Archives of Current Research International

Volume 24, Issue 12, Page 197-206, 2024; Article no.ACRI.123810
ISSN: 2454-7077

Comparative Evaluation of Nutritional Composition, Fatty Acid Profile and Sensory Attributes of Commercial Plant-Based Meat Analogues and Chicken Nuggets

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/acri/2024/v24i121010

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:
https://www.sdiarticle5.com/review-history/123810

Original Research Article

Received: 22/07/2024
Accepted: 24/09/2024
Published: 23/12/2024

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Cite as: *ahseen, Aaliya, Sathu. T, Muthukumar Muthupalani, Vasudevan. V. N., Irshad. A, Preethy John, K. Raji, and MHS Abrar Basha. 2024. "Comparative Evaluation of Nutritional Composition, Fatty Acid Profile and Sensory Attributes of Commercial Plant-Based Meat Analogues and Chicken Nuggets". Archives of Current Research International 24 (12):197-206. https://doi.org/10.9734/acri/2024/v24i121010.*

ABSTRACT

This study provides a comprehensive evaluation of the proximate composition, fatty acid profile, and sensory attributes of commercial plant-based meat analogue (PBMA) nuggets compared to traditional commercial chicken nuggets. Fatty acid methyl esters (FAMEs) of the samples were prepared for analysing the fatty acid profile. Nutritional analysis revealed that PBMA nuggets contain higher levels of polyunsaturated fatty acids (PUFAs), ranging from 18.92% to 45.97%, and lower levels of saturated fatty acids (SFAs), with a maximum of 47.61%, potentially offering cardiovascular benefits. Notably, PBMA nuggets are cholesterol-free, while chicken nuggets exhibit cholesterol levels ranging from 50.69±0.37 mg/100g to 54.74±0.31 mg/100g. Total phenolic content (TPC) analysis showed that PBMA nuggets possess superior antioxidant capacity, with TPC values ranging from 2.00±0.02 to 2.94±0.02 mg gallic acid equivalent (GAE)/g, compared to chicken nuggets, which have TPC values of 0.913±0.02 and 1.23±0.03 mg GAE/g. Physico-chemical assessments indicate that PBMA nuggets generally have lower moisture content (46.69±0.11% to 51.87±0.12%) and protein content (5.15±0.04% to 12.12±0.03%) but higher fat (11.43±0.02% to 18.21±0.05%), fibre (1.09±0.02% to 1.20±0.02%), carbohydrate (21.12±0.06% to 28.89±0.13%), and ash content (1.94±0.007% to 3.83±0.02%) compared to chicken nuggets. Sensory evaluation revealed that chicken nuggets scored significantly higher in appearance (7.75±0.16), texture (7.25±0.16), juiciness (7.75±0.16), and overall acceptability (7.25±0.16) compared to PBMA nuggets. Despite their nutritional advantages, PBMA nuggets did not meet the sensory attributes of chicken nuggets, with lower scores in key sensory parameters. This indicates that while PBMA nuggets offer a healthier, plant-based alternative with beneficial nutritional profiles, further research and development are necessary to enhance their sensory attributes to better meet consumer preferences and expectations.

Keywords: Plant-based meat analogues; nuggets; fatty acid; sensory.

1. INTRODUCTION

Meat analogues, as defined by (Chiang et al., 2021), are "plant-based food products designed to mimic the appearance, texture and nutritional content of traditional meat." These novel plant-based meat analogues (PBMAs) are developed with the goal of providing near-equivalent substitutes for animal-derived meat in terms of taste, texture and nutritional composition (Rubio et al., 2020). Key considerations in PBMA production include consumer acceptability, microbial and chemical safety, as well as the protein source and quality (He et al., 2020). The present study examines three commercially available plant-based meat analogue nuggets, designated as PN-1, PN-2 and PN-3, in comparison with two commercial chicken nugget products, CN-1 and CN-2. These products were evaluated for their nutritional composition and quality characteristics, which are critical for consumer perception and market acceptance. A major advantage of PBMAs lies in their use of protein concentrates or isolates derived from sources such as soy, pea, and other plants. These purified proteins exhibit lower anti-nutritional factors, offering digestibility comparable to that of animal-based proteins, including meat (Hodgkinson et al., 2018). However, scientific evidence is essential to validate the nutritional quality and potential health benefits of PBMAs in comparison to conventional meat products. While PBMAs may be nutritionally inferior to whole, minimally processed plant-based foods, the addition of health-promoting ingredients can enhance their nutritional profile.

A critical question in this field is whether plant-based substitutes can adequately meet the nutritional requirements typically satisfied by animal-based foods. While certain nutrients are readily available from plant sources, others may be more efficiently obtained from animal products. Thus, this study aims to identify the nutritional gaps between PBMAs (PN-1, PN-2, PN-3) and standardized meat products (CN-1, CN-2).

2. MATERIALS AND METHODS

2.1 Proximate Parameters

The moisture content was estimated by hot air oven, protein using automatic digestion and distillation unit, fat was estimated by ether extraction, crude fibre, carbohydrate and ash content following standard procedure of (AOAC, 2016).

2.2 Cholesterol Content

The total cholesterol of the sample was determined by a method described by (Hanel & Dam, 1955). 100 µl of lipid extract (prepared from 2g of sample volume made to 5ml with chloroform) was pipetted and 50 µl of standard cholesterol solution was added separately into test tubes and evaporated to dryness in a water bath. The dried residue in each tube was dissolved in 2 ml of chloroform to which 1 ml $ZnCl_2$ reagent and 1 ml acetyl chloride were added. The samples were then heated in a water bath at 50℃ for 10 min. For blank, 2 ml of chloroform to which 1 ml $ZnCl_2$ reagent and 1 ml acetyl chloride were added. The colour complex formed was measured by reading the optical density (pink-red colour) at 528 nm in a spectrophotometer (UV-1700 PharmaSpec, Shimadzu, Japan), and cholesterol content was expressed as mg per 100g of sample.

$$\text{Cholesterol}\left(\frac{\text{mg}}{100\text{g}}\right) = \frac{\text{OD of unknown} \times \text{Conc. of standard} \times 5 \times 100}{\text{OD of standard} \times 0.1 \times 2 \times 1000}$$

2.3 Assay of Fatty Acid Profile

Fatty acid methyl esters (FAMEs) of the samples were prepared following the method described by (Wang et al., 2015). The fatty acid composition of extract was determined by injecting 1µL of sample in to gas chromatograph on a SP™-2560 capillary column with an internal diameter of 0.25 mm (100 m × 0.25 × 0.2 μm film thickness). The analysis was performed on a Varian 450 gas chromatograph equipped with a flame ionization detector. Nitrogen was used as carrier gas. The injection port temperature was 220℃, and the detector temperature was 220 ℃. The oven temperature was ramped to 175℃ for five min and increased to 220 ℃ at 15℃/min; it was then held at 220℃ for 30 min. A software calculated retention times and peak area percentages. Fatty acids were identified by comparing sample retention times with standard retention times (Supelco 37 component FAME mix, Merck). The results of the fatty acid profile were expressed as relative percentage of the peak areas.

2.4 Total Phenolic Content

The sum of the phenolic compounds of the samples was determined using the method of Folin and Ciocalteu (Szpicer et al., 2022) with modifications. Samples of 0.1 g were homogenized in 20 mL of ethanol and water (1:1). The extraction was kept in a shaking water bath (Kemi water bath incubator shaker, India) at 40℃ for 10 min and then centrifuged for 10 min at 5000 rpm in a centrifuge (Eppendorf centrifuge 5430 R, Germany). The filtered extract (1 mL) was mixed with 5 ml Folin–Ciocalteu solution (1ml of Folin–Ciocalteu reagent (Loba Chemie Pvt Ltd., India) in 10 ml water) and 4 ml sodium carbonate (75 g/L) (Sigma Aldrich Inc., USA) and incubated in darkness for 30 min. The absorbance was measured spectrophotometrically at a wavelength of 765 nm (UV-1700 PharmaSpec, Shimadzu, Japan). The calibration curve was plotted by mixing 1 ml aliquots of 0.1, 0.5, 1.0, 2.5 and 5.0 mg/ml Gallic acid solutions with 5.0 ml of Folin Ciocalteu reagent (diluted tenfold) and 4.0 ml of sodium carbonate solution (75 g/l). The absorbance was measured after 30 min at 765 nm. The sum of phenolic compounds was expressed as mg/gallic acid equivalents (GAE)/g sample.

2.5 Instrumental Colour

The colour of the sample was determined objectively as per (Navneet & Kshitji, 2011) using a calibrated colour reader (Konica Minolta CR-20, Singapore Pvt Ltd). The instrument was set to measure L^*, a^*, and b^* values. It was calibrated using black and white calibration tiles before starting the measurement and the colorimeter score was recorded with 'L' of black equals zero and 'L' of white equals 100, 'a' of lower numbers equals more green (less red), higher numbers equal more red (less green) and 'b' of lower numbers equals more blue (less yellow), higher numbers equals yellow (less blue). The colour coordinates L^* (lightness), a^* (redness), and b^* (yellowness) of the samples was measured thrice and mean values were taken.

2.6 Sensory Attributes

The sensory quality of the samples was judged based on appearance, juiciness, flavour, tenderness and overall palatability characteristics. Sensory attributes of the PBMA were evaluated organoleptically using an eight-point hedonic score card (AMSA, 1983) with the help of a semi-trained taste panelists during each trial. A minimum of seven values were collected for each sample and the sensory evaluation was repeated four times. The changes noticed in the sensory characteristics of all the samples were judged by the panel using a score card.

3. RESULTS AND DISCUSSION

3.1 Proximate Composition

The proximate composition of both chicken and PBMA nuggets is presented in Table 1. Significant differences (p<0.001) were observed between the chicken and PBMA nuggets across various nutritional parameters. The moisture content of chicken nuggets ranged from 60.96±0.18% to 67.65±0.11%, which was significantly higher (p<0.001) than that of PBMA nuggets, ranging from 46.69±0.11% to 51.87±0.12%. The moisture content followed a descending trend: CN-2 > CN-1 > PN-1 > PN-2 > PN-3. This difference is likely due to the lower water-holding capacity of wheat gluten used in PBMA formulations (Dekkers et al., 2016; Roccia et al., 2009).

In terms of protein content, chicken nuggets exhibited significantly higher values (p<0.001), ranging from 14.84±0.06% to 15.87±0.03%, compared to PBMA nuggets, which ranged from 5.15±0.04% to 12.12±0.03%. The protein content followed the descending order: CN-2 > CN-1 > PN-3 > PN-2 > PN-1. This aligns with the findings of (Hamid et al., 2020), who reported protein contents of 20.67% and 14.26% in jackfruit-based meat analogues and commercial PBMA, respectively.

Fat content also varied significantly (p<0.001) between the nugget types. Chicken nuggets (CN-1 and CN-2) contained 10.59±0.07% and 12.16±0.09% fat, respectively, while for PBMA nuggets ranged from 11.43±0.02% to 18.21±0.05%. PBMA nuggets exhibited higher fat content, following the order: PN-1 > PN-3 > CN-2 > PN-2 > CN-1. Higher fat content in PBMA enhances sensory attributes such as juiciness, tenderness and flavour retention (Egbert & Borders, 2006; Kyriakopoulou et al., 2021).

Carbohydrate content showed significant differences (p<0.001) between the two nugget types. Chicken nuggets had lower carbohydrate levels (2.53±0.03% to 11.10±0.30%) compared to PBMA nuggets (21.12±0.06% to 28.89±0.13%). The ascending carbohydrate content order was CN-2 < CN-1 < PN-1 < PN-3 < PN-2. These findings are consistent with the work of (Fresan et al., 2019), who reported similar carbohydrate levels in PBMA containing wheat and soy, and (Toth et al., 2021)), who found 15.97% carbohydrate content in vegan meatballs.

Crude fibre content did not differ significantly in chicken nuggets (0.83% to 0.89%), while PBMA nuggets exhibited significantly higher crude fibre levels (1.09±0.02% to 1.20±0.02%) (p<0.001). The crude fibre content followed the order: PN-2 > PN-1 = PN-3 > CN-1 = CN-2. Similar results were reported by (Hamid et al., 2020)), who found 3.41% and 1.67% crude fibre content in jackfruit-based and commercial PBMA, respectively. The ash content was significantly lower (p<0.001) in chicken nuggets (0.95±0.003% to 1.62±0.002%) compared to PBMA nuggets (1.94±0.007% to 3.83±0.02%). These findings align with the results of (Hamid et al., 2020), who reported ash contents of 3.76% and 2.88% in jackfruit-based and commercial meat analogues, respectively. Total dietary fibre (TDF) content in chicken nuggets ranged from 1.32% to 1.37%, significantly lower (p<0.001) than in PBMA nuggets, which ranged from 1.94% to 2.0%. The ascending order of TDF content was CN-2 < CN-1 < PN-2 < PN-1 < PN-3, consistent with the findings of (Katidi et al., 2023), who noted that plant-based products generally exhibit higher fibre content compared to animal-based foods.

3.2 Cholesterol Content

The cholesterol content in CN-2 was significantly higher (p<0.001) than in CN-1, as presented in Table 1. Specifically, the cholesterol levels in CN-1 and CN-2 were 50.69±0.37 mg/100g and 54.74±0.31 mg/100g, respectively. Cholesterol was undetectable in all PBMA nuggets, corroborating findings by (Fresan et al., 2019), who reported zero cholesterol across 56 PBMA samples, reaffirming the absence of cholesterol in plant-based products.

3.3 Fatty Acid Profile

The detailed fatty acid composition of the chicken and PBMA nuggets is outlined in Table 2 and visualized in Fig. 1, highlighting distinct variations in monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA) and saturated fatty acids (SFA) across both nugget types.

Table 1. Mean (±) SE of nutritional parameters of different PBMA and chicken nuggets

Parameters	CN-1	CN-2	PN-1	PN-2	PN-3
Moisture (%)	60.96±0.18[b]	67.65±0.11[a]	51.87±0.12[c]	49.62±0.14[d]	46.69±0.11[e]
Protein (%)	14.84±0.06[b]	15.87±0.03[a]	5.15±0.04[e]	6.95±0.04[d]	12.12±0.03[c]
Fat (%)	10.59±0.07[e]	12.16±0.09[c]	18.21±0.05[a]	11.43±0.02[d]	14.56±0.08[b]
Carbohydrate (%)	11.10±0.30[d]	2.53±0.03[e]	21.12±0.06[c]	28.89±0.13[a]	21.66±0.14[b]
Crude fibre (%)	0.89±0.02[d]	0.83±0.02[d]	1.09±0.02[b]	1.20±0.02[a]	1.14±0.02[ab]
Ash (%)	1.62±0.002[d]	0.95±0.003[e]	2.56±0.02[b]	1.94±0.01[c]	3.83±0.02[a]
Cholesterol content (mg/100g)	50.69±0.37[b]	54.74±0.31[a]	ND	ND	ND

CN-1: Chicken nuggets -1, CN-2: Chicken nuggets -2, PN-1: PBMA nuggets -1, PN-2: PBMA nuggets -2 and PN-3: PBMA nuggets -3, ND: not detected

Table 2. Fatty acid profile of different PBMA and chicken nuggets

Fatty acids	CN-1	CN-2	PN-1	PN-2	PN-3
C8:0	0.03±0.01[c]	0.01±0.01[c]	0.03±0.01[c]	0.59±0.03[a]	0.25±0.02[b]
C10:0	0.03±0.01[c]	0.01±0.01[c]	0.01±0.01[c]	0.50±0.02[a]	0.27±0.03[b]
C12:0	0.04±0.01[d]	0.13±0.01[c]	0.29±0.01[c]	5.07±0.06[a]	3.52±0.19[b]
C14:0	0.31±0.01[d]	0.72±0.01[c]	0.66±0.01[a]	2.30±0.02[a]	1.80±0.05[b]
C16:0	13.83±0.05[d]	28.83±0.07[b]	29.43±0.53[b]	10.32±0.39[e]	36.69±0.30[a]
C17:0	2.11±0.01[b]	3.21±0.02[a]	0.19±0.01[c]	0.11±0.01[d]	0.075±0.01[d]
C18:0	3.83±0.01[d]	4.55±0.03[b]	4.07±0.03[c]	4.92±0.06[a]	4.85±0.09[a]
C18:1n9c	34.23±0.08[c]	41.43±0.04[a]	35.67±0.01[b]	28.46±0.27[e]	32.30±0.32[d]
C18:2n6c	42.55±0.27[b]	18.35±0.03[d]	28.03±0.11[c]	44.75±0.32[a]	18.59±0.12[d]
C18:3n3	0.70±0.01[b]	0.47±0.14[c]	0.18±0.02[d]	1.22±0.04[a]	0.33±0.01[cd]
C21:0	0.08±0.08[a]	0.23±0.15[a]	0.17±0.05[a]	0.01±0.01[a]	ND
C22:0	0.31±0.01[b]	0.04±0.01[d]	0.27±0.02[b]	0.47±0.02[a]	0.15±0.01[c]
SFA	20.58±0.08[e]	37.73±0.13[b]	35.13±0.43[c]	24.28±0.34[d]	47.61±0.27[a]
MUFA	34.23±0.08[c]	41.43±0.04[a]	35.67±0.01[b]	28.46±0.27[e]	32.30±0.32[d]
PUFA	43.26±0.08[b]	18.82±0.15[d]	28.21±0.35[c]	45.97±0.68[a]	18.92±0.29[d]
MUFA/SFA	1.66±0.01[a]	1.10±0.01[c]	1.02±0.01[d]	1.17±0.01[b]	0.68±0.01[e]
PUFA/SFA	2.10±0.01[a]	0.50±0.01[d]	0.80±0.02[c]	1.90±0.05[b]	0.40±0.01[e]
UFA	77.48±0.04[a]	60.25±0.12[d]	63.87±0.35[c]	74.43±0.43[b]	51.22±0.23[e]
UFA/SFA	3.76±0.01[a]	1.60±0.01[d]	1.82±0.03[c]	3.07±0.06[b]	1.08±0.01[e]

n=6, Mean ± SE with same superscripts in a row does not differ significantly
*** Significant at 0.01 level, *Significant at 0.05 level and ns- non significant*
MUFA: mono unsaturated fatty acid, PUFA: poly unsaturated fatty acid, UFA: unsturated fatty acid and SFA: saturated fatty acid, ND: not detected
CN-1: Chicken nuggets -1, CN-2: Chicken nuggets -2, PN-1: PBMA nuggets -1, PN-2: PBMA nuggets -2 and PN-3: PBMA nuggets -3

Chicken nuggets exhibited MUFA contents ranging from 34.23% in CN-1 to 41.43% in CN-2, with CN-2 showing the highest MUFA content among all samples. PBMA nuggets displayed slightly lower MUFA levels, ranging from 28.46% in PN-2 to 35.67% in PN-1. Notably, oleic acid (C18:1n9c) was the predominant MUFA in chicken nuggets. In terms of PUFA, chicken nuggets ranged from 18.82% (CN-2) to 43.26% (CN-1). PBMA nuggets, in contrast, ranged from 18.92% (PN-3) to 45.97% (PN-2), with PN-2 exhibiting the highest PUFA content across all samples. Linoleic acid (C18:2n6c) was the principal PUFA in both chicken and PBMA nuggets, consistent with findings by (Katidi et al., 2023), who noted that PBMA products generally possess lower SFA levels than traditional meat products.

The analysis also revealed substantial differences in SFA content. In chicken nuggets, SFA ranged from 20.58% in CN-1 to 37.73% in CN-2. PBMA nuggets showed a broader range, with SFA content varying from 24.28% (PN-1) to 47.61% (PN-3), with PN-3 containing the highest SFA levels. Palmitic acid (C16:0) was the most prevalent SFA across all nugget samples.

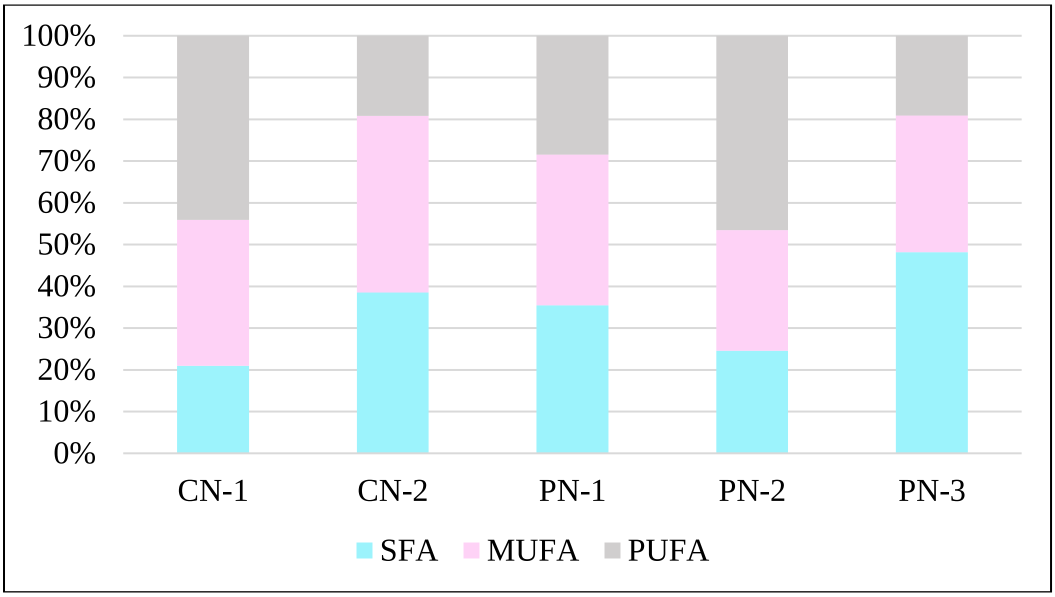

Fig. 1. Fatty acid profile of different PBMA and chicken nuggets

MUFA: mono unsaturated fatty acid, PUFA: poly unsaturated fatty acid and SFA: saturated fatty acid, CN-1: Chicken nuggets -1, CN-2: Chicken nuggets -2, PN-1: PBMA nuggets -1, PN-2: PBMA nuggets -2 and PN-3: PBMA nuggets -3

A comparative examination highlights that CN-2 had the highest MUFA content among the chicken nuggets, while CN-1 demonstrated the lowest SFA levels. Conversely, PN-3 had the highest SFA content and the lowest MUFA/SFA ratio among the PBMA nuggets. Interestingly, PN-2, with the highest PUFA content, exhibited the most favorable PUFA/SFA ratio. Total unsaturated fatty acids (UFA) content was highest in CN-1 (77.48%) and lowest in PN-3 (51.22%). The UFA/SFA ratio also followed this trend, with CN-1 displaying the highest ratio (3.76), while PN-3 exhibited the lowest (1.08).

The fatty acid composition is a critical factor influencing dietary health, particularly with respect to cardiovascular risk and the development of atherosclerosis (Martinez & Ramos-Escudero, 2024). Numerous randomized controlled trials have demonstrated that replacing saturated fatty acids (SFA) with polyunsaturated fatty acids (PUFA) can lower the incidence of myocardial infarctions and ischemic heart disease. This emphasizes the nutritional benefits of a higher PUFA/SFA ratio in human diets (Ozdemir et al., 2024). A review by (Bohrer, 2019) comparing PBMA and traditional meat products supports similar findings regarding fatty acid distribution patterns.

In this study, significant differences were observed in the fatty acid profiles of PBMA and chicken nuggets, particularly in terms of monounsaturated fatty acids (MUFA), PUFA and SFA content. Chicken nuggets exhibited higher concentrations of MUFA and SFA, notably oleic (C18:1n9c) and palmitic (C16:0) acids. Conversely, PBMA nuggets displayed elevated PUFA levels, with linoleic acid (C18:2n6c) being the predominant fatty acid. These distinctions underscore the unique nutritional attributes of PBMA and traditional chicken nuggets, providing insight into their potential health implications.

3.4 Total Phenolic Content

The total phenolic content (TPC) analysis (Table 3) revealed substantial variation among the nugget samples, with PBMA nuggets exhibiting significantly higher TPC values compared to chicken nuggets ($p<0.001$). The TPC values for CN-1 and CN-2 were recorded as 0.913±0.02 mg and 1.23±0.03 mg gallic acid equivalent (GAE)/g, respectively. In contrast, the PBMA nugget samples ranged from 2.00±0.02 to 2.94±0.02 mg GAE/g, with PN-3 displaying the highest phenolic content ($p<0.001$). The trend of TPC was PN-3 > PN-1 > PN-2 > CN-2 > CN-1. This elevated phenolic content in PBMA nuggets can be attributed to the presence of soybeans, a well-established source of phenolic compounds with strong antioxidant activity (2022). However, soy proteins are often deficient in essential amino acids like methionine and lysine, which may limit their overall nutritional profile when compared to animal proteins (Friedman & Brandon, 2001).

3.5 Instrumental Colour

Instrumental colour measurement provides an objective evaluation of the visual attributes of food products, which is a key indicator of consumer appeal. Significant differences (p<0.001) were observed across all groups for lightness (L*), redness (a*), and yellowness (b*) values (Tabel 3). For lightness (L*), PBMA nuggets exhibited higher values compared to chicken nuggets, with PN-2 showing the highest L* value at 53.95±0.15 (p<0.001). This observation aligns with findings by (Chiang et al., 2021), who reported that increasing wheat gluten concentrations in meat analogues enhanced their L* values.

Redness (a*) values also showed considerable variation, with PN-3 having the highest value (14.35±0.11, p<0.001), followed by CN-2 and CN-1. The incorporation of colouring ingredients in PBMA, as observed in studies such as (Botella-Martinez et al., 2022), contributes to these variations in a* values. Regarding yellowness (b*), PBMA nuggets consistently exhibited higher b* values, with PN-3 achieving the highest value (29.70±0.16, p<0.001). The relationship between ingredient composition and instrumental colour values in PBMA, particularly with increasing wheat gluten and reducing pea protein levels, was previously noted by (Yuliarti et al., 2021), who reported similar trends of increasing L* values and decreasing a* and b* values with higher wheat gluten concentrations.

3.6 Sensory Analysis

The sensory attributes of chicken and plant-based meat analogue (PBMA) nuggets were evaluated using an eight-point hedonic scale and the results are presented in Table 4 and Fig. 2. Significant differences (p<0.001) were observed in the appearance and colour between the chicken and PBMA nuggets. Specifically, CN-2 exhibited the highest appearance score among all groups, while PN-1 and PN-2 did not differ significantly. The mean ± SE appearance scores for PN-1, PN-2, and PN-3 were 7.13±0.08, 7.13±0.08, and 6.75±0.16, respectively, with the ranking of appearance scores following the order: CN-2 > CN-1 = PN-1 = PN-2 > PN-3. These findings are in agreement with (Hamid et al., 2020), who demonstrated that varying the incorporation of jackfruit by-products into meat analogues significantly impacts their sensory characteristics, including appearance, colour, odour and overall acceptability.

Table 3. Total phenolic content and Instrumental colour values of different PBMA and chicken nuggets

Parameters	CN-1	CN-2	PN-1	PN-2	PN-3
Total phenolic content (mg GAE /g)	0.913±0.02^{e}	1.23±0.03^{d}	2.33±0.03^{b}	2.00±0.02^{c}	2.94±0.02^{a}
L* (lightness)	46.50±0.16^{c}	46.44±0.14^{c}	53.13±0.09^{b}	53.95±0.15^{a}	43.06±0.14^{d}
a* (redness)	11.86±0.14^{c}	13.25±0.10^{b}	10.09±0.10^{d}	9.50±0.08^{e}	14.35±0.11^{a}
b* (yellowness)	25.14±0.18^{d}	26.36±0.12^{c}	26.04±0.13^{c}	28.00±0.13^{b}	29.70±0.16^{a}

n=8, Mean ± SE with same superscripts in a row does not differ significantly (p>0.05)
CN-1: Chicken nuggets -1, CN-2: Chicken nuggets -2, PN-1: PBMA nuggets -1, PN-2: PBMA nuggets -2 and PN-3: PBMA nuggets-3

Table 4. Sensory score values of different PBMA and chicken nuggets

Parameters	CN-1	CN-2	PN-1	PN-2	PN-3
Appearance and colour	7.00±0.00^{b}	7.75±0.16^{a}	7.13±0.08^{b}	7.13±0.08^{b}	6.75±0.16^{c}
Flavour	7.44±0.15^{a}	7.06±0.06^{b}	6.13±0.08^{c}	6.13±0.08^{c}	6.00±0.00^{c}
Juiciness	7.25±0.16^{a}	7.75±0.16^{a}	6.50±0.19^{b}	6.50±0.19^{b}	6.50±0.19^{b}
Texture/tenderness	7.31±0.16^{ab}	7.63±0.08^{a}	7.00±0.00^{bc}	7.00±0.00^{bc}	6.75±0.16^{c}
Overall acceptability	7.25±0.16^{a}	7.13±0.08^{a}	6.13±0.08^{b}	6.25±0.09^{b}	6.13±0.08^{b}

n=8, Mean ± SE with same superscripts in a row does not differ significantly
**Based on eight point Hedonic scale (1=extremely undesirable; 8 = extremely desirable)*
*** Significant at 0.01 level*
CN-1: Chicken nuggets -1, CN-2: Chicken nuggets -2, PN-1: PBMA nuggets -1, PN-2: PBMA nuggets -2 and PN-3: PBMA nuggets-3

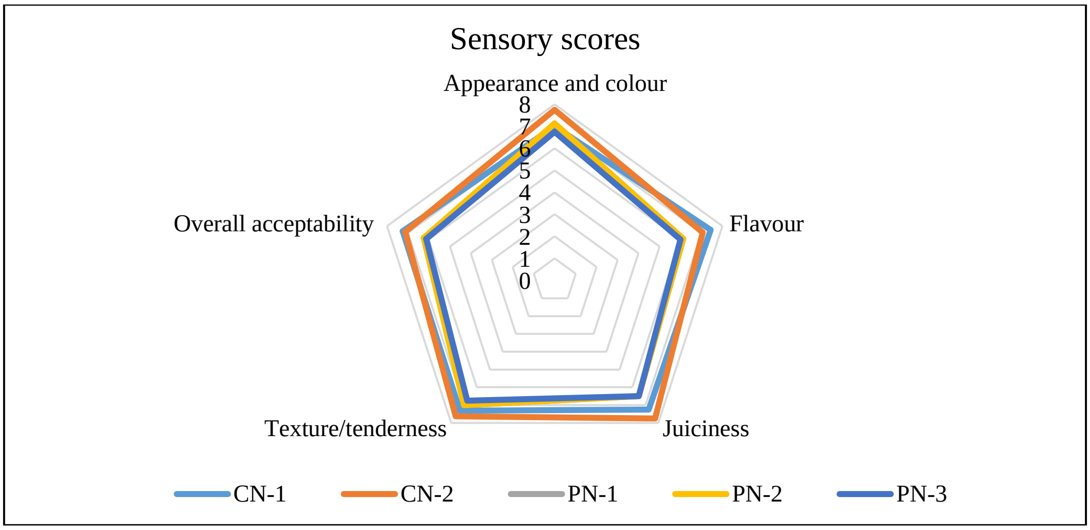

Fig. 2. Sensory scores of different PBMA and chicken nuggets

CN-1: Chicken nuggets -1, CN-2: Chicken nuggets -2, PN-1: PBMA nuggets -1, PN-2: PBMA nuggets -2 and PN-3: PBMA nuggets-3

Regarding flavour, chicken nuggets exhibited significantly higher values ($p<0.001$) compared to PBMA nuggets. The flavour scores for CN-1 and CN-2 were 7.44±0.15 and 7.06±0.06, respectively, with CN-1 showing the highest flavour rating among all samples. No significant differences were noted among the PBMA variants (PN-1, PN-2, and PN-3), whose flavour scores were comparatively lower. The ranking of flavour scores followed a descending order of CN-1 > CN-2 > PN-1 = PN-2 = PN-3. These results align with the observations of (Kaleda et al., 2020), who reported that fermented pea-oat protein extrudates exhibited a more intense flavour profile, albeit with increased sour and bitter taste attributes compared to non-fermented counterparts.

The juiciness scores between chicken and PBMA nuggets also demonstrated significant differences ($p<0.001$). Chicken nuggets scored consistently higher in juiciness, with CN-1 and CN-2 scoring 7.25±0.16 and 7.75±0.16, respectively. No significant variation was observed among the PBMA nuggets, all of which received comparable scores of 6.50±0.19. The juiciness scores ranked as follows: CN-2 = CN-1 > PN-1 = PN-2 = PN-3. Similarly, the texture or tenderness values revealed that chicken nuggets (CN-1 and CN-2) outperformed PBMA nuggets in terms of texture ($p<0.001$). Among the PBMA variants, PN-1 and PN-2 exhibited no significant differences in texture. The mean ± SE texture values for PN-1, PN-2 and PN-3 were 7.00±0.00, 7.00±0.00, and 6.75±0.16, respectively. CN-2 achieved the highest texture score ($p<0.001$) across all groups, with texture scores following the order: CN-2 = CN-1 > PN-1 = PN-2 > PN-3.

In terms of overall acceptability, the chicken nuggets scored significantly higher ($p<0.001$) compared to the PBMA variants. The overall acceptability values among the chicken nuggets (CN-1 and CN-2) did not differ significantly, with scores of 7.25±0.16 and 7.13±0.08, respectively. The PBMA nuggets (PN-1, PN-2, and PN-3) showed no significant differences among themselves, but their overall acceptability scores were lower compared to the chicken nuggets. The ranking of overall acceptability followed an order of CN-2 = CN-1 > PN-1 = PN-2 = PN-3. These findings are consistent with (Ettinger et al., 2022), who noted the ongoing challenges in developing plant-based products that meet consumer expectations for sensory attributes such as taste and texture, which are traditionally associated with animal-derived products (Abdullah et al., 2022).

4. CONCLUSION

The nutritional assessment of the plant-based meat analogues (PBMA) indicates their potential as a viable alternative to traditional chicken products, particularly in terms of health benefits. PBMA exhibited higher levels of polyunsaturated fatty acids (PUFAs) and lower saturated fatty acids (SFAs), which may contribute to reducing the risk of cardiovascular diseases. The fatty acid profile of PBMA nuggets indicated higher levels of linoleic acid and palmitic acid. Additionally, the absence of cholesterol in PBMA offers an advantage in lowering LDL cholesterol, contrasting with the higher cholesterol content in chicken products. The higher total phenolic content in PBMA suggests an enhanced antioxidant capacity, while the elevated ash and fibre content further highlight the superior mineral and dietary fibre composition of these plant-based alternatives compared to their chicken counterparts.

However, the sensory evaluation revealed that PBMA products still fall short in consumer acceptance when compared to traditional chicken nuggets, with lower scores for appearance, flavour, texture and overall acceptability. These results underscore the challenges in meeting sensory expectations, despite the promising nutritional profile of PBMA. Future research should focus on optimizing the sensory attributes of PBMA to improve their consumer acceptance, while maintaining their nutritional advantages.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

ACKNOWLEDGEMENT

We wish to thank Dean, College of Veterinary and Animal Sciences, Mannuthy, Thrissur for providing all facilities for the conduct of the research. The authors also gratefully acknowledge the ICAR-National Meat Research Institute, Hyderabad and Kerala Veterinary and Animal Sciences University, Pookode, Wayanad, for providing financial assistance to the first author.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/123810