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The Impacts of Different Pea Protein Isolate Levels on Physiochemical, Textural, and Sensory evaluation of Ready-to-Cook Plant-Based Minced Meatballs from Oyster Mushroom

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Keywords

Pea protein isolate; Plant-based minced meatball; Texture; Nutritional value; Sensory evaluation.

The effects of different ratios of pea protein isolate (PPI) (5%, 10%, 15%, and 20% w/w) on ready-to-cook plant-based minced meatballs made from oyster mushrooms were investigated. Increasing the PPI ratio resulted in higher protein content, while values for lightness (L*), yellowness (b*), hardness, adhesiveness, and chewiness decreased compared to the control. Sensory evaluation indicated that all treatments received overall liking scores ranging from 6.50 to 7.23. The study demonstrated that incorporating 10% PPI led to optimal production of plant-based minced meatballs with high protein content (10.79 g/100 g), low-fat content (2.08 g/100 g), and an overall liking score exceeding 7.0, indicating acceptability. These findings confirm that PPI is a practical alternative to meat proteins for producing plant-based meat products.

1. Introduction

The Food and Agriculture Organization (FAO) has highlighted a concerning report on global hunger. In the year 2020, an estimated 720 to 811 million people, equivalent to one in three individuals worldwide, experienced hunger, as stated by the FAO. This alarming statistic emphasizes the pressing issue of food insecurity. Furthermore, with the projected global population reaching 9.80 billion by 2050, the challenges related to food security are expected to intensify (FAO, IFAD, UNICEF, WFP, & WHO, 2021). However, there is a limit to the resources available for food production, and overuse of these resources will have unfavorable effects on food production. This in turn has increased the search for plant-based protein ingredients to replace animal-based proteins (Zhu & Begho, 2022). There is a clear consumer trend towards plant protein-rich diets, driven by the recognized sustainability and health benefits of plant-based eating, as well as the need to address the environmental impact of animal agriculture (Gravel et al., 2023). In addition, the United Nations has recommended a significant decrease in the consumption of red meat and a transition towards plant-based diets to promote a healthy and sustainable diet for the increasing global population (United Nations, 2022).

Consequently, plant-based meat products have garnered substantial attention as alternatives to traditional meat due to their positive impact on the environment, human health, and animal ethics (Yang et al., 2023). According to the report by Grand view research (2023), the global plant-based meat market size had a market value of USD 4.40 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 24.9% from 2023 to 2030 (Fig. 1). Especially, meatballs, burgers, and meat patties are highly accepted and consumed worldwide (Turgut et al., 2017). Most of these food items are made with beef as their primary ingredient. Oostindjer et al (2014) reported that red meat contained a high content of fat, especially saturated fat. Consuming more than 500 grams of red meat per week increases the risk of various diseases, including cancer, obesity, and cardiovascular disorders. Yiannakou et al. (2022) reported that individuals with high intakes of red meat have an increased association between colorectal cancer risk and saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs), which are the primary types of fat found in red meat. Therefore, plant-based meat products are an important alternative for individuals who prioritize their health. Plant-based meat ingredients such as mushrooms, soy protein, pea protein, wheat gluten, and insects are processed in combination with flavoring additives to produce a final product that tastes like meat (Kyriakopoulou et al., 2019; Sha & Xiong, 2020). The oyster mushroom (Pleurotus eryngii) is highly popular and in high demand in many countries, primarily due to its meaty texture, long shelf life, firm flesh, cap and stem consistency, delightful taste, remarkable flavor, and ease of cultivation (Sardar et al., 2022). Nakpatchimsakun et al (2023) reported that oyster mushrooms are a good alternative for plant-based minced meatball production due to their richness in sulfur-containing amino acids and fiber. They can help achieve a meaty flavor and texture, which are widely accepted by consumers.

Moreover, mushrooms are rich in biological activity components, which can provide many health benefits, including an antitumor property (He et al., 2020). However, some studies consider that replacing more than 60% of meat with plant-based meat can cause a deficiency of nutrients (van der Weele et al., 2019), especially protein (Lima et al., 2023). Therefore, a challenge in creating plant-based minced meatballs with both high protein content and satisfactory meat-like characteristics involves the development of meat alternatives using ingredients like mushrooms, pea protein, and other plant-based sources.

Pea (*Pisum sativum* L.) is one of the most abundant and sustainable alternative sources of protein, especially in good quantities of most of the essential amino acids (Das et al., 2023). Pea has been a promising source of plant-based protein. It is commonly utilized in various food applications as protein isolates produced from pea flour through protein solubilization and concentration processing steps (Boye et al., 2010). Pea protein isolate (PPI) has the potential to be used for plant-based meat production because of its low cost, availability, low allergenicity, and high nutritional value (Lam et al., 2018). In addition, pea cultivation has a lower greenhouse gas intensity per unit of nutritional density compared to animal foods; its cultivation requires a negligible amount of nitrogen fertilizer, and has a less negative impact on biodiversity due to low pesticide use (Sajib et al., 2023).

In this context, the main objective of this experiment was to investigate the influence of different pea protein isolate levels on the qualities to improve the physicochemical properties, texture, and sensory evaluation of ready-to-cook plant-based minced meatballs made from oyster mushrooms. The findings of this study could have practical applications in the food industry in the development of healthier plant-based meat and promote a sustainable environment.

2. Materials and Methods

2.1 Preparation of raw materials

Pea protein isolate was purchased from Krungthepchemi (Bangkok, Thailand) (Composition: 80g protein, 6.90g fat, 5.60g carbohydrate, and 4.40g dietary fiber, per 100g). Beef meat (red meat)and king oyster mushrooms were purchased from a supermarket in Bangkok. The raw materials were ground using a meat mincer with a 6 mm center square hole knife (SIR1-TC8 VEGAS, Italy) and stored at -18°C.

2.2 Plant-based minced meatball production

The plant-based minced meatballs (PBMM) were pro-

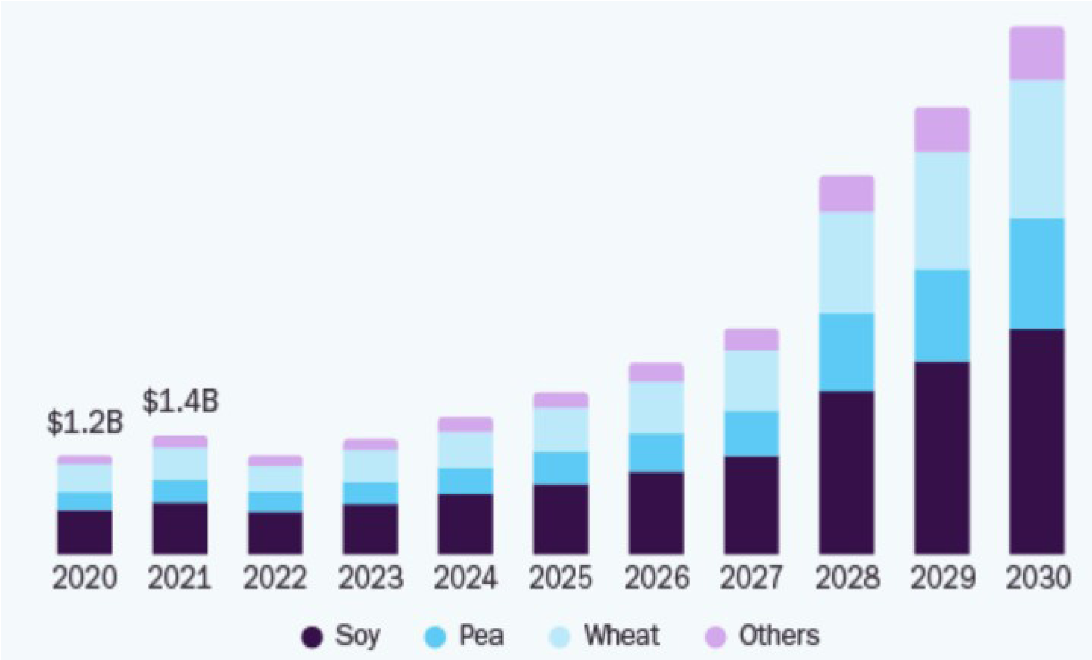

Figure 1. The global plant-based meat market size, 2020-2030 (Source: Grand View Research, 2023).

duced following Nakpatchimsakun et al (2023), which was used to produce plant-based minced meatballs. Each composite ratio contained ice water (~4°C) 57%, 18% potato starch, 3.50% vegetable oil, 0.20% calcium chloride, 0.30% salt, 2.50% baking powder, and 1.50% moisture content (MC) in order to make 100g of ground oyster mushroom. All ingredients were homogenized in a food processor for 3 min at low speed; deionized water was used throughout the study. This step was carried out to fully hydrate the sample. Pea protein isolate (PPI) at four different ratios (5, 10, 15, and 20% w/w) was added to the samples. The commercially available plant-based minced meatball was served as a control. The ground raw materials in each group were mixed and emulsified using a refrigerator at a temperature of 0°C–4°C for 3 hours. This temperature range ensures optimal emulsification for producing meatballs. Subsequently, the mixture was shaped into round forms with a diameter of 2.50 cm and a weight of 15 g. It is important to note that the internal end-point temperature of the minced meatballs should not exceed 4°C. The minced meatballs were pan-fried in canola oil (preheated to 180°C) for 5 min. The internal end-point temperature (75°C) of the minced meatballs was measured by inserting a digital thermometer with an accuracy and resolution of ±1°C and 0.10°C, respectively. After cooking, the minced meatballs were placed on a paper towel for 10 min to remove excess oil from their surface. Before further analysis, all minced meatballs were naturally cooled at room temperature (25°C ±2°C) for 15 min (Wang et al., 2023).

2.3 Instrumental analysis of samples

2.3.1 Analysis of moisture and protein content

The moisture and protein content were measured in triplicate according to the methods of the Association of Official Analytical Chemists (AOAC, 2019). Moisture content was measured according to the AOAC method 952.08. Samples were dried in a hot air oven (Binder, FD 115, Germany) at 105°C for 24 hours or until constant weight comes, and moisture content was estimated by comparing the mass before and after drying. Protein content was determined using the macro-Kjeldahl method (method 992.15, N ×6.25).

2.3.2 Color analysis

The color of the fried samples was measured directly on the surface of meatballs using a Hunter Lab apparatus (Hunter Lab, UltraScan PRO, USA) (Wang et al., 2023), which measured three parameters: L*(lightness), a*(redness) and b*(yellowness) values. The L*, a*, and b* values were recorded as the average of ten measurements.

2.3.3 Texture profile analysis (TPA)

Texture profile analysis was determined according to Nakpatchimsakun et al. (2023). Briefly, a compression test was performed on a TA.XTplus Texture Analyzer (Stable Micro Systems, TA.XT PlusC, UK) fitted with a 100 mm cylindrical probe (P/100) set to 50% depth and load cell of 50 kg. The cooked samples were cooled to room temperature for 30 min and measured for pre-test speeds 1.0 mm/sec, test speeds 2.0 mm/sec, and post-test speeds 5.0 mm/sec, respectively, the compression value was 50%, trigger force type was automatic, and the triggered ability was set at 5.0 g. The following parameters were quantified; hardness, adhesiveness, cohesiveness, springiness, and chewiness. Results are the mean of at least ten reproducible runs for each treatment per batch.

2.3.4 Sensory analysis

The sensory evaluation of fried samples was carried out at the Department of Applied Science, Suan Sunandha Rajabhat University, Bangkok, Thailand, using a sensory evaluation questionnaire. Samples were served to 50 untrained panelists experienced in the sensory evaluation of foods. The inclusion criteria were panelists who were between 18 and 60 years old, were regular minced meatballs, plant-based meat consumers, and had no history of food allergy. Panelists with asthma or an allergy were excluded. The samples were served on disposable paper plates; the samples were pre-coded with three random digit codes and presented to the panelists in random order at a temperature of approximately 40°C. Panelists were provided with drinking water to clean their mouths between consecutive tastings. They were instructed to first visually evaluate the acceptability of product appearance and color and then to bite and swallow each sample before scoring it for odor, taste, texture (firmness), and overall liking using a 9-point hedonic scale (1 = disliked extremely, 5 = neither like nor dislike, and 9 = like extremely) according to Nakpatchimsakun et al. (2023).

2.3.5 Analysis of nutrition values

Based on the results from step 2.3.4, a nutritional analysis was measured in triplicate to compare nutritional differences between the commercially available beef minced meatball, plant-based minced meatball, and the developed plant-based minced meatballs according to the Association of Official Analytical Chemists (AOAC, 2019). Total energy, moisture, total fat, protein, carbohydrate, dietary fiber, ash, and sodium (Na) were included. The moisture and protein content (g/100 g) was the same procedure as described in the previous method section 2.3.1. Crude fat content (g/100 g) was measured in accordance with method 948.15 by extracting a known weight of the sample with petroleum ether, using a Soxhlet apparatus. In determining ash content (g/100 g), samples were burned at 550°C±25°C for 4 h in a muffle furnace in accordance with method 945.46. Dietary fiber (g/100 g) was measured using the Enzymatic-Gravimetric Method following method 985.29. Sodium content was determined through extract preparation and titration in accordance with method 985.35. The results were expressed as mg NaCl/100 g of samples. Carbohydrates and Total energy were calculated based on Equations (1) and (2).

Carbohydrate (g/100 g) = 100 – Protein – Fat – Fiber – Ash **(1)**

Total Energy (kcal/100 g) = (4 × g protein)+(4 × g Carbohydrate) + (9 × g Fat) **(2)**

2.3.6 Data analysis

Three batches of each treatment were performed, and each sample was measured in triplicate unless otherwise stated. The data were expressed as means ± standard deviations of each sample. The data were analyzed using analysis of variance facilitated by the IBM SPSS® version 23 software (IBM SPSS Inc.; USA). Duncan's multiple range test was used to determine multiple comparisons of mean values with a statistically significant difference established at $p < 0.05$.

3. Results and discussion

3.1 Moisture and protein content

The moisture and protein content of the plant-based minced meatball with different pea protein isolate (PPI) levels are shown in Table 1. There was a significant difference between the different treatment levels

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Table 1. Moisture and protein content of the plant-based minced meatball with different pea protein isolate levels

Treatments	Moisture, % wb	Protein, % db
Control	67.300.30^{a}	8.210.03^{e}
5% PPI	58.250.50^{b}	9.150.02^{d}
10% PPI	56.811.20^{bc}	10.60 0.00^{c}
15% PPI	55.84 0.90^{c}	12.600.06^{b}
20% PPI	52.322.00^{d}	15.800.30^{a}

PPI = pea protein isolate; Control = the commercially available plant-based minced meatball
wb = wet basis; db = dry basis
Mean ± SD with different lowercase superscripts in each column are significantly ($p<0.05$) different

of moisture and protein content ($p<0.05$). Moisture content is an important factor that can affect the storage properties of food, as it is the factor most strongly linked to microbial growth (Vera Zambrano et al., 2019). The results showed that samples with the addition of PPI had a lower moisture content than that of the control. The lowest moisture content belonged to PPI at 20% w/w, while the highest value was observed at 5% w/w. The increase in PPI led to a decrease in the final moisture content of the final product. This could have been due to the higher water-holding capacity of PPI (Lee et al., 2023). Protein was the main constituent of the PPI (80g/100g), therefore it determined these properties. Water binds to hydrophilic groups of protein side chains via hydrogen bonds. Thus, moisture content depends on the water-holding capacity of proteins (Kaleda et al., 2021). Lee et al. (2023) also reported the same finding. The moisture content of meat analog products decreased within the PPI ratio range of 55.6% to 59.5%. Protein content is an essential macro-nutritional measure for assessing plant-based meat products (Yang et al., 2023). By increasing the PPI, the protein content increased from 9.15% (5% PPI) to 15.80% (15% PPI) on a dry basis (db), respectively. These values were notably higher compared to the commercially available plant-based minced meatball. Because the PPI is an excellent source of protein. Pea proteins mainly exist as globulins (65–80%), which are also the main components in pea protein isolate products (Meng & Cloutier, 2014). Hence, the use of PPI in the food industry for the formulation of new food products is very interesting because of its nonallergenic characteristics, despite its high nutritive value and good functional properties (Meng & Cloutier, 2014). This study revealed that pea protein isolate can be a favorable ingredient for the development of plant-based minced meatballs and other novel food products that offer health benefits to consumers.

3.2 Color

Color is an important factor in assessing the acceptability of plant-based meat products. According to the results in Table 2, there was a significant difference ($p<0.05$) in the lightness (L*), redness (a*), and yellowness (b*) of the plant-based minced meatball with varying levels of PPI. The addition of PPI resulted in higher L* and b* values for the plant-based minced meatball compared to the control, while the a* value decreased. The control sample had a reddish-brown color, while the plant-based minced meatball with added PPI had a brown color, as shown in Fig. 2. Because the control sample is a commercially available plant-based minced meatball made from soy protein containing protein as a component, the color change occurs due to a Maillard browning reaction involving amino acids and reducing sugars. The heat from the frying process acts as an accelerator for this reaction (Nakpatchimsakun et al., 2023). In contrast, the experimental plant-based minced meatball made from oyster mushrooms, which have a lower protein content compared to soy protein, exhibits a lighter appearance compared to the control sample. However, it should be noted that the increase in PPI can significantly enhance the lightness of the resulting plant-based minced meatball product. The 20% PPI showed the highest lightness, followed by 15%, 10%, and 5% PPI, respectively. The high protein content of PPI may lead to an increase in the size and quantity of internal air cells in the product. This is attributed to the swelling of proteins caused by the uptake of water and accommodation between the protein chains, resulting in the formation of air cells within the product and contributing to its enhanced lightness (Muhialdin & Ubbink, 2023). This can be attributed to the protein's functionalities, such as emulsification, foaming, and water-holding capacities, which play important roles in the formation of the meat structure (Sajib et al., 2023). Similar effects of an increase in pea protein isolate-amylose/amylopectin on lightness and yellowness have been reported for pea protein-based meat substitutes (Chen et al.,)

3.3 Texture properties

The texture is one of the most important qualities of plant-based meat products (Xia et al., 2022). To determine the effect of PPI on plant-based minced meatballs, the hardness, adhesiveness, cohesiveness, springiness, and chewiness of samples were tested by a texture analyzer. Hardness relates to the maximum force required to compress the sample, adhesiveness is the amount of work required to overcome the attractive forces of the food to another contact surface, cohesiveness indicates the strength of internal bonds, springiness is how much the sample recovers after deformation, and chewiness is the energy required to chew solid food until it can be swallowed (Chandra & Shamasundar, 2015). As illustrated in Table 3, increasing the PPI ratio resulted in a decrease in hardness, adhesiveness, and chewiness compared to the control. Proteins are the main components contributing to the three-dimensional internal structure of meat products, which are held with hydrophobic interactions and stabilized by hydrogen and disulfide bonds (Kaleda et al., 2021). Therefore, using oyster mushrooms

Table 2. Color parameters of the plant-based minced meatball with different pea protein isolate levels

Treatments	L*	a*	b*
Control	21.401.20^{d}	4.420.40^{a}	6.400.50^{c}
5% PPI	23.520.92^{c}	1.600.20^{c}	6.900.50^{c}
10% PPI	25.001.00^{b}	2.22 2.30^{b}	8.230.30^{b}
15% PPI	25.511.10^{ab}	2.302.30^{b}	8.700.73^{ab}
20% PPI	26.350.44^{a}	2.300.13^{b}	9.100.32^{a}

PPI = pea protein isolate; Control = the commercially available plant-based minced
L*= lightness; a*= redness; b*= yellowness
Mean ± SD with different lowercase superscripts in each column are significantly (p<0.05) different

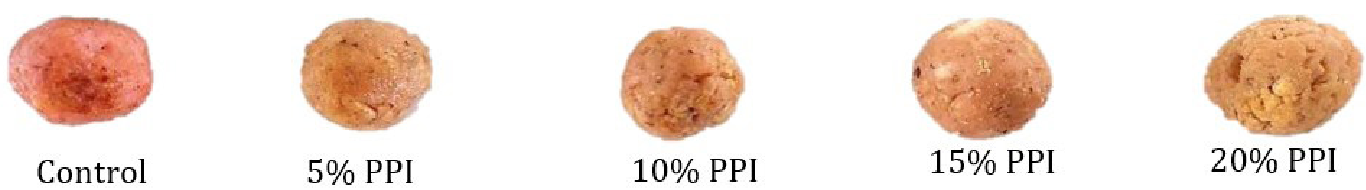

Figure 2. Color of the commercially available plant-based minced meatball (control) and plant-based minced meatball with different pea protein isolate levels (5%, 10%, 15%, and 20%, w/w).

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in plant-based minced meatballs results in a meaty texture that is lower compared to using soybeans as a meat substitute. However, adding PPI can indeed help improve the texture of plant-based minced meatballs made from oyster mushrooms. Due to the presence of PPI, it can fill the interstitial spaces within the network (Alves & Tavares, 2019). Especially, incorporating 15% to 20% PPI can result in hardness, cohesiveness, springiness, and chewiness that closely resemble those of the most well-controlled sample. The results agree with Xia et al. (2022), who found that the hardness, springiness, and chewiness of meat analogues decreased by adding pea protein powder. A similar observation was found in fibrous meat analogs from oat-pea protein blends by Kaleda et al. (2021). Furthermore, Mena et al. (2020) also reported that hardness is an important determinant for consumers and producers in assessing the texture of meat products, where lower hardness is generally preferred by elderly consumers. These results suggested that can be used as a tenderizer (texture modifier) in PPI plant-based meat for the elderly by reducing the force required to masticate. This is because the elderly prefer soft and easy-to-swallow foods over hard and chewy foods due to their weakening of teeth and jaw muscles (Lee et al., 2023). Similar to previous studies, the involvement of pea proteins considerably decreased the chewiness of meat analogs (Xia et al., 2022).

3.4 Sensory evaluation

The PPI was the most important parameter affecting the sensory liking of plant-based minced meatballs. Table 4 shows that overall liking scores for all PPI ratios slightly decreased ($p<0.05$) compared to the control, whereas appearance, odor, taste, and texture (firmness) scores had no significant differences ($p>0.05$). The sensory evaluation results of plant-based minced meatballs with different ratios of PPI indicated that acceptability scores of all sensory attributes ranged from 6.43-7.23 (like slightly-like moderately). This demonstrates the acceptance of consumers towards the product. Giménez et al. (2008) reported that an average value of 6 on a 9-point hedonic scale is the minimum acceptability limit for consumers liking a product. Additionally, it was also observed that the plant-based minced meatball with 5%-10% PPI tended to increase the overall liking scores more than those with 15%-20%. The sensory liking of the PPI-meat product followed a similar trend as the taste scores.

Grasso et al. (2019) also reported that no significant differences in taste attributes were observed in the hybrid sausage containing PPI. A similar observation was found in taste and odor liking scores of fibrous meat analogs from oat-pea protein blends (Kaleda et al., 2021). Besides, Giménez et al. (2008) established a minimum acceptability limit for consumer liking of a product using an average value of 6 on a 9-point hedonic scale. This might have been due to the combination of oyster mushroom and pea protein isolate, which provides a meat-like flavor. He et al. (2020) and Nakpatchimsakun et al. (2023) reported that oyster mushrooms were rich in sulfur-containing amino acids, which helped to achieve a meaty flavor. Pea proteins are primarily utilized as raw materials to produce meat substitutes. This is due to their excellent fat and water binding capacity, as well as their ability to form stable emulsions. These properties contribute to the creation of a desirable meat-like texture for meat products (Broucke et al., 2022). Therefore, it can be inferred that the inclusion of oyster mushrooms and PPI in plant-based minced meatballs could enhance consumer acceptance. Analysis of texture and sensory scores suggests that incorporating an appropriate amount of 10% PPI can improve the overall acceptability of plant-based minced meatballs. However, the excessive addition of PPI resulted in reduced adhesiveness, cohesiveness, and overall liking scores of the product.

3.3 Nutritional values

The nutritional values of the plant-based minced meatball with 10% PPI are shown in Table 5. The moisture contents and other nutritional values of the developed plant-based minced meatballs differed significantly from those of the commercially available plant-based minced meatballs. The moisture content of this product was 56.32 g/100 g lower than that of the commercially available plant-based minced meatball. These results fairly agree with the reported literature (Lee et al., 2023). The calculation of total energy in 100 g of the developed product revealed a lower energy content compared to commercial products, with values of 371.48 kcal and 429.07 kcal, respectively. This difference in energy content can be attributed to variations in protein, total fat content, and carbohydrate levels between developed and commercial products. This was due to the main ingredients, such as oyster mushroom and pea protein isolate of the developed product, which have low fat. According to the recommendations of the Food and Agriculture Organization (FAO), the total energy content of this product should ideally align with that of meat foods, which is around 4.27 kcal/g.

Additionally, the FAO (2004) suggests that the recommended energy intake for the average healthy individual per meal should be within the range of 400–500 kcal. However, it's important to note that these are general guidelines, and individual energy requirements may vary based on factors such as age, gender, weight, height, activity level, and specific health goals. Protein is an important nutrient in people's diets, and the protein content is one of the most vital properties for assessing the quality of plant-based meat products. The addition of PPI ingredients affected the protein content. The developed product had higher protein content compared to the commercial products; on the other hand, fat content decreased. The developed product will be beneficial for consumers who aim to control their weight and build muscle in their bodies for better health. This could have been due to the PPI being a source of protein (65–80%; Meng & Cloutier, 2014). Ferawati et al. (2021) reported that the protein content of the raw material plays an important role in nutritional values and texture formation in meat products. For fat, it was observed that this developed product had a 7.25 times lower amount of fat than the commercial. Therefore, this product could be claimed as low fat according to The public health ministry (1998), which stated that food claimed as low fat must contain fat < 3 g/ 25 g serving size in meat, fish, and shellfish – fried and dry packed product. It seemed that the fat content decreased when the level of PPI increased. According to Chen et al. (2021), the reported fat content of 0.27 ± 0.01 g/100g (dry basis) falls within the lower end of the range, indicating a relatively low-fat content. In addition, the developed product also contained 77.40 g of carbohydrates and 6.76 g of dietary fiber per 100 g. Based on the sodium analysis, the developed product contained 521.54 mg/100 g, which was 1.47 times lower than that of the commercially available product. The study findings reveal that the developed plant-based minced meatballs offer health benefits to consumers.

4. Conclusion

PPI has gained considerable interest in the agri-food market as a plant protein source, driven by consumer perceptions of plant-based products as ethical, healthy, and environmentally friendly. In this study, we evaluated the feasibility of producing plant-based minced meatballs with PPI as a raw material. PPI was utilized to enhance the plant-based minced meatball made from oyster mushrooms. The increase in the PPI ratio resulted in higher protein content in plant-based minced meatballs while decreasing moisture, lightness, and redness. However, the addition of PPI contributed to texture qualities (hardness, cohesiveness, springiness, and chewiness) and overall liking scores that closely resembled those of the well-controlled sample. PPI protein can promote the formation of a stable and elastic network structure in plant-based

Table 3. Texture parameters of the plant-based minced meatball with different pea protein isolate levels

Treatments	Hardness (N)	Adhesiveness (N x sec)	Cohesiveness	Springiness (cm)	Chewiness (N × cm)
Control	29.10 ± 5.73[a]	1.501.00[c]	0.300.04[a]	0.400.10[ab]	3.530.90[a]
5% PPI	15.633.52[c]	0.740.63[a]	0.300.04[a]	0.410.10[a]	2.000.40[b]
10% PPI	15.892.10[c]	0.200.10[b]	0.220.02[b]	0.300.05[b]	1.000.20[c]
15% PPI	21.73 2.66[b]	0.400.20[ab]	0.300.03[a]	0.430.08[a]	2.820.80[a]
20% PPI	22.422.40[b]	0.300.30[c]	0.200.05[b]	0.400.10[ab]	1.510.70[b]

PPI = pea protein isolate; Control = the commercially available plant-based minced meatball
Mean ± SD with different lowercase superscripts in each column are significantly (p<0.05) different

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Table 4. Sensory liking of the plant-based minced meatball with different pea protein isolate levels

Treatments	Appearance^{ns}	Color^{ns}	Odor^{ns}	Taste^{ns}	Texture^{ns}	Overall liking
Control	7.301.23	7.101.24	7.13 1.40	7.131.30	6.901.20	7.40 1.30^{a}
5% PPI	7.001.30	6.901.12	7.001.23	6.701.40	6.931.14	7.231.30^{a}
10% PPI	7.001.50	6.631.20	6.701.23	6.831.34	6.601.30	7.191.33^{a}
15% PPI	6.901.40	6.731.22	6.631.60	6.531.50	6.601.30	6.501.30^{b}
20% PPI	6.701.50	6.601.40	6.501.40	6.431.33	6.601.33	6.501.30^{b}

PPI = pea protein isolate; Control = the commercially available plant-based minced meatball
Mean ± SD with different lowercase superscripts in each column are significantly (p<0.05) different; ns = not significantly (p>0.05) different

Table 5. Nutritional values of developed plant-based minced meatballs and commercially available plant-based minced meatball based on 100 g

Nutritional values	Developed plant-based minced meatballs	The commercially available plant-based minced meatball
Moisture (g)	56.32 ± 0.40^{b}	67.90 ± 0.84^{a}
Total energy (kcal)	371.48 ± 0.04^{b}	429.07 ± 0.17^{a}
Protein (g)	10.79 ± 0.03^{a}	8.77 ± 0.02^{b}
Total fat (g)	2.08 ± 0.01^{b}	15.09 ± 0.08^{a}
Carbohydrate (g)	77.40 ± 0.05^{a}	64.56 ± 0.07^{b}
Dietary fiber (g)	6.76 ± 0.03^{a}	5.04 ± 0.08^{b}
Ash (g)	2.97 ± 0.01^{b}	6.55 ± 0.04^{b}
Sodium (mg)	521.54 ± 2.26^{b}	765.45 ± 3.12^{a}

Mean ± SD with different lowercase superscripts in each column are significantly (p<0.05)

meat products. Especially for 10% PPI, it was the most suitable for producing plant-based minced meatball products. Furthermore, our findings indicate that the addition of PPI has a positive impact on the nutritional values of plant-based minced meatballs, especially with higher protein content and lower energy and fat content compared to commercially available plant-based minced meatballs. This could potentially reduce the risk of non-communicable diseases (NCDs).

Therefore, this study demonstrates that PPI can be considered a desirable ingredient for the development of novel foods that offer health benefits to consumers. Further studies are needed to determine the effect of PPI on the microstructure, investigate the mechanisms, and provide more opportunities to expand the utilization of PPI in plant-based meat products.

Ethics statements

This study was approved by the Ethics Committee of Suan Sunandha Rajabhat University (Approval no. COE. 1-004/2023).

Conflict of interest

The authors declare no conflict of interest.

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