Food and Humanity 6 (2026) 101074

Contents lists available at ScienceDirect

Food and Humanity

journal homepage: www.editorialmanager.com/foohum/journal_overview.html

Sensory analysis and consumer willingness to purchase a lentil-based muffin formulation

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ARTICLE INFO

Keywords:
Consumer acceptability
Legume-based snack
Sensory attributes

ABSTRACT

Lentils are nutrient-rich legumes with high protein, fibre, and bioactive compounds, offering health and environmental benefits. Incorporating lentil flour in baked goods provides sensory challenges due to its unique flavour, texture and colour. This study compared muffins made with 50% lentil flour to an oatmeal flour control. Sixty untrained participants evaluated their sensory attributes. Lentil muffins scored lower in appearance and smell, while texture, flavour and overall acceptability were similar between muffins. Willingness to purchase was comparable, suggesting that lentil flour can be successfully incorporated into baked products. Improving appearance may enhance consumer appeal, further supporting health-focused, sustainable food innovation.

1. Introduction

The increasing consumer interest in healthier food alternatives, driven by the desire to improve personal well-being and reduce environmental impacts, has led to a growing demand for products enriched with plant-based ingredients (Estell et al., 2021). However, despite this growing demand, consumers may sometimes show reluctance toward unfamiliar formulations due to food neophobia. This highlights the importance of clear and informative labelling, together with appealing sensory characteristics, to build trust and encourage the acceptance of plant-based products (Alcorta et al., 2021; Pasqualone, 2022). Legume-based foods, in particular, have gained attention for their high nutritional value, as they are excellent sources of protein, dietary fibre, complex carbohydrates, essential minerals and vitamins (Geraldo et al., 2022). Furthermore, legumes offer potential health benefits, including antioxidant and anti-inflammatory properties (Geraldo et al., 2022; Shea et al., 2024). Additionally, legumes are naturally gluten-free, making them an appealing choice for the growing celiac market and those with gluten sensitivity (Carboni et al., 2024). Alongside providing these nutritional advantages, legumes provide excellent environmental benefits.

Among legumes, lentils (*Lens culinaris* L.) are particularly promising ingredients for the development of functional foods, given their nutritional quality and versatility. The diverse varieties of lentils, characterised by different seed coat colours such as brown, green, red, and black, are associated with varying concentrations of bioactive compounds like phenolics and flavonoids (Mirali et al., 2017). Green lentils, in particular, stand out due to their higher concentrations of these compounds and antioxidant activity, making them especially suitable for functional food development (Geraldo et al., 2024; Mirali et al., 2017). Lentil flours can be applied to various food products, such as muffins, breads, pastas, doughnuts, and crackers, among others (Eckert et al., 2018; Geraldo et al., 2024; Jarpa-Parra et al., 2017). Incorporating lentil flour into commonly baked foods offers an opportunity to increase legume consumption as well as align with consumers' taste preferences and growing demand for sustainable food options (Carboni et al., 2024). While oatmeal baked foods are widely accepted and consumed due to their mild flavour, soft texture and versatility, using lentil flour in baked products has challenges, especially regarding sensory characteristics that must be managed to ensure consumer acceptance (Romano et al., 2021). Lentils possess a distinct earthy flavour, firmer texture, and darker colour, which vary depending on the lentil variety and can significantly influence consumer perception and acceptance (Aghababaei et al., 2024). While lentil-based products offer nutritional

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https://doi.org/10.1016/j.foohum.2026.101074
Received 16 October 2025; Received in revised form 2 December 2025; Accepted 10 February 2026
Available online 11 February 2026

benefits, sensory adjustments may be needed to meet consumer expectations for taste, texture and overall enjoyment. Although previous research on lentils has primarily focused on their nutritional and functional properties, emphasising their value as a protein-rich alternative to animal sources, there is a gap in the literature concerning the sensory evaluation of lentil-based foods, with only a few studies reported (Carboni et al., 2024; Hajas et al., 2022). Understanding the sensory profile, including flavour, texture, and appearance, is critical in adapting these foods for broader consumer application. Furthermore, with the rising interest in plant-based diets, enhancing this sensory acceptability could support dietary shifts toward greater legume consumption, aligning with health and environmental goals (Viroli et al., 2023).

To address these concerns, this study aimed to evaluate how the incorporation of lentil flour influences the sensory attributes and consumer acceptance of muffins compared to an oatmeal formulation. To this end, a comparative sensory analysis was conducted on muffins prepared with 50 % lentil flour and 50 % oatmeal flour (LM) compared to a control muffin with 100 % oatmeal flour (OM), assessing consumer perceptions related to flavour, texture, colour, and overall acceptability. This work provides complementary insights into previously published nutritional and environmental data on these muffins (Geraldo et al., 2024), focusing specifically on consumer perception. To our knowledge, this is among the first studies to evaluate lentil-based muffins in Portugal, a region where lentil consumption is relatively low, offering novel insights into the feasibility of introducing legume-based innovations in bakery products. Sensory analysis is essential for evaluating how the addition of lentil flour affects overall product acceptance and consumer willingness to purchase, as sensory acceptance is a decisive factor in the success of such products. These findings support the translation of nutritional and sustainability benefits into real-world dietary choices.

2. Materials and methods

2.1. Products

The products used in this study were formulated based on the recipe described previously (Geraldo et al., 2024), where two muffin formulations were prepared: LM and OM. All ingredients were commercially sourced, except for the green lentil variety Kermit, which was provided by the University of Saskatchewan, Canada, and was milled in-house into a fine powder using a stone mill (Häussler Kostlich, Germany), with a particle size comparable to that of commercial oatmeal flour. Internal trials were conducted using different proportions of lentil flour blended with oat flour to evaluate sensory and textural properties. The 50 % formulation was selected as it offered the best balance of flavour and texture. The LM dry mix (per 100 g) consisted of 37.9 g oat flour, 37.9 g lentil flour, 19.0 g xylitol, 2.9 g baking powder, 1.5 g baking soda, and 0.8 g powdered vanilla essence, combined with 5.7 mL of olive oil and 94.3 mL of water. The OM dry mix (per 100 g) consisted of 69.3 g oat flour, 22.4 g xylitol, 6.3 g baking powder, and 1.9 g powdered vanilla essence, combined with 7.9 mL of olive oil and 92.1 mL of water. Both batters were portioned into silicone moulds and baked in a convection electric oven at 180 °C for 15 min (LM) and 25 min (OM). Muffins were prepared on the same day as the sensory evaluation and served fresh, with no storage period.

2.2. Ethical statement

All procedures followed the Declaration of Helsinki for medical research involving humans and were approved by the Ethics Committee in Technology, Social Sciences and Humanities (CETCH) of the Catholic University of Portugal under CETCH2023–31 (30/01/2023). Informed consent was obtained from participants before the experiment, ensuring volunteers understanding of the study's purpose/ procedures. Sensory analysis was performed through a quantitative blind effective test and an anonymous questionnaire, which is provided as supplementary material (Supplementary material S1). Portuguese written questionnaires were developed following the Sensorial Platform established methodologies of the Faculty of Biotechnology of the Catholic University of Portugal (ESB-UCP). Research files will be stored for five years for potential validation and subsequently destroyed.

2.3. Participant recruitment

The study was performed in Porto, Portugal, with participant recruitment and assessments at ESB-UCP. Volunteers were recruited through email, social media, poster affixation, and word-of-mouth. Inclusion criteria were: individuals over 18 years old; no food allergies or intolerances; no severe chronic inflammatory, infection, endocrine, or metabolic diseases, including gastrointestinal disorders; not pregnant or breastfeeding. The study involved 60 untrained participants (54 women; 6 men) aged 18–59. Socio-demographic data such as income, residence type, and education level were not included in the questionnaire, as they were not considered essential to the scope of this sensory evaluation.

2.4. Sensory analysis

Sensory analyses occurred on February 24th 2023, 9 am-5 pm, at ESB-UCP, through a quantitative blind effective test, using coded samples (three-digit numbers/letters) and presented randomly to each untrained participant (Lawless & Heymann, 2010). The test took place within individual sensory booths in a special room, equipped in compliance with ISO 8589:2007.

A nine-point hedonic scale (1 =dislike extremely; and 9 =like extremely) was used to assess the attributes acceptance (appearance, texture, flavour, aroma, and overall appreciation). Participants also rated the importance of different factors when buying food products (from '1 = completely disagree' to '5 = completely agree') and expressed their willingness to purchase the muffins if commercially available.

2.5. Statistical analysis

Data were analysed using GraphPad Prism (v.9.0.0 for Windows, GraphPad Software, San Diego, California, USA). The Kolmogorov-Smirnov test was used to assess the normality of the distribution of sensorial analysis data, revealing that variables did not adhere to a normal distribution, and therefore, the non-parametric Mann-Whitney and Kruskal-Wallis tests were performed. *p*-values below 0.05 were considered to be statistically significant.

3. Results

3.1. Participant preferences

A total of 60 volunteers aged 18–59 (mean=29; standard deviation=10) participated in the sensory analysis. Of these, 75 % were regular muffin consumers. The majority (57 %) ate muffins only at bakeries, 20 % consumed them both at home and bakeries, and 17 % prepared them at home. Only one participant used premade dry mixes, and 2 % reported consuming muffins in various forms.

The participants were also asked to rate the importance of different factors when purchasing muffins (Fig. 1). Key factors (score >4) were good flavour, texture, nutritional value, health benefits, and environmental sustainability. Less important were richness in protein, low calories, and low-fat content (Fig. 1).

3.2. Sensory analysis

Fig. 2 displays the sensory attribute analysis for LM and OM. Texture and flavour attributes received similar scores, while OM had

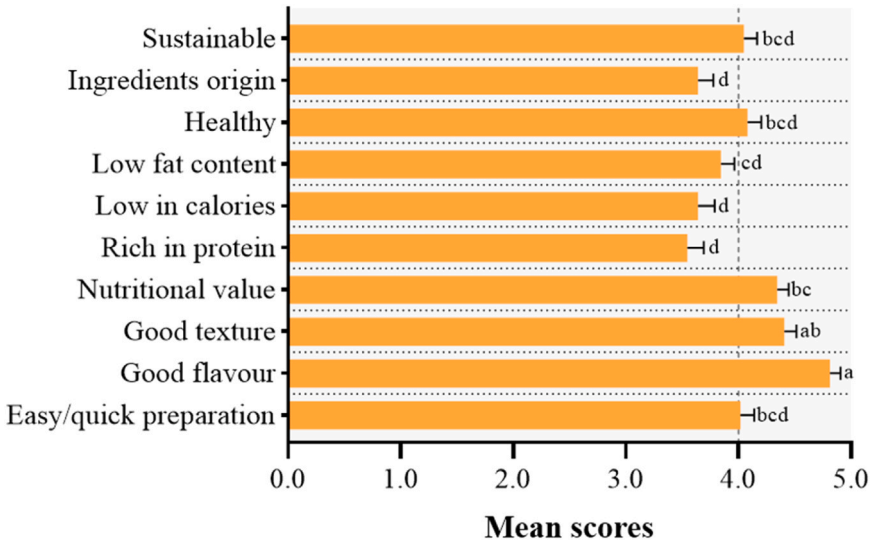

Fig. 1. Factors influencing purchase decisions. Mean scores attributed to different factors when purchasing muffins from '1 = completely disagree' to '5 = completely agree'. Bars indicate the mean ± SEM. Comparisons by the Kruskal-Wallis test. Significant differences are indicated with different letters at $p < 0.05$ (n = 60).

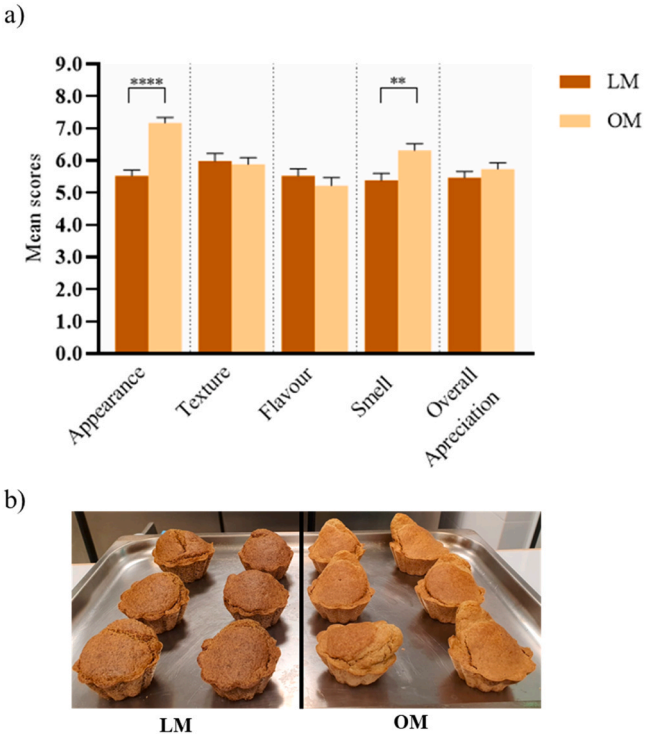

Fig. 2. Sensory evaluation of lentil (LM) and oatmeal (OM) muffins. a) Mean sensory scores attributed to appearance, texture, flavour, smell, and overall appreciation of lentil (LM) and oatmeal (OM) muffins. The assessment was based on an anchored nine-point hedonic scale, from 1 = dislike extremely to 9 = like extremely. Bars indicate the mean ± SEM. Comparisons by the Mann-Whitney test. Significant differences are indicated at ** $p < 0.01$ and **** $p < 0.0001$ (n = 60). b) Visual comparison of lentil (LM, left) and oatmeal (OM, right) muffins.

significantly higher scores for appearance and smell. Overall acceptance was similar for both muffins (Fig. 2).

Participants were also asked about their willingness to purchase LM and OM if available on the market. The majority answered with "3 =I have doubts if I would consume or not" for both muffins, with the mean willingness scores being 3.00 ± 0.11 (mean ± SEM) for LM and 3.02 ± 0.12 for OM ($p = 0.8615$).

4. Discussion

The results of the sensorial analyses highlight both challenges and opportunities in promoting lentil-based baked goods and provide valuable insights into consumer preferences. A notable number of participants regularly consumed muffins, with a small percentage reporting using premade dry mix at home, suggesting that this trend is relatively new in Portugal. Convenience and commercially available products are particularly appealing to consumers, especially in urban areas where time constraints and limited household help make convenience foods an attractive option (Negi et al., 2021). Muffin premade dry mix provides an easy solution by containing all the essential ingredients for muffin preparation except for liquids and fat (Negi et al., 2021). Interestingly, when considering factors that influence purchasing decisions, attributes related to product sensory characteristics, such as flavour and texture, held greater influence than convenience (easy and quick to prepare) or nutritional factors. Sustainability was rated in the 6th position, which aligns with other research demonstrating that the factor of "environmentally sustainable" is not a top concern for Europeans in these types of food products (de Boer & Aiking, 2022). This highlights an important opportunity for education and marketing campaigns that not only emphasise the health benefits, versatility, and enhanced flavour of legume-based foods but also the reduced environmental impact of their production. Such efforts could help shift existing biases against legumes and promote their integration into everyday diets. It should be noted that while the discussion refers to general consumer trends, socio-demographic variables such as residence type and education level were not collected in this study. These references are based on existing literature rather than participant-specific data. Future studies could benefit from incorporating a broader range of socio-demographic information to explore potential influences on consumer preferences more directly.

Regarding the sensory characteristics, the use of lentil flour in baking can introduce a subtle nutty flavour and a slightly denser, darker texture to the final product (Gallo et al., 2022), which may be perceived as a potential drawback. To minimise variability in texture, the lentil flour was milled in-house into a fine powder, with a particle size comparable to that of commercial oatmeal flour, reducing the likelihood that texture

differences were due to milling. A proportion of 50 % green lentil flour was used, resulting in a significantly lower score for appearance due to the darker colour compared to the OM. Additionally, although silicone moulds were used to ensure uniform shape, the muffins exhibited some irregularities in appearance, most likely due to uneven heat distribution in the oven (Shahapuzi et al., 2015). This may have affected the way batter rose and set during baking. Future improvements could include optimising oven conditions or rotating trays during baking to enhance visual consistency. The lentil-based muffins also received lower scores for smell compared to those made with oatmeal flour. This difference may be attributed to the earthy aroma associated with lentils, which can be less appealing to some consumers (Vurro et al., 2024). Furthermore, the presence of lentil flour appeared to neutralise the aroma of vanilla powder, while in the oatmeal flour muffins, this neutralising effect was not registered. Notably, the OM contained a higher amount of vanilla powder, as determined during preliminary trials to enhance its mild and bland flavour profile. In contrast, a lower concentration was used in the lentil muffins, based on the assumption that their stronger base flavour would require less aromatic enhancement. However, the results suggest that the lentil aroma may overpower or mask the vanilla, indicating that a higher vanilla concentration could be beneficial in future formulations. Despite these differences in aroma, no significant impact was observed on texture and flavour, both critical factors in consumer acceptance (Forde, 2018). It should be noted that other ingredient adjustments were made between formulations to ensure product feasibility, including variations in xylitol, baking powder, water, and oil, not only in vanilla powder. These changes were necessary to achieve acceptable texture and baking performance in both formulations, as simply replacing oatmeal flour with lentil flour without adjustments resulted in poor product quality during preliminary trials. Nevertheless, these modifications may have influenced sensory outcomes, making it difficult to attribute differences solely to lentil flour. Future studies should aim to isolate the effect of lentil flour by maintaining other ingredients constant. It is also important to note that different lentil varieties can influence the sensory profile of the final product. Green lentils, used in this study, are known for their higher concentrations of bioactive compounds such as phenolics and antioxidants, which could contribute to both the health benefits but also for the distinct colour and flavour of the final product (Geraldo et al., 2024; Mirali et al., 2017). Other lentil varieties, such as red, could be explored in future research to expand product diversity. Incorporating lentil flour, besides adding potential health benefits to the muffins (Geraldo et al., 2024), contributed to their positive taste quality and also made the product appealing to those seeking gluten-free options. The relatively high acceptance scores for LM muffins demonstrate that consumers may be willing to embrace legume-based products as part of their regular diet, consistent with previous studies (PC et al., 2021; Santos & Vasconcelos, 2023). It is also important to consider that this study was conducted in Portugal, where lentil consumption is relatively low compared to other legumes (Duarte et al., 2020). This regional context may influence consumer familiarity and acceptance of lentil-based products. Therefore, future research should examine consumer preferences in countries with different dietary habits to assess the generalizability of these findings.

5. Conclusion

The study assessed the sensory attributes of LM and OM developed in previous research. Results showed that incorporating lentil flour into innovative recipes, like muffins, could be well-received by consumers, despite the slightly darker appearance of LM. This suggests that consumers are open to legume-based foods. Future product development efforts should focus on improving the appearance and smell of legume-based baked foods to enhance their marketability further. Additionally, exploring different flour ratios or combinations with other flours may yield even better sensory properties, potentially broadening consumer acceptance. Beyond product formulation improvements, it is also important to acknowledge that this study was conducted in Portugal, where lentil consumption is relatively low. Future research should explore consumer acceptance in other regions to confirm the broader applicability of these findings. With growing consumer interest in healthier and more sustainable options, lentil-based muffins hold significant promise for becoming a popular alternative in the bakery sector.

CRediT authorship contribution statement

Rafaela Geraldo: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Carla S. Santos:** Writing – review & editing, Methodology. **Elisabete Pinto:** Writing – review & editing, Supervision. **Delminda Neves:** Writing – review & editing, Supervision. **Marta W. Vasconcelos:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization, Project administration, Resources.

Funding

This work was supported by the European Union's Horizon 2020 Research and Innovation Programme through projects “Realising Dynamic Value Chains for Underutilized Crops” (RADIANT) [Grant Agreement number 10100062], “Intelligent Collections of Food Legumes Genetic Resources for European Agrofood Systems” (INCREASE) [Grant Agreement number 862862] and by the Fundação para a Ciência e Tecnologia (FCT, Portugal) [grant numbers 10.54499/2021.05683.BD; 10.54499/2022.01903.CEECIND/CP1745/CT0002].

Declaration of Competing Interest

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

Acknowledgements

The authors thank the scientific collaboration under the FCT project UID/50016/2025 and LA/P/0076/2020. This work was carried out under contract ref. 2023.15056.TENURE.060, funded by national funds through FCT and by the Recovery and Resilience Plan (PRR) – Portuguese Republic, through the Recuperar Portugal Mission Structure.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.foohum.2026.101074.

Data availability

Data supporting the findings of this study can be obtained from the corresponding author, [MWV], upon reasonable request.

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