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Effect of tapioca starch on physicochemical and nutritional qualities of mung bean protein-based burger patties

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Abstract

This study determined how tapioca starch influenced the physicochemical properties, cooking qualities, dietary fiber, and sensory evaluation of mung bean protein-based burger patties. The experiment used four levels of tapioca starch (0%, 1%, 2%, and 3%) added by calculating the total mass. The results showed that tapioca starch significantly (p <0.05) increased burger patties' carbohydrates, calories, hardness, springiness, and dietary fiber but reduced the moisture, protein, and fat. Applying 3% tapioca starch enhanced the carbohydrates, calories, hardness, springiness, dietary fiber, and cooking yield by 19.14% wb, 143.55 kcal, 3.14 N, 1.84 mm, 5.93%, 84.49% respectively. Still, it decreased cooking loss, moisture, protein, and fat content by 15.51%, 67.11% wb, 8.01% wb, and 3.89% wb, respectively. Applying 2% tapioca starch has also enhanced the carbohydrates, calories, hardness, and springiness, lowered cooking loss, and improved cooking yield. Moreover, it retained brightness (L^*) and yellowness (b^*) better than 3% tapioca starch applications, 44.52 and 7.6, respectively. Interestingly, for the burger patty containing 2% tapioca starch, the panelists gave the highest 9-point hedonic scores for appearance and flavor, 6.90 and 6.73, respectively. This indicates that, compared to other treatments and commercial products, the panelists moderately preferred the appearance and flavor. So, 2% tapioca starch bound the ingredients of mung bean protein-based burger patties. Further study is required to improve the quality of these plant-based burger patties.

Keywords: Burger patties, Meat analogs, Mung bean protein, Plant-based, Tapioca starch

1. Introduction

Human's awareness of health and the environmental impact of animal protein intake has changed the trend toward a plant-based protein diet [1-3]. It has raised world demand for plant-based protein foods, including burger patties as a meat analog. Plant-based protein is cheaper and healthier than animal-based protein [4]. Thus, the creation and use of plant-based protein to replace animal protein have gained popularity [5].

Mung bean is famous as a protein-rich (14.8-32.6%) legume [6] and is native to India. There, it has been planted and consumed for generations [7,8]. It is also rich in vitamins and minerals [6], has low fat (0.7-1.9%), but contains high dietary fiber (18.8-24.5%) [6,8]. Various bioactivities effects, such as angiotensin-converting enzyme (ACE) inhibitory, anti-diabetic, anti-tumor, and antioxidant activity, have been attributed to mung bean extracts [9]. According to Brishti et al. [10], mung bean protein is readily digestible, and its amino acid composition adheres to soy and FAO/WHO protein standards [11], except for insufficient sulfur-containing amino acids (methionine and cysteine). It has adequate essential amino acids, including lysine, comparable to an egg [11]. Mung bean protein isolate (MBPI) has high albumin, globulin, gliadin, and glutelin with human-like patterns. It could be modified into textured vegetable protein, produced as meat analogs and egg substitutes [10,12].

Meat analogs are generally believed as healthy as it is cholesterol-free, have a meat-like texture, and are affordable, like plant-based burger patties [13]. Plant-based meat analogs can be manufactured from plant-based protein, mushrooms, fat or oil, gum, coloring and flavoring additives, and wheat [3,13-15]. Wheat contains gluten, forms strong bonds, and creates meat-like aggregates [5]. However, customers with celiac disease avoid it because it may be allergenic [16]. Thus, gluten-free binding agent options should be affordable, accessible, and safe.

Meat analogs and processed meat were reported to contain tapioca starch. According to Pereira et al. [17], adding tapioca starch to sausages boosted the cooking yield and moisture retention, resulting in a stiffer and more homogeneous gel network structure. Additionally, tapioca starch decreased beef patties' cohesion, hardness, and chewiness levels [18]. Tapioca starch can improve the pH, emulsion stability, cooking yield, and texture score of chicken patties [19]. Tapioca starch can bind and gel material to mimic the texture of meat [18,20].

Tapioca starch has not been applied in manufacturing mung bean protein-based burger patties. Previously, Morbos et al. [21] reported using mung bean flour at five different levels (10, 20, 30, 40, and 50%) to substitute lean meat in burger patty. Meanwhile, this study investigated the effect of adding tapioca starch as a binder agent in the manufacture of plant-based burger patties, without the use of real meat but primarily with extracted mung bean protein. Therefore, this research aimed to study the effect of tapioca starch addition on the physicochemical, color, texture, cooking properties, dietary fiber, and sensory analysis of mung bean protein-based burger patties.

2. Materials and methods

2.1 Raw material

All ingredients for manufacturing burger patties were obtained from a supermarket in Thailand, consisting of peeled mung bean (Raithip brand), fresh button mushroom, instant oatmeal (Quaker™), kidney beans (Tops brand), beetroot, garlic, refined sunflower oil (Naturel brand), coconut oil (Naturel brand), tapioca starch (Five Stars Fish brand), salt, pepper powder, and yeast extract. Chemicals for protein extraction, proximate analysis, and dietary fiber analysis consisted of distilled water, $MgSO_4$ (Thermo Fisher Scientific), pepsin (Merck), pancreatin (Merck), HCl (Merck), NaOH (Merk), phosphate buffer (Cepham Life Sciences), and sodium dodecyl sulfate (Sigma-Aldrich).

2.2 Preparation of fresh mung bean protein

Fresh mung bean protein was precipitated based on a method modified from Ratnaningsih and Songsermpong [22]. After cleaning, the mung beans were soaked overnight. Then, they were re-washed and peeled to remove the beany taste and green color before being grounded. It was ground with tap water (mung bean-to-water ratio = 1:3). The crude fiber was separated through centrifugation at 800 rpm for 20 min and a cloth filter. Here, the mung bean starch was sedimented, and the protein solution was decanted.

Two liters of mung bean protein solution were heated to 80°C before being added with $MgSO_4$ at a concentration of 10 g/L and they were stirred until the protein precipitated. After three cycles of filtering and rinsing to remove the $MgSO_4$ residue from the precipitated protein, the fresh mung bean protein was ready. The moisture content was lowered to around 80% wb by squeezing the fresh protein using a cloth filter (hand squeezing). Before used, the mung bean protein was refrigerated overnight.

2.3 Preparation of mung bean protein-based burger patties

Table 1 Treatment and formulation of mung bean protein-based burger patties added with tapioca starch.

Ingredient	Tapioca starch addition (%)			
	0 (control)	1	2	3
Fresh mung bean protein (g) (80% wb of moisture content)	49.2	49.2	49.2	49.2
Fresh button mushroom (g)	13.7	13.7	13.7	13.7
Instant oatmeal (g)	9.3	9.3	9.3	9.3
Boiled peeled kidney beans (g)	13.7	13.7	13.7	13.7
Grated beetroot (g)	5.5	5.5	5.5	5.5
Garlic (g)	3.3	3.3	3.3	3.3
Sunflower oil (cc)	2.5	2.5	2.5	2.5
Coconut oil (cc)	1.25	1.25	1.25	1.25
Salt (g)	0.85	0.85	0.85	0.85
Pepper powder (g)	0.35	0.35	0.35	0.35
Yeast extract (g)	0.35	0.35	0.35	0.35
Tapioca starch (g)	-	1	2	3

Notes: 0 (control), formula without tapioca starch; 1, formula with 1% tapioca starch; 2, formula with 2% tapioca starch; 3, formula with 3% tapioca starch.

Each ingredient was weighed according to the composition in Table 1. The coconut oil was frozen in the freezer. Garlic, mushrooms, and boiled, peeled kidney beans were chopped and stir-fried in sunflower oil until the vegetables wilted and a scent emerged. Then, the ingredients including oats, fresh mung bean protein, grated beetroot, salt, pepper powder, and yeast extract were blended using a food processor (Robot Coupe C. L. Foods, Thailand). Following this, tapioca starch was added in line with the experimental treatment procedure, and frozen coconut oil was added. After all the ingredients had been mixed well, around 50 g per patty was placed in a circular mold and steamed for five min, removed, and cooled in the freezer (air blast freezer, Toshiba, Thailand) overnight at -18°C.

2.4 Proximate analysis

The Association of Official Analytical Chemists (AOAC)'s procedure was applied to investigate the moisture, ash, protein, fat, and crude fiber contents of the pre-cooked burger patties from mung bean protein isolate in triplicate [23]. The moisture content was evaluated using the oven-drying method according to AOAC method 925.10. The quantity of ash was determined using the dry-ashing procedure (AOAC method 923.03). The Kjeldahl method was used to determine the total nitrogen content of the burger patties, and a conversion factor of 6.25 was applied to compute the protein level according to AOAC method 991.20. The fat percentage was measured using Soxhlet methods based on the protocol in AOAC method 922.06. The crude fiber was determined gravimetrically as the residue remaining after acid and alkaline digestions in compliance with the procedure in AOAC method 978.10. The carbohydrate content was measured using different methods, with a reduction of 100 by the total percentage of moisture, ash, protein, fat, and crude fiber, and expressed in percent. Total calories were calculated by multiplying the protein, carbohydrates, and fat contents by 4, 4, and 9 kilocalories/g, respectively [24]. The values were expressed in kilocalories per 100 g.

2.5 Color analysis

The surface color of the pre-cooked mung bean protein-based burger patties was determined using a portable Minolta CR-410 chromameter (Minolta Co., Japan) based on the CIELAB color system and D65 illumination. Using the methods of Jia et al. [25], the L^*, a^*, and b^* values were recorded. The lightness was measured using L^* values (0 for darkness to 100 for whiteness). The a^* values indicated the amount of redness by positive values and the level of greenness by negative values. In contrast, the b^* values represented the level of yellowness by positive values and the level of blueness by negative values.

2.6 Texture analysis

The texture profile of the pre-cooked mung bean protein-based burger patties was analyzed using a texture analyzer (TexturePro CT V1.2, Stable Micro Systems, UK) using the modified methods of Samard et al. [26]. The profile of the material texture was investigated using a 25 mm cylindrical probe in a two-cycle compression test. The samples were crushed twice to 30% of their original thickness at a rate of 1 mm/sec, triggering a load of 5 kg. Hardness, adhesiveness, cohesiveness, springiness, and chewiness values were recorded.

2.7 Cooking properties

The pre-cooked burger patties were defrosted in the 20°C refrigerator overnight. Then, it was cooked in a pan fryer (non-stick frying pan, Monotaru, Japan) that was preheated to 140°C. Sunflower oil (5 mL) was used to lubricate the non-stick cooking surface before placing the samples on the pan. Two patties were cooked and flipped every 1 min. Burger patties were removed for testing after 4 min of cooking. Three replications were performed.

2.7.1 Cooking loss

The cooking loss of the burger patties was assessed using the modified procedure of Samard et al. [26] as below:

$$\text{Cooking loss (\%)} = \frac{\text{Raw patty weight (g)} - \text{Cook patty weight (g)}}{\text{Raw patty weight (g)}} \times 100 \quad (1)$$

2.7.2 Cooking yield

The cooking yield was estimated using the following Equation [26]:

$$\text{Cooking yield (\%)} = \frac{\text{Cooked patty weight (g)}}{\text{Raw patty weight (g)}} \times 100 \quad (2)$$

2.7.3 Moisture retention

Moisture retention was determined using following method of Samard et al. [26]. The moisture content of the cooked patty was evaluated by drying each sample at 105°C until reaching a constant weight [23].

$$\text{Moisture retention (\%)} = \frac{\text{Cooking yield (\%)} \times \text{Moisture of cooked patty (\%)}}{100} \quad (3)$$

2.8 Dietary fiber analysis

Dietary fiber was evaluated using the alimentary digestive enzymes pepsin and pancreatin [27]. After mixed, isoamyl alcohol and thymol crystals were added to make up 1 L of suspension. Then, 50 mL of the starch solution, 50 mL of 0.2 N HCl, and 100 mg of pepsin were pipetted into a 250 mL beaker. After mixed, the preparation was left for 18 hours at 40℃. After pepsin digestion, 4 N NaOH and 50 cc pH 6.8 phosphate buffer were added to neutralize the mixture. Sodium dodecyl sulfate and pancreatin were added and stirred for 1 h at 40℃. After digestion, 4 N HCl was used to lower the pH to 4-5, followed by two times of centrifugation at 3,000 rpm for 30 min. A 15 mm thick sand 1-G-3 glass filter (Iwaki, Japan) was used to filter the supernatant. The precipitate was rinsed three times using distilled water and then, three times using acetone through a 1-G-3 glass filter. The dietary fiber was dried overnight at 105℃. The dry residue weight represented the dietary fiber content of the sample calculated using Equation (4):

$$\text{Dietary fiber (\%)} = \frac{\text{Weight of cup and sample after analysis and dried} - \text{Weight of the dry cup} - \text{Bla}}{\text{Sample weight}} \times 100 \quad (4)$$

2.9 Sensory evaluation

The mung bean protein-based burger patties were evaluated by 30 untrained panelists who were volunteer graduate students from the Department of Food Science and Technology, Faculty of Agro-Industry, Kasetsart University, Bangkok, Thailand. The samples were kept in the refrigerator overnight to defrost, then shallow fried using pan frying with 5 mL sunflower oil (Naturel brand), flipped every 1 min until golden brown. Then, around $1.5\times1.5\times1.0$ cm^3 of cooked burger patties were served to each panelist. They were asked to evaluate some attributes including appearance, aroma, flavor, texture, and general acceptability based on a 9-point hedonic scale with 9 = extremely like to 1 = extremely dislike.

2.10 Statistical analysis

The study employed a completely randomized design, with various concentrations of tapioca starch (0%, 1%, 2%, and 3%). The effect of the tapioca starch on the mung bean protein-based burger patties was determined using one-way ANOVA with a 95% confidence level. Duncan's new multiple range tests were used after the ANOVA, with significant differences determined at the $p \leq 0.05$ level. Three replications were used for all treatments in the experiment. The results were reported as mean ± SD.

3. Results and discussion

3.1 Effect of tapioca starch addition on proximate compositions of pre-cooked plant-based burger patties

Tapioca starch was added to the plant-based burger patties as a binder ingredient, to improve product stability [14]. This ingredient improves the interaction between all ingredients, such as protein, fat, and water components to be incorporated in the plant-based burger patties processing systems.

As shown in Table 2, tapioca starch altered the burger patties' moisture, protein, fat, carbohydrate, and calorie ($p \leq 0.05$) but had no impact on the ash. Tapioca starch at 1-3% lowered moisture from 70.0% wb to 67.11-67.97% wb. There were no significant differences in moisture contents after the addition of 1%, 2%, or 3% tapioca starch. It indicated that water had been absorbed by tapioca starch during the 5 min of steaming processes at 100°C. In the steaming process, the heated starch granules absorbed water and expanded [29]. As the temperature and water absorption increased, the starch granules were broken through disruption of their chain organization, and the starch was gelatinized [29]. It bound all ingredients and formed the burger patties. After steaming, the burger patties were frozen at -18°C to solidify the processed product. However, retrogradation happened during freezing processes and caused syneresis (the release of water from the patties). The retrogradation involved the ordered chains being re-associated via molecular interactions and hydrogen bonds when the gelatinized system was cooled [30]. The starch chains were re-organized, and the water molecules were expelled from the system as a consequence of the re-crystallization process [30]. In addition, when ice crystals formed, binding properties lowered so that more water was released after thawing pre-cooked burger patties [37].

The protein content decreased from 9.75% wb to 8.01% wb when 3% tapioca starch was added (Table 2). The addition of 2% or 3% tapioca starch shows no difference due to the low protein content the tapioca starch has (0.13-0.27%) [31]. A decrease in the protein content of plant-based burger patties due to the binder ingredient application should be avoided in developing plant-based burger patties products because it challenges it to compete with animal-based protein processed products. Animal-based protein products, such as beef patties, meatballs, and nuggets, contain 15 to 26% protein [14]. Consequently, adding tapioca starch as a binder agent in the raw materials lowered the protein content. Tapioca starch might bind and glue all ingredients, making up a starch-protein matrix in the burger patties systems. So, the proportion of protein per whole dry matter might decrease. In this study, the burger patties have lower protein content than McDonald's ground beef patty (20.3%) and the commercial plant-based burger patties manufactured by Beyond Burger (17.7%) and Impossible Burger (16.8%) [14]. It is related to the protein sources from the burger patties in this study including mung bean protein, kidney bean, instant oat, and mushroom which contain relatively lower protein than ground beef, nor soy/pea protein used by commercial burger patties. So, further research was still required to improve the protein content of the mung bean protein-based burger patties.

Table 2 Moisture, ash, protein, fat, carbohydrate, and calorie contents of pre-cooked mung bean protein-based burger patties added with tapioca starch.

Tapioca starch addition (%)	Moisture (%, wb)	Ash (%, wb)	Protein (%, wb)	Fat (%, wb)	Crude fiber (%, wb)	Carbohydrate (%, wb)	Calories (kcal)
0	70.00±0.95^{a}	1.02±0.09^{a}	9.75±1.08^{a}	4.52±0.04^{a}	1.25±0.15^{a}	13.58±1.05^{c}	133.47±3.87^{b}
1	67.97±2.57^{b}	1.01±0.10^{a}	9.73±0.67^{a}	4.20±0.69^{a}	1.02±0.31^{ab}	16.15±1.40^{b}	141.31±4.35^{a}
2	67.86±1.29^{b}	1.04±0.07^{a}	8.63±1.23^{ab}	3.99±0.72^{ab}	0.93±0.25^{b}	17.52±2.51^{ab}	140.75±4.35^{a}
3	67.11±1.18^{b}	1.00±0.18^{a}	8.01±0.81^{b}	3.82±0.42^{b}	0.88±0.33^{b}	19.14±0.37^{a}	143.55±0.64^{a}

Notes: values (mean±SD) in the same column with different lowercase superscripts ($^{a, b, c}$) are significantly ($p \leq 0.05$) different.

The addition of tapioca starch as binder agent had no significant effect on the fat content of the burger patties, except for the 3% tapioca starch addition. The fat content reduced from 4.52% wb to 3.82% wb after 3% tapioca starch had been added (Table 2). There was no significant difference in the fat contents between the 2% and 3% tapioca starch additions. It might be caused by the water holding capacity of the pre-cooked product during steaming, which increased every time the tapioca starch concentrations increased and reduction of the oil holding capacity of the pre-cooked products. In addition, tapioca starch had a very low fat content in the range 0.22-0.37% [31], so the addition of tapioca starch merely increased the total dry matter and did not raise the fat content. The fat content ranged from 3.82 to 4.52% wb in the current study, mainly coming from the sunflower oil and the coconut oil added into the ingredients. These fat content were lower than for the McDonald's beef patty (20.0%), Tyson homestyle beef patty (16.4%), and commercial plant-based patties of Beyond Burger (15.9%), and Impossible Burger (12.4%) [14]. It is influenced by the volume of oil in the ingredients.

The crude fiber content tended to decline when tapioca starch was added, from 1.25% wb to 0.93% and 0.88% wb with 2% and 3% tapioca starch additions, respectively (Table 2). There were no significant differences in the crude fiber contents among the samples after the addition of 1%, 2%, or 3% tapioca starch. It might be due to the water holding capacity of the pre-cooked product during steaming that increased along increasing tapioca starch concentrations and reduced the oil holding capacity of the pre-cooked products. Tapioca starch added as a binder agent bound all ingredients during the steaming process and formed the products. It might also associated with the low crude fiber content of the tapioca starch in the range 0.20-0.23% [32], enhancing the total dry matter in the burger patties, without affecting the crude fiber content. With increasing amounts of tapioca starch, the percentage of crude fiber to total dry matter declined. In contrast to actual meat, which has zero fiber [14], the plant-based burger patties contained fiber. The crude fiber was in the range of 0.88-1.25% wb. The presence of crude fiber is an additional value for the meat substitutes. Crude fiber, an insoluble fiber composed of plant cell wall components like cellulose, pentosan, and lignin, may support gut flora.

Tapioca starch addition as a binder agent not only bound and glued all ingredients in the burger patties product all together, improved the interaction between ingredients, and formed a stable structure, but also increased the carbohydrate content (Table 2) from 13.58% wb to 16.15%, 17.52%, and 19.14% after adding 1%, 2%, and 3% tapioca starch additions, respectively. There was no significant difference in the carbohydrate contents of meat after applied with the 2% or 3% tapioca starch applications. It is because tapioca starch is a complex carbohydrate [20]. These findings were comparable with the commercial plant-based burger patties of Morningstar Farms (12.5%) [14].

Adding the 3% tapioca starch significantly enhanced the calories in the burger patties from 133.47 kcal to 143.55 kcal. There were no significant differences in the energy values among the samples after being added with 1%, 2%, or 3% tapioca starch, indicating that it is a complex carbohydrate and a calory-producing substance [20]. The finding energy value per 100 g serving of burger patties was 133.47-143.55 kcal that were lower than those for commercial plant-based burger patties from Beyond Burger (221.24 kcal) and Impossible Burger (212.39 kcal) [14]. It was likely related to the fat content of the Beyond Burger and Impossible Burger, which produced higher calorie.

3.2 Effect of tapioca starch addition on color parameters of pre-cooked plant-based burger patties

As demonstrated in Figure 1, the inclusion of tapioca starch had a significant impact on the lightness (L^*), redness (a^*), and yellowness (b^*) of burger patties. The lightness level tended to be lower with increasing tapioca starch addition (3%), from 46.42 to 41.37. There were no significant differences in the lightness levels among the control and 1% and 2% tapioca starch additions. It demonstrated that adding 3% tapioca starch declined the lightness level, which could be attributed to the heat treatment during the steaming process at 100°C, which induced gelatinization of starch and denaturation of protein. Gelatinization was the transformation of organized semi-crystalline granules of starch into an amorphous structure inhibiting the Maltese cross formation [29]. Typically, gelatinization of starch was accomplished by heating the starch in water. The amorphous starch quickly absorbs water and becomes a viscous paste after gelatinization [29]. Starch would create a gel when cooled, that decreases the lightness, mirroring the fish balls added with tapioca starch [38]. Furthermore, the cooling and freezing at -18ºC after steaming induced retrogradation of the starch and denaturation of the protein.

Similarly, the redness (a^*) and yellowness (b^*) levels declined from 16.46 and 7.98 to 13.87 and 6.80, respectively. There was no significant difference in the redness level (a^*) between the control and 1% tapioca starch addition, nor between the 1% and 2% tapioca starch addition. The red coloration of burger patties could have been associated with the red color of the grated beetroot and kidney beans. There were no significant differences in the yellowness levels (b^*) of the control and the 1% and 2% tapioca starch additions. The yellowish coloration of the burger patties could be believed to be caused by the yellow color of the mung bean protein ingredient that affected the quality of the final burger patties [15].

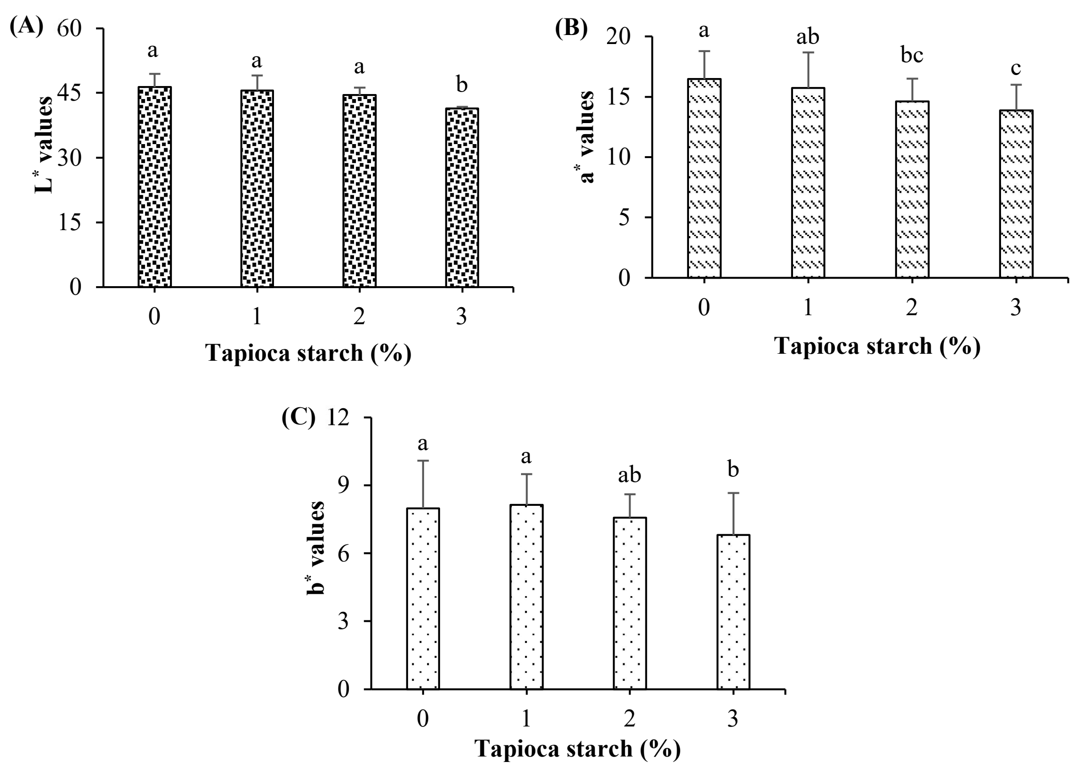

Figure 1 Color of pre-cooked mung bean protein-based burger patties added with tapioca starch at parameters (A) lightness, (B) redness, and (C) yellowness.

The color changes because of the Maillard reaction between the reducing sugar and the amino acids in the burger patties. The Maillard reaction is a fundamental process influencing food products' color, flavor, and aroma, imparting distinctive taste, smell, and color. The Maillard reaction, which is the interaction between the amino group of free amino acids, peptides, and proteins and the carbonyl group of reducing sugars, is primarily responsible for brown coloring during the steaming process. Additionally, grated beetroot may contain enzymes, such as polyphenol oxidase, which is suspected to stimulate the browning of burger patties [15]. These findings were consistent with the impact of tapioca starch inclusion in meat products, such as frankfurters, surimi-beef gel, and duck sausages [18].

3.3 Effect of tapioca starch on texture parameters of pre-cooked plant-based burger patties

Texture profile analysis simulates chewing by using a twofold compression test and derives sensory relevance from the resultant force-time curves. The presence of tapioca starch significantly affected the hardness, adhesiveness, and springiness, as shown in Table 3, but had no significant effect on cohesiveness and chewiness. After adding 3% tapioca starch, the hardness increased from 2.03±0.55 N to 3.14±1.20 N. There were no significant differences in hardness values between the control, 1%, and 2% tapioca starch additions or between 1%, 2%, and 3% of tapioca addition. Hardness represented the most significant initial compression force, which measured the compressive strength of the burger patties [33]. Adding more tapioca starch significantly enhanced the hardness of the burger patties. This could be attributed to the increasing amount of amylose in the tapioca starch because the amylose content of the system had an important role in determining its hardness [34].

The adhesiveness increased from 0.09±0.03 to 0.30±0.13. There were no significant differences in the adhesiveness scores among the control, 1%, and 2% tapioca starch additions. Adhesiveness was necessary to overcome the attractive forces between the surface of the product and the surface of the material with which the product comes in contact [33]. Springiness, the rate of a product to return to its original position after deformation of force was exerted [33], also increased from 1.69±0.28 to 1.84±0.19. There was no significant difference in springiness between 1%, 2%, and 3% tapioca starch additions. Springiness represents the burger patties' elasticity [33], which increased after the application of tapioca starch.

Hardness, adhesiveness, and springiness influenced the panelist's preference scores. Adhesiveness was related to the level of stickiness of the product, and springiness was related to product elasticity. A more preferable plant-based burger patties should be less sticky but more elastic, which should resemble the hardness of real meat patties.

Table 3 Texture parameter of pre-cooked mung bean protein-based burger patties added with tapioca starch.

Tapioca starch addition (%)	Hardness (N)	Adhesiveness (mJ)	Cohesiveness	Springiness (mm)	Chewiness (mJ)
0	2.03±0.55^{b}	0.09±0.03^{b}	0.37±0.07^{a}	1.69±0.28^{b}	1.82±1.57^{a}
1	2.59±0.72^{ab}	0.10±0.03^{b}	0.40±0.04^{a}	1.89±0.20^{a}	2.24±0.91^{a}
2	2.85±0.88^{ab}	0.13±0.02^{b}	0.40±0.14^{a}	1.87±0.16^{ab}	2.38±1.01^{a}
3	3.14±1.20^{a}	0.30±0.13^{a}	0.37±0.05^{a}	1.84±0.19^{ab}	1.43±0.71^{a}

Notes: values (mean±SD) in the same column with different lowercase superscripts ($^{a, b}$) are significantly ($p \leq 0.05$) different.

3.4 Effect of tapioca starch addition on cooking properties of cooked plant-based burger patties

Cooking loss indicates resilience to breakdown during cooking, while cooking yield indicates integrity, indicating that burger patties manufactured from mung bean protein have good quality. Table 4 shows that adding 1%, 2%, or 3% tapioca starch to burger patties lowered cooking loss from 19.07% to 18.64%, 17.05%, and 15.51%, respectively. There were no significant differences in cooking losses between the control and the addition of 1% and 2% tapioca starch, nor between 2% and 3% tapioca starch addition. In contrast, the cooking yield increased from 80.93% with no tapioca starch to 81.36%, 82.95%, and 84.49% with the additions of 1%, 2%, and 3% tapioca starch, respectively. There were no significant differences in the cooking yields between the control and the additions of 1%, and 2% tapioca starch, nor between 2% and 3%. These results demonstrated that starch was a minor element among other components, but it often served as a filler and may boost the cooking yield [20]. However, in this study, adding 1-3 % tapioca starch had no significant effect on the moisture retention of burger patties. It is possibly because the molecule water is released in the retrogradation process during freezing. Further study is still required for improvement, including considering hydrocolloid application to maintain moisture retention.

The burger patty developed a more robust protein-starch bound during the steaming process. Gelatinization occurred in the starch during the steaming process, which broke down the starch granules and generated a gel that was ultimately linked to forming a protein-starch bound in the burger patty. The protein-starch bound remained intact after freezing, thawing, and frying; hence, including starch decreased the cooking loss and boosted the cooking yield in the burger patty [20,35].

3.5 Effect of tapioca starch addition on dietary fiber of pre-cooked plant-based burger patties

Table 4 shows that adding 1-3% tapioca starch to burger patties significantly increased dietary fiber from 4.39% to 5.47-5.93%. These results seem to be inconsistent with the crude fiber of pre-cooked burger patties in Table 2. It is probably because more accurate measurements of dietary fiber were used to describe the complex mixture of substances in plant-based burger patties, which were not fully digested by human enzymes in the small intestine, rather than crude fiber measurements that represented the indigestive portion of plant foods, primarily cellulose and lignin. In crude fiber analysis, burger patties samples were treated with a series of chemical reagents to remove components that were soluble in weak acids and bases, whereas in dietary fiber analysis, all indigestible components that contribute to overall dietary fiber, including soluble fiber (e.g. pectins and gums), and insoluble fiber (e.g. cellulose) were measured. The burger patties with and without tapioca starch contained dietary fiber from 9.3 g of instant oats per 100 g of raw materials. Another study found that β-glucan in oats is a dietary fiber [36]. Tapioca starch significantly increased total dietary fiber in burger patties. The initial total dietary fiber of tapioca starch used in this experiment was 0.44 g/100 g samples, before the cooking process. Total dietary fiber in pre-cooked burger patties products with the addition of tapioca starch increased due to gelatinization and amylose leaching, followed by retrogradation processes. This happens because the starch granules in the burger patties mixture ingredients absorb water and are swollen during steaming, known as gelatinization. The heat during steaming lost the organized structure of the starch granules, and the starch molecules dispersed in the water, forming a paste-like consistency. During the gelatinization process, amylose molecules, which were linear chains of glucose units, leached out from the starch granules and became solubilized in the cooking water. This thickened the cooking mixtures. As the steamed starch in the burger patties cooled, the starch molecules started to re-associate and re-organize. Amylose molecules, previously dispersed in the cooking water, began to bond the hydrogen with amylopectin molecules. This re-association led to a retrogradation process. During retrogradation, the re-association of amylose and amylopectin molecules started to form ordered crystalline structures. These structures were more resistant to digestion by enzymes in the small intestine than the original amorphous starch structure. This resistance to digestion contributed to the dietary fiber content in plant-based burger patties. Heating and cooling tapioca starch formed dietary fiber due to retrogradation processes [27]. Retrograded starch could be a dietary fiber source [27] as resistant starch type 3. Retrogradation occurs when gelatinized starch is cooled or frozen for several hours or days. In this study, tapioca starch in the burger patties was gelatinized during steaming and retrograded during cooling and freezing. In addition, freezing and thawing processes also formed dietary fiber. Freezing and subsequent thawing of starchy foods could lead the retrogradation and increase the resistant starch content. Plant-based burger patties with dietary fiber could add the value of the products.

Table 4 Cooking properties of cooked and dietary fiber of pre-cooked mung bean protein-based burger patties added with tapioca starch.

Tapioca starch addition (%)	Cooking properties			Dietary fiber (%)
	Cooking loss (%)	Cooking yield (%)	Moisture retention (%)	
0	$19.07{\pm}1.93^{a}$	$80.93{\pm}1.92^{b}$	$35.18{\pm}2.78^{a}$	$4.39{\pm}1.36^{b}$
1	$18.64{\pm}4.17^{a}$	$81.36{\pm}4.17^{b}$	$32.54{\pm}2.93^{a}$	$5.47{\pm}0.75^{a}$
2	$17.05{\pm}1.52^{ab}$	$82.95{\pm}1.52^{ab}$	$33.12{\pm}3.73^{a}$	$5.73{\pm}0.72^{a}$
3	$15.51{\pm}3.91^{b}$	$84.49{\pm}3.91^{a}$	$34.54{\pm}6.83^{a}$	$5.93{\pm}0.71^{a}$

Notes: values (mean±SD) in the same column with different lowercase superscripts ($^{a, b}$) are significantly ($p \leq 0.05$) different.

3.6 Sensory evaluation of cooked plant-based burger patties

Mung bean protein-based burger patties were investigated for panelists' responses. Samples were compared to commercial plant-based patties from the “Meat Zero” brand (Charoen Pokphand Foods PLC, Thailand). Table 5 shows the sensory liking of mung bean protein-based burger patties for control, 1%, 2%, 3%, and commercial products. Burger patties with 2% tapioca starch got the highest score (6.90) (almost moderately like). In contrast, burger patties containing 3% tapioca starch got the lowest score (5.70), (neither like nor dislike to slightly like) for appearance. 1%, 2% tapioca starch, and commercial products had the same appearance score. Surprisingly, burger patties with 2% tapioca starch got a score of 6.73 (almost moderately like) for flavor attributes, higher than commercial products which scored 5.43 (neither like nor dislike to slight like). It shows that the flavor of mung bean protein-based burger patties was preferred by the panelists and has the potential to be developed into commercial products. The texture, aroma, and overall acceptance of all treatment was not significantly different. A further development is required to eliminate the beany odor that dominates legume-based foods, which may impact audience approval.

Table 5 Sensory evaluation score of cooked mung bean protein-based burger patties added with tapioca starch.

Tapioca starch addition (%)	Appearance	Flavor	Texture	Odor	Overall acceptance
0 (control)	6.00±1.55^{bc}	5.53±1.72^{b}	5.00±1.88^{a}	6.57±1.43^{a}	5.63±1.47^{a}
1	5.97±2.14^{abc}	5.97±1.54^{ab}	5.70±1.80^{a}	6.73±1.26^{a}	6.03±1.73^{a}
2	6.90±1.16^{a}	6.73±1.36^{a}	5.93±1.74^{a}	7.53±1.22^{a}	6.77±1.22^{a}
3	5.70±1.66^{c}	5.70±1.39^{b}	5.47±1.63^{a}	6.63±1.33^{a}	5.70±1.42^{a}
Commercial	6.83±1.70^{ab}	5.43±1.25^{b}	6.33±1.97^{a}	5.50±2.27^{a}	5.67±2.14^{a}

Notes: values (mean±SD) in the same column with different lowercase superscripts ($^{a, b, c}$) are significantly ($p \leq 0.05$) different.

4. Conclusion

Tapioca starch as a binding agent in plant-based burger patties production which is primarily mung bean protein-based can bound all ingredients together, formed the product, and improve interaction between all ingredients. Tapioca starch significantly increases the dietary fiber content of plant-based burger patties, while reducing fat content, which is good for human health. It improves the plant-based burger patties' texture by increasing the burger patties's hardness, chewiness, and springiness. It also lowers the cooking loss and increases the cooking yield without affecting moisture retention on the cooked burger patties. Panelists scored burger patties with 2% tapioca starch the highest on appearance and flavor. Therefore, tapioca starch at 2% can be utilized as binder agent in plant-based burger patties production.

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