Development of the lexicon, trained panel validation and sensory profiling of new ready-to-eat plant-based "meatballs" in tomato sauce [version 2; peer review: 1 approved with reservations]

Clara Talens, Maider Lago, Eder Illanes, Ana Baranda, Mónica Ibargüen, Elena Santa Cruz

AZTI, Food Research, Basque Research and Technology Alliance (BRTA), Derio, Bizkaia, 48160, Spain

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 develop 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.

**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.

**Keywords**
healthy nutritional habits, sensory analysis, trained panel, ready-to-eat meals, plant-based, meat analogues
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**Corresponding author:** Clara Talens (ctalens@azti.es)

**Author roles:**
- **Talens C:** Conceptualization, Data Curation, Methodology, Software, Supervision, Writing – Original Draft Preparation, Writing – Review & Editing
- **Lago M:** Data Curation, Formal Analysis, Investigation, Methodology, Software, Writing – Original Draft Preparation
- **Illanes E:** Formal Analysis, Writing – Original Draft Preparation
- **Baranda A:** Formal Analysis, Investigation, Methodology
- **Ibargüen M:** Methodology, Supervision, Writing – Original Draft Preparation
- **Santa Cruz E:** Funding Acquisition, Investigation, Methodology, Resources, Writing – Original Draft Preparation

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Amendments from Version 1

In this revised version of our article, we have made several significant updates and improvements compared to the previously published version. Firstly, we have provided more detailed information regarding the criteria for ingredient selection, addressing the importance of considering nutritional factors and amino acid profiles in plant-based meat substitutes. Acknowledging the reviewer's suggestions, we have included explanations about the selection of reference products and the panel training process. The references were chosen based on a market search in local supermarkets and online platforms, ensuring a comprehensive representation of available plant-based meatball options. The training sessions involved panellists generating descriptors individually on post-it notes, followed by group discussions to reach a consensus.

Regarding outliers in the data, we have acknowledged their presence in the boxplots and highlighted their potential impact on the analysis, while cautioning about their interpretation. We explained that outliers can arise from individual differences in sensory perception and measurement errors. In response to the comment about a control group, we have clarified the fundamental difference between trained panel evaluations and consumer studies. Trained panel assessments aim to obtain objective and quantified measurements of sensory attributes, whereas consumer studies focus on overall acceptance and preference. However, we recognized the value of incorporating consumer studies in future research.

We outlined future implications, including ongoing shelf-life stability assessments and the potential application of the trained panel for assessing sensory profiles of other plant-based products. We highlighted the benefits of a trained panel, such as reduced training time and the reliability provided by experienced assessors.

Overall, this revised version addresses the reviewer's comments, providing additional details, clarifications, and future directions to enhance the quality and comprehensiveness of our article on sensory analysis of plant-based meatballs in sauce.

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

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 the generation of the future, children who, from a young age, have learnt that vegetables are not their enemies, but rather their salvation, and from a very early age they have been taught to combine different types of food, especially plant-based, to make them aware that in the not-too-distant future this could be a real scenario.

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.

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. 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. 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. 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. 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.

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.

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.

The biggest challenge facing the developers of meat analogues is obtaining meat-like texture and flavour. 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\textsuperscript{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\textsuperscript{22}. Protein sources such as quinoa, lentils and oats have been reported as sustainable protein sources\textsuperscript{13} with potential beneficial effects for human health\textsuperscript{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\textsuperscript{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\textsuperscript{16}.

Several studies have reviewed consumer acceptance of alternative proteins, innovative food and novel food technologies\textsuperscript{17} and meat consumption\textsuperscript{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\textsuperscript{19}.

Recently, many alternative protein sources (e.g., plants, insects or fungi) have been explored as replacements for animal-derived proteins\textsuperscript{20,21}. However, a lack of familiarity with novel foods affects expectations and can negatively impact sensory perception and overall liking\textsuperscript{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\textsuperscript{13}. 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\textsuperscript{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\textsuperscript{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\textsuperscript{24} or fully plant-based meatballs\textsuperscript{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 ingredients were carefully chosen based on their nutritional properties and compatibility to ensure a well-balanced plant-based meatball product. The selected ingredients, including textured soy protein (with approximately 50% protein content, essential amino acids, iron, and calcium), quinoa (containing around 15% protein, essential amino acids, dietary fiber, iron, magnesium, and phosphorus), red lentil flour (providing about 25% protein, dietary fiber, folate, iron, and various vitamins and minerals like potassium and zinc), and oat flour (with roughly 10% protein, dietary fiber, beta-glucan, magnesium, phosphorus, and antioxidants), were carefully chosen based on 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. The 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 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 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 panellists who were also consumers of meat analogues. 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). 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.

Generation of descriptors and training of judges
The specific judge training was performed according to international standards. 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 panelists were presented with three commercially available types of ready-to-eat plant-based meatballs in tomato sauce (Figure 1). 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 panelists decided which product would serve as the reference in the subsequent sessions. A standardised procedure for sensory analysis was used, following ISO 11035:1994.

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.

We conducted a series of training sessions (S1-S6) with the panelists to develop a comprehensive sensory lexicon for the selected commercial product, which served as the reference (Figure 2). To facilitate the process, each panelist 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, utilising the agreed-upon descriptors to evaluate the sensory characteristics of the plant-based meatballs.

A structured scale of nine points 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 (the sauce was removed using a napkin). Through iterative sessions and discussions, the panelists achieved a consensus on the intensity of each descriptor for the reference product after seven sessions. 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). 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 sensory evaluation for the product. After 7 sessions, the consensus on 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 panellists 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 panellist) 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 panellist, 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 panellists. 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 panellist was > 1. To confirm the repeatability of a panellist 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

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

<table>
<thead>
<tr>
<th>Descriptors</th>
<th>Definition and procedure used for their evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual</strong></td>
<td></td>
</tr>
<tr>
<td>Outer colour</td>
<td>1, raw meat colour; 5, medium meat colour; 9, light brown</td>
</tr>
<tr>
<td>Brightness</td>
<td>1, low brightness; 9, high brightness</td>
</tr>
<tr>
<td>Elasticity</td>
<td>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.</td>
</tr>
<tr>
<td>Inner colour</td>
<td>1, raw meat colour; 5, medium meat colour; 9, light brown</td>
</tr>
<tr>
<td>Compactness</td>
<td>The internal appearance of the meat: 1, loose-consistency meat and 9, very compact meat.</td>
</tr>
<tr>
<td><strong>Odour</strong></td>
<td>The higher the intensity, the higher the score assigned (within the scale).</td>
</tr>
<tr>
<td>Characteristic odour</td>
<td></td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td>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).</td>
</tr>
<tr>
<td>Cohesiveness/Fragility</td>
<td>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.</td>
</tr>
<tr>
<td>Juiciness</td>
<td>The sensation of moisture in the mouth during chewing. The greater the sensation of juiciness, the higher the score.</td>
</tr>
<tr>
<td>Chewiness</td>
<td>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).</td>
</tr>
<tr>
<td>Adherence</td>
<td>Force required to detach the product from the palate (1, not very adherent; 9, very adherent).</td>
</tr>
<tr>
<td>Graininess</td>
<td>Detection of granules or small particles</td>
</tr>
<tr>
<td>Pastiness</td>
<td>The effort required to swallow the product (1, a little; 9, very doughy)</td>
</tr>
<tr>
<td>Fat perception</td>
<td>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).</td>
</tr>
<tr>
<td><strong>Taste</strong></td>
<td></td>
</tr>
<tr>
<td>Characteristic taste</td>
<td>Meaty flavour</td>
</tr>
<tr>
<td>Aftertaste</td>
<td>The higher the persistence, the higher the score assigned (within the scale).</td>
</tr>
</tbody>
</table>
### Table 2. Sensory results per judge and descriptor in Step 1 (4 sessions).

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Coefficients Mean panel ± SD</th>
<th>Statistics</th>
<th>Mean panel ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>descriptor</td>
<td>Judge 1</td>
<td>Judge 2</td>
<td>Judge 3</td>
</tr>
<tr>
<td>Brightness</td>
<td>5.75±0.50</td>
<td>5.75±0.50</td>
<td>6.50±0.58</td>
</tr>
<tr>
<td>Elasticity</td>
<td>1.75±0.50</td>
<td>2.25±0.50</td>
<td>3.00±0.82</td>
</tr>
<tr>
<td>Compactness</td>
<td>0.00±0.82</td>
<td>5.00±0.00</td>
<td>5.25±0.50</td>
</tr>
<tr>
<td>Characteristic odour</td>
<td>0.25±0.50</td>
<td>0.00±0.00</td>
<td>0.50±1.00</td>
</tr>
<tr>
<td>Firmness</td>
<td>2.00±0.00</td>
<td>1.50±0.58</td>
<td>1.63±0.48</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>6.00±2.94</td>
<td>5.75±1.50</td>
<td>7.25±1.50</td>
</tr>
<tr>
<td>Juiciness</td>
<td>2.50±1.73</td>
<td>3.25±1.71</td>
<td>2.75±1.50</td>
</tr>
<tr>
<td>Chewiness</td>
<td>3.00±1.41</td>
<td>3.00±0.00</td>
<td>2.88±0.63</td>
</tr>
<tr>
<td>Adherence</td>
<td>2.25±0.50</td>
<td>2.75±0.96</td>
<td>2.00±0.00</td>
</tr>
<tr>
<td>Graininess</td>
<td>1.25±0.50</td>
<td>0.25±0.50</td>
<td>1.50±0.58</td>
</tr>
<tr>
<td>Pastiness</td>
<td>5.75±0.50</td>
<td>5.50±0.58</td>
<td>6.25±0.50</td>
</tr>
<tr>
<td>Fat perception</td>
<td>2.50±0.58</td>
<td>2.00±0.00</td>
<td>2.63±0.48</td>
</tr>
<tr>
<td>Taste</td>
<td>2.50±1.29</td>
<td>3.25±2.75</td>
<td>1.50±1.91</td>
</tr>
<tr>
<td>Aftertaste</td>
<td>1.75±0.50</td>
<td>1.50±0.58</td>
<td>1.00±0.82</td>
</tr>
</tbody>
</table>

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).

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 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.

The additional three sessions (S7, S8 and S9) were conducted to re-train the panellists 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 taste).

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 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

---

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

<table>
<thead>
<tr>
<th>STEP 1</th>
<th>STEP 2</th>
<th>AGREED QDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3, S4, S5, S6</td>
<td>S7, S8, S9</td>
<td>+Inner colour</td>
</tr>
<tr>
<td>Brightness</td>
<td>+Brightness</td>
<td>+Outer colour</td>
</tr>
<tr>
<td>Elasticity</td>
<td>Elasticity</td>
<td>Elasticity</td>
</tr>
<tr>
<td>Compactness</td>
<td>-Compactness</td>
<td></td>
</tr>
<tr>
<td>Odour</td>
<td>Odour</td>
<td></td>
</tr>
<tr>
<td>Firmness</td>
<td>Firmness</td>
<td>Firmness</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>Cohesiveness</td>
<td>+Fragility</td>
</tr>
<tr>
<td>Juiciness</td>
<td>Juiciness</td>
<td>Juiciness</td>
</tr>
<tr>
<td>Chewability</td>
<td>Chewability</td>
<td>Chewability</td>
</tr>
<tr>
<td>Adherence</td>
<td>Adherence</td>
<td>Adherence</td>
</tr>
<tr>
<td>Graininess</td>
<td>Graininess</td>
<td>Graininess</td>
</tr>
<tr>
<td>Pastiness</td>
<td>Pastiness</td>
<td>Pastiness</td>
</tr>
<tr>
<td>Fat perception</td>
<td>Fat perception</td>
<td>Fat perception</td>
</tr>
<tr>
<td>Flavour</td>
<td>Flavour</td>
<td>Taste</td>
</tr>
<tr>
<td>Aftertaste</td>
<td>Aftertaste</td>
<td>Aftertaste</td>
</tr>
</tbody>
</table>

---

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.

The additional three sessions (S7, S8 and S9) were conducted to re-train the panellists 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).

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

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

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

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 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 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\textsuperscript{33}. Carrageenan, used in gel formation, is associated with a perception of pastiness during oral breakdown\textsuperscript{34}. These are some of the undesirable sensory attributes of meat analogues\textsuperscript{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\textsuperscript{37}, taste and juiciness were highly correlated with consumer liking. In another recent study by Starowicz, Kubura Poznar\textsuperscript{38}, juiciness and meaty taste have been reported among the main sensory attributes determining the acceptance of meat alternatives.
The fat perception was stronger in the commercial sample than in the new product. Godschalk-Broers, Sala\(^\text{27}\) 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 results presented here showed that the performance of the expert panel assembled and trained for this study was suitable and appropriate. A descriptor set developed for the sensory evaluation of ready-to-eat plant-based meatballs in sauce was used to obtain sensory profiles of two products of this type (the improved prototype and the commercial reference). The analysis of these profiles demonstrated that the improved formula, based on a blend of lentils, quinoa and oats, increased the intensity of sensory properties associated with juiciness and taste (understood as a meaty flavour). The scores for adhesiveness, pastiness and elasticity (undesirable characteristics) were higher for the commercial sample than for the new product. The present study showed that, even though the appearance, firmness, fragility and chewiness of the tested foods were similar, adding a blend of quinoa, oats and lentils improved the taste and juiciness of a popular plant-based ready-to-eat meal without using texturizing agents. In conclusion, future research can focus on expanding the application of the trained panel to evaluate the sensory properties of other plant-based products. Additionally, continued shelf-life stability assessments and the development of new lexicons specific to different product categories will contribute to the advancement of sensory analysis in the field of plant-based food innovation.

**Data availability**

**Underlying data**


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).

**Acknowledgements**

The authors would like to thank Ewa Gubb for her help during English language editing.

**References**


Open Peer Review

Current Peer Review Status: Version 1

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Kaiser Younis

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.

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 trained 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 panellists.
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.
Open Peer Review

Current Peer Review Status: ?

Version 1

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Kaiser Younis
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 trained 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.