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Mushroom-legume-based alternative chicken nuggets: Physico-chemical and sensory properties

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ABSTRACT

The consumer demand for meat analogs (MAs) is on the rise. Soy proteins are frequently used as the primary ingredient in MAs, but soybean may negatively impact human health and cognitive functions. The aim of this research was to develop alternative chicken nuggets using mushroom and chickpea flour. Effect of different sources of mushroom and starch in the textural and sensory quality of nuggets were determined. Phoenix mushroom was chosen based on nuggets' textural and sensory qualities. Different ratios of mushroom and chickpea flour (0:70, 15:55, 55:15, and 70:0, w/w) were tested to prepare the nuggets. Based on protein, textural and sensory qualities compared to chicken and commercial plant-based nuggets, the mushroom to flour ratio of 55:15 was chosen. The results showed that tapioca starch-containing nuggets had a better texture and were more palatable to consumers. The processed nuggets demonstrated lower protein (6.88 vs 11.72%, dry wt. basis) but better cooking yield (87.65 vs 85.29%), moisture retention (77.86 vs 75.16%), fat retention (90.55 vs 88.39%) and higher consumer acceptability than commercially available soy-based nuggets. The results of the study suggest that mushroom and chickpea flour may replace soy protein in meat analogs.

1. Introduction

The global population is rising, and the world faces the challenge of feeding the entire population. Nonetheless, sustainable food production and consumption are attracting the attention of global food experts and industry players. Since ancient times, people have believed that meat is a necessary component of the human diet (Geiker et al., 2021). Due to substantial economic growth and population expansion, the requirement for meat has increased by more than 60 % during the past 20 years (Williams & Hill, 2017). There is a strong negative correlation between the production and consumption of meat and human health problems. This raises the possibility of developing chronic diseases, zoonoses, and other air pollution-related health problems (Domingo et al., 2021; Gilbert et al., 2021). Many consumers restrict their meat intake as much as possible due to health problems. In 2019, about 8 % of Thai people retrieved meat consumption. This percentage will rise over the next years, hitting 15 % by 2025. In Thailand, the market for meatless food products was expected to be worth around 28 billion Thai baht in that same year (Statista, 2023).

The food sector has seen a sharp increase in the production of plant-based proteins due to the variety of plant sources and their potential to displace traditional animal-based proteins. Soy proteins are the main source of plant-based proteins. They are extensively eaten by various populations globally due to their high protein content and adaptability in food product development (Qin, 2022). However, soy is listed as one of the top 8 food allergies by the Food and Agriculture Organization (FAO). There are now at least 16 known possible allergies to soy proteins. In order to produce plant-based (PB) meat, food researchers are currently searching for alternative new raw materials like pulses and mushrooms. Many elderly people in Thailand have made the decision to

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eat less meat and more PB meals including, fungi-based. Food scientists are researching methods to create PB and/or mushroom-based meat substitutes that closely resemble real meat based on firmness, flavor, taste and appearance (Mazumder et al., 2023a; Mazumder et al., 2023b; Mazumder et al., 2023c, Ketwana & Rawdkuen, 2023). Mushroom-derived meat analogs which are protein-rich may imitate several types of meat and meat products based on texture, flavor, color and nutrition (Choudhury et al., 2020). Thailand is a home of different types of cultivated and wild mushrooms with 6000 species (Thongklang et al., 2020). Few of them were used in this study, such as *Pleurotus pulmonarius* (Nang Fah Bhutan, phoenix), *Pleurotus eryngii* (Hed nang rom luang, king oyster), *Lentinus squarrosulus* (Hed Khon Kaw, log white), and *Schizophyllum commune* Fr. (Hed Krang, Split gill). There have been many traditional applications and benefits of mushrooms for the Thai people. In Thailand, mushrooms are also used for therapeutic and medicinal purposes. Mushrooms are among the healthiest foods due to a high (20–30 % dry weight basis) protein content. It can support most of the essential amino acids required for nutrition. They contain no cholesterol, have little fat, lots of dietary fiber, and are easy to digest. Mushrooms are also a good source of minerals and vitamins (Liuzzi et al., 2023). Furthermore, mushrooms include a number of components that are beneficial to health, such as adenosine, terpenoids, phenolic compounds, starch, and glycogen, as well as functional polysaccharides (Liuzzi et al., 2023). They also include a unique molecule known as β-glucan, mostly made up of β-D-glucose.

Chickpeas (*Cicer arietinum* L.) have so much adaptability that they might be a viable soy protein substitute. This is one of the most widely used and popular pulses globally, usually available as seeds, flour, or canned products. Chickpeas provide 17–22 % of the dietary protein compared to other plant protein sources (Boukid, 2021). Research on the characteristics and interaction with food components in food matrices is still underway. Chickpea protein (CP) offers a board range of biological activity including better digestion of protein, and prove significant amounts of essential amino acids in the right ratios (Boukid, 2021). Their flavor (mild), color (light), and taste (neutral) make them perfect for use in food products, including breads, sausages, noodles, and nuggets. CP and its hydrolysates might be effective ingredients in meat alternatives for PB (Boukid, 2021). Starch is used in a variety of food products such as thickening, gelling, provide stability, and replace or prolong more expensive components. However, the addition of starch to the formulations significantly improved the crispness during the final stages of frying (Altunakar et al., 2004).

A nugget is a type of culinary item that is made of a little bit of battered or breaded meat that is either baked or deep-fried. According to gastronomy, the striking likeness in form and color to genuine gold nuggets is the reason behind the name "nugget." Even while animal meat-based nuggets include saturated fat, plant-based nuggets often have far less saturated fat than animal meat while still having high protein content and some crude fiber. Plant-based nuggets are a healthy alternative to meat-based ones. Customers are choosing more plant-based meat and less animal meat due to the negative health effects of meat products. However, not many studies have been done on the use of mushrooms in producing nuggets. So, this study takes into account the preparation of nuggets based on mushrooms and chickpeas. However, a suitable concentration of mushroom and chickpea flour, and a source of starch, is necessary to maintain the textural properties and sensory quality of nushroom-based nuggets. This study aimed to develop alternative chicken nuggets based on mushroom and chickpea flour and compare the nutritional, textural and sensory qualities of the developed nuggets with commercial plant-based nuggets and commercial chicken nuggets.

2. Materials and methods

2.1. Raw materials

Phoenix, king oyster, log white and dried split gill were bought from Bannhedkrang farm, Songkhla, Thailand. Other food grade ingredients as shown in Table 1 were purchased from Krungthep Chemipan Co. Ltd., Bangkok, Thailand.

2.2. Mushroom preparation

All the mushrooms were cleaned using drinkable water. Water was eliminated from mushrooms by a vegetable spinner. Each mushroom was cut into 2.5 mm thick slices, which were then steam-blanched at 130 °C for 5 s. Mushrooms were stored at -20 °C in a zipper (Ziploc®) until further use.

2.3. Formulations optimization and processing of nuggets

To optimize the mushroom-based nuggets, the following experimental design was studied: i) the effects of mushroom varieties on the protein, textural and sensory qualities of the nuggets; ii) the effects of mushroom and chickpea flour (CF) concentrations on the protein, textural, color parameters and sensory qualities of the nuggets (Supplement Table 1) and (iii) the effects of starch sources (corn, tapioca, wheat and potato) on the textural and sensory qualities of the nuggets (Supplement Table 2). Commercial plant-based nuggets (MEAT ZERO, Thailand) and commercial chicken nuggets (CP Brand, Thailand) were used as control in this study, containing soy protein (59 %), fired batter (31 %), seasoning (8 %), egg white powder (2 %) and chicken (57 %), friend batter (25 %) and seasonings (18 %), respectively.

Modified methods by Sharima-Abdullah et al. (2018) were used for the following base formulations of the nuggets. Mushrooms (55 %) were blended with CF (15 %), honey (6 %), white pepper (2 %, seasoning sauce (3.5 %), coriander root powder (2 %), garlic powder (2 %), baking powder (0.5 %), salt (1.5 %), tapioca starch (9.5 %), and canola oil (3 %) (Table 1). All the ingredients were measured on weight/weight basis and mixed properly using a lab scale mixer machine and shaped into nuggets using a nugget mold. The nuggets were shaped into 3.0 cm x 4.0 cm x 0.5 cm and weighed 18 g. The nuggets were steamed at 80 °C for 10 min. Gogi crispy flour (composition: wheat flour, modified tapioca starch, raising agent, salt, flavor enhancer) was mixed with cold water (4 ±1 °C) for 30 min. The raw nuggets were wetted into the cold batter and coated with previously prepared bread crumbs prior to pre-frying at 150 °C for 2 min. After frying, the nuggets were 3.0 cm x 3.5 cm x 1.0 cm and weighed 16 g.Similar to mushroom-based nuggets, commercial plant-based and chicken nuggets were fried at 150 °C for 2 min.

Table 1
Base formulation of mushroom-based nuggets (MBN).

Ingredients (%)	Types of mushrooms			
	Phoenix	King Oyster	Split gill	Log white
Mushroom	55.00			
Chickpea flour	15.00			
Honey	6			
Seasoning	3.5			
White pepper	2			
Coriander root powder	2			
Garlic powder	2			
Baking powder	0.5			
Salt	1.5			
Corn starch	9.5			
Canola oil	3			

Table 2
Effect of different mushroom on the nutritional, textural and sensory quality of mushroom-based nuggets (MBN).

Composition (%)	Mushroom-based nuggets				Commercial chicken nuggets	Commercial plant-based nuggets
	Phoenix	King oyster	Log white	Split gill		
Protein	7.25±0.07[c]	7.55±0.14[c]	7.30±0.11[c]	7.41±0.08[c]	15.92±0.26[a]	11.72±0.44[b]
Textural profile analysis						
Hardness (N)	141.83±15.57[b]	148.70±18.91[b]	145.22±22.12[b]	140.14±25.20[b]	111.47±27.80[c]	188.97±5.33[a]
Springiness (mm)	0.68±0.10[c]	0.67±0.02[c]	0.65±0.06[c]	0.63±0.08[c]	0.94±0.02[a]	0.84±0.06[b]
Cohesiveness	0.55±0.12[c]	0.54±0.04[a]	0.52±0.04[c]	0.53±0.04[c]	0.80±0.02[a]	0.68±0.02[b]
Chewiness	80.25±16.36[b]	83.40±15.35[b]	82.11±17.03[b]	79.98±16.01[b]	83.56±20.00[b]	141.20±3.77[a]
Sensory attributes						
Overall acceptance	6.5±1.25[c]	6.1±1.45[d]	6.2±1.37[d]	6.3±1.21[d]	8.17±1.76[a]	6.9±1.66[b]
Texture	6.1±1.24[c]	5.6±1.45[d]	5.5±1.70[d]	5.6±1.13[a]	8.20±1.18[a]	6.0±1.29[b]
Taste	6.3±1.18[b]	5.9±1.50[c]	5.9±1.22[c]	5.7±1.32[c]	8.22±1.19[a]	6.4±1.37[b]
Aroma	6.0±1.40[c]	5.5±1.62[d]	5.5±1.35[d]	5.4±1.42[d]	8.34±1.75[a]	7.0±1.39[b]
Appearance	6.3±1.78[b]	5.5±1.49[a]	5.7±1.94[a]	5.9±1.71[a]	8.44±1.33[a]	6.5±1.25[b]
Acceptance (%)	43.0	24.5	20.0	12.5	40.0	70.0

Values are given as mean ± SD from n = 3. Different superscripts in the row indicate a significant difference (p-value < 0.05). Panelists were marked separately based on 100 for acceptance (100 for all mushroom-based, 100 for commercial plant-based and 100 for commercial chicken nuggets)

2.4. Determination of mushroom-based nuggets qualities

2.4.1. Texture profile analysis (TPA)

The TPA of mushroom-based nuggets was evaluated by a TA.XT double-arm and SMSP/75 compression platen texture analyzer (Stable Micro System Ltd., United Kingdom). The conditions of the texture analyzer are as follows: 1.0 mm/sec pre-test speed, 3.0 mm/sec test speed, 10.0 mm/sec post-test speed, 5 g trigger force and 23.0 mm distance. 50 % sample thickness was compressed by a 2-cycle sequence with 10.0 kg load cell (Bakhsh et al., 2021). Samples were positioned in the middle of the texture analyzer.

2.4.2. Color determination

Color parameter of mushroom-based nuggets was measured by a Hunter colorimeter (Hunter Lab/color Quest XE, Reston, Color Global, Bangkok, Thailand) using illuminant D65 and 10° standard. The colorimeter was calibrated using a standard white plate. The CIELAB color space L* represented lightness (black, L* = 0 and white, L* = 100). The positive a* represents red and negative a* represents green spectra, respectively. While the negative b* denotes blueness, the positive b* denotes yellowness.

2.4.3. Cooking properties of nuggets

Cooking properties such as cooking yield, moisture and fat retention of mushroom-based, commercial plant-based and commercial chicken nuggets were calculated using the standard methods. Cooking yield was calculated using the Eq. (1) (Naveena et al., 2014).

$$cooking\,yield(\%) = \frac{weight\,of\,cooked\,nuggets}{weight\,of\,raw\,nuggets} \times 100 \tag{1}$$

Percent fat retention was determined using the Eq. (2) (Murphy et al., 1975):

$$Fat\,retention(\%) = \frac{Fat\,of\,cooked\,nuggets\,(\%)}{Fat\,of\,raw\,nuggets\,(\%)} \times cooking\,yield(\%) \tag{2}$$

Percent moisture retention was calculated using the Eq. (3) (El-Magoli et al., 1996):

$$Moisture\,retention(\%) = \frac{Moisture\,of\,cooked\,nuggets\,(\%)}{Moisture\,of\,raw\,nuggets\,(\%)} \times cooking\,yield(\%) \tag{3}$$

2.4.4. Sensory evaluation

The sensory quality of mushroom-based nuggets was performed by 50 untrained panelists in the age range of 18–50 from Chiang Rai province Thailand. The panelists were chosen from both vegan and no-vegan consumers. Small pieces of samples were presented to the panelists. To minimize the impact of sample order presentation, samples were distributed to panelists one at a time using coding system including 101, 202, and 303. Between samples, participants were encouraged to drink water to refresh their palate. The sensory session was held in separate rooms (individual cabins) at 25 °C in a controlled atmosphere with 54 % relative humidity and white light (300 lx) (Mazumder et al., 2023a). The sensory qualities (overall acceptance, texture, color, taste, aroma, and appearance) were evaluated using a 9-point hedonic scale (1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much and 9 = like extremely). In this study, aroma was measured as an odor with a pleasant connotation in smell of the samples and appearance includes color, size, and shape, consistency of liquid and semisolid products. Acceptance was measured by how many panelists were accepting the product among 50 untrained panelists?

2.4.5. Nutritional labeling and amino acid analysis of mushroom-based nuggets

Nutritional labeling as well as amino acid composition of Phoenix mushroom-based nuggets was evaluated at Central Laboratory, Muang, Chaing Mai, Thailand using In-house methods (Supplement Table 3).

2.5. Statistical analysis

All the experimental values were measured three times. However, TPA and color parameters were measured five and ten times, respectively, and presented as mean ± standard deviation (SD). To assess the analysis of variance (ANOVA), statistical analysis was performed using SPSS software version 25.0 (SPSS Inc. Chicago, USA) SPSS for Windows version 25.0, SPSS Inc., Chicago, USA). To assess the significant differences, Duncan's multiple range tests were performed at a 95 % confidence level.

3. Results and discussion

3.1. Effect of mushroom types on the quality of mushroom-based nuggets

The protein content of nuggets using four different types of mushrooms is shown in Table 2. The results suggest that commercial chicken nuggets contained higher protein than commercial plant-based nuggets and mushroom-based nuggets. However, four mushroom-based nuggets did not show any differences in protein content. To find the best mushroom source for the processing of nuggets, textural and sensory properties were conducted.

The textural change of the nuggets prepared from four different mushrooms is shown in Table 2. The TPA demonstrated that the textural

Table 3
Effect of different concentration of mushroom and chickpea flour on the nutritional, textural and sensory quality of MBN.

Composition (%)	Phoenix mushroom: chickpea flour-based nuggets				Commercial chicken nugget	Commercial plant-based nugget
	A (0:70)	B (15:55)	C (55:15)	D (70:0)		
Nutritional composition						
Protein	8.15±0.09[d]	8.31±0.14[d]	8.65 ±0.18[c]	8.61±0.14[c]	15.92±0.26[a]	11.72±0.44[b]
Textural profile analysis						
Hardness (N)	361.85±14.16[b]	307.18±40.77[c]	145.63±36.00[d]	139.10±12.57[d]	111.47±27.80[e]	188.97±5.33[a]
Springiness (mm)	0.64±0.04[c]	0.68±0.05[c]	0.79±0.03[b]	0.82±0.04[b]	0.94±0.02[a]	0.84±0.06[b]
Cohesiveness	0.50±0.02[c]	0.56±0.04[c]	0.62±0.05[bc]	0.67±0.05[b]	0.80±0.02[a]	0.68±0.02[b]
Chewiness	261.73±35.34[a]	131.32±14.40[c]	102.42±4.48[d]	77.16±16.45[e]	83.56±20.00[c]	141.20±3.77[b]
Sensory attributes						
Overall acceptance	5.15±1.70[e]	5.65±1.66[d]	7.22±1.68[b]	6.30±1.54[c]	8.17±1.76[a]	6.95±1.66[b]
Appearance	5.72±1.25[d]	5.83±1.55[d]	7.20±1.88[b]	6.12±1.90[c]	8.20±1.18[a]	6.80±1.29[c]
Texture	5.40±1.77[c]	5.74±1.21[bc]	7.11±1.33[b]	6.35±1.22[a]	8.22±1.19[a]	6.74±1.37[b]
Color	5.48±1.52[d]	5.53±1.79[d]	7.13±1.40[b]	6.15±1.81[c]	8.34±1.75[a]	7.10±1.39[b]
Aroma	6.51±1.28[c]	6.60±1.90[c]	7.10±1.51[b]	6.71±1.70[bc]	8.44±1.33[a]	6.85±1.25[b]
Taste	5.60±2.1[e]	5.83±2.0[e]	7.24±2.2[b]	6.29±1.7[d]	8.17±1.76[a]	6.79±1.66[c]
Acceptance (%)	15.0	27.5	40.0	17.5	70.0	40.0

Values are given as mean ± SD from n = 3. Different superscripts in the row indicate a significant difference ($p< 0.05$). Panelists were marked separately based on 100 for acceptance (100 for all mushroom-based, 100 for commercial plant-based and 100 for commercial chicken nuggets)

characteristics of nuggets were not significantly ($p>0.05$) influenced by different types of mushrooms. Table 2 suggests that the hardness of nuggets ranges from 148.70 N (King oyster) to 140.14 N (Split gill), cohesiveness values from 0.55 (Phoenix) to 0.52 (Log white), and springiness values from 0.68 mm (Phoenix) to 0.68 mm (Split gill). King oyster-based nuggets having highest hardness and chewiness values (Table 2) though they do not significantly differ from other mushroom-based nuggets.

The results showed that the split gill-based nuggets had the lowest (0.63 mm) springiness value, which means split gill-based nuggets showed the highest capacity to regain their original dimension after compression. However, springiness values did not differ ($p>0.05$) from each other. Moreover, formulations containing king oyster mushroom showed the highest chewiness of nuggets but did not significantly ($p>0.05$) differ between Phoenix-, Log white- and Split gill-based nuggets. The result correlates to the hardness value. Hardness predominates since it has higher values than the other treatments, although chewiness is partially generated from hardness and springiness. All four mushroom-based nuggets showed higher ($p<0.05$) hardness and chewiness values than the chicken nuggets. The hardness value for all nuggets was 140.14–148.70 N, whereas the chicken nuggets had a value of 111.47 N. Textural properties of all nuggets were much better ($p<0.05$) than in commercial plant-based nuggets, showing lowered hardness and chewiness (Table 2). For meat analogs to be extensively accepted by vegan and/or non-vegan if, textural properties may closely mimic those present in real animal meat and meat products. The TPA demonstrated that nuggets made by four different types of mushrooms had similar textural properties. Based on the above discussion; to find the best mushroom source with the best consumer acceptance, it is necessary to conduct the sensory evaluation.

Table 2 indicates that the sensory properties of Phoenix-, King oyster-, Log white- and Split gill-based nuggets overall acceptability is in the range of Like Slightly, but other sensory qualities, such as texture, taste, aroma and appearance, are in the range of neither like nor dislike. Nonetheless, the acceptability of chicken nuggets was very high compared with mushroom-based and commercial plant-based (soy) nuggets (Table 2). However, the overall acceptability of mushroom-based and commercial plant-based nuggets might be varied due to the composition, ingredients, seasoning and raw materials of these products. In the commercial plant-based nuggets there may be few food additives or hydrocolloids are used to improve the taste and texture of the nuggets. Setiaboma and Kristanti (2021) suggest that the addition of hydrocolloids and food additives could affect the overall acceptability of the nuggets. This is to be expected as this is a novel kind of food product and many consumers might not approve of it at first (Cordelle et al., 2022; Szenderák et al., 2022). This could be related to the fragrance molecules that are typically present in mushrooms, such as 1-octen-3-ol, hexadecanoic acid, and octadecenoic acid (Mazumder et al., 2023b). These ingredients are unusual in real meat products. Thus, it's possible that they influenced an adverse evaluation of a product that was supposed to replace real animal meat. Phoenix mushroom was chosen for further study since 43 % of consumers approved of it as shown in Table 2.

Meat consumers often compare meat alternatives to conventional beef, mutton, or pork. It has been suggested to consumers to consume less meat for a healthier life and a better environment. A potential solution for substituting animal meat is for mushroom-based meat analogs; nonetheless, consumer acceptability of these products is still very low, perhaps because of their flavor and taste (Szenderák et al., 2022). Thus, it is very essential to determine the sensorial attributes that need to be optimized in order to improve palatability (Cordelle et al., 2022). According to our research, more than 65 % of consumers consume meat as a substantial part of their regular diet. Nonetheless, the acceptance or affordability of meat alternatives may differ from region to region. For instance, (i) In the USA, people are less likely to buy meat alternatives due to a strong affiliation to meat. Attitudes such as appeal, enthusiasm, and low disgust were found to be predictive of the desire to buy. (ii) Women in China are more prone to buy meat analogs than men. Vegans and non-vegans are far less prone than meat eaters to buy meat analogs. Less food neophobia and more familiarity predict purchasing intent. (iii) In India, omnivores or who eat a lot of meat prefer to eat PB meat alternatives more frequently. Customers from higher socioeconomic class groups showed increased interest in meat substitutes, as did highly educate and liberal-ideological consumers. Food neophobia suggested lower purchase intent, while product familiarity predicted higher buying desire. Perceived sustainability, eagerness, need, and goodness predicted Indian consumers' desire to purchase PB meat substitutes (Mazumder et al., 2023c). One-third or less than one-third is recognized as vegetarians, vegans, or pescatarians. Environmental and health issues may be prioritized more while adopting PB meat analogs. Despite several challenges, the market for meat analogs, including alternative chicken nuggets is increasing day by day (Cordelle et al., 2022).

3.2. Effect of different ratios of mushroom and CF on quality of nuggets

Apart from being a commonly used ingredient in cooking, CF is also commonly used as binding and texturing agent in meat analogs (Sharima-Abdullah et al., 2018). Food matrices are often seen to become harder due to the addition of CF to any food formulations (Sanjeewa et al., 2010). Thus, the objective of this investigation was to evaluate the effect of different ratios of CF on protein, textural and sensory qualities of nuggets. This was accomplished by adding CF to the Phoenix mushroom, ranging from 0 to 70 % (Table 3). This section focused on the effect of different concentrations of mushrooms and CF on the quality of nuggets. Despite the fat, the nutrient composition of other ingredients as shown in Supplement Table 1 was determined. Honey contained 19.1 % moisture, 80.4 % carbohydrate, 0.2 % protein and 0.1 % ash. The nutritional composition of white pepper was 11.7 % moisture, 8.7 % protein, 74.8 % carbohydrates, 1.2 % ash and 2.5 % fat. Garlic powder was composed of 67.8 % carbohydrates, 18.1 % protein, 0.3 % fat, 3.7 % ash, and 8.9 % moisture. Moisture, protein, fat, ash and carbohydrates content were 11.9 %, 18.5 %, 2.8, 3.7 and 61.6 %, respectively, for coriander root powder. The main ingredients of seasoning sauces are salt, aromatic herbs, and spices.

3.2.1. Protein content

The protein content was higher in Phoenix to CF ratios of 55:15, and the value was 9.64 % (Table 3). Regarding protein content, the nuggets with Phoenix to CF ratios of 55:15 and 70:0 exhibited no differences ($p>0.05$). The results indicate that Phoenix mushroom-based nuggets had lower protein than chicken and commercial-plant-based nuggets. It is suggested that increasing the Phoenix-mushroom increased the protein content of the nuggets. However, Mazumder et al. (2023a, b) found that increasing the mushroom content increased the protein content of mushroom-derived minced meat and emulsified sausages. These findings demonstrate that Phoenix-mushroom-based nuggets may significantly increase the amount of protein in a human diet, and more studies on the quality of protein should be done to examine the amino acids' bioavailability.

3.2.2. Textural properties

The textural change of the nuggets with increasing CF was examined in this phase. The TPA demonstrated that the textural characteristics of nuggets were significantly influenced by the addition of CF (Table 3). Results suggest that the hardness of Phoenix-mushroom-based nuggets ranges from 361.85 N (CF = 0:70) to 139.10 N (CF = 70:0), cohesiveness from 0.50 (CF = 0:70) to 0.67 (CF= 70:0), and springiness from 0.64 mm (CF = 0:70) to 0.82 mm (CF = 70:0). Similar trends were seen for chewiness and hardness, with 70 % CF having the highest hardness and chewiness. The Phoenix-mushroom content (55 and 70 %) also had the lowest hardness values of 145.63 and 139.10 N, respectively (Table 3). The results showed that increasing the Phoenix-mushroom concentration reduced the compression force, significantly affecting how a product feels in the mouth. This might be because of higher porosity due to higher Phoenix-mushroom and lower cross-linking of proteins (water-soluble), which is thought to improve the hardness of nuggets with higher concentrations of CF (Mazumder et al., 2023a). The addition of 70 % CF in the formulations shows higher hardness of nuggets due to high bulk density, a decrease in porosity and water-holding capacity (Jongrak Attarat and Phermthai, 2015).

The results showed that the nuggets prepared by increasing the concentration of CF reduced springiness. The nuggets with only Phoenix-mushroom (no CF)-based nuggets showed the maximum capacity to recover their original dimensions after compression. This demonstrates an extreme level of texturization of protein, which permits elastic deformation and energy conservation through the production of disulfide bond cross-links. The 70 % Phoenix-mushroom (0 % CF)-based nuggets exhibited a sponge-like springiness, but it wasn't a meaty texture. The addition of CF in nuggets showed significantly less springiness, indicating high starch content in the formulation that changed the textural characteristics of nuggets' matrix (Jongrak Attarat and Phermthai, 2015). Conversely, a low springiness value indicates plastic deformation of the material (Toontom et al., 2022). Moreover, formulations containing 70 % CF (0 % Phoenix-mushroom) showed the highest chewiness of nuggets. According to Table 3, adding 15 to 55 % Phoenix-mushroom significantly reduced chewiness by more than 50 %.

The TPA indicates that chicken nuggets had significantly ($p<0.05$) better textural qualities than Phoenix-mushroom-based nuggets. The developed mushroom-based nuggets show higher ($p<0.05$) hardness and chewiness than commercial chicken nuggets. The hardness value for the Phoenix-mushroom-based nuggets was 139.10–361.85 N, whereas the chicken nuggets had a value of 111.47 N. Textural properties of nuggets were much better ($p<0.05$) than in commercial plant-based nuggets, showing lowered hardness and chewiness (Table 3).

The TPA results demonstrated that optimizing Phoenix-mushroom and CF content may help to control the protein-to-starch ratio, which is an important component in defining acceptable quality attributes. A higher level of springiness without optimum hardness, as like 70 % Phoenix-mushroom, can lower consumer acceptance due to the detrimental impacts of decreased chewiness. Based on the above discussion, it is expected that the nuggets with the best consumer acceptance would be one that contains 15 % CF and 55 % Phoenix-mushroom (Table 3). In order to elucidate the response to this query, a sensory examination was conducted.

3.2.3. Sensory evaluation

The highest protein concentration was found in the nuggets with Phoenix-mushroom to CF ratios of 55:15 and 70:0. However, the nuggets with 70 % Phoenix-mushroom were probably less suitable for nugget processing due to the unfavorable textural characteristics found in the TPA measurements. The composition study revealed that the nuggets had the highest protein content, with Phoenix-mushroom to CF ratios of 55:15 and 70:0. Notwithstanding, the nuggets containing 70 % Phoenix-mushroom were likely less suited for use in nugget processing due to the undesirable textural properties seen in the TPA testing. As a consequence, 50 untrained panelists were used to assess consumer preferences. As previously predicted in the TPA experiments, sensory analysis revealed that 55 % Phoenix-mushroom and 15 % CF demonstrated the maximum acceptability followed by only 70 % Phoenix-mushroom nuggets, 15 % Phoenix-mushroom & 55 % CF nuggets, and only 70 % CF nuggets, respectively. The appearance evaluations of nuggets also indicate that the optimal ratio for nugget processing was 55 % PM and 15 % CF. According to the consumer preference test, 15 % CF and 55 % Phoenix-mushroom-based nuggets exhibited better texture ($p<0.05$) acceptability in comparison to the other samples. The nuggets with 70 % CF had the hardest texture and higher chewiness, which made it the least consumer-acceptable. Consumer choice for meat analogs is influenced by the aroma, texture, color, and texture of the products (Cordelle et al., 2022). The nuggets prepared from Phoenix-mushroom and CF in ratios of 0:70, 55:15, 55:15, and 70:0 was between neither Like nor Dislike (consumer preference score above 5.0) and Like Moderately (consumer preference score above 7.0). The nuggets prepared from 55 % Phoenix-mushroom and 15 % CF were the best, according to the consumer preference test. It revealed that consumers moderately Like (scores 7.22) Phoenix-mushroom-based nuggets; however, chicken nuggets were Like very much (scores 8.17). Table 3, demonstrated that the nuggets based on 15 % CF and 55 % Phoenix-mushroom had the highest textural and sensory acceptance. As a consequence, nuggets containing 55 % Phoenix-mushroom and 15 % CF were selected for further experiments.

3.3. Effect of different starch sources on quality of mushroom-based nuggets

3.3.1. Textural properties

The TPA demonstrated that the textural characteristics of nuggets were significantly influenced by the addition of starch. Table 4 suggests that hardness of nuggets ranges from 187.27 N (potato starch) to 135.65 N (tapioca starch), cohesiveness values from 0.56 (corn starch) to 0.66 (tapioca starch), and springiness values from 0.75 mm (wheat starch) to 0.81 mm (tapioca starch). Potato starch shows maximum values ($p<0.05$) of hardness and chewiness. However, tapioca and corn starch

Table 4
Effect of different starch sources on the textural and sensory quality of MBN.

Composition (%)	Mushroom-based nuggets				Commercial chicken nuggets
	Corn	Potato	Wheat	Tapioca	
Textural profile analysis					
Hardness (N)	149.26 ±50.33^{b}	186.27 ±41.76^{a}	182.45 ±39.50^{a}	135.65 ±33.92^{c}	111.47 ±27.80^{d}
Springiness (mm)	0.78 ±0.12^{c}	0.77 ±0.05^{c}	0.75 ±0.11^{c}	0.81 ±0.02^{b}	0.94±0.02^{a}
Cohesiveness	0.56 ±0.03^{d}	0.58 ±0.04^{d}	0.61 ±0.09^{c}	0.66 ±0.02^{b}	0.80±0.02^{a}
Chewiness	93.88 ±31.98^{b}	105.29 ±43.62^{a}	92.21 ±35.58^{b}	87.90 ±18.21^{c}	83.56±20.0^{d}
Sensory attributes					
Overall acceptance	6.4 ±1.24^{c}	6.6 ±1.27^{c}	6.9 ±1.55^{c}	7.5 ±1.22^{b}	8.17±1.76^{a}
Appearance	6.6 ±1.35^{a}	6.5 ±1.75^{c}	6.8 ±1.74^{c}	7.1 ±1.31^{b}	8.20±1.18^{a}
Texture	6.0 ±1.21^{c}	6.0 ±1.22^{c}	6.0 ±1.80^{c}	7.2 ±1.64^{b}	8.22±1.19^{a}
Color	5.7 ±1.66^{d}	5.8 ±1.16^{d}	6.5 ±1.65^{c}	6.9 ±1.22^{b}	8.34±1.75^{a}
Aroma	6.5 ±1.48^{c}	6.3 ±1.37^{c}	6.6 ±1.47^{c}	7.2 ±1.74^{b}	8.44±1.33^{a}
Taste	6.6 ±1.74^{c}	6.1 ±1.50^{d}	6.5 ±1.27^{ab}	7.2 ±1.47^{a}	8.17±1.76^{a}
Acceptance (%)	16.7	20.0	23.3	40.0	70.0

Values are given as mean ± SD from n = 3. Different superscripts in the row indicate a significant difference (p-value < 0.05). Panelists were marked separately based on 100 for acceptance (100 for all mushroom-based, and 100 for commercial chicken nuggets)

had the lowest hardness values of 135.65 and 149.26 N, respectively (Table 4).

The results showed that nuggets of prepared wheat starch decreased springiness and that the wheat starch-nuggets showed the maximum capacity to recover their original dimensions after compression. A low springiness value indicates plastic deformation of the material (Toontom et al., 2022). Moreover, formulations containing potato starch showed the highest chewiness of nuggets. The result correlates to the hardness value. Hardness predominates since it has higher values than the other treatments, although chewiness is partially generated from hardness and springiness. The hardness value for the nuggets was 135.65–186.27 N, whereas the chicken nuggets had a value of 111.47 N. Textural properties of nuggets were much better ($p<0.05$) than in commercial plant-based nuggets, showing lowered hardness and chewiness (Table 4).

Starch is used for a variety of food products such as thickening, gelling, and stabilizing of a variety of vegan and non-vegan meals. Thickening properties of tapioca starch is reduced, when cooked over a longer period of time. Tapioca starch is very useful in frozen foods since it helps to keep their texture even after being thawed. Tapioca starch has a high viscosity and is a great binder. Corn, wheat, potato, tapioca, and rice are some of the most prevalent starches available on the market. Starches are widely utilized in the food industry to enhance product quality. As for example, corn starch aids to reduce sponge cake texture as compared to wheat flour (Li et al., 2015). Wheat starch has been shown to provide gelling qualities to food products (Witczak et al., 2014). Potato starch has been shown to be an effective pasting and gelling agent (da Rosa Zavareze et al., 2012). A recent study found that tapioca starch helped to improve the gluten-free quality of jasmine rice bread (Agudelo et al., 2014). Tapioca starch is also an effective thickening agent in fruit filling manufacture, such as blueberry filling in a blueberry cheesecake (Wongsagonsup et al., 2014). However, vegan and/or non-vegan consumers will accept the meat analogs if the textural characteristics closely mimic the animal meat. The TPA demonstrated that tapioca starch may help to control the protein-to-starch ratio, which is an important component in defining acceptable quality attributes. Based on the above discussion, it is expected that the tapioca starch-based nuggets would show the best consumer acceptance. In order to elucidate the response to this query, a sensory examination was conducted.

3.3.2. Sensory evaluation

The nuggets containing potato starch were likely less suited for use in nugget processing due to the undesirable textural properties observed in the TPA analysis. Sensory analysis revealed that tapioca starch-based nuggets demonstrated the highest acceptability, followed by wheat-, potato- and corn-starch-based nuggets. According to the consumer preference, tapioca starch-based nuggets exhibited better texture ($p < 0.05$) acceptability in comparison to wheat-, potato- and corn-starch-based nuggets. The nuggets with the hardest texture and higher chewiness made them the least consumer-acceptable. The nuggets prepared from corn, potato and wheat starch are in the range of Like Slightly (consumer preference score above 6.0). The tapioca starch-based nuggets were the best, according to the consumer preference test (score above 7.0). It revealed that consumers moderately Like (scores 7.5) tapioca nuggets; however, chicken nuggets were Like very much (score 8.17). Nuggets prepared with tapioca starch had the highest textural and sensory acceptance (Table 4). As a consequence, Phoenix-mushroom-based nuggets containing tapioca starch were selected for further experiments.

3.4. Quality attributes of phoenix mushroom-chickpea flour-tapioca starch-based nuggets

3.4.1. Physico-chemical properties

The TPA indicated that chicken nuggets showed significantly better textural qualities than Phoenix-mushroom- and commercial plant-based nuggets. The commercial PB nuggets show significantly higher hardness and chewiness than Phoenix-mushroom- and chicken nuggets. The hardness value for chicken nuggets was 111.47 N, whereas Phoenix-mushroom- and commercial plant-based nuggets had values of 124.16 N and 188.97 N, respectively. The results suggest that Phoenix-mushroom-nuggets show significantly better textural qualities than commercial plant-based nuggets, including lower hardness and chewiness (Table 5). The studies demonstrated that chicken nuggets had higher springiness than Phoenix-mushroom-nuggets, while commercial plant-based nuggets have the greatest capacity to restore their original dimensions after compression. However, Phoenix-mushroom nuggets

Table 5
Textural and physico-chemical properties of Phoenix-mushroom based nuggets.

Attributes	Composition/values		
	Phoenix mushroom-based nuggets	Commercial plant-based nuggets	Commercial chicken nuggets
Texture profile analysis (TPA)			
Hardness (N)	124.16±55.41^{b}	188.97±5.33^{a}	111.47±27.80^{c}
Springiness (mm)	0.77±0.08^{b}	0.74±0.06^{b}	0.94±0.02^{a}
Cohesiveness	0.46±0.02^{b}	0.81±0.02^{a}	0.80±0.02^{a}
Chewiness (N)	86.18±11.90^{b}	141.20±3.77^{a}	83.56±10.00^{c}
Color parameter			
L*	55.73±0.36^{c}	59.40±1.31^{a}	57.58±0.27^{b}
a*	5.10±0.27^{a}	1.06±0.12^{b}	1.07±0.93^{b}
b*	21.10±1.77^{a}	15.07±1.00^{b}	12.71±0.96^{c}
Physical properties			
Cooking yield (%)	87.65±1.75^{b}	85.29±2.18^{c}	89.51±1.18^{a}
Moisture retention (%)	77.86±1.45^{b}	75.16±2.67^{c}	80.15±1.23^{a}
Fat retention (%)	90.55±1.50^{b}	88.39±1.15^{c}	92.55±1.03^{a}

All values are means ± SD of three replicates; Values with different superscripts in the same row are significantly different (p<0.05).

had a higher springiness value than commercial pant-based nuggets. The decreased springiness of plant-based nuggets might be attributed to component variations. Furthermore, the highest chewiness was reported in plant-based nuggets. The result correlates to the hardness value. The presence of CF and mushrooms in the Phoenix-mushroom nuggets was linked to an increase in the textural properties of commercial chicken nuggets. Zeraatkar et al. (2019) discovered that substituting plant-based protein for meat enhanced the hardness of chicken sausage. This might be attributed to the use of mushrooms and chickpeas different dosages and amounts. Adding 5 % pea protein isolates to mushroom and chickpea helped to enhance hardness.

This study found a substantial ($p < 0.05$) difference in color characteristics between commercial plant-based, Phoenix-mushroom-, and commercial chicken nuggets. The Phoenix-mushroom nuggets had a lower lightness value of L* = 55.58 due to intrinsic color of mushroom and reddish color were developed by honey and Maillard browning during baking process. The Phoenix-mushroom nuggets had higher a* and b* values than the commercial plant-based due to the raw materials' inherent color. Commercial plant-based nuggets are prepared from 50 % w/w soy flour or 70 % w/w soy protein concentrate mixed with other ingredients such as water, NaCl, to develop a white or light -yellow powder. The processed nuggets had the same color as a chicken nugget; however, when cooked, the chicken nugget turned whitter than the Phoenix-mushroom nuggets.

3.4.2. Cooking properties of nuggets

Commercial chicken nuggets show higher ($p < 0.05$) cooking yield than commercial plant-based and Phoenix-mushroom nuggets. However, commercial plant-based and Phoenix-mushroom nuggets did not differ from each other (Table 5). Both retained less ($p < 0.05$) moisture and fat than chicken nuggets. Sodium chloride is required for the solubilization of myofibrillar proteins, which leads to denaturation and aggregation, in order to provide meat gels with sufficient stiffness and elasticity, as well as enough water retention (Gordon and Barbut, 1992). This research demonstrated the changes ($p < 0.05$) in cooking yield for chicken nuggets, commercial plant-based and Phoenix-mushroom nuggets, demonstrating that salt increases the water retention capacity of meat products. The added fat and salt groups showed higher ($p < 0.05$) water and fat retention. Nevertheless, salt and fat content was higher in chicken and commercial plant-based nuggets (more than 2 %). Research revealed that conjugation of sodium chloride (NaCl) and phosphates increased water retention and, therefore, lowered drip loss and cooking loss in meat products (Gordon and Barbut, 1992). Similarly, injecting of different quantities of tripolyphosphate and sodium chloride into UK-style grill steaks dramatically decreased ($p < 0.05$) cooking loss (Sheard et al., 1990). On the other hand, NaCl, sodium lactate, and phosphate treated beef exhibited reduced ($p < 0.5$) cooking loss and re-heating loss (McGee et al., 2003). This suggests sodium lactate can operate synergistically with NaCl and phosphate to increase their functionality.

3.4.3. Amino acid analysis

More than 30 % of the amino acids in mushrooms were present in free form, with the remaining being linked with other amino acids for protein formation. Table 6 indicates nine essential amino acids were present in Phoenix-mushroom nuggets. Legumes and grains are often low in lysine, tryptophan, isoleucine, and phenylalanine; in contrast, mushrooms are a particularly good source of these amino acids. Mushrooms contain higher levels of isoleucine, methionine, phenylalanine, and tryptophan than the majority of fruits and vegetables (Pandey et al., 2021). All the essential amino acids were significantly higher in chicken nuggets than those in Phoenix-mushroom nuggets. Tryptophan and methionine content was lower than 150 and 50 mg/100g in Phoenix-mushroom nuggets. Phoenix-mushroom nuggets also contained a significant quantity of branched-chain amino acids. However, it is much lower than chicken nuggets. Branched-chain amino acids have been shown to help grow muscle, reduce muscular fatigue, and alleviate muscle soreness (Hegsted, 1973). Methionine, a sulfur-containing amino acid and two aromatic amino acids, phenylalanine and tyrosine, were higher in chicken nuggets than in Phoenix-mushroom nuggets. Additionally, Table 6 demonstrates that chicken had higher amounts of all non-essential amino acids than Phoenix-mushroom nuggets. However, tyrosine and cystine content was lower than 250 and 100 mg/100g. However, the stability and structural contribution of meat analogs depends on the composition of amino acids. For instance, inter-molecular disulfide bonds are one of the crucial factors for the stabilization of meat analogs (Hager, 1984).

Table 6
Amino acid composition of phoenix mushroom-based nuggets.

Composition	Phoenix mushroom-based nuggets	Commercial chicken nuggets	% RP
Essential amino acids (mg/100g)			
Threonine	224.28±11.7	1,034.73 ± 20.33b	3.4
Valine	330.34±10.1	1,014.26 ± 30.08b	3.5
Lysine	235.83±12.2	2,007.21 ± 41.15a	5.08
Methionine	<50.0	709.21 ± 29.33b	2.4b
Isoleucine	265.76±13.0	1,407.25 ± 18.88a	2.8
Leucine	512.29±10.0	2,066.04 ± 24.62b	6.6
Phenylalanine	411.96±11.0	972.99 ± 58.12b	6.3a
Histidine	163.90±12.5	4,072.48 ± 22.96a	1.9
Tryptophan	<150±0.0	283.67 ± 10.58a	
Non-Essential amino acids (mg/100g)			
Aspartic acid	444.13±13.1	2,351.12 ± 22.28b	-
Serine	373.94±11.2	1,006.46 ± 51.04b	-
Glutamic acid	2221.47±14.2	4,023.59 ± 63.22b	-
Glycine	274.93±11.5	1,038.31 ± 31.61b	-
Alanine	262.36±12.6[c]	1,270.72 ± 10.46a	-
Cystine	<100±0.0	210.36 ± 15.06b	-
Tyrosine	<250.0±0.0	990.29 ± 40.46	-
Proline	661.80±14.1[c]	1,024.73 ± 45.96a	-
Arginine	350.83±13.1[a]	2,069.58 ± 44.25a	-

All the values are mean ± SD; n = 3. % RP = Requirement Pattern in Protein (%) (Mazumder et al., 2023b), a = Phenylalanine with Tyrosine, b = Cysteine with Methionine, ND = Not Determined.

3.4.4. Challenges, limitation and future work

The major challenges are product formulations, and maintaining a product quality similar to traditional chicken nuggets. Among the challenges, increasing the mouth-feel attributes of Phoenix-mushroom-based alternative chicken nuggets, which are currently lacking, may receive the highest attention. Production of meat analogs will remain a challenge until the sensory properties are improved.

The difference in ingredients, seasoning and raw materials between commercial plant-based nuggets and developed Phoenix-mushroom-based alternative chicken nuggets are the main limitations of this research. Subsequent investigations may concentrate on determining the bioavailability of Phoenix-mushroom nuggets and their influence on allergenicity.

4. Conclusion

According to this research, mushrooms can be an alternative meaty-like ingredient to prepare meatless mushroom-based nuggets when mixed with other suitable ingredients. Chickpea proteins and Phoenix-mushrooms may be utilized as an alternative protein source that has the ability to replace up to 70 % (15:55) of the chicken in nuggets. This study suggests that Phoenix-mushroom-based nuggets can provide more than 18 % RDI of protein. Nutritional and textural analysis indicates that Phoenix-mushroom nuggets are comparable to commercial chicken nuggets and commercial plant-based nuggets. However, the amino acid content was much higher in commercial chicken nuggets than that of Phoenix-mushroom nuggets. Sensory analysis demonstrated that Phoenix-mushroom nuggets had better acceptability than commercial plant-based nuggets (soy-based) and almost similar acceptability as chicken nuggets. It is anticipated that the processing of mushroom-based nuggets will open up the uses of mushrooms, raise the economic value, satisfy consumer demands, ensure sustainability of protein supply, and dietary fiber

Ethical approval

The authors declare that this work has no any studies in Humans and Animals samples. Sensory analysis was carried out in the Food Sensory Lab (S4) (Mae Fah Luang University, Chiang Rai, Thailand) with ethical approval (protocol no.: EC: 23171-14) for consumer testing. Sensory analysis was permitted by Mae Fah Luang University, Chiang Rai, Thailand (COE 183/2023).

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Md. Anisur Rahman Mazumder: Conceptualization, Writing – original draft, Writing – review & editing. **Kanokwan Jongraksang:** Writing – original draft, Investigation, Formal analysis, Data curation. **Kanyarat Kaewsiri:** Writing – original draft, Investigation, Formal analysis, Data curation. **Supravee Keawnualborvornnij:** Writing – original draft, Investigation, Formal analysis, Data curation. **Worranitcha Nenjatee:** Writing – original draft, Investigation, Formal analysis, Data curation. **Lovedeep Kaur:** Writing – review & editing, Supervision. **Wanli Zhang:** Writing – review & editing. **Suphat Phongthai:** Writing – review & editing. **Saroat Rawdkuen:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare no conflict of interest. The funders had no role in the design of the study

Data availability

Data will be made available on request.

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Supplementary materials

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