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Development of gluten-free and soy-free plant-based chicken meat from young jackfruit

Leelawat, B.*and Taikerd, T.

Department of Food Science and Technology, Faculty of Science and Technology, Thammasat University, Rangsit Centre, Thailand, Thammasat University Center of Excellence in Food Science and Innovation, Pathum Thani, Thailand.

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Abstract Three levels of pea protein to water (1:0, 1:1, and 1:2 by weight) were determined the optimal ratio. It was found that as the water content increased, the hardness and chewiness of the plant-based chicken meat decreased. The redness (a*) and yellowness (b*) values decreased while the brightness (L*) was increased. Afterward, the ratios between hydrated pea protein isolate:young jackfruit at 3 different levels (25:50, 20:55, 15:60 by weight) were evaluated. It was shown that when the ratio of young jackfruit increased, the hardness and chewiness decreased. The a* value was decreased while the values of L* and b* increased. The mixture of Benecel MX (BM) (20%, 30%, 40%) and Transglutaminase (TG) (0%, 0.15%, 0.3%) were investigated to determine the suitable level for texture enhancement. The hardness and chewiness were significantly increased with an increasing amount of BM ($p < 0.05$), The L* increased as BM content increased, whereas a* and b* decreased. The hardness and chewiness also increased as TG increased, except for the 0.3% by weight. From the texture properties, the four formulas out of nine were selected, based on different group of texture characteristics, for sensory evaluation using the 9-Point Hedonic Scale method. The result revealed that 40% BM without TG received the highest overall acceptability score. Therefore, this formulation was chosen to determine nutrition contents. In 100 g of plant-based chicken meat, it contains 72.4 g of moisture, 7.29 g fat, 8 g of protein, 1.67 g of ash and 10.6 g of total carbohydrate.

Keywords: Plant-based meat, Chicken, Gluten-free, Soy-free, Young jackfruit

Introduction

Jackfruit (*Artocarpus heterophyllus*) is a giant and unique tropical composite fruit grown extensively in tropical countries (Saxena *et al.*, 2011). The jackfruit as a fruit tree is a simple to cultivate fruit tree that tolerates drought well while not necessitating a lot of land or water. Therefore, jackfruit is suitable for growing in all conditions in Thailand. In the harvesting process, the unripe fruit must be sorted out to obtain the desired size of ripe jackfruit.

* **Corresponding Author:** Leelawat, B.; **Email:** jafood@hotmail.com

It results in a young jackfruit, a by-product of the jackfruit harvesting process that has not been used as effectively.

Nowadays, young jackfruit is another alternative raw material that vegans and vegetarians are interested in. It has a neutral flavor and, when shredded, resembles meat in texture, making it easy to add flavor to the desired product. Furthermore, in recent years, the interest in using alternative sources of plant-based ingredients in industrial plant-based products has been increasing. Hence, many researchers have paid attention to young jackfruit as a potent source of the plant-based ingredient. In addition, it contains functional compounds that can reduce various diseases such as high blood pressure, heart diseases, strokes, and bone loss. It is also rich in potassium which aids in lowering blood pressure and reversing the effects of sodium that causes a rise in blood pressure that affects the heart and blood vessels (Swami *et al.,* 2012). For the reasons already mentioned, this makes young jackfruit more widely used in the plant-based product industry.

Another point of interest is that the most common raw materials for plant-based meats are mainly made from soy products such as tofu, which often contain gluten, and therefore people who are allergic to soy or gluten will not be able to consume them. Pea proteins are increasingly used as an alternative to soy protein due to their non-GMO status. Pea plants may be grown in more moderate climates than soy (Lam *et al.,* 2018). In addition, Pea protein isolate has an amino acid profile close to that recommended by the FAO and WHO. This is because of its high levels of branched amino acids, glutamic acid, and arginine, as well as its richness in lysine (AP Food Online, 2019). However, gluten and soy protein are vital in producing plant-based meats for good texture. Therefore, in developing gluten-free and soy-free plant-based meats, it is necessary to use a texture-improving agent such as methylcellulose and transglutaminase, etc. Methylcellulose is derived from the treatment of naturally occurring cellulose to create a tasteless, colourless powder. It is regularly used as a highly effective binding agent, and its success in plant-based alternatives comes mainly from its ability to help retain succulence (Andina Ingham, 2015). Transglutaminase is an enzyme that catalyzes an acyl-transfer reaction introducing a covalent cross-link between glutamine and lysine residues, improving the binding properties, and promoting protein gelation and water-holding capacity. (Imm and Lian, 2000).

Therefore, the research aimed to develop gluten-free and soy-free plant-based chicken meat from beneficial nutrients from young jackfruit by studying the optimum ratio between pea protein isolate and water as well as the optimum ratio between pea protein isolate and young jackfruit to produce plant-based chicken meat. Furthermore, the optimum mixture of benecel MX emulsion and transglutaminase for texture enhancement was investigated.

Materials and methods

Young jackfruits (*Artocarpus heterophyllus*) (Talad Thai, Pathumtani Province), pea protein isolate (Questex co., ltd), methylcellulose (Benecel™ MX modified cellulose, Ashland from Questex co., ltd), kappa carrageenan (Krungthepchemi.co., ltd), canola oil (Natural from Lam Soon (Thailand) Public co., ltd), salt (Prung Trip from Thai Refine Salt co., ltd), disodium 5-ribonucleotide (Miwon from Gloden interbiz co., ltd) and chicken flavor powder for vegan (Questex co., ltd) were used in the experiments.

Preparation of young Jackfruit

The young jackfruit (YJ) was cleaned and boiled at 100 ℃ for 30 min. After that, the core was removed and the water in jackfruit was squeezed out using a hand squeezer. After that, the dewatered jackfruit was dried at 60 ℃ for 2 hr in a tray dryer before being used to prepare plant-based chicken meat samples.

Plant-based chicken meat preparation

The initial ingredient formulation of plant-based chicken meat used in this research was modified from Questex co., ltd. As shown in Table 1. First, all components used were weighed according to the formulation. Pea protein isolate (PPI) was hydrated in water and blended with a Benecel MX emulsion (BM), canola oil, salt, kappa carrageenan, disodium 5-ribonucleotide and chicken flavor powder in a food processor (Tefal, DO821, China) at speed 2 for 1.5 min. The BM was prepared by blending 8% methylcellulose powder, 11% canola oil, and 81% cold water (~4 ℃) in a food processor (Tefal, DO821, China) at speed 2 for 1.5 min. The ingredients were transferred to the bowl of the stand mixer (KitchenAid, 5KSM150ER, USA). The YJ was then added and mixed with a flat beater at speed 8 for 15 min. Then, the finished dough was placed in a silicone mold (5 cm x 5 cm x 2.5 cm), freeze at -18 ℃ for 1 hr, followed by steaming by a food steamer (Tefal, VC145130, China) at 75 ℃ for 20 min. Then sample was allowed to cool down for 5 min and stored in a refrigerator at 4 ± 2 ℃ for further analysis.

The optimum ratio between PPI and water in plant-based chicken meat was investigated by varying 3 ratios of PPI to water of 1:0, 1:1, and 1:2 by weight. Then, the optimum ratio between hydrated PPI and YJ was studied by varying 3 ratios of hydrated PPI to YJ of 25:50, 20:55, and 15:60 by weight. The experimental design was a randomized complete block design (RCBD) with two replications for each. Transglutaminase concentrations of 0, 0.15, and 0.3% by weight and the Benecel MX emulsion of 20, 30, and 40% by weight were evaluated for improving the texture of plant-based chicken meat. The experimental design was 2 x 3 Factorial in RCBD with two replications for each. The results were reported as the mean value with standard deviation. Statistic was analyzed using SPSS for Windows and Duncan's multiple range test (DMRT) was used for comparing the differences among mean values at the 95% confidence level ($p \leq 0.05$).

Table 1. Initial ingredient formulation of chicken meat analog

Ingredients	gram per 100 grams
Young jackfruit (YJ)	50.00
Pea protein isolate (PPI)	16.67
Water for pea protein	8.33
Canola oil	4.20
Kappa carrageenan	0.45
Salt	1.34
disodium 5-ribonucleotide	0.20
Chicken flavor powder	1.01
Benecel MX emulsion (BM)	1.60
Cold water	16.2

Color

Color of plant-based chicken meat samples were measured using colorimeter (Hunter Lab model, Colorflex45/0, USA). The color measurements were determined according to the CIELAB system. Color was expressed as L* (100 = white; 0 = black), a* (+, redness; -, greenness), and b* (+, yellowness; -, blueness). Each experiment was replicated three times.

Textural properties

The texture of plant-based chicken meat samples were performed by Texture Profile Analysis as described by Chiang *et al.* (2021) with modification, using a Texture Analyzer TA-XTplusC (Stable Micro Systems, UK), equipped with cylinder probe P/50. Samples were cut into a dimension of 15 mm x 15 mm x 20 mm and compressed using a P/50 twice to 50% of the original thickness at room temperature. The TPA settings were: pre-test speed of 1 mm/s, test speed of 1 mm/s, post-test speed of 5 mm/s, Target mode strain, and trigger force of 5 g. Hardness and chewiness were obtained from the TPA curves for each sample.

Sensory evaluation

The plant-based chicken meat samples were selected based on a different group of texture characteristics (hardness and chewiness) for sensory evaluation using the 9-Point Hedonic Scale method of 40 panelists. Samples were evaluated to rate the liking of quality attributes according to appearance, fibrousness, color, flavor, taste, texture, and overall acceptability of each sample using a 9-point hedonic scale (1 = dislike extremely and 9 = like extremely). A three-digit code number is assigned to each sample, and water is served between the samples to be tested.

Nutritional composition

The method used for all the analyses of the sample composition was based on the methods provided by AOAC. The nutritional composition, including moisture, fat, ash, protein, and total carbohydrate, of optimal formulation of plant-based chicken meat. The moisture, fat, ash, and protein content of plant-based chicken meat was determined using AOAC (2019). The total carbohydrate content of plant-based chicken meat was determined by using the method of Shapiro (1995).

Results

The physical properties of plant-based chicken meat from various ratios of PPI:water, including color (L*, a*, and b*) and texture properties, were shown in Table 2. Plant-based chicken meat color values had significant differences ($p \leq 0.05$) on the L*, a*, and b*. The ratio of PPI:water of 1:2 had the highest L* and the lowest a* and b*. The texture properties of plant-based chicken meat from various ratios of PPI:water showed significant differences ($p \leq 0.05$) in the hardness and chewiness. The ratio of PPI:water of 1:0 had the highest hardness and chewiness. While the ratio of PPI: water of 1:1 and 1:2 had no significant differences ($p > 0.05$) in the hardness and chewiness.

The image of plant-based chicken meat from various ratios of PPI:water is presented in Fig. 1. The samples were dissected and shredded. The plant-based chicken meat from a ratio of PPI:water of 1:0 showed dark color with the appearance of fracture lines, no adhesion, and dispersed white spots. The ratio of PPI:water of 1:1 showed lightness, firmness, and visible jackfruit fibers. And the ratio of PPI:water of 1:2 showed the lighter color, softer, and clearly visible jackfruit fiber. Therefore, the ratio of PPI:water of 1:1 was chosen for further studying for the optimum ratio between hydrated pea protein isolate and young jackfruit in plant-based chicken meat.

Table 2. Physical properties of plant-based chicken meat from various ratios of pea protein isolate and water

PPI: W[/1]	Color			Texture properties	
	L*	a*	b*	Hardness (g_f)	Chewiness (g_f)
1:0	$48.20^c \pm 2.22$	$1.95^a \pm 0.17$	$11.53^a \pm 0.44$	$3234.98^a \pm 813.54$	$767.11^a \pm 374.23$
1:1	$56.08^b \pm 0.83$	$1.85^a \pm 0.18$	$11.68^a \pm 0.48$	$1560.92^b \pm 492.66$	$371.22^b \pm 284.33$
1:2	$58.71^a \pm 0.78$	$1.61^b \pm 0.11$	$10.54^b \pm 0.58$	$1467.19^b \pm 1074.10$	$402.97^b \pm 351.48$

[a,b,c] Mean values in a column with different letters are significantly different ($p \leq .05$)
[/1] PPI: Pea protein isolate, W: Water

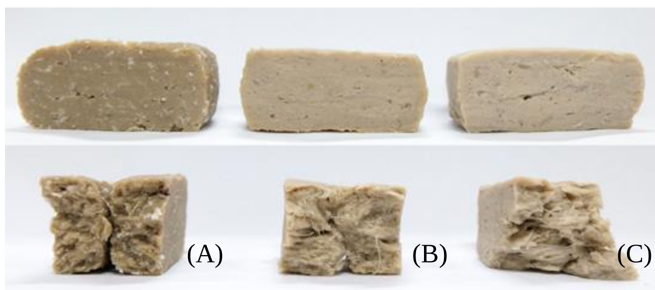

Figure 1. Plant-based chicken meat prepared from various ratios of pea protein isolate and water when dissected (top) and shredded (bottom): (A) 1:0, (B) 1:1, and (C) 1:2 by weight, respectively

The physical properties of plant-based chicken meat from various ratios of hydrated PPI: YJ, including color (L*, a*, and b*) and texture properties, were shown in Table 3. Plant-based chicken meat color values had significant differences ($p \leq 0.05$) on the L*and b*. The ratio of hydrated PPI:YJ of 15:60 had the highest L* and b*. The texture properties of plant-based chicken meat from various ratios of hydrated PPI:YJ showed significant differences ($p \leq 0.05$) in the hardness and chewiness. The ratio of hydrated PPI:YJ of 25:50 had the highest hardness and chewiness.

The image of plant-based chicken meat from various ratios of hydrated PPI:YJ is presented in Fig. 2. The plant-based chicken meat from various ratios of hydrated PPI:YJ showed no significantly differences in the color characteristics. When considering the characteristics of the fibers, the ratio of hydrated PPI:YJ of 25:50 showed less fiber characteristics and more firmness, the ratio of hydrated PPI:YJ of 20:55 showed more fiber characteristics and less firmness, and the ratio of hydrated PPI:YJ of 15:60 showed the most fiber characteristics and the least firmness. Therefore, the ratio of hydrated PPI:YJ of 20:55 was chosen for further studying in the optimum level of Benecel MX emulsion (BM) and transglutaminase (TG).

Table 3. Physical properties of plant-based chicken meat from various ratios of hydrated pea protein isolate and young jackfruit

PPI*: YJ[/1]	**Color**			**Texture properties**	
	L*	**a*[ns]**	**b***	**Hardness (g_f)**	**Chewiness (g_f)**
25:50	52.89[c] ± 2.34	1.90 ± 0.18	10.33[c] ± 0.67	1878.54[a] ± 625.62	445.56[a] ± 324.74
20:55	56.79[b] ± 1.21	1.76 ± 0.04	10.83[b] ± 0.33	1643.30[b] ± 474.95	390.09[ab] ± 256.16
15:60	58.53[a] ± 1.19	1.76 ± 0.07	11.29[a] ± 0.16	1535.35[b] ± 457.84	364.67[b] ± 215.82

[a,b,c] Mean values in a column with different letters are significantly different ($p \leq .05$)
[ns] Mean values are not significantly different ($p > .05$)
[/1] PPI* = hydrated pea protein isolate, YJ = Young jackfruit

(A) (B) (C)

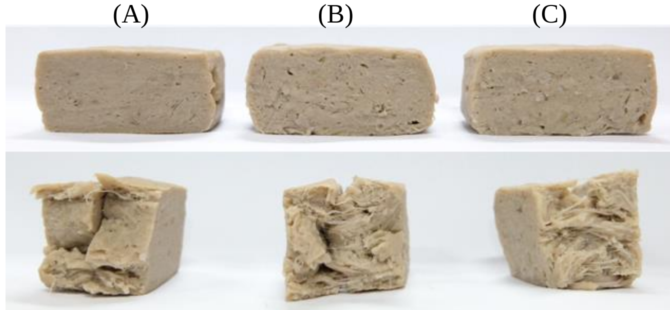

Figure 2. Plant-based chicken meat prepared from various ratios of hydrated pea protein isolate and young jackfruit when dissected (top) and shredded (bottom): (A) 25:50, (B) 20:55, and (C) 15:60 by weight

The image of plant-based chicken meat from various levels of BM and TG is presented in Fig. 3. It was found that the appearance of the plant-based chicken meat with an increased level of BM resulted in an increased lightness with reduced fiber characteristics but more fine fibers. While plant-based chicken meat with an increased level of TG content showed a reduction in lightness but an increase in firmness. The color of plant-based chicken meat from various levels of BM and TG is shown in Table 4. Plant-based chicken meat color values had significant differences ($p \leq 0.05$) on the L*, a*, and b*. The level of BM increased, increasing L* and a* values while b* decreased, and the level of TG increased, L* a* and b* values decreased. In addition, the texture properties of plant-based chicken meat from various levels of BM and TG (Table 5) had significant differences ($p \leq 0.05$) on the hardness and chewiness. The level of BM increased, increasing hardness and chewiness, and the level of TG increased, also resulting in an increase in hardness and chewiness. However, the 0.3% TG resulted in reduced hardness and chewiness. The texture properties (hardness and chewiness) of samples were used as criterior for selecting the plant-based chicken meat samples for sensory evaluation. The nine formulas of plant-based chicken meat were categorized into 4 groups as followings: group 1 (the sample with low hardness and moderate chewiness; 30BM), group 2 (the sample with low hardness and chewiness; 20BM, 20BM:0.15TG, and 20BM:0.30TG), group 3 (the sample with moderate hardness and chewiness; 40BM, 30BM:0.15TG, and 30BM:0.30TG), and group 4 (the sample with high hardness and chewiness; 40BM:0.15TG and 40BM:0.30TG). The formula with the middle values of hardness and chewiness in each group was chosen for sensory evaluation (30BM, 40BM, 20BM:0.15TG, and 40BM:0.15TG).

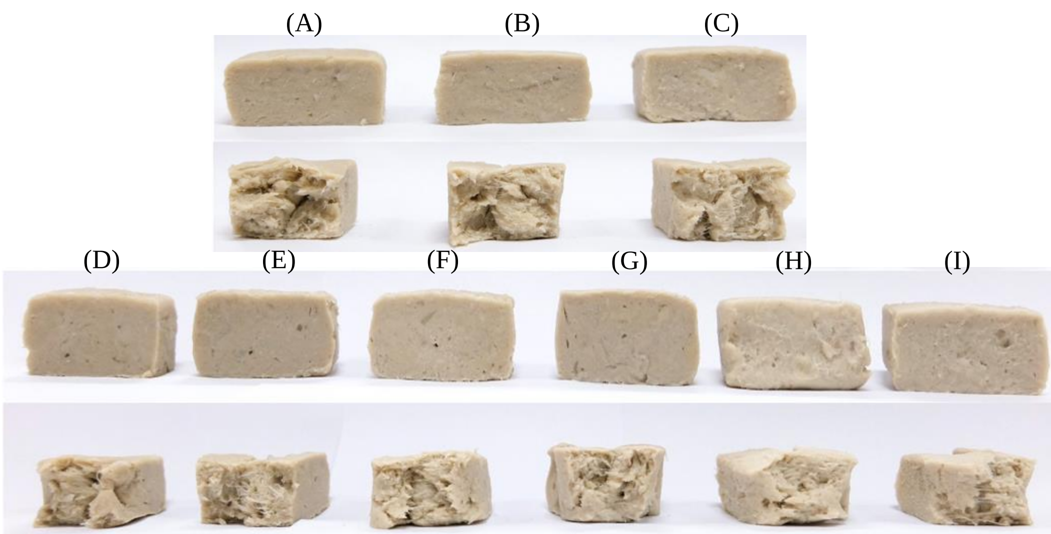

Figure 3. Plant-based chicken meat prepared from various percentage of methyl cellulose and transglutaminase when dissected (top) and shredded (bottom): (A) 20BM, (B) 30BM, (C) 40BM, (D) 20BM 0.15TG, (E) 20BM 0.30TG, (F) 30BM 0.15TG, (G) 30BM 0.30TG, (H) 40BM 0.15TG, and (I) 40BM 0.3TG. BM = benecel MX emulsion, TG = Transglutaminase

Table 4. Color of plant-based chicken meat from various level of methyl cellulose and transglutaminase

Sample[/1]	Color		
	L*	**a***	**b***
20BM	$60.65^{c} \pm 0.74$	$1.03^{b} \pm 0.21$	$13.10^{a} \pm 0.25$
30BM	$62.26^{b} \pm 0.81$	$1.31^{a} \pm 0.25$	$12.69^{b} \pm 0.42$
40BM	$64.18^{a} \pm 0.46$	$1.08^{b} \pm 0.22$	$12.31^{bc} \pm 0.28$
20BM 0.15TG	$58.63^{e} \pm 1.16$	$1.05^{b} \pm 0.17$	$12.24^{cd} \pm 0.59$
20BM 0.30TG	$57.55^{f} \pm 0.57$	$0.98^{b} \pm 0.10$	$11.86^{de} \pm 0.24$
30BM 0.15TG	$60.94^{c} \pm 0.32$	$0.88^{b} \pm 0.05$	$12.33^{bc} \pm 0.20$
30BM 0.30TG	$59.69^{d} \pm 1.18$	$1.01^{b} \pm 0.08$	$11.35^{fg} \pm 0.22$
40BM 0.15TG	$64.05^{a} \pm 0.58$	$0.95^{b} \pm 0.06$	$11.68^{ef} \pm 0.27$
40BM 0.30TG	$62.89^{b} \pm 0.21$	$0.91^{b} \pm 0.13$	$11.16^{h} \pm 0.26$

[a,b,c] Mean values in a column with different letters are significantly different ($p \leq .05$)
[/1] BM = Benecel MX emulsion, TG = Transglutaminase

Table 5. Texture properties of plant-based chicken meat from various level of methyl cellulose and transglutaminase

Sample[/1]	Texture properties	
	Hardness (g_f)	**Chewiness (g_f)**
20BM	$1465.35^{c} \pm 299.27$	$510.68^{ef} \pm 253.87$
30BM	$1393.00^{c} \pm 159.19$	$573.33^{de} \pm 239.89$
40BM	$1801.26^{b} \pm 271.66$	$864.40^{ab} \pm 150.06$
20BM 0.15TG	$1464.17^{c} \pm 226.11$	$388.82^{fg} \pm 99.03$
20BM 0.30TG	$1412.15^{c} \pm 143.34$	$370.84^{g} \pm 103.94$
30BM 0.15TG	$1837.86^{b} \pm 430.84$	$702.98^{cd} \pm 206.72$
30BM 0.30TG	$1777.06^{b} \pm 361.07$	$641.94^{cde} \pm 187.65$
40BM 0.15TG	$2053.82^{a} \pm 681.06$	$938.05^{a} \pm 296.60$
40BM 0.30TG	$1887.49^{ab} \pm 285.57$	$774.21^{bc} \pm 190.57$

[a,b,c] Mean values in a column with different letters are significantly different ($p \leq .05$)
[/1] BM = Benecel MX emulsion, TG = Transglutaminase

The sensory evaluation of plant-based chicken meat from different groups of texture characteristics is shown in Table 6. The sensory evaluation score showed no significant differences ($p > 0.05$) in appearance, fibrousness, and odor but significant differences ($p \leq 0.05$) in color, flavor, taste, and overall acceptability. The sample 40BM, which had moderate hardness and chewiness, received the highest overall acceptability score of 7.90 (like moderately to like very much). Therefore, the 40% BM without TG of plant-based chicken meat was chosen as the optimum formulation of gluten-free and soy-free plant-based chicken meat from young jackfruit to determine its nutritional value.

Table 6. Sensory evaluation of plant-based chicken meat from various level of methyl cellulose and transglutaminase

Attributes	Sample[/1]			
	30BM	**40BM**	**20BM 0.15TG**	**40BM 0.15TG**
Appearance ^{ns}	6.85 ± 1.18	6.72 ± 1.63	6.30 ± 1.55	6.80 ± 1.68
Fibrousness ^{ns}	6.62 ± 1.59	6.65 ± 1.47	6.07 ± 1.78	6.57 ± 1.75
Color	6.95^{ab} ± 1.78	7.55^{a} ± 1.10	6.77^{b} ± 1.86	7.12^{ab} ± 1.43
Odor ^{ns}	6.32 ± 1.83	6.22 ± 1.44	5.75 ± 1.86	6.35 ± 1.51
Flavor	6.32^{ab} ± 1.74	6.50^{a} ± 1.50	5.70^{b} ± 1.96	6.80^{a} ± 1.22
Taste	6.62^{a} ± 1.65	6.80^{a} ± 1.57	5.70^{b} ± 1.95	6.67^{a} ± 1.32
Overall acceptability	7.53^{ab} ± 0.97	7.90^{a} ± 1.03	7.00^{b} ± 1.23	7.57^{ab} ± 1.10

^{a,b,c} Mean values in a row with different letters are significantly different ($p \leq .05$)
^{ns} Mean values are not significantly different ($p > .05$)
[/1] BM = Benecel MX emulsion, TG = Transglutaminase

The optimum formulation of gluten-free and soy-free plant-based chicken meat from young jackfruit was used to determine its nutritional value. The nutritional value of gluten-free and soy-free plant-based chicken meat from young jackfruit is shown in Table 7. As a result, 100 g of plant-based chicken meat contains 72.4 g of moisture, 7.29 g of fat, 8 g of protein, 1.67 g of ash, and 10.6 g of total carbohydrate.

Table 7. Nutritional value of plant-based chicken meat from young jackfruit

Composition	gram per 100 gram
Moisture	72.4
Fat	7.29
Ash	1.67
Protein (N*6.25)	8.00
Total Carbohydrate	10.6

Discussion

The pea protein isolate hydrated from three levels of the ratio between pea protein isolate and water (1:0, 1:1, and 1:2 by weight) was investigated for their physical properties. The results revealed that the L* increased, but the b* and a* decreased as the water ratio increased because, generally, the PPI could be a natural colorant, making plant-based chicken meat a light yellow. In addition, PPI proteins are precursors to the maillard reaction. Therefore, when the ratio of water increased, the total solids to liquid content of the product decreases, resulting in a decrease in the maillard reaction that produces the brown compound, resulting in the L* increasing but the b* and a* decreasing. This finding was in accordance with Palanisamy *et al*. (2019) and do Carmo *et al*. (2021) in that the effect of increased feed water content caused the increase in the lightness of meat analogs. The hardness and chewiness decreased as the ratio of water increased because increased water content resulted in a loose and soft product. This finding was in accordance with Hamid *et al*. (2020) in that hardness and chewiness decreased as the YJ content in the formula increased. Additionally, Lin *et al.* (2000) reported that when the moisture content was increased, the hardness and chewiness of meat analogs decreased. The PPI:water ratio of 1:1 demonstrated more lightness than the PPI:water ratio of 1:0 and more firmness than the PPI:water ratio of 1:2, as well as clearly discernible jackfruit fibers. To determine the optimal ratio between hydrated PPI and YJ in plant-based chicken meat, the 1:1 ratio of PPI to water was therefore chosen for further investigation. The ratio of hydrated PPI to YJ in the plant-based chicken meat formula was varied to three different weight ratios of 25:50, 20:55, and 15:60. The physical properties of the different ratios of plant-based chicken meat were subsequently investigated. The results revealed that the L* and b* increased as the ratio of YJ increased. This can be explained by the fact that the young jackfruit used in the experiment has a white color that caused an increase in the L* value. In terms of texture properties, the hardness and chewiness decreased with decreasing PPI content and increasing YJ. In general, PPI in plant-based meat has the role of forming a complex, three-dimensional gel network in which fine particles of emulsified meat are trapped, using the starch and non-meat protein as a filler (Farooq and Boye, 2011), resulting in higher values of textural properties. So, the decrease in hardness and chewiness of plant-based chicken meat was because of the low content of PPI. In addition, as the ratio of YJ increased, the hardness and chewiness decreased because YJ is a dietary fiber that effects the association of protein chains association during gelation by anionic groups (-OH) on the surface of the dietary fiber, which decreases protein-protein interaction, led to less stable network structure with decreased textural properties results from the low hydrophobic interaction (Noh *et al*., 2005). This finding was in accordance with Hamid *et al*. (2020) in that hardness and chewiness decreased as the YJ content in the formula increased. In terms of visual characteristics, there was no difference in the color. When considering the characteristics of the fibers and texture properties, it was found that the ratio of hydrated PPI:YJ of 25:50 showed less fiber and highest firmness, the ratio of hydrated PPI:YJ of 20:55 showed more fiber and moderate firmness, and the ratio of hydrated PPI:YJ of 15:60 showed the most fiber but least firmness. By ideal plant-based chicken meat should really be firm and have the appearance of fibers when shredded. Therefore, the ratio of hydrated PPI:YJ of 20:55 was chosen for further studying in the optimum percentages of Benecel MX emulsion (BM) and transglutaminase (TG).

The mixed texturing agents from three percentage ratios of BM (20%, 30%, 40%) and TG (0%, 0.15%, 0.3%) were investigated for the texture enhancement of plant-based chicken meat. The image of plant-based chicken meat from various levels of BM and TG exhibited that the plant-based chicken meat with an increased level of BM resulted in an increased lightness with reduced fiber characteristics but more fine fibers. While the plant-based chicken meat has an increased TG content, resulting in a decreased lightness but increased firmness. The measurement of physical properties revealed that increasing the BM level resulted in higher L* and a* values while decreasing b* because the BM used in plant-based chicken meat preparation had a whiteness that promotes an increase in L* value. In contrast, the level of TG increased, L* a* and b* values decreased. This may be because a high level of TG catalyzed a higher amount of cross-linking reactions of proteins, causing tighter and denser structure proteins (Chareonthaikij *et al*., 2018) that had opaque characteristics. The texture properties of plant-based chicken meat from various levels of BM and TG revealed that the hardness and chewiness increased as the percentage of BM increased. This can be explained by the fact that methylcellulose used in combination with plant protein and plant-based ingredients gives a very firm texture because hydroxyl groups engage in extensive hydrogen bonding. (Spelzini *et al*. 2005). Bakhsh *et al*. (2021) also reported that increasing the concentration of methylcellulose proportionally increased the hardness and chewiness of the product. Accordingly, the hardness and chewiness increased as the percentage of TG increased because TG can be used to improve protein binding by catalyzing the formation of covalent bonds (glutamyl-lysine bonds) cross-linking glutamine (Gln) and lysine (Lys) residues (Ikura *et al*., 1981), resulting in a firm network structure (Gómez *et al*., 2020). However, at the highest BM (40%), the chewiness value was significantly decreased ($p \leq 0.05$) when the level of TG was increased from 0.15% to 0.3%. It could be that the addition of excessitive TG (0.3%) catalyze was not conducive to molecular rearrangement (Qin *et al*., 2022). When selecting the samples of plant-based chicken meat for sensory evaluation, the textural characteristics (hardness and chewiness) were taken into account. The nine formulas of plant-based chicken meat were categorized into 4 groups as followings: group 1 (the sample with low hardness and moderate chewiness; 30BM), group 2 (the sample with low hardness and chewiness; 20BM, 20BM:0.15TG, and 20BM:0.30TG), group 3 (the sample with moderate hardness and chewiness; 40BM, 30BM:0.15TG, and 30BM:0.30TG), and group 4 (the sample with high hardness and chewiness; 40BM:0.15TG and 40BM:0.30TG). The formula with the middle values of hardness chewiness in each group was chosen for sensory evaluation was chosen for sensory evaluation (30BM, 40BM, 20BM:0.15TG, and 40BM:0.15TG).

The sensory evaluation results of plant-based chicken meat from different groups of texture characteristics revealed that the sensory score showed no significant differences ($p > 0.05$) in appearance, fibrousness, and odor but significant differences ($p \leq 0.05$) in color, flavor, taste, and overall acceptability. The sample 40BM, which had moderate hardness and chewiness, received the highest overall acceptability score of 7.90 (like moderately to like very much). Therefore, the 40% BM without TG of plant-based chicken meat was chosen to the optimal formulation of gluten-free and soy-free plant-based chicken meat from young jackfruit to determine the nutritional value.

The nutritional value of gluten-free and soy-free plant-based chicken meat from young jackfruit in 100 g of plant-based chicken meat contains 72.4 g of moisture, 7.29 g fat, 8 g of protein, 1.67 g of ash, and 10.6 g of total carbohydrate.

In summary, the optimum formulation for producing gluten-free and soy-free plant-based chicken meat was found to be hydrated pea protein isolate and young jackfruit at a ratio of 20:55 by weight and hydrated pea protein isolate from pea protein isolate and water at a ratio of 1:1 by weight. The suitable level for texture enhancement by 40% BM without TG resulted in a plant-based chicken meat product that had the highest overall acceptability from sensory evaluation.

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References

Andina Ingham (2015). Methylcellulose in plant-based meat alternatives? To use or not to use. Retrieved from https://www.andina-ingham.co.uk/methylcellulose-in-plant-based-meat-alternatives-to-use-or-not-to-use/

AP Food Online (2019). The Pulse of Pea Protein. Retrieved from https://www.apfoodonline.com/industry/the-pulse-of-pea-protein/

AOAC (2019). Official Methods of Analysis of the Association of Official Analytical Chemists. 21st Edition. Official Methods of Analysis of AOAC International, Washington, DC, UAS.

Bakhsh, A., Lee, S. J., Lee, E. Y., Sabikun, N., Hwang, Y. H. and Joo, S. T. (2021). A Novel Approach for Tuning the Physicochemical, Textural, and Sensory Characteristics of Plant-Based Meat Analogs with Different Levels of Methylcellulose Concentration. Foods, 10:560.

Chareonthaikij, P., Srilarp, J., Winnavoravej, N. W., Uan-On, T., Torrico, D. D. and Phitchayaphon, C. (2018). Effects of Transglutaminase and Kappa-carrageenan on the Physical and Sensory

Qualities of Fish (*Pangasius hypophthalmus*). Current Journal of Applied Science and Technology, 18:12-23.

Chiang, J. H., Tay, W., Ong, D. S. M., Liebl, D., Ng, C. P. and Henry, C. J. (2021). Physicochemical, textural, and structural characteristics of wheat gluten-soy protein composited meat analogues prepared with the mechanical elongation method. Food Structure, 28:2213-3291.

do Carmo, C. S., Knutsen, S. H., Malizia, G., Dessev, T., Geny, A., Zobel, H., Myhrer, K. S., Varela, P. and Sahlstom, S. (2021). Meat analogues from a faba bean concentrate can be generated by high moisture extrusion. Future Foods, 3:100014.

Farooq, Z. and Boye, J. (2011). Novel Food and Industrial Applications of Pulse Flours and Fractions. In: Pulse Foods Processing, Quality and Nutraceutical Applications, pp.283-323.

Gómez, I., Janardhanan, R., Ibañez, F. C. and Beriain, M. J. (2020). The Effects of Processing and Preservation Technologies on Meat Quality: Sensory and Nutritional Aspects. Foods, 9:1416.

Hamid, M. A., Tsia, F. L. C., Okit, A. A. B., Xin, C. W., Cien, H. H., Harn, L. S., Patrick, P. N., Samirin, S., Azizi, W. A. A. W., Irfanian, A. and Yee, C. F. (2020). The application of Jackfruit by-product on the development of healthy meat analogue. IOP Conference Series: Earth and Environmental Science, 574:012001.

Ikura, K., Yoshikawa, M., Sasaki, R. and Chiba, H. (1981). Incorporation of amino acids into food proteins by transglutaminase. Agricultural and Biological Chemistry, 45:2587-2592.

Imm, J. Y. and Lian, P. (2000). Gelation and Water Binding Properties of Transglutaminase-treated Skim Milk Powder. Journal of Food Science, 65:200-205.

Lam, A. C. Y., Can Karaca, A., Tyler, R. T. and Nickerson, M. T. (2018). Pea protein isolates: structure, extraction, and functionality. Food Reviews International, 34:126-147.

Lin, S., Huff, H. E. and Hsieh, F. (2000). Texture and chemical characteristics of soy protein meat analog extruded at high moisture. Journal of Agricultural and Food Chemistry, 65:264-269.

Noh, E. J., Park, S. Y., Pak, J. I., Hong, S. T. and Yun, S. E. (2005). Coagulation of soymilk and quality of tofu as affected by freeze treatment of soybeans. Food Chemistry, 91:715-721.

Palanisamy, M., Franke, K., Berger, R. G., Heinz, V. and Töpfl, S. (2019). High moisture extrusion of lupin protein: influence of extrusion parameters on extruder responses and product properties. Journal of the Science of Food and Agriculture, 99:2175-2185.

Qin, J., Zhao, Y., Zhou, J., Zhang, G., Li, J. and Liu, X. (2022). Rheological properties of transglutaminase-treated concentrated pea protein under conditions relevant to high-moisture extrusion processing. Frontiers in Nutrition, 9:970010.

Saxena, A., Bawa, A. and Raju, S. P. (2011). Jackfruit (*Artocarpus heterophyllus* Lam.). Postharvest Biology and Technology of Tropical and Subtropical Fruits. In: Cocona to Mango, pp.275-298.

Shapiro, R. (1995). Nutrition Labeling Handbook. Marcel Dekker, Inc. New York.

Spelzini, D., Rigatusso, R., Farruggia, B. and Picó, G. (2005). Thermal Aggregation of Methyl Cellulose in Aqueous Solution: A Thermodynamic Study and Protein Partitioning Behaviour. Cellulose, 12:293-304.

Swami, S. B., Thakor, N. J., Haldankar, P. M. and Kalse, S. B. (2012). Jackfruit and its many functional components as related to human health: a review. Comprehensive Reviews in Food Science and Food Safety, 11:565-576.

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