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Plant-based Alternatives to Chicken Nuggets from Commercial Textured Pea and Soy: Physicochemical Properties, and Sensory Evaluation

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Abstract

Interest in meat alternatives has driven the development of plant-based analogs from legume extrudates. Two commercial textured pea (TC) and soy (TS) were used to formulate chicken-nugget analogs with different TC:TS ratios (100:0, F1; 75:25, F2; 50:50, F3; 25:75, F4; 0:100, F5), and their physicochemical properties and sensory characteristics were evaluated. Proximate composition, water-retention capacity (WRC), oil-holding capacity (OHC), least gelation concentration (LGC), emulsifying activity (EA), and emulsion stability (ES) were determined in TC and TS. Nugget formulations were evaluated for texture profile, color, and compared with commercial chicken nuggets. Consumer sensory tests of texture, flavor, and appearance were conducted for F2, F3, and F4 formulations. Results showed that TC had higher fat and protein content ($P < 0.05$) than TS, while moisture and ash contents were lower. TC showed higher WRC (2.71 g/g), EA (34.62%), and ES (16.52%) than TS (2.31 g/g, 14.27%, and 10.47%, respectively). No significant differences in OHC or LGC were found between TS and TC. No differences ($P > 0.05$) were observed in the texture profile of F1 compared to commercial chicken nuggets. For color, the a* values were lower ($P < 0.05$) in fried chicken nuggets compared to all formulations, while there were no significant differences in L*; for b*, all formulations were similar ($P > 0.05$), except for F1. Finally, nuggets prepared with formulations F2, F3, and F4 were well evaluated on the hedonic scale in the sensory test. TC and TS demonstrated potential to produce plant-based nuggets with physicochemical properties comparable to those of animal-based products, and good consumer acceptability.

1 Introduction

In recent years, dietary patterns have been changing, driven by both consumers' growing concern for improving their nutritional status and an increasing interest in more sustainable consumption choices. For instance, the world's population is projected to reach 10.3 billion by 2080 [1], and such a large population will require more food and water. Thus, global food production should increase by at least 70%, resulting in higher demand for land, water, and energy [2, 3].

In terms of food production, several studies have shown that the livestock sector is among the sectors with the greatest environmental impact due to its high greenhouse gas emissions, thereby contributing significantly to climate change [2, 4]. Although meat is recommended as an essential component of the regular diet and has been considered a fundamental part of Western diets for decades, its production and consumption, given an expanding population, are not sustainable. Consequently, there has been a rise in the adoption of plant-based or flexitarian diets, which require fewer natural resources and result in a reduced overall environmental impact [5].

Aside from sustainability targets, the overconsumption of red and processed meat also has negative health impacts. Several studies have shown an association between high intakes of red and processed meats and an increased risk of certain cancers, cardiovascular diseases, and type 2 diabetes [6–8]. However, the nutritional benefits of red meat, their high-quality protein content, iron, and essential nutrients, are well established. Therefore, it is essential to develop alternative meat products that offer nutritional and technological properties comparable to those of their conventional counterparts.

In recent years, the development of meat analogs has been explored using various processing techniques, such as extrusion, electrospinning, and 3D printing, as well as through the search for novel ingredients that provide functionality and sensory characteristics acceptable to consumers [9]. The search for protein sources that can provide acceptable meat analogs in terms of nutrition, cost, functionality, and sustainability is ongoing and remains under research [10]. From a nutritional standpoint, some plant-based sources, such as soy, pea, quinoa, and amaranth, contain all essential amino acids and are therefore considered promising protein sources for the development of meat analogs. However, several studies suggest that there are still limitations regarding the nutritional, functional, and sensory quality of the commercially available products. The objective of this work was to evaluate the physicochemical characteristics of commercial texturized soy and pea protein ingredients, and to formulate meat analog alternatives to chicken nuggets, assessing their physicochemical properties and consumer acceptance.

2 Materials and Methods

The material and methods section is described in the Supplementary Material S1. The formulations used to prepare the plant-based alternatives to chicken nuggets and the list of ingredients are shown in Tables S1 and S2, respectively.

3 Results and Discussion

3.1. Physicochemical Properties of Commercial Textured Proteins

Proximate composition. The proximate composition of the commercial pea and soy texturized proteins is shown in Table 1. The differences in the chemical composition between commercial pea and soy texturized proteins could be attributed to the inherent characteristics of the raw materials and the processing conditions used during protein isolation and extrusion. The moisture and ash contents of the pea texturized ($P < 0.05$) were lower than those of soy (2.04 and 5.74%, vs. 6.24 and 7.38%, respectively). The fat and protein composition was higher ($P < 0.05$) in pea than in soy texturized proteins, as previously reported for less intensive defattening processes and higher protein concentration in commercial pea proteins [11]. The carbohydrates were higher in the soy texturized protein. In general, compositional differences should be considered when selecting ingredients for meat analog formulations, as they can affect the functional, textural, and nutritional properties of the final products [12].

Table 1
Proximate composition of commercial pea and soy texturized proteins.

Sample	Component (%)				
	Moisture	Fat	Protein	Ash	Carbohydrates*
Pea texturized	2.04 ± 0.25[a]	5.86 ± 0.06[b]	77.93 ± 0.35[b]	5.74 ± 0.24[a]	8.40
Soy texturized	6.24 ± 0.13[b]	1.26 ± 0.24[a]	47.19 ± 0.13[a]	7.38 ± 0.03[b]	37.92

* Carbohydrate content was calculated by difference (100 – [%Protein + %Fat + %Moisture + %Ash]). Different superscript letters between columns indicate significant differences ($P < 0.05$).

Water retention capacity. The WRC values of commercial pea and soy texturized are presented in Table 2. The WRC was higher ($P < 0.05$) in the pea texturized (2.71 g/g) than in the soy texturized (2.31 g/g). The differences in WRC may be attributed to variations in protein composition, molecular structure, and the presence of polar amino acid residues that are capable of forming hydrogen bonds with water. Previous studies have reported that pea-based texturized proteins often exhibit higher WRC than soy-based counterparts, likely due to their higher protein content and lower degree of denaturation [12, 13]. Higher WRC is a desirable attribute in meat analogs, as it contributes to improved juiciness, cooking yield, and the final product's texture.

Table 2
Physicochemical properties of commercial pea and soy texturized proteins.

Samples	WRC (g/g)	OHC (g/g)	EA (%)	ES (%)	LGC (% p/v)
Pea texturized	2.71 ± 0.04[b]	1.34 ± 0.06[a]	34.62 ± 0.01[b]	16.52 ± 4.69[b]	22
Soy texturized	2.31 ± 0.01[a]	1.25 ± 0.15[a]	14.27 ± 2.05[a]	10.47 ± 2.65[a]	22

WRC, water retention capacity; OHC, Oil holding capacity; EA, emulsion activity; ES, emulsion stability; LGC, least gelation concentration. Different superscript letters between columns indicate significant differences ($P < 0.05$).

Oil holding capacity. The OHC did not present significant differences ($P > 0.05$) between samples (Table 2). These values are similar to those reported by Hong et al. [12] for textured pea and soy proteins, who reported values of OHC between 0.82–1.04 $g \cdot g^{-1}$ and 0.69–0.84 $g \cdot g^{-1}$ for pea and soy, respectively. Particularly in chicken-type nuggets, the OHC is an important functional property that determines juiciness, tenderness, and structural integrity during cooking [14].

Least gelation concentration. The LGC (Table 2) was similar between the two proteins ($P > 0.05$), although differences in other functional properties were observed; both matrices possess a comparable capacity to form three-dimensional structures that retain water. Protein gelation depends not only on the type of protein but also on the process conditions, including temperature, moisture, and mechanical intensity during extrusion, which could explain the similarity between pea and soy texturized proteins [15, 16]. According to these results, pea proteins offer functional advantages over soy texturizers, particularly in water retention and emulsifying properties. This suggests that pea texturized could be a promising ingredient for developing meat analogs with improved juiciness and structural stability. Based on their gel-forming capacity, both proteins can be effectively used in the development of meat analogs, depending on the final product type and its formulation.

Emulsifying activity and emulsion stability. The EA was higher (P□0.05) in the pea texturized protein (Table 2). This could be due to their higher protein content and a more balanced distribution of polar and nonpolar amino acids, which facilitate adsorption at the oil-water interface and enhance emulsion stability. It has been reported that processes such as extrusion can improve the interfacial properties of pea proteins, leading to partial denaturation and structural rearrangements of the protein chains [17, 18]. Similarly, the ES was higher in pea than in soy texturized, suggesting greater resistance to emulsion breakdown during storage or thermal treatment. This behavior has been linked to the formation of interfacial films, increased cohesiveness, and elasticity [13, 19].

Protein solubility. The protein solubility profile of pea and soy texturized proteins is shown in Fig. 1. The pH strongly influences protein solubility, especially near their isoelectric point, because under these conditions, the net charge is minimal and protein aggregation occurs [20]. Differences in solubility depend on pH, with soy proteins showing higher solubility at higher pH. At acidic conditions, solubility was lower in both samples, which may be due to their isoelectric points. The protein solubility was higher at neutral and alkaline conditions in soy texturized (pH 7–12), while at pH 6–8 it was higher for pea texturized. According to Osen et al. [21], protein solubility also reflects prior thermal treatments, with lower solubility observed in those with extensive heat treatment.

3.2. Plant-based alternatives to chicken nuggets

Figure 2 shows plant-based alternatives to chicken nuggets prepared from different formulations of TVP (Table S1, F1-F5) derived from pea and soy, and a commercial chicken nugget as a control (CT). No visible differences were observed between samples from TVP formulations. However, slight

differences from the CT were noted, which may be due to differences in the breader type between TVP formulations (F1-F5) and the commercial nugget. All the nuggets had a homogeneous surface and were easy to bread and fry.

3.3. Color

The results of the color analysis parameters in plant-based nuggets alternatives are shown in Table 3. In the unbreader nuggets, the a* parameter increases (P 0.05) with increasing pea texturized in the formulations, with values of 0.15, 0.66, 1.38, 2.13, and 2.87 for F1, F2, F3, F4, and F5, respectively. Conversely, the L* parameter (63.27, 61.58, 61.59, 59.80, and 58.64), and b* (30.22, 28.76, 28.05, 26.63, and 24.746) decreased. Positive values of a*and b* make references to red and yellow colors, respectively; those colors are expected for this kind of product [22]. L* parameter represents the luminosity of the product.

The breader plant-based nuggets were compared with commercial chicken nuggets as a control. The a* and b* parameters (6.12–9.63 and 34.30-42.42, respectively) were significantly higher in the plant-based nugget than in the control (a*= 3.51, and b*= 32.63). Those differences could be explained by the different types of breader used in the commercial nuggets, rather than the one used in this study. The L* parameter was similar in CT and F1, but lower in the rest of the formulations (F2-F5).

The color of the fried nuggets was more homogeneous; however, the a* parameter was lower in the control (7.90) than in all the formulations (11.98, 11.54, 11.48, 10.86, and 11.28). According to Dogan et al. [23] and Gutiérrez et al. [24], when food products are fried, a* values increase due to a series of reactions that occur during frying. Also, it is expected and favorable to obtain positive values of b*, related to golden colors in this type of product, due to the Maillard reaction. In luminosity (L*), no statistically significant differences were observed across all samples. The color characteristics of the fried plant-based nuggets demonstrate their viability as a replacement for chicken with vegetable proteins, yielding a final product with a similar appearance to commercial chicken nuggets available in local markets.

3.4. Texture Profile Analysis

The textural properties, which include hardness, cohesiveness, chewiness, and springiness of the plant-based nugget alternatives compared with a commercial chicken nugget, are presented in Table 4. The hardness across all plant-based alternative nuggets was similar to that of the control nugget. Significant differences ($P < 0.05$) were observed in cohesiveness. The control sample and the F1 showed similar cohesiveness values of 0.45 and 0.51, respectively, while F2-F3 exhibited lower values, ranging from 0.39 to 0.34.

Table 3
Color measurement parameters of unbreaded, breaded, and fried plant-based alternatives and chicken nuggets.

Sample†	Unbreaded			Breaded			Fried		
	L*	a*	b*	L*	a*	b*	L*	a*	b*
CT	ND	ND	ND	55.48 ± 2.59^{b}	3.51 ± 0.84^{a}	32.63 ± 0.77^{a}	35.37 ± 1.70^{a}	7.90 ± 0.85^{a}	27.36 ± 1.52^{ab}
F1	63.27 ± 1.17^{c}	0.15 ± 0.09^{a}	30.22 ± 0.71^{ad}	54.31 ± 1.19^{b}	8.75 ± 0.62^{c}	42.46 ± 0.45^{d}	38.63 ± 3.81^{a}	11.98 ± 1.53^{b}	30.57 ± 2.96^{c}
F2	61.58 ± 0.86^{b}	0.66 ± 0.34^{b}	28.76 ± 0.78^{c}	49.50 ± 2.00^{a}	9.63 ± 0.37^{c}	39.71 ± 1.44^{c}	38.87 ± 2.20^{a}	11.54 ± 1.12^{b}	30.16 ± 2.19^{bc}
F3	61.59 ± 1.01^{b}	1.38 ± 0.45^{c}	28.05 ± 1.20^{c}	48.55 ± 1.80^{a}	9.57 ± 0.94^{c}	38.95 ± 1.16^{c}	36.72 ± 1.85^{a}	11.48 ± 0.64^{b}	27.06 ± 1.11^{ab}
F4	59.80 ± 0.96^{a}	2.13 ± 0.20^{d}	26.63 ± 0.92^{b}	50.84 ± 0.79^{a}	6.12 ± 0.40^{b}	34.30 ± 0.76^{b}	37.50 ± 0.99^{a}	10.86 ± 0.24^{b}	27.04 ± 1.30^{ab}
F5	58.64 ± 0.83^{a}	2.87 ± 0.22^{e}	24.76 ± 0.37^{a}	48.48 ± 0.92^{a}	9.20 ± 0.62^{c}	38.40 ± 0.91^{c}	35.57 ± 2.10^{a}	11.28 ± 0.64^{b}	24.94 ± 1.81^{a}

†CT, Commercial chicken nugget (control); F1:100:0, F2:75:25, F3:50:50, F4:25:75, and F5:0:100 (Pea texturized:Soy texturized). Different superscript letters between columns indicate significant differences ($P < 0.05$).

Table 4
Texture profile of plant-based alternatives to chicken nuggets.

Sample*	Hardness (N)	Cohesiveness	Chewiness	Springiness
CT	39.68 ± 7.98^{a}	0.51 ± 0.03^{b}	18.37 ± 3.65^{c}	0.82 ± 0.05^{b}
F1	37.99 ± 4.56^{a}	0.45 ± 0.02^{ab}	13.30 ± 1.52^{bc}	0.75 ± 0.03^{ab}
F2	36.85 ± 2.28^{a}	0.39 ± 0.04^{a}	10.79 ± 2.21^{ab}	0.72 ± 0.05^{ab}
F3	33.30 ± 2.97^{a}	0.35 ± 0.02^{a}	7.89 ± 0.28^{a}	0.67 ± 0.02^{a}
F4	37.96 ± 4.55^{a}	0.34 ± 0.03^{a}	8.30 ± 3.43^{ab}	0.68 ± 0.05^{a}
F5	36.96 ± 5.85^{a}	0.39 ± 0.11^{a}	10.54 ± 3.60^{ab}	0.70 ± 0.13^{ab}

*CT, Commercial chicken nuggets (control); F1:100:0, F2:75:25, F3:50:50, F4:25:75, and F5:0:100 (Pea texturized:Soy texturized). Different superscript letters between columns indicate significant differences ($P < 0.05$).

Similar cohesiveness results were reported for plant-based nuggets by Kitcharoenthawornchai and Harnsilawat [25], with values of 0.51 for nuggets made with wheat gluten, isolated soy protein, and 70% texturized vegetable protein.

Chewiness values differed significantly among samples ($P < 0.05$). The control sample showed the highest chewiness (18.37), while nuggets with higher levels of soy texturized showed lower values, ranging from 7.89 to 10.79. The values of chewiness are similar to those reported by Verma et al. [26] for low-fat chicken nuggets, ranging from 9.11 to 12.46. The springiness also showed significant differences among samples ($P < 0.05$). The control exhibited the highest springiness value (0.82), similar to the higher pea texturized content formulations (F1 and F2). Formulations F3 and F4 presented the lowest springiness values. Based on the TPA results, it is possible to infer that those formulations with a higher pea content, especially F1, are more similar to the chicken nuggets evaluated in this study.

3.5. Sensory Evaluation

The F2, F3, and F4 (75:25; 50:50; 25:75, pea texturized: soy texturized, respectively) nuggets were evaluated for their sensory properties, using a 15-point hedonic scale. F2 formulation (75% pea, 25% soy) nuggets had the highest scores in appearance, texture, and flavor. The three formulations were well-rated by the panelists (above 9.0). The F2 nuggets were the best evaluated by consumers in terms of appearance, flavor, and texture. The appearance was the most highly evaluated attribute, which is important because visual cues have a greater influence on consumer acceptance than flavor and texture before consumption [18]. Liking scores for flavor did not differ significantly across formulations. Nuggets with higher pea content had the best textural properties and received the highest panelist scores for texture (Table 4 and Table 5, respectively). Nevertheless, a trained panel is required to develop well-defined descriptors that provide a more precise description of the nuggets' sensory properties. Finally, we asked the panelists whether they would buy the plant-based nuggets and which sample they would choose. 85% of the panelists indicated they could buy the plant-based nuggets evaluated; 43% chose the F2 nuggets, followed by 31% for the F3 nuggets and 23% for the F4 nuggets.

Table 5
Sensory evaluation of the plant-based nuggets

Formulation*	Appearance	Texture	Flavor
F2	11.46 ± 2.85^{b}	10.57 ± 3.19^{b}	10.22 ± 3.95^{a}
F3	10.17 ± 3.60^{a}	9.90 ± 3.60^{ab}	9.79 ± 4.05^{a}
F4	10.48 ± 3.46^{ab}	9.33 ± 3.24^{a}	9.83 ± 3.46^{a}

*F2:75:25; F3:50:50; and F4:25:75 (Pea texturized: Soy texturized). Fifteen-point scale, where 15 indicated “extremely desirable,” 7.5 “indifferent,” and 0 “extremely undesirable”. Different superscript letters between columns indicate significant differences ($P < 0.05$).

4 Conclusions

Commercial textured soy and pea products have functional properties that make them viable for the development of plant-based chicken nugget alternatives. The nuggets prepared with the combination of pea and soy texturized products (F2, F3, and F4 formulations) were acceptable (consumer preference above 9.0) and had good textural properties. Based on texture profile analysis, including the commercial chicken nugget, the nuggets had similar hardness; however, differences were observed in cohesiveness, chewiness, and springiness. Nuggets prepared with F2, F3, or F4 formulations had lower cohesiveness and chewiness than commercial chicken nuggets. However, these lower values did not affect consumer perception, as the panelists did not notice the disintegration of the F2-F4 nuggets at the first bite of the sample. Future research should include descriptive sensory analysis with a trained panel to provide a more comprehensive characterization of the products and to better understand the relationship between instrumental measurements and sensory perception.

Declarations

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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Author Contribution

R.P.: Methodology, Validation, Formal analysis, Investigation, Writing - Original Draft. G.N.: Methodology, Supervision. M.B.: Methodology, Resources, Supervision. V.L.: Formal analysis, Writing - Review & Editing. I.R.: Conceptualization, Formal analysis, Resources, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition. H.S.: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration

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Figures

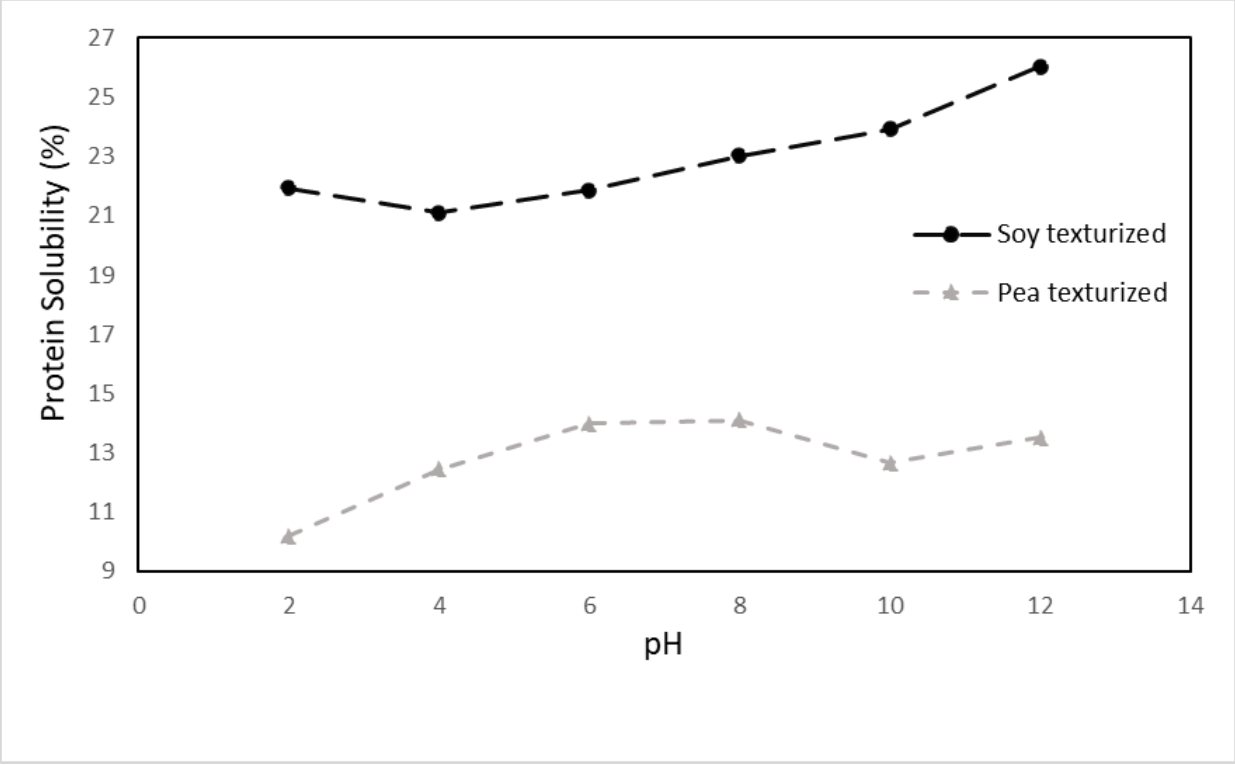


Figure 1

Protein solubility of commercial pea and soy texturized proteins.

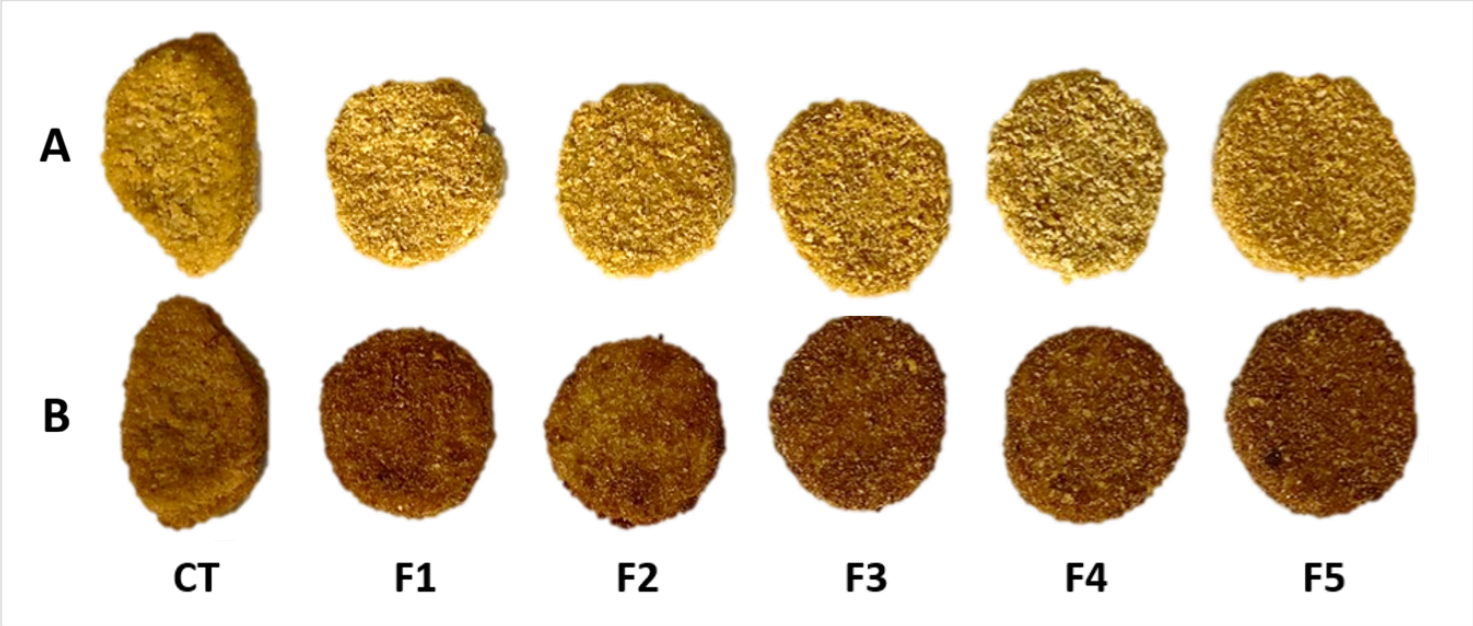


Figure 2

Plant-based chicken nugget alternatives formulated with F1–F5 and control (CT). (A) raw and (B) fried. F1:100:0, F2:75:25, F3:50:50, F4:25:75, and F5:0:100 (Pea texturized:Soy texturized).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SM.Physicochemicalpropertiesandgeneralacceptabilityofplant.docx