



# Effect of Hydrocolloids and Tapioca Starch on Physicochemical and Nutritional Characteristics of Mung Bean Protein-Based Patties

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**Abstract**— Hydrocolloids are essential ingredients to enhance the quality of plant-based meat analogs due to their affinity for binding water and gel formation. Developing plant-based meat analogs remains a challenge, as they still struggle to mimic the texture, juiciness, and structure of real meat. This research aimed to study the influence of hydrocolloids and tapioca starch application on the physicochemical, dietary fiber, cooking qualities, and sensory evaluation of plant-based burger patties. The experiment used four treatments of hydrocolloids (without hydrocolloid (WH), and xanthan gum (XG), guar gum (GG), and carboxymethyl cellulose (CMC) at 0.5% of the total weight), combined with tapioca starch (0% and 2%) application. The results showed that the hydrocolloid application significantly enhanced moisture, ash, protein, carbohydrate, dietary fiber, lightness, yellowness, and hardness. At the same time, tapioca starch increases carbohydrates, calories, dietary fiber, hardness, and springiness. Tapioca starch decreased the cooking loss and water retention but increased cooking yield. A combination of 0.5% XG or 0.5% GG with 2% tapioca starch application showed no significant differences in appearance, flavor, or overall acceptability compared with commercial products, which are potentially developed for commercial use.

**Keywords**— Burger patties; hydrocolloids; mung bean; plant-based protein; tapioca starch

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## I. INTRODUCTION

Nowadays, demand for alternative proteins, especially plant-based sources, is increasing. Various factors are the cause, including rapid population growth, climate change and global warming, and shortages of food, fresh water, and fertile land [1]. In addition, plant-based proteins are considered healthier and cheaper [2] than animal proteins, which, if consumed excessively, can cause health problems [3]. Livestock and meat production are considered to contribute to greenhouse gas pollution [1], [4], and the decline in the quality of fresh water and fertile land. In addition, the spread of diseases from animals to humans has also raised public awareness about the impact of animal protein consumption. Therefore, the development of meat analogs made from plant proteins is considered a possible solution. Plant-based meat analogs are meat analogs made from

plant proteins that are made to resemble real meat. Although they still face various challenges in their development, such as texture, juiciness, and meat structure, as well as nutritional content, meat analogs have gained popularity recently [5]. Previous research reported that the texture and sensory qualities of meat analogs can be improved by adding hydrocolloids and starch [6]. Legume proteins (flour, concentrate, or isolate), usually soy protein, can be used to produce meat analogues. Their functional qualities (such as water and oil absorption and emulsification capacity) allow them to be produced as meat alternatives [2]. In addition to soybeans, other legumes such as mung beans can also be developed as meat analogues.

Mung bean is well known as a protein-rich (14.8–32.6%) legume [7] and is native to India, where it has been cultivated

and consumed for generations, according to historical records [8, 9]. It is also valued for its vitamin and mineral richness [7], its low fat content (0.7–1.9%), and its high dietary fiber content (18.8–24.5%) [7],[9]. Various biological effects, such as angiotensin-converting enzyme (ACE) inhibitory, anti-diabetic, anti-tumor, and antioxidant activity, have been attributed to mung bean extracts [10]. According to Brishti, Zarei [11], mung bean protein is readily digestible, and its amino acid composition adheres to soy and FAO/WHO protein standards [12]. It contains adequate amounts of all essential amino acids, including lysine, for which the content is comparable to that of an egg [12]. High albumin with human-like patterns, globulin, gliadin, and glutelin are predominant in mung bean protein isolate (MBPI) [13]. MBPI can be processed into textured plant-based protein, which has the potential to be developed into a meat analog [11]. Schlangen, Taghian Dinani [14] stated that MBPI is an excellent plant-based material for producing meat analogs and egg substitutes.

In meat analog formulations, hydrocolloids can enhance quality by acting as thickeners or gelling agents. Hydrocolloids are water-soluble polysaccharides that improve texture by cross-linking with protein filaments [6]. Xanthan gum (XG) is a common anionic hydrocolloid with a rigid backbone of  $\beta$ -glucan and a charged hydrophilic trisaccharide side chain [15]. It is frequently utilized due to its excellent emulsifying stability and gel-thickening properties [16]. Guar gum (GG) is a plant-derived, hydrophilic polysaccharide extracted from the embryos of guar seeds. It is a galactomannan consisting of a (1 $\rightarrow$ 4)-linked- $\beta$ -D-mannopyranose backbone with branches from their positions linked to  $\alpha$ -D-galactose. It is an economical thickener and stabilizer. Carboxymethyl cellulose (CMC) is a cellulose derivative formed by its reaction with alkali and chloroacetic acid. The structure is based on the  $\beta$ (1 $\rightarrow$ 4)-D-glucopyranose polymer of cellulose. It is a common, negatively charged hydrocolloid widely used in the food sector due to its high water solubility [17].

Hydrocolloid applications have been reported in meat analogs and processed meat products in previous studies. Starch, gum, and fiber were used in meat products to enhance functional characteristics, compensate for reduced fat and salt, and improve freeze/thaw stability [18]. Sarteshnizi, Hosseini [18] added hydrocolloids to nugget batter to prevent oil absorption and promote moisture retention during frying. As a binding agent, hydrocolloid improved the texture of mushroom sausage, water loss, and emulsion stability [19]. Nanta, Skolpap [20] reported that adding hydrocolloids enhanced the viscosity and plasticity of meat analogs relative to the control sample. Applying xanthan gum and guar gum potentially replaces gluten in soy protein-based meat substitutes. Dinani, Broekema [6] reported that adding xanthan gum, carboxymethyl cellulose, and guar gum strengthened the structure and fiber growth of pea protein-wheat gluten meat analogs.

Starch is a vital natural biopolymer utilized in the food and polymer industries. Tapioca starch was claimed to be used in

meat analogs and processed meat products. The application of tapioca starch to cooked sausages increased cooking yield and moisture retention, resulting in a more rigid and homogenous gel network structure [21]. It also lowered the cohesiveness, hardness, and chewiness of beef patties [22]. The application of tapioca starch to chicken patties increased the cooking yield and texture score [23]. Tapioca starch was also reported as a potential binder and gelling agent to simulate the texture of meat products [22, 24]. However, no studies have reported the effect of hydrocolloids and tapioca starch on mung bean protein-based meat analogues.

The objective of this study was to evaluate the effect of hydrocolloids (without hydrocolloids, XG, GG, CMC at 0.5%), and tapioca starch (0% and 2%) application on the physicochemical and nutritional qualities of plant-based burger patties made from mung bean protein formulation.

## II. MATERIAL AND METHODS

### A. Raw Materials

All raw materials used to produce plant-based burger patties were purchased from a store in Thailand.

Main ingredients, including mung bean (Raithip), button mushroom (Tops), instant oatmeal (Quaker<sup>TM</sup>), kidney beans (Tops), beetroot (Tops), garlic (Tops), refined sunflower oil (Naturel), coconut oil (Naturel), iodine refined salt (Prung Thip), pepper powder, and yeast extract (Organic seed); hydrocolloids including xanthan gum (XG) (The One), guar gum (GG) (The One), carboxymethyl cellulose (CMC) (The One); and tapioca starch (Five Star-Fish).

Chemicals were utilized for protein extraction, proximate analysis, and dietary fiber analysis, including distilled water,  $MgSO_4$  (Thermo Fisher Scientific), pepsin (Merck), pancreatin (Merck), HCl (Merck), NaOH (Merck), phosphate buffer (Cepharm Life Sciences), and sodium dodecyl sulfate (Sigma-Aldrich).

### B. Fresh Mung Bean Protein Preparation

Using a modified approach based on the methods of Ratnaningsih and Songsermpong [25], fresh mung bean proteins were precipitated. The mung bean was cleaned and soaked overnight in water. It was then rewashed and peeled to eliminate the beany flavor and green color, then ground with tap water (ratio of mung bean to water = 1:3). Basket centrifugation with a fine cloth filter was used to remove the crude fiber. The starch was then precipitated from the protein solution, and the protein solution was decanted.

Two liters of mung bean protein solution were heated to 80°C before 10 g/L of  $MgSO_4$  was added and stirred until the protein precipitated. Fresh mung bean protein was suitable for use after three cycles of filtering and washing to remove the  $MgSO_4$  residue from the precipitated protein. By manually squeezing fresh protein through a cloth filter, the moisture content was reduced to around 80% wb. The fresh proteins were stored in the refrigerator overnight before usage.

### C. Formulation and Plant-Based Burger Patties Manufacturing

Each ingredient was measured following the formulation in **Table 1**. Garlic, button mushrooms, and peeled, cooked kidney beans were diced and stir-fried in sunflower oil until they began to wilt, releasing an aroma. The components were blended with oats, fresh mung bean protein, grated beetroot, salt, pepper powder, and yeast extract in the food processor. Following the experiment treatment formula, hydrocolloids at 0 and 0.5% and tapioca starch at 0 and 2% were added. Additionally, frozen coconut oil was added. After thoroughly combining all ingredients, about 50 g were weighed, inserted into the circular mold, and steamed for 5 minutes. The precooked burger patties were then taken from the steamer and placed in the freezer at -18°C.

TABLE 1  
 FORMULATION OF MUNG BEAN PROTEIN-BASED BURGER PATTIES

Materials	Formulas							
	F1	F2	F3	F4	F5	F6	F7	F8
Xanthan gum (g)	0	0.5	0	0	0	0.5	0	0
Guar gum (g)	0	0	0.5	0	0	0	0.5	0
Carboxymethyl cellulose (g)	0	0	0	0.5	0	0	0	0.5
Tapioca starch (g)	0	0	0	0	2	2	2	2
Others	100	100	100	100	100	100	100	100

**Notes:** With other ingredients for each formula: fresh mung bean protein concentrate (49.2 g), mushroom (13.7 g), instant oatmeal (9.3 g), boiled peeled kidney bean (13.7 g), grated beetroot (5.5 g), garlic (3.3 g), sunflower oil (2.5 cc), coconut oil (1.25 cc), salt, pepper, nutritional yeast (1.55 g).

F1 (also referred to without hydrocolloid, without tapioca starch (T0WH)); F2 (also referred to with xanthan gum 0.5%, without tapioca starch (T0XG)); F3 (also referred to with guar gum 0.5%, without tapioca starch (T0GG)); F4 (also referred to with carboxymethyl cellulose 0.5%, without tapioca starch (T0CMC)); F5 (also referred to without hydrocolloid, with tapioca starch 2% (T2WH)); F6 (also referred to with xanthan gum 0.5%, with tapioca starch 2% (T2XG)); F7 (also referred to with guar gum 0.5%, with tapioca starch 2% (T2GG)); F8 (also referred to with carboxymethyl cellulose 0.5%, with tapioca starch 2% (T2CMC)).

### D. Proximate Analysis

Moisture, ash, protein, fat, and crude fiber content of burger patties produced with mung bean protein isolate were analyzed using AOAC methods [26]. Using an oven-drying process, the moisture content was determined. Using the dry ashing procedure, the quantity of ash was determined. The Kjeldahl technique was used to quantify the total nitrogen content of burger patties, and a conversion factor of 6.25 was used to determine the protein content. The fat content was determined using the Soxhlet apparatus. Gravimetric analysis revealed the crude fiber as the residue left after acid and alkaline digestions. While the carbohydrate content was measured using the by-difference method. The total calories were determined by multiplying the protein, carbohydrate, and fat content by factors

4, 4, and 9 cal/g, respectively [27]. The numbers were given in kcal per 100 g.

### E. Color Analysis

Minolta CR-410 portable chromameter (Minolta Co., Japan) was used to assess plant-based burger patties' color. Burger patties were analyzed using the CIELAB color system and D65 illuminant. L\*, a\*, and b\* values were measured using the Joshi et al. methods [28]. L\* values measured the lightness of the product (0 for darkness to 100 for whiteness); a\* values signified redness for the positive value and greenness for the negative value, while b\* values denoted yellowness for the positive value and blueness for the negative value.

### F. Texture Analysis

Texture profile analysis was performed using a texture analyzer (TexturePro CT V1.2, Stable Micro Systems, UK) using the modified Samard, Gu [29] method. Using a 25 mm cylindrical probe to assess a two-cycle compression test, a profile analysis of the burger patties' texture was conducted. The samples were crushed twice to 30% of their initial thickness at a rate of 1 mm/s, under a 5 kg force that was activated. The values for hardness, adhesiveness, cohesiveness, springiness, and chewiness were collected.

### G. Cooking Properties

The samples were kept at room temperature for an hour to defrost the ice, then fried in a non-stick frying pan (Monotaru, Japan) at 140°C. Before putting the samples in the pan, the non-stick cooking surface was lubricated with 5 mL of sunflower oil. Two patties were cooked and flipped every min. After 4 minutes of cooking, when the core of the burger patties reached 90°C, the patties were removed for testing. Three replications were conducted.

The cooking properties, including cooking loss, cooking yield, and moisture retention, were determined using a modified Samard, Gu [29] method.

**Cooking loss.** The cooking loss of the burger patties was determined using Equation 1, the percentage of cooking loss was calculated by dividing the weight of raw and cooked patty samples.

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

**Cooking yield.** The cooking yield was calculated by dividing the cooked patty weight by the raw patty weight, multiplied by 100, using Equation 2:

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

**Moisture retention.** Equation 3 was used to calculate moisture retention. The moisture content of cooked patties was determined by drying each sample at 105°C until constant weight.

Moisture retention (%) =

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

#### H. Dietary Fiber Analysis

Dietary fiber was assessed based on the use of digestive enzymes pepsin and pancreatin [30]. Isoamyl alcohol and thymol crystals were added after mixing. The suspension yielded 1 liter, 50 mL of starch solution, 50 mL of 0.2 N HCl, and 100 mg of pepsin, which were pipetted into a 250 mL beaker. After mixing, 18 hours were spent at 40°C. After pepsin digestion, the mixture was neutralized by adding 4N NaOH and 50 cc of pH 6.8 phosphate buffer. Sodium dodecyl sulfate and pancreatin were added and mixed for one hour at 40°C. Following digestion, the pH was brought down to 4 to 5 using 4 N HCl, and then the sample was centrifuged at 3000 rpm. The supernatant was filtered through a 1-G-3 glass filter with a sand thickness of 15 mm. After being centrifuged twice, the precipitate was cleaned with distilled water three times, followed by three acetone rinses using a 1-G-3 glass filter. The dietary fiber content was dried overnight at 105°C. The dry residue weight reflected the dietary fiber content of the sample using Equation 4.

Dietary fiber (%) =

$$\frac{\text{Weight of sample after analysed and dried} - \text{Blank}}{\text{Sample weight}} \times 100\% \quad \text{eq (4)}$$

#### I. Sensory Evaluation

30 untrained panelists evaluated the mung bean protein-based burger patties, volunteer graduate students from the Department of Food Science and Technology, Faculty of Agro-Industry, Kasetsart University, Bangkok, Thailand. The samples were kept at room temperature for an hour to defrost the ice, and then shallow fried using pan frying with 5 mL sunflower oil (Naturel brand), flipped every 1 min until they became golden brown, and removed. Then, around 1.5x1.5x1.0 cm<sup>3</sup> of cooked burger patties were served to each panelist. The panelists were asked to evaluate the attributes of appearance, aroma, flavor, texture, and general acceptability based on a 9-point hedonic scale, with 9 being remarkably like and 1 being extremely disliked.

#### J. Statistical Analysis

A completely randomized factorial design was used in this study, with types of hydrocolloids (WH, XG, GG, and CMC, at 0.5% of total weight, respectively) and tapioca starch concentration (0% and 2% of total weight). Eight treatment groups were formed. Data were analyzed using one-way ANOVA with a 95% confidence interval, followed by Duncan's multiple range test ( $p < 0.05$ ) with three replications, using SPSS software 22 (SPSS Institute, Chicago, USA). Results were presented as mean  $\pm$  standard deviation.

### III. RESULT AND DISCUSSION

#### K. Effect of hydrocolloids on the burger patties characteristics

*Proximate analysis.* The proximate composition of mung bean protein-based burger patties influenced by hydrocolloids is summarized in **Table 2**. The inclusion of hydrocolloids significantly altered the moisture, ash, protein, fat, crude fiber, carbohydrates, and calories of burger patties ( $p < 0.05$ ). The result indicated that when hydrocolloid was applied to the formulation, the moisture content increased significantly ( $p < 0.05$ ). XG application provided the highest moisture content, 69.37%. There was no significant difference in moisture content between the GG and CMC applications, which were 68.69% and 68.92%, respectively. This finding was related to the ability of hydrocolloid molecules to bind water, thereby affecting the moistness of the burger patties [31]. Hydrocolloids increase product moisture content, mainly because of their capability to bind water strongly and organize it into a gel network. Hydrocolloids are long, hydrophilic polymers that carry many hydroxyls and/or charged groups along their chains. These groups form hydrogen bonds and electrostatic interactions with water molecules, so that many water molecules become associated with the polymer chains rather than remaining as free, mobile water; as hydrocolloid concentration increases, each chain hydrates and swells, increasing its hydrodynamic volume and the viscosity of the continuous phase [50].

Hydrocolloid application on burger patties significantly increased the ash content, from 0.92% to 1.04% ( $p < 0.05$ ) (**Table 2**). There was no significant difference in the ashes of burger patties between WH, XG, GG, and CMC. The presence of ash in the burger patties was related to the contained minerals, such as magnesium, which was contained in mung bean protein as a result of the protein extraction [25]. The addition of salt also contributed to the mineral content of burger patties. Minerals are either naturally present in the foods or added during processing and cooking. Hydrocolloids and mineral components in the food, including compounds, complexes, and free ions, could interact through electrostatic interactions [32].

Hydrocolloid application on burger patties significantly increased the protein content, from 8.04% to 9.15% - 10.22% ( $p < 0.05$ ). There were no significant differences in protein content between GG and CMC application in the burger patties. However, hydrocolloids significantly increased protein content, and XG application yielded the highest protein content among the patties. Hydrocolloid application significantly reduced the fat content of burger patties ( $p < 0.05$ ), from 4.84% to 3.42 - 4.31%.

Hydrocolloid applications significantly increased the crude fiber content of burger patties, from 0.91% to 1.01% - 1.30% ( $p < 0.05$ ). There was no significant difference in crude fiber between XG, GG, and CMC applications. It was related to hydrocolloids, which contained dietary fibers and could increase the fiber in burger patties [33].

Hydrocolloid application had no significant impact on the carbohydrate content of burger patties, except for XG. It was related to a small number of hydrocolloids that were added. While XG is a kind of carbohydrate biopolymer. Hydrocolloid application significantly increased the calories of burger patties ( $p < 0.05$ ), except for CMC. There was no difference in the calories of burger patties between the control and CMC applications.

TABLE 2  
 CHEMICAL COMPOSITION AND DIETARY FIBER OF MUNG BEAN PROTEIN-BASED BURGER PATTIES INFLUENCED BY HYDROCOLLOIDS

Parameters	Type of hydrocolloids			
	WH	XG	GG	CMC
Moisture (%)	67.25±0.27 <sup>c</sup>	69.37±0.27 <sup>a</sup>	68.69±1.25 <sup>b</sup>	68.93±1.42 <sup>b</sup>
Ash (%)	0.92±0.04 <sup>a</sup>	1.01±0.06 <sup>a</sup>	1.04±0.09 <sup>a</sup>	1.00±0.09 <sup>a</sup>
Protein (%)	8.04±0.09 <sup>c</sup>	10.22±1.20 <sup>a</sup>	9.15±1.25 <sup>b</sup>	9.27±0.11 <sup>b</sup>
Fat (%)	4.31±0.09 <sup>ab</sup>	3.42±0.42 <sup>c</sup>	4.84±0.41 <sup>a</sup>	4.15±0.06 <sup>ab</sup>
Crude fiber (%)	3.12±1.24 <sup>b</sup>	3.58±0.26 <sup>a</sup>	3.60±0.24 <sup>a</sup>	3.63±1.23 <sup>a</sup>
Carbohydrate (%)	17.28±0.33 <sup>b</sup>	16.43±0.64 <sup>c</sup>	16.29±0.55 <sup>c</sup>	18.42±0.29 <sup>a</sup>
Calories (kcal)	139.03±9.18 <sup>c</sup>	151.98±12.18 <sup>a</sup>	142.03±5.33 <sup>b</sup>	138.84±6.51 <sup>c</sup>
Dietary fiber (%)	4.39±1.36 <sup>b</sup>	5.47±0.75 <sup>a</sup>	5.93±0.72 <sup>a</sup>	5.93±0.71 <sup>a</sup>

Notes: Values denoted by the same superscript(s) were not significantly different within the same row at  $p < 0.05$ . The value indicated the mean ± standard deviation of three independent measurements. Without hydrocolloid was denoted by WH; xanthan gum 0.5% was denoted by XG; guar gum 0.5% was denoted by GG, and carboxymethyl cellulose CMC denoted 0.5%

**Dietary fiber.** Hydrocolloid application significantly increased the dietary fiber of plant-based burger patties ( $p < 0.05$ ), from 4.39% to 5.47% to 5.93%, as shown in **Table 2**. This was because the three hydrocolloids, XG, GG, and CMC, were all soluble fibers [34,35]. Dietary fibers are usually classified as soluble (e.g., pectin, galactomannans, alginate, psyllium fiber, agar, and gums) or insoluble (e.g., cellulose, hemicellulose, and lignin) [34]. Dietary fiber increases when hydrocolloids are added because most food hydrocolloids are non-digestible polysaccharides (dietary fiber) and because they structurally integrate with the protein network, altering how water and solids are organized in the matrix. Most plant-derived hydrocolloids (xanthan gum, guar gum, CMC, etc.) are classified as soluble dietary fiber since they resist digestion in the small intestine and are fermentable in the colon [51]. When these hydrocolloids are incorporated into a formulation (meat analogs), their mass directly contributes to the total dietary fiber content on a proximate analysis and the nutritional content. At the molecular level, hydrocolloids form non-covalent interactions with protein side chains, promoting cross-linking

and altering network structure. These interactions can be synergistic, supporting each other to form a protein-polysaccharide network that traps more water and increases viscoelasticity.

**Color.** Hydrocolloid application significantly increased the lightness level ( $L^*$ ) of plant-based burger patties ( $p < 0.05$ ), from 42.66 without hydrocolloids to 47.92, 47.29, and 44.01 for XG, GG, and CMC, respectively, as shown in **Table 3**. This was associated with the hydrocolloid's contribution to glossiness and the formation of sheen in foods. Hydrocolloid-stabilized products were often much brighter, glossier, and richer in natural color [36].

The hydrocolloid application decreased the redness level ( $a^*$ ) of burger patties, especially on XG and GG applications, which were 23.04 and 22.85, respectively. There was no difference in the redness level ( $a^*$ ) of burger patties between the control and CMC applications. This was conceivable due to the presence of hydrogen bonding and/or hydrophobic interactions between the red pigment generated from grated beetroot with hydrocolloids [32].

Hydrocolloid application significantly increased the yellowness level ( $b^*$ ) of burger patties, becoming 1.35, 2.97, and 4.04 for CMC, XG, and GG, respectively (**Table 3**). This was likely due to interactions between the yellow pigments and the hydrocolloids, which enabled hydrogen bonding or hydrophobic interactions [32].

TABLE 3  
 COLOR AND TEXTURE OF MUNG BEAN PROTEIN-BASED BURGER PATTIES INFLUENCED BY HYDROCOLLOIDS

Parameters	Type of hydrocolloids			
	WH	XG	GG	CMC
<b>Color:</b>				
$L^*$	42.66±0.81 <sup>d</sup>	47.92±2.47 <sup>a</sup>	47.29±1.09 <sup>b</sup>	44.01±0.31 <sup>c</sup>
$a^*$	26.81±0.70 <sup>a</sup>	23.04±2.18 <sup>b</sup>	22.85±0.42 <sup>b</sup>	26.85±3.45 <sup>a</sup>
$b^*$	-0.12±0.65 <sup>d</sup>	2.97±1.17 <sup>b</sup>	4.04±1.05 <sup>a</sup>	1.35±0.99 <sup>c</sup>
<b>Texture:</b>				
Hardness (N)	1.84±0.41 <sup>b</sup>	2.50±0.83 <sup>a</sup>	2.59±1.25 <sup>a</sup>	2.82±0.32 <sup>a</sup>
Springiness (mm)	1.90±0.25 <sup>a</sup>	1.83±0.13 <sup>a</sup>	1.70±0.38 <sup>a</sup>	1.69±0.11 <sup>a</sup>
Chewiness (mJ)	2.33±0.29 <sup>a</sup>	2.03±0.61 <sup>a</sup>	2.04±0.58 <sup>a</sup>	2.01±0.40 <sup>a</sup>
Adhesiveness	0.14±0.03 <sup>a</sup>	0.08±0.05 <sup>a</sup>	0.07±0.03 <sup>a</sup>	0.04±0.01 <sup>a</sup>
Cohesiveness	0.41±0.08 <sup>a</sup>	0.39±0.05 <sup>a</sup>	0.36±0.06 <sup>a</sup>	0.38±0.03 <sup>a</sup>

Notes: Values denoted by the same superscript(s) were not significantly different within the same column at  $p < 0.05$ . The value indicates the mean ± standard deviation of three independent measurements. Without hydrocolloid is denoted by WH; xanthan gum 0.5% is denoted by XG; guar gum 0.5% is denoted by GG, and carboxymethyl cellulose 0.5% is denoted by CMC

**Texture.** Texture is one of the most significant features to consider when creating plant-based meat analogs since it is linked to customer acceptability [37]. Texture profile analysis uses a two-fold compression test to simulate chewing and derive sensory-relevant force-time curves from the findings. Hydrocolloid application significantly increased the hardness of burger patties ( $p < 0.05$ ) from 1.84 N without hydrocolloid to 2.50 N – 2.82 N in 0.5% hydrocolloid application, shown in **Table 3**. This finding was in agreement with Nanta and Skolpap [20], who reported that a low concentration of xanthan gum resulted in a higher hardness due to its long, string-like molecules interacting well with water molecules. Gum's pseudoplasticity affected the mouthfeel and adhesion of the product, so gum was suitable as a thickener and stabilizer [38]. The three types of hydrocolloids had no significant effect on springiness, chewiness, adhesiveness, or cohesiveness.

**Cooking properties.** Hydrocolloid application had no significant effect on cooking loss and cooking yield, which ranged from 17.05% to 18.68%, and 81.33% to 82.96%, respectively. This cooking yield percentage was consistent with the cooking yield of ground beef patties, 85.23% [39].

Hydrocolloid application increased moisture retention from 32.43% to 33.95–35.40%. This was related to hydrocolloids' ability to capture and retain water in the product [31]. Ball, Wyatt [39] also stated that plant-based proteins retained moisture better during cooking than whole ground beef.

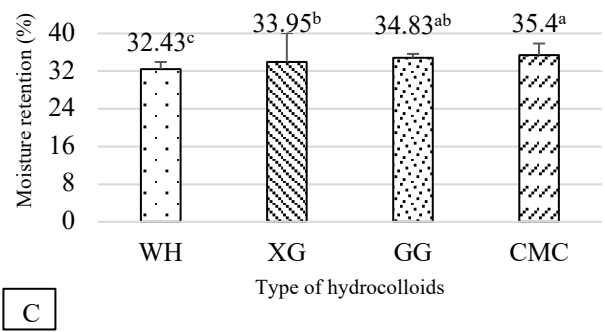


Fig. 1 Cooking properties: [A] Cooking loss (%), [B] Cooking yield (%), and [C] Moisture retention of mung bean protein-based burger patties added with hydrocolloids

**L. Effect of tapioca starch on the characteristics of burger patties**

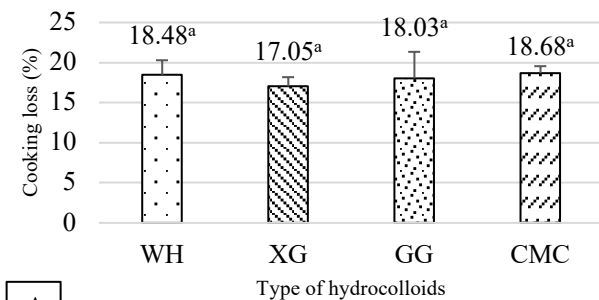
**Proximate analysis.** Tapioca starch addition significantly altered the moisture, ash, protein, fat, crude fiber, carbohydrate, and calories of mung bean protein-based burger patties, as shown in **Table 4**. Tapioca starch at 2% application lowered the moisture content on the patties ( $p < 0.05$ ), from 69.33% to 67.78%. It was associated with retrogradation during freezing, which caused water to be released from the burger patties. Burger patties are steamed for 5 minutes at 100°C, which allows the gelatinization process to occur [40]. It was followed by freezing at -18°C, which potentially promoted the retrogradation of starch in the patties and led to water release from the patties [41].

Tapioca starch addition at 2% level significantly decreased the ash content of the burger patties ( $p < 0.05$ ). This was associated with a decrease in the proportion of ash per total dry matter with increasing tapioca starch addition.

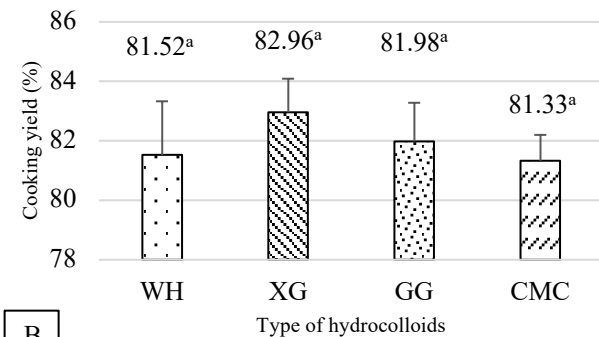
Tapioca starch application at 2% level significantly decreased the protein content of burger patties ( $p < 0.05$ ), from 9.52% to 8.85%. This was related to the proportion of the protein per total dry matter per amount of tapioca starch added. Previous research reported that tapioca starch contained low protein, 0.13% – 0.27% [42].

Tapioca starch inclusion at 2% level also significantly decreased the fat content of burger patties ( $p < 0.05$ ), from 4.43% to 3.92%. This was also related to the proportion of fat per total dry matter per amount of tapioca starch added. Tapioca starch had low lipid, ranging from 0.22% to 0.37% [42].

Tapioca starch application also significantly decreased the crude fiber of burger patties ( $p < 0.05$ ) from 1.11% to 0.91%. This was influenced by the amount of tapioca starch added to the dry matter.



A



B

TABLE 4  
 CHEMICAL COMPOSITION, DIETARY FIBER, COLOR, AND  
 TEXTURE OF MUNG BEAN PROTEIN-BASED BURGER  
 PATTIES INFLUENCED BY TAPIOCA STARCH

Parameters	Tapioca starch addition (%)	
	0	2
Moisture (%)	69.33±1.29 <sup>a</sup>	67.78±1.10 <sup>b</sup>
Ash (%)	0.95±0.12 <sup>b</sup>	1.04±0.07 <sup>a</sup>
Protein (%)	9.52±0.63 <sup>a</sup>	8.82±1.75 <sup>b</sup>
Fat (%)	4.43±0.41 <sup>a</sup>	3.92±0.75 <sup>b</sup>
Crude fiber (%)	1.11±0.14 <sup>a</sup>	0.91±0.32 <sup>b</sup>
Carbohydrate (%)	16.46±1.28 <sup>b</sup>	17.74±0.55 <sup>a</sup>
Calories (kcal)	138.46±5.52 <sup>b</sup>	147.47±11.21 <sup>a</sup>
Dietary fiber (%)	3.99±1.17 <sup>b</sup>	6.04±0.22 <sup>a</sup>
<i>Color:</i>		
L*	46.42±3.04 <sup>a</sup>	44.52±1.73 <sup>b</sup>
a*	25.92±2.84 <sup>a</sup>	23.85±2.39 <sup>b</sup>
b*	2.06±0.80 <sup>a</sup>	2.06±0.66 <sup>a</sup>
<i>Texture:</i>		
Hardness (N)	2.03±0.55 <sup>b</sup>	2.85±0.88 <sup>a</sup>
Springiness (mm)	1.69±0.28 <sup>b</sup>	1.87±0.16 <sup>a</sup>
Chewiness (mJ)	1.82±1.57 <sup>a</sup>	2.39±1.02 <sup>a</sup>
Adhesiveness	0.09±0.06 <sup>a</sup>	0.03±0.02 <sup>a</sup>
Cohesiveness	0.37±0.08 <sup>a</sup>	0.40±0.04 <sup>a</sup>

Notes: Values denoted by the same superscript(s) were not significantly different within the same row at  $p < 0.05$ . The value indicated the mean  $\pm$  standard deviation of three independent measurements.

**Dietary fiber.** As shown in **Table 4**, adding tapioca starch to burger patties significantly increased their dietary fiber content ( $p < 0.05$ ), from 3.99% to 6.04%. Due to retrogradation, steamed tapioca starch followed by freezing affected the development of resistant starch type 3, a dietary fiber [30]. Retrogradation occurred when gelatinized starch was chilled (4°C) or frozen for many hours or days. In this study, steaming tapioca starch resulted in the gelatinization of its molecules. Then, retrogradation occurred during freezing, with the ordered chains reassociating via molecular interactions and hydrogen bonds as the gelatinized system cooled [41]. Hydrogen bonding occurred when the gelatinized starch and water were cooled. The starch chains were reorganized, and water molecules were expelled from the system because of the recrystallization process [41].

**Color.** Tapioca starch application at 2% level significantly reduced the lightness level ( $L^*$ ) of the burger patties ( $p < 0.05$ ), from 46.02 to 44.52. This was related to the formation of a gel in the product after starch gelatinization in the burger patties during steaming, thereby reducing the product's lightness [40]. Starch created a gel when cooled. Furthermore, the cooling and freezing at -18°C processes after steaming induced retrogradation of the starch and denaturation of the protein.

The application of 2% tapioca starch reduced the redness level of burger patties to 23.85, which was attributed to the formation of a gel during steaming after gelatinization. The red coloration of the burger patties could have been associated with the red color of the grated beetroot and kidney beans. The 2% tapioca

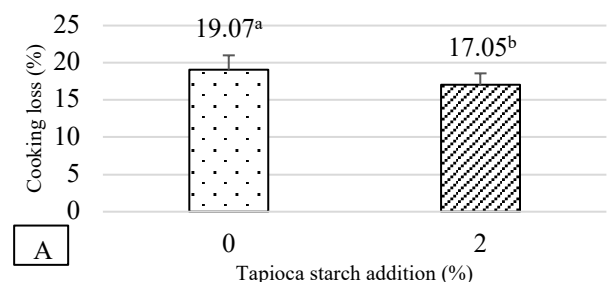
starch application had no significant effect on the yellowness of burger patties.

Changes in the lightness and redness level of the burger patties were caused by the Maillard reaction between the reducing sugar and amino acids found in burger patties. The Maillard reaction is a fundamental process that influences the color, flavor, and aroma of food products, thereby imparting distinctive flavor, aroma, and color [44]. The Maillard reaction, which involved the interaction between the amino groups of free amino acids, peptides, and proteins and the carbonyl groups of reducing sugars, was primarily responsible for the production of brown color during the steaming process [44]. Additionally, grated beetroot contained enzymes, such as polyphenol oxidase, which caused enzymatic browning reactions of burger patties [45].

**Texture.** Tapioca starch application significantly increased the hardness and springiness of burger patties ( $p < 0.05$ ), from 2.03 N to 2.85 N and 1.69 mm to 1.87 mm, respectively, as shown in **Table 4**. However, 2% tapioca starch application did not affect the chewiness, adhesiveness, and cohesiveness of plant-based burger patties. This finding was in line with Dobson et al. [46], who stated that a combination of starch and pea protein isolates (47% w/w db) produced supporting matrices that increased product hardness. Ahamed et al. [47] reported that starch plays a significant role in food texture, and the type of starch and the gelatinization process during cooking affect the final texture. According to Chatterjee et al. [22], the inclusion of tapioca starch significantly reduced the hardness, cohesiveness, and chewiness level of the cooked chicken meat patty, as well as improving the texture of the buffalo meat patty.

**Cooking properties.** Tapioca starch addition significantly reduced the cooking loss from 19.07% to 17.05% and increased the cooking yield from 80.93% to 82.95% ( $p < 0.05$ ), as shown in **Figure 2A** and **2B**, respectively. The protein-starch network remained intact during freezing, thawing, and frying; thus, incorporating starch reduced cooking loss and increased cooking yield in the burger patties [24, 46].

Tapioca starch application significantly reduced the moisture retention of burger patties, from 35.18% to 33.12% ( $p < 0.05$ ), as shown in **Figure 2C**. It was associated with burger patties that had undergone retrogradation during freezing, which released water [24]. Previous studies reported that the addition of tapioca starch to meat products was intended to serve as a binder, enhancing the binding of meat and fat and boosting their moisture-retention capacity [48].



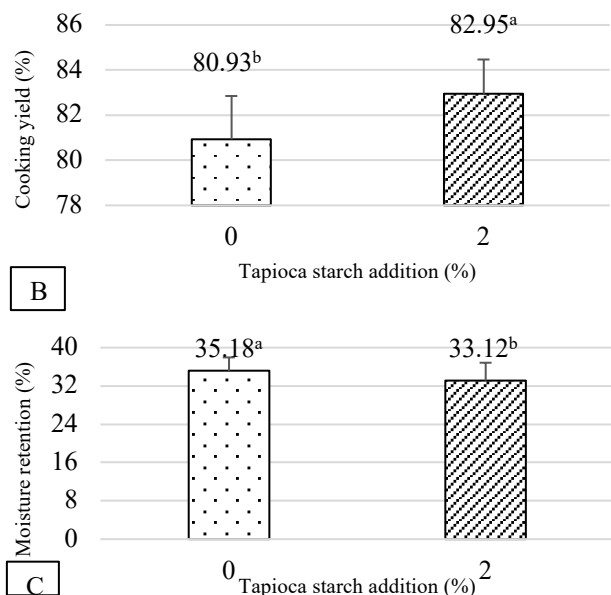


Fig. 2 Cooking properties: [A] Cooking loss (%), [B] Cooking yield (%), and [C] Moisture retention of mung bean protein-based burger patties added with tapioca starch

M. Effect of interaction between hydrocolloids and tapioca starch on the burger patties' characteristics

**Proximate analysis.** There were significant influences of interaction between hydrocolloids and tapioca starch ( $p < 0.05$ ) on the moisture, ash, protein, fat, crude fiber, carbohydrate, and calories of plant-based burger patties, as shown in **Table 5**. There was no significant difference in moisture content between the control and T0CMC, nor between the control and T2CMC. Although the application of T0XG and T0GG significantly increased the moisture content of burger patties, which might be related to the hydrocolloid's ability to bind water, the application of T2WH, T2XG, and T2GG significantly reduced the moisture content of burger patties. This is possible because the burger patties contain tapioca starch. Besides, XG and GG in T2XG and T2GG, respectively, had amounts lower than the tapioca starch amount, so the syneresis phenomenon observed during the starch retrogradation process still occurred. The moisture content of burger patties ranged from 66.53% to 71.19%, in line with that of mushroom-based sausages produced with a binding agent [19].

TABLE 5  
 CHEMICAL COMPOSITION AND DIETARY FIBER OF MUNG BEAN PROTEIN-BASED BURGER PATTIES INFLUENCED BY INTERACTION BETWEEN HYDROCOLLOIDS AND TAPIOCA STARCH

Parameters	Treatment							
	T0WH	T0XG	T0GG	T0CMC	T2WH	T2XG	T2GG	T2CMC
Moisture (%)	68.34±0.26 <sup>c</sup>	71.19±0.10 <sup>a</sup>	69.83±0.24 <sup>b</sup>	67.97±0.14 <sup>c</sup>	67.55±0.34 <sup>d</sup>	69.49±0.19 <sup>b</sup>	67.55±0.20 <sup>d</sup>	66.53±0.18 <sup>c</sup>
Ash (%)	0.96±0.05 <sup>ab</sup>	0.95±0.08 <sup>ab</sup>	1.09±0.04 <sup>a</sup>	0.79±0.06 <sup>b</sup>	1.04±0.04 <sup>a</sup>	1.07±0.10 <sup>a</sup>	0.99±0.03 <sup>ab</sup>	1.05±0.03 <sup>a</sup>
Protein (%)	6.75±0.07 <sup>c</sup>	11.51±0.09 <sup>a</sup>	9.03±0.23 <sup>c</sup>	8.01±0.09 <sup>d</sup>	9.34±0.11 <sup>c</sup>	8.93±0.12 <sup>cd</sup>	9.26±0.08 <sup>c</sup>	10.53±0.25 <sup>b</sup>
Fat (%)	4.44±0.11 <sup>b</sup>	3.81±0.10 <sup>c</sup>	4.67±0.20 <sup>ab</sup>	4.82±0.10 <sup>a</sup>	4.19±0.06 <sup>bc</sup>	3.04±0.02 <sup>e</sup>	5.00±0.08 <sup>a</sup>	3.47±0.15 <sup>d</sup>
Crude fiber (%)	1.17±0.01 <sup>b</sup>	1.26±0.04 <sup>b</sup>	1.13±0.04 <sup>b</sup>	0.88±0.00 <sup>c</sup>	0.65±0.00 <sup>c</sup>	0.77±0.03 <sup>c</sup>	1.47±0.00 <sup>a</sup>	0.78±0.01 <sup>c</sup>
Carbohydrate (% db)	16.67±0.26 <sup>c</sup>	15.39±0.33 <sup>d</sup>	15.38±0.28 <sup>d</sup>	18.42±0.30 <sup>a</sup>	17.89±0.40 <sup>b</sup>	17.46±0.25 <sup>b</sup>	17.20±0.25 <sup>b</sup>	18.42±0.28 <sup>a</sup>
Calories (kcal)	130.72±1.40 <sup>f</sup>	140.89±1.31 <sup>d</sup>	137.47±1.96 <sup>e</sup>	144.77±0.46 <sup>c</sup>	147.34±1.25 <sup>b</sup>	163.06±0.74 <sup>a</sup>	146.59±2.22 <sup>bc</sup>	132.92±0.65 <sup>f</sup>
Dietary fiber (% db)	2.14±0.14 <sup>e</sup>	4.24±0.16 <sup>cd</sup>	4.78±0.06 <sup>c</sup>	4.79±0.02 <sup>c</sup>	5.82±0.10 <sup>ab</sup>	5.97±0.14 <sup>ab</sup>	6.07±0.07 <sup>a</sup>	6.32±0.06 <sup>a</sup>

Notes: Values denoted by the same superscript(s) were not significantly different within the same row at  $p < 0.05$ . The value indicated the mean ± standard deviation of three independent measurements. Tapioca starch 0% and without hydrocolloids was denoted by T0WH; tapioca starch 0% with xanthan gum 0.5% was denoted by T0XG; tapioca starch 0% with guar gum 0.5% was denoted by T0GG; tapioca starch 0% with carboxymethyl cellulose 0.5% was denoted by T0CMC; tapioca starch 2% without hydrocolloids was denoted by T2WH, tapioca starch 2% with xanthan gum 0.5% was denoted by T2XG, tapioca starch 2% with guar gum 0.5% was denoted by T2GG, and tapioca starch 2% with carboxymethyl cellulose 0.5% was denoted by T2CMC.

All treatments showed ash content that was not significantly different from the control, except for T0XG. This relates to the ash and mineral content in the burger patties and to XG's ability to interact with minerals, whether in the form of compounds, complexes, or free ions [32]. The Ash content of burger patties

ranged from 0.95% to 1.09%, consistent with that of mushroom-based sausages with a binding agent [19].

All treatments significantly increased the protein content of burger patties. There was no significant difference between the control with T2WH and between T0XG, T0GG, and T2GG, and between T2XG, T2GG, and T2CMC. The protein content of

burger patties ranged from 6.75% to 11.51%. These results were consistent with those of mushroom-based sausages processed with xanthan gum [19].

T0GG and T0CMC provided higher fat content, while T0XG, T2XG, T2GG, and T2CMC provided lower fat content. There was no difference between T0GG and T0CMC, between T0GG and T2WH; between the control and T2WH; and between T2XG and T2CMC. The fat content of burger patties ranged from 3.04% to 5.00%, with the highest being T2GG. This finding was comparable to mushroom-based sausages processed with XG at a 0.5% level, 4.55% [49]. However, the combination of tapioca starch at the 2% level and GG, or CMC, reduced the lipid content in the burger patties. It was associated with an interaction between tapioca starch and hydrocolloids that could bind more water or other components rather than lipids. The lipid content of plant-based burger patties ranged from 3.04% to 5.00%, and it was in agreement with the lipid content of mushroom-based sausages with a binding agent [19].

Treatment T2GG resulted in higher crude fiber content in burger patties, while T0CMC, T2WH, T2XG, and T2CMC resulted in lower crude fiber content. There was no significant difference between the control (T0WH) with T0XG and T0GG; and between T2WH and T2XG and T2CMC. The crude fiber of burger patties ranged from 0.65% to 1.47%, with the highest for T2GG. It was related to GG derived from plant cellulose.

All treatments significantly increased the carbohydrate content of burger patties ( $p < 0.05$ ). There was no difference between the T0CMC with T2CMC, and T2WH with T2XG and T2GG. The carbohydrate of burger patties ranged from 15.38% to 18.42%, with the highest was T0CMC and T2CMC.

All treatments significantly increased the calories content of burger patties ( $p < 0.05$ ), except T2CMC. There was no significant difference in calories between control and T2CMC; between T2WH and T2GG; and between T2GG with T0CMC. The calories for burger patties ranged from 130.72 kcal to 163.06 kcal, with the highest was T2XG. It was associated with tapioca starch and hydrocolloids, which were polysaccharides and complex carbohydrates, and a source of calories.

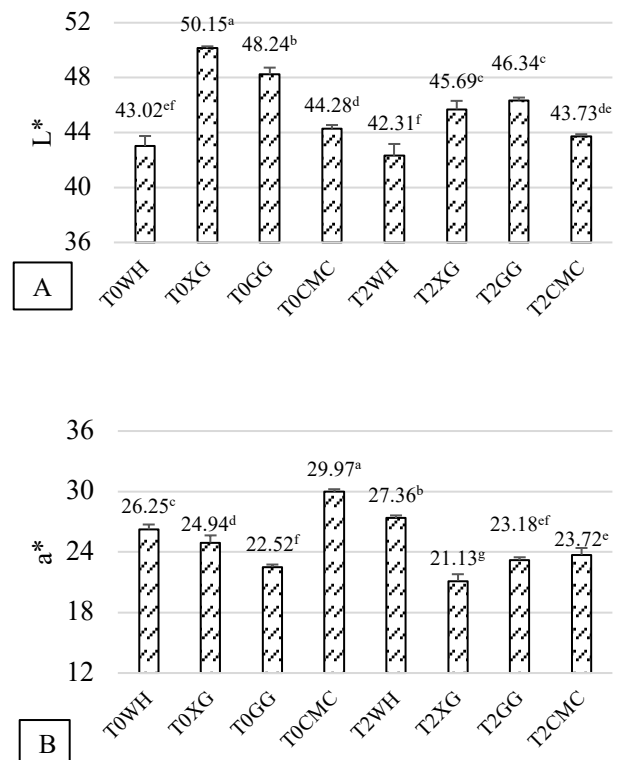
**Dietary fiber.** All treatments significantly increased the dietary fiber content of burger patties ( $p < 0.05$ ). Treatment T2GG had the highest dietary fiber content, 6.32%. There was no difference between the T2WH, T2XG, T2GG, and T2CMC. This was related to XG, GG, and CMC, which were soluble fibers [34, 35], and the application of tapioca starch combined with XG, GG, or CMC increased dietary fiber due to retrograded starch formed after the retrogradation process. The retrogradation process influenced the development of resistant starch type 3 in the product, a type of dietary fiber [30].

**Color.** There was a significant interaction between hydrocolloids and tapioca starch ( $p < 0.05$ ) on the lightness and redness levels of burger patties (Figure 3A and 3B). T0XG, T0GG, T0CMC, T2XG, and T2GG provided higher lightness values of burger patties ( $p < 0.05$ ). There was no significant difference between control and T2CMC; between control and

T2WH; and between T2XG and T2GG. While T0CMC and T2WH provided a higher redness level of burger patties (Figure 3B).

**Texture.** There were significant influences of interaction between hydrocolloids and tapioca starch ( $p < 0.05$ ) on the hardness of plant-based burger patties (Figure 3C). T2WH, T2XG, T2GG, and T2CMC produced burger patties with higher hardness. There was no significant difference between control, T0XG, T0GG, and T0CMC. There was no significant difference between T2WH, T2CMC, and T2XG. T2GG had the highest hardness level among burger patties (3.69 N), and there was no significant difference compared with T2XG. This finding was lower than that of meat analogs from soy protein isolate-based with hydrocolloids application [20].

**Cooking properties.** There were significant influences of interaction between hydrocolloids and tapioca starch ( $p < 0.05$ ) on moisture retention of plant-based burger patties (Figure 3D). T0XG, T2GG, and T2CMC showed higher moisture retention than the control, while T2WH and T2XG showed lower moisture retention. There was no significant difference between the control and T0GG, between T0CMC and T0GG, or between T0GG and T2GG. Without tapioca starch application, XG could provide higher moisture retention in the burger patties; however, when combined with 2% tapioca starch, GG and CMC showed better moisture retention. It indicates that XG, an anionic hydrocolloid with a hydrophilic trisaccharide side chain, is cross-linked with legume protein and, during processing, binds more moisture, forming a stable gel and thus exhibiting much better moisture retention [16].



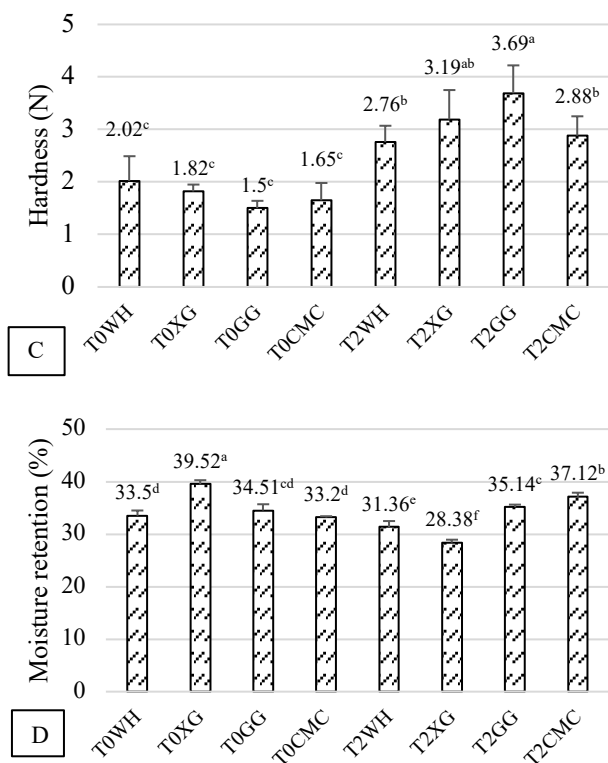


Fig. 3 [A] Lightness (L\*), [B] Redness (a\*), [C] Hardness (N), and [D] Moisture retention (%) of mung bean protein-based burger patties influenced by the interaction between hydrocolloids and tapioca starch

Hydrocolloids (XG, GG, CMC) are high-molecular-weight hydrophilic polymers that bind large amounts of water and form viscous or gelled networks. Hydrocolloids hydrate, swell, and create a 3-dimensional polymer network that traps water within its structure, reducing the amount of “free” water that can diffuse out during cooking. This increases water-holding capacity, so less water and fewer soluble solids (starch, proteins) leach into the cooking medium, lowering cooking loss and raising cooking yield.

In noodle and pasta, adding XG, GG, and CMC significantly reduces cooking loss and increases cooking yield because the hydrocolloids network reinforces the starch-protein matrix and traps more water. By immobilizing water, hydrocolloids reduce purge and syneresis, increase juiciness, and keep products softer or more cohesive after cooking and storage.

Role of tapioca starch in gel formation and retrogradation. Tapioca starch is a nearly pure starch widely used as a gelatinizer, thickener, and water-retaining agent in many foods. When heated in water beyond its gelatinized temperature, tapioca starch granules absorb water, swell significantly, and leach amylose, forming a viscous paste and, on cooling, a gel. This swollen, continuous starch gel traps water in and between granules, increasing moisture retention and contributing to higher cooking yield and lower cooking loss, because the gel matrix prevents solids from efficiently diffusing out. After cooling, amylose and then amylopectin chains begin to

reassociate (retrograde), forming more ordered, crystalline regions. Retrogradation can strengthen the gel and increase firmness/elasticity. Promote syneresis if crystalline becomes too high, which can reduce moisture retention over time. The extent and rate of retrogradation determine whether tapioca starch primarily retains water or, conversely, slowly releases it during storage.

Combined view of hydrocolloids and tapioca starch application. During cooking, tapioca starch gelatinizes and forms the primary gel network that holds water and gives body. Hydrocolloids integrate into or surround this starch network, increasing viscosity, sealing micro-voids, and further immobilizing water. And the results are lower cooking loss, higher cooking yield, and higher moisture retention during and after cooking, with improved texture and reduced syneresis over storage [52, 53, 54].

#### N. Sensory Evaluation

Panelists were asked to rate their preferences for appearance, taste, texture, odor, and general acceptability of the burger patty samples (Table 6) on a hedonic scale of 1 to 9. Samples of T2WH, T2XG, T2GG, and T2CMC were compared to commercial plant-based product (CPB) burger patties from Let's Plant Meat (Startup Plant-based meat, Thailand) and McDonald's burger patties (MD). Appearances are an essential factor in the respondents' opinions. There was no discernible variation in appearance between all samples (5.73 to 6.87). Some respondents stated that the reddish coloration of plant-based products made them more attractive. In terms of taste, the addition of T2WH and T2CMC had a significant impact on the taste score (5.90), which was lower than that of CPB and MD. T2XG and T2GG (6.30 and 6.33, respectively) were considered to have taste ratings that were not significantly different from CPB and MD. Several respondents mentioned that the plant-based burger patties had a unique taste. They did, however, say they enjoyed the flavor. All samples had texture ratings (5.83 to 6.20) that were significantly different from McDonald's burger patties (7.17).

TABLE 6  
 SENSORY SCORE OF MUNG BEAN PROTEIN-BASED BURGER PATTIES

Attributes	Treatment					
	T2WH	T2XG	T2GG	T2CMC	CPB	MD
Appearance	6.53±1.20 <sup>a</sup>	6.77±1.25 <sup>a</sup>	6.87±1.41 <sup>a</sup>	6.37±1.19 <sup>a</sup>	5.73±2.07 <sup>a</sup>	6.17±1.68 <sup>a</sup>
Taste	5.90±1.30 <sup>b</sup>	6.30±1.37 <sup>ab</sup>	6.33±1.61 <sup>ab</sup>	5.90±1.30 <sup>b</sup>	6.50±1.82 <sup>a</sup>	6.83±1.88 <sup>a</sup>
Texture	5.83±1.29 <sup>b</sup>	6.23±1.48 <sup>b</sup>	5.90±1.47 <sup>b</sup>	5.93±1.31 <sup>b</sup>	6.20±1.90 <sup>b</sup>	7.17±1.64 <sup>a</sup>
Odor	6.03±1.50 <sup>a</sup>	6.17±1.62 <sup>a</sup>	6.50±1.50 <sup>a</sup>	6.40±1.35 <sup>a</sup>	6.67±1.79 <sup>a</sup>	5.80±1.96 <sup>a</sup>
Over all acceptance	5.83±1.11 <sup>b</sup>	6.37±1.30 <sup>ab</sup>	6.18±1.58 <sup>ab</sup>	6.02±1.18 <sup>b</sup>	6.45±1.88 <sup>a</sup>	6.68±1.71 <sup>a</sup>

Notes: Mean ± SD values with different lowercase superscripts in the same column were significantly different at p<0.05. Tapioca starch 2%

without hydrocolloids was denoted by T2WH, tapioca starch 2% with xanthan gum 0.5% was denoted by T2XG, tapioca starch 2% with guar gum 0.5% was denoted by T2GG; and tapioca starch 2% with carboxymethyl cellulose 0.5% was denoted by T2CMC, commercial plant-based burger patties was denoted by CPB, and McDonald's burger patties was denoted by MD.

It was clear that plant-based products, both experimental and commercial, could not make burger patties with a mouthfeel similar to real meat. As a result, more study is required to enhance its texture. For odor, all samples received ratings that were not statistically different (5.80 to 6.67). Several respondents stated that the plant-based product samples released a beany, unpleasant odor, whereas McDonald's products emitted a strong beef odor, influencing the panelists' preference level. T2WH and T2CMC applications received significantly lower overall acceptability (5.83 and 6.02, respectively) than CPB and MD. T2XG and T2GG, on the other hand, received overall acceptability that was not statistically different from CPB and MD. This demonstrated that T2XG and T2GG had similar responses from CPB or MD.

#### IV. CONCLUSION

Except for lipids and crude fiber in GG, the addition of hydrocolloids to mung bean protein-based burger patties tended to enhance their proximate composition, whereas tapioca starch increased carbohydrate, calories, and dietary fiber while decreasing other proximate parameters. The use of hydrocolloids maintained the burger patties' lightness and yellowness level, but tapioca starch decreased the product's lightness and redness values. Hydrocolloid and tapioca starch treatments only influenced the hardness measurements. Tapioca starch enhanced hardness and springiness. Three hydrocolloids did not affect cooking qualities, although they enhanced water retention. Hydrocolloids were excellent for preserving water retention. In terms of cooking qualities, tapioca starch had a greater impact on cooking loss and yield.

Overall, the combination of 0.5% XG or 0.5% GG with 2% tapioca starch application provided no significant difference in preference of appearance, flavor, and overall acceptability compared with commercial products, which are potentially developed to be commercial products

#### ACKNOWLEDGMENT

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#### CONFLICT OF INTEREST

The authors declare no conflicts of interest to disclose.

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