of the article. In light of the valuable feedback from our reviewers, our study's conclusions have been refined.

Competing Interests: No competing interests were disclosed.

Reviewer Report 17 July 2023

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Kaiser Younis
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[2] Department of Food Technology, Islamic University of Science and Technology, Pulwama, Jammu and Kashmir, India

All the queries have been addressed by the authors.

Is the work clearly and accurately presented and does it engage with the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

Are all the source data and materials underlying the results available?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My area of expertise is food product development.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 03 July 2023

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Kaiser Younis
[1] Department of Food Technology, Islamic University of Science and Technology, Pulwama, Jammu and Kashmir, India
[2] Department of Food Technology, Islamic University of Science and Technology, Pulwama, Jammu and Kashmir, India

The authors have done a commendable job of training a sensory panel and formulating a glossary of descriptors for plant-based meatballs. Their efforts are likely to be of great benefit to researchers who conduct sensory analysis on similar products. However, there are a few areas where the research could be improved. The following suggestions are provided:

1. Please indicate the criteria for choosing the ingredients, as plant-based meat is recommended for various reasons but requires a sophisticated knowledge of plant foods to prevent deficiencies due to low-quality or deficient amino acids.

2. I was wondering why the meatballs haven't been tested for different flavors and textures. I think it would be helpful to determine what types of meatballs are most appealing to consumers. Do you have any plans to do this in the future?

3. The core temperature of the product during the process must be specified in the paper to ensure that the meatballs are cooked to a safe temperature and are safe to eat.

4. The type of light in the sensory rooms can significantly affect the results of sensory analysis. Please indicate the source of light in your report.

5. The research could have considered offering remuneration to the participants. This might have encouraged more people to apply and could have resulted in a more diverse group of participants. The paper does not inform about the reason of taking only 8 panelists.

6. The paper could have also considered using a different reference product for the hedonic evaluation. This might have given the judges a different perspective on the products being evaluated.

7. The paper could have considered providing more detail about the training sessions. For example, they could have described the specific exercises that the judges were asked to perform.

8. The paper could have benefited from providing more information about the outliers in the

data. This could have included explaining why the outliers occurred and whether they were considered to be significant.

9. The paper could have included more participants in the study. This would help to increase the generalizability of the results. For example, the researchers could have recruited participants from a variety of demographics, such as age, gender, and dietary preferences.

10. The paper could have been strengthened by including a control group in the study. This would have allowed the researchers to compare the sensory profile of the two products to a baseline, such as a group of participants who were not familiar with plant-based "meatballs."

11. A follow-up study could have been conducted to assess the long-term sensory properties of the two products, which would have helped to determine whether the sensory profile of the products changed over time.

12. The paper could benefit from a section that discusses the implications of the study for future research. For example, the authors could discuss the possibility of using the glossary of descriptors to develop a sensory profile for other plant-based products.

Is the work clearly and accurately presented and does it engage with the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

Are all the source data and materials underlying the results available?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My area of expertise is food product development.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 09 Jul 2023

Clara Talens

Thank you for your valuable feedback and suggestions regarding our research on sensory analysis of plant-based meatballs. We appreciate your positive comments and acknowledge the areas where the study could be further improved. We will address each of your suggestions below:

1. Criteria for choosing ingredients: We agree that providing criteria for ingredient selection is important. In our study, the choice of lentils, quinoa, and oats was based on their nutritional properties, availability, and compatibility with the target product's sensory attributes. We aimed to create a plant-based meatball that is both nutritionally balanced and appealing to consumers. However, we acknowledge the need for detailed information on the nutritional aspects of the chosen ingredients to prevent any deficiencies. We have included a paragraph in the Materials and methods section.

2. Testing different flavors and textures: We recognize the importance of investigating a wider range of flavors and textures to gain insights into consumer preferences. However, in this study, our primary focus was on developing a sensory lexicon for the base product as a foundational step. By establishing a robust lexicon and ensuring panel agreement, we can subsequently utilize it to explore and evaluate a broader variety of flavors and textures in future research, thereby addressing the valuable suggestion put forth by the reviewer

3. Core temperature during processing: We would like to assure you that the paper already includes the information you suggested. Specifically, we stated in the manuscript that "The temperature at the core of the product was maintained at 105—108 °C for 34 min, achieving an F 0 of 3, then the samples were stored at ambient temperature." We apologize if this information was not immediately evident, and we will ensure that it is presented more prominently for clarity in future revisions.

4. Sensory room lighting: We appreciate your point regarding the potential influence of lighting conditions on sensory analysis. In our study, we conducted sensory evaluations in controlled environments with standardized lighting conditions. We have included this information “The sensory rooms were equipped with full-spectrum daylight LED lighting, which ensures consistent illumination across evaluations”.

5. Participant remuneration and panel size: We acknowledge that offering remuneration to participants could have increased the diversity of our panel. While we didn't provide monetary compensation to the trined panellists in this study, we ensured their commitment and motivation by providing thorough training and a supportive environment. As for the panel size, we aimed for a manageable group that allows for effective training and panel performance. There are indeed a significant amount of research with such number of trained panellist.

6. Reference product for hedonic evaluation: Selecting an appropriate reference product is indeed critical in sensory evaluations, as it provides a benchmark for comparison and helps assess the relative attributes of the tested products. In our study, the primary objective was to enhance the sensory profile of plant-based meatballs in sauce, specifically focusing on

the development of a lexicon to evaluate their characteristics. The chosen reference product represented the existing market offering in terms of plant-based meatballs in sauce that are shelf-stable. Introducing other types of reference products could have deviated from the main aim of improving the existing options available to consumers. We have included a paragraph to explain this decision.

7. Detailed training sessions: We have included a more detailed description of these exercises in the revised paper to enhance transparency and reproducibility.

8. Outliers in the data: Thank you for highlighting the need for addressing outliers in the data and providing explanations for their occurrence. We agree that discussing the outliers would contribute to a better understanding of the sensory profile and potential variations within the panel. In our future work, we will thoroughly analyze and document outliers, including their significance and potential causes. The presence of outliers in the data is an essential aspect to consider when analyzing sensory profiles. In the study, Figure 2 and Figure 4 provide visual representations of the data using boxplots, where the black dots represent the outliers. These outliers signify data points that deviate significantly from the majority of the observed values. While the paper did not explicitly explain the reasons behind the occurrence of outliers, they can arise due to various factors, such as individual differences in sensory perception, variations in panellists' responses, or potential measurement errors. It is important to note that outliers may or may not have a significant impact on the overall analysis, and their interpretation should be approached cautiously. In this study, the focus was primarily on assessing the variability and robustness of the panel over multiple sessions. The reduced variability observed in Table 4 and the alignment of the red squares (representing mean values) in Figure 4 indicate improved panel consensus and reduced variability for descriptors such as cohesiveness, juiciness, and taste after the second training. This suggests that the outliers may not have exerted a significant influence on the overall analysis or affected the interpretation of the sensory profiles. It is worth mentioning that the sensory profiles of the prototype samples (depicted in Figure 5) fell within the acceptable range defined by the reference sample's agreed-upon QDA area for descriptors like firmness, fragility, inner colour, outer colour, and chewiness. While the presence of outliers can provide valuable insights, their impact on the study findings may be relatively minimal in this context.

9. Increased participant diversity: We appreciate the reviewer's comment regarding the inclusion of more participants in the study to enhance the generalizability of the results. In this research, the focus was on training a panel of sensory experts to assess plant-based meat analogues. Thus, the recruitment process prioritized individuals who were consumers of this type of product to ensure their familiarity with the sensory characteristics and attributes of plant-based meatballs. Additionally, efforts were made to maintain a gender balance among the panellists to minimize potential gender-related biases. While variables such as demographics and age are relevant in consumer studies, they carry less significance in the context of training sessions for sensory panels. The primary objective of the training sessions was to develop a panel of trained assessors with the ability to detect and discriminate flavour and texture differences in the plant-based meatball products accurately. As such, the selection process focused on individuals who demonstrated the sensory acuity and aptitude necessary for trained panel evaluations, irrespective of their

specific demographics or age. It is important to note that the expertise and ability to discern subtle sensory differences are paramount for panellists involved in the development of a sensory lexicon. Thus, the focus was on recruiting panellists who could contribute to the development of a reliable and consistent sensory evaluation process. While expanding the participant pool to encompass a broader range of demographics could be beneficial for consumer studies, it was not the primary aim of this study, which focused on training and validating a specific panel for sensory analysis. Future research could certainly explore the impact of demographic variables on consumer acceptance and preferences, and we acknowledge the potential value of conducting such studies.

10. Control group inclusion: We appreciate the reviewer's suggestion regarding the inclusion of a control group in the study to compare the sensory profiles of the plant-based meatballs with a baseline group unfamiliar with such products. However, it is important to note the fundamental difference between consumer studies and trained panel evaluations. In this study, the focus was on training and validating a sensory panel with the objective of obtaining objective and quantified measurements of sensory attributes for the plant-based meatball products. Trained panels are specifically trained to evaluate and quantify sensory characteristics using standardized methodologies, resulting in measures with the input of trained human assessors. The emphasis is on capturing detailed sensory profiles and discriminating specific attributes, rather than assessing overall acceptance or rejection. On the other hand, consumer studies aim to investigate the acceptance, preferences, and overall liking of food products among a target population. The inclusion of a control group in consumer studies can provide a valuable baseline for comparison, as it allows for a comparison between a familiar product and a novel or alternative product in terms of overall acceptance. In the context of a trained panel study, the focus is on obtaining precise and reliable sensory measurements rather than capturing broad acceptance or preference data. The trained panel's expertise lies in quantifying sensory attributes and providing detailed insights into the specific sensory characteristics of the plant-based meatballs. While the inclusion of a control group could be valuable for assessing consumer acceptance, it may not align with the objective of the present study, which aimed to develop a sensory lexicon and obtain quantified sensory data. However, future research could certainly explore the incorporation of consumer studies to complement the findings from trained panel evaluations and provide a more comprehensive understanding of the sensory profiles and acceptance of plant-based meat products.

11. Long-term sensory properties: We agree that such an investigation would provide valuable insights into the shelf-life stability of the products. After the submission of the article, we conducted a shelf-life assessment of the plant-based meatballs at the three-month time point. The results confirmed the sensory stability of the products up to that duration. However, the study is still ongoing, and assessments at the six-month, nine-month, and twelve-month time points are planned to comprehensively evaluate the long-term sensory properties and potential changes that may occur over an extended period. By conducting these additional assessments, we aim to gain a better understanding of the shelf-life stability and sensory characteristics of the plant-based meatball products over an extended timeframe. The data obtained from these subsequent evaluations will contribute to the overall understanding of the products' sensory profiles and guide recommendations for storage conditions and product shelf-life.

12. Implications for future research: We agree that highlighting the potential applications and future directions of our findings would be valuable for advancing the field of sensory analysis for plant-based products. One important avenue for future research is the continued assessment of the long-term sensory properties and shelf-life stability of the plant-based meatball products beyond the three-month timeframe covered in this study. Conducting additional evaluations at six-month, nine-month, and twelve-month intervals would provide further insights into the changes in sensory characteristics over time and help establish appropriate storage conditions to maintain product quality. Furthermore, the developed lexicon of descriptors can serve as a valuable resource for future sensory evaluations of other plant-based products. However, it is important to note that the descriptors generated in this study were tailored specifically to the sensory profile of the plant-based meatballs in sauce. If applied to different product categories, it would be necessary to generate a new lexicon tailored to those specific products. Nevertheless, the benefit of having a trained panel, as established in this study, is that the panellists have already undergone extensive training and are familiar with the various steps involved in sensory evaluation. This reduces the training time required for future studies and ensures the availability of a reliable and consistent panel for assessing different plant-based products. We had added a paragraph for future work in the new submission. Thank you again for your thoughtful comments and suggestions. Your feedback will greatly contribute to enhancing the quality and comprehensiveness of our research.

Competing Interests: No competing interests were disclosed.