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Research article

Effect of young jackfruit, wheat gluten and soy protein isolate on physicochemical properties of chicken meat analogs

Tanwarat Taikerd[a,†], **Bootsrapa Leelawat**[a,b,†,*]

[a] Department of Food Science and Technology, Faculty of Science and Technology, Thammasat University, Pathum Thani 12120, Thailand

[b] Thammasat University Center of Excellence in Food Science and Innovation, Pathum Thani 12120, Thailand

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Abstract

Importance of the work: Young jackfruit (*Artocarpus heterophyllus*) is a raw material that is increasingly used in plant-based meat products because of its fiber-like texture.
Objectives: To investigate the effect of young jackfruit, wheat gluten and soy protein isolate on the physicochemical properties of chicken meat analogs.
Materials & Methods: The seven formulas of chicken meat analogs were created using mixture design. The effect was investigated of three independent variables—30–50% young jackfruit (YJ), 10–15% wheat gluten (WG) and 1–2% soy protein isolate (SPI)—on the physicochemical properties of the chicken meat analogs.
Results: The chicken meat analog with a high level of YJ had a higher moisture content and brightness value, whereas hardness, chewiness and shear force had lower values. The shear force and integrity index were higher with higher concentrations of WG. Hardness and chewiness were higher with higher levels of SPI. Compared to mock chicken and steamed chicken, the chicken meat analogs had lower hardness, chewiness and shear force. The microstructure of the analog sample with a high level of YJ exhibited fiber-like characteristics and contained some pores between the fiber strands. The analog samples with high amounts of SPI displayed a dense structure with no layers, in contrast to the analog samples with high levels of WG, which displayed layered structures. The sensory evaluation results revealed that 40.64% YJ, 20.32% WG and 1.35% SPI received the highest overall acceptability score.
Main finding: Young jackfruit improved the microstructure of chicken meat analogs and provided better texture characteristics exhibiting anisotropic (layered or fibrous) structures when used in combination with wheat gluten and soy protein isolate.

† Equal contribution.
* Corresponding author.
E-mail address: leelawat@tu.ac.th (B. Leelawat)

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Introduction

Meat analogs are plant-based food products that resemble meat in terms of flavor, texture, and appearance; they are increasing being used due to the increase in world population and changes in consumer behavior nowadays, with people being more concerned about their health, environmental effects and animal welfare issues, including limitations based on religion (Apostolidis and Mcleay, 2016). The consumer's expectation of flavor and texture that are similar to real meat presents the biggest challenge in the production of meat analog products (Asgar et al., 2010).

Meat analogs can be produced by a variety of methods that involve the rearrangement of protein fibers to produce textures and structures similar to meat. Common and modern approaches include extrusion, freeze structuring, shear cell technology, mixing of proteins and hydrocolloids (Dekkers et al., 2018a), and the use of a texture-improving agent such as methylcellulose (Bakhsh et al., 2021) and transglutaminase.

Numerous studies have investigated the effect of components on the characteristics of meat analog products. Most often protein isolate has been used in various combinations such as wheat gluten (Schreuders et al., 2019), soy protein concentrate (Grabowska et al., 2016), soy protein concentrate combined with wheat gluten (Chiang et al., 2019), soy protein isolate combined with wheat gluten (Grabowska et al., 2014; Dekkers et al., 2018b), and soy protein isolate combined with pectin (Dekkers et al., 2016).

Jackfruit (*Artocarpus heterophyllus*) is a popular fruit planted by farmers because as a fruit tree that is easy to grow, there is no need for a large amount of land or water for cultivation and it tolerates drought conditions well (Posomboon, 2015). Therefore, jackfruit can be grown widely in Thailand. In the harvesting process, the unripe fruit must be sorted out to obtain the desired size of ripe jackfruit, resulting in young jackfruit as a by-product that is primarily used as an ingredient in cooking, such as jackfruit curry (Lakshmana et al., 2013).

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 that can be dispersed into a continuous phase (mostly consisting of proteins), which causes the fibrousness characteristic in products, making it easy to add flavor to the desired end product (Workman, 2020). In addition, it is a plant rich in fiber and essential nutrients, such as vitamin B6, vitamin C and potassium (Swami et al., 2012). For the reasons already mentioned, young jackfruit could be more widely used in the meat substitute industry.

Therefore, this research aimed to study the effect of components on the physicochemical properties of chicken meat analog products containing jackfruit in combination with the use of gluten and soy protein isolate. A secondary aim was to use the experimental results as guidelines for further development of chicken meat analogs and for the use of young jackfruit as the main raw material in meat analog products to help minimize productivity loss and add value to local raw materials.

Materials and Methods

Materials

The young jackfruits (*Artocarpus heterophyllus* cv. Malaysia, YJ) used in this study were purchased from Talaad Thai market at Khlong Luang, Pathum Thani, Thailand. Wheat gluten (WG) and soy protein isolate (SPI) were obtained from Krungthepchemi Co. Ltd. (Thailand) and disodium 5-ribonucleotide from Gloden Interbiz Co. Ltd; (Thailand). All-purpose flour, canola oil, salt, and onion powder were purchased from a local market in Pathum Thani, Thailand, transglutaminase enzyme (ProtiAct® TG-AK) from Rama Production Co. Ltd; (Thailand) and methylcellulose (Benecel™ MX modified cellulose, Ashland) from Questex Co. Ltd; (Thailand).

Preparation of young jackfruit

The young jackfruit samples were cleaned and boiled at 100 °C for 30 min; then the core was removed and the juice squeezed out using a hand squeezer before drying the fruit at 60 °C for 2 h until it reached 75±2% moisture content before being used in the preparation of chicken meat analog samples.

Preparation of chicken meat analog samples

Seven different chicken meat analog formulations were investigated using the simplex-centroid mixture design. The three components consisted of 30–50% young jackfruit (YJ, X_1), 10–15% wheat gluten (WG, X_2) and 1–2% soy protein isolate (SPI, X_3), as shown in Table 1. The three components were controlled to have a total amount of 62.31%, with the other ingredients–water, methylcellulose emulsion,

Table 1 Simplex-centroid coded design for chicken meat analogue production from young jackfruit, wheat gluten and soy protein isolate

Formula	Variable level		
	Young jackfruit (X_1)	Wheat gluten (X_2)	Soy protein isolate (X_3)
1	1	0	0
2	0	1	0
3	0	0	1
4	0.3	0.3	0.3
5	0.5	0.5	0
6	0	0.5	0.5
7	0.5	0	0.5

transglutaminase, all-purpose flour, canola oil, seasonings (salt, onion powder and disodium 5-ribonucleotide) being kept constant. The chicken meat analog sample preparation method used in this research was modified from Full of Plants Tasty Vegan Recipes (2021). First, all components used were weighed according to the formulation. The SPI was hydrated in water and blended with a methylcellulose emulsion, canola oil, salt and onion powder in a food processor (Tefal; DO821; China) at speed 2 for 1 min. The ingredients were transferred to the bowl of the stand mixer (KitchenAid; 5KSM150ER; USA), and YJ was added and mixed using a flat beater at speed 5 for 5 min. Then, the wheat gluten, all-purpose flour and transglutaminase were added and mixed using a flat beater at speed 5 for 5 min, followed by mixing using a dough hook at speed 5 for 30 min. The finished dough was placed in a silicone mold (5 cm × 5 cm × 2.5 cm) and frozen at -18 °C for 24 h, followed by steaming in an electric steamer (Tefal; VC145130; China) at 75 °C for 30 min. The sample was allowed to cool for 5 min and subsequently stored in a chilled room at 4±2 °C prior to further analysis.

The methylcellulose emulsion was prepared by blending 8% methylcellulose powder, 11% canola oil and 81% cold water (approximately 4 °C) in a food processor (Tefal; DO821; China) at speed 2 for 1 min.

Preparation of control samples

Samples of commercially available mock chicken and steamed chicken were used as reference samples. Mock chicken (Veggie SPA half chicken from Nutrition House Co. Ltd; Thailand) consisted of 80% soy protein, 10% seasoning and 10% vegetable oil. Chicken breast was prepared by steaming in an electric steamer (Tefal; VC145130; China) at 75 °C for 30 min and then cooled for 5 min and stored in a chilled room at 4 ± 2 °C prior to further analysis (Chiang et al., 2021).

Moisture content

The moisture content of the chicken meat analog samples, mock chicken and steamed chicken were determined using the hot-air oven method (Association of Official Analytical Chemists, 2000).

Color

The color of the chicken meat analog samples, mock chicken and steamed chicken were measured using a colorimeter (Hunter Lab; Colorflex45/0; USA). The color was determined according to the CIELAB system as L* (100 = white; 0 = black), a* (+, redness; -, greenness) and b* (+, yellowness; -, blueness). Each experiment was replicated three times. The browning index (BI) was calculated as: $BI = [100 \times (x - 0.31)] / 0.172$, where $x = (a^* + 1.75L^*) / (5.645L^* + a^* - 0.312b^*)$, according to Subhashree et al. (2017).

Texture properties

Texture profile analysis

The texture of chicken meat analog samples, mock chicken and steamed chicken were performed based on texture profile analysis (TPA, Chiang et al., 2021) using a texture analyzer TA-XTplusC (Stable Micro Systems; UK) equipped with a P/50 cylinder probe. Samples were cut into dimensions of 15 mm × 15 mm × 10 mm and compressed using the probe 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 and trigger force of 5 g. Hardness and chewiness were obtained from the TPA curves for each sample.

Shear force

The shear force of the chicken meat analog samples, mock chicken and steamed chicken were performed using a Texture Analyzer TA-XTplusC (Stable Micro Systems; UK) equipped with a Warner-Bratzler blade as described by Sreeitthiyawet (2019) with modifications. Samples with dimensions of 15 mm × 15 mm × 10 mm were evaluated at a speed of 20 mm/min.

Integrity index

The integrity index of the chicken meat analog samples, mock chicken and steamed chicken was adapted from the procedure of Samard et al. (2019). Each sample was weighed at 5 g (dry basis), soaked in 100 mL of distilled water and placed in an autoclave (Tomy; SX-700; Japan) at 121 °C for 30 min. The autoclaved sample was drained on a 20-mesh sieve, cooled rapidly with tap water for 30 s and transferred to a 200 mL beaker, where it was suspended in 100 mL distilled water and processed using a homogenizer (Ystral; Laboratory Series X40; Germany) at 16,000 revolutions per minute for 1 min. Then, the sample was filtered through a 20-mesh sieve and product remaining on the sieve was dried at 105 °C until it reached equilibrium. The integrity index (in grams per kilogram) was calculated as integrity index = (weight of dry residue / weight of sample) × 1,000, where both weights were measured in grams.

Scanning electron microscopy

Each sample was cut into a piece of 0.5 cm × 0.5 cm × 1 cm (width × length × thickness) for observation and chemically fixed by immersion in 2.5% glutaraldehyde in 0.1 M phosphate buffer at pH 7.2 overnight in the refrigerator. The solution with phosphate buffer was rinsed twice, followed by distilled water once, (10–15 min each time). After washing with distilled water, the samples were dehydrated using a series of ethanol solutions at different concentrations (30%, 50%, 70%, 95%, and 100%) for 15 min each time. Samples were dried at a critical point using a critical point dryer (Leica; EM CPD300; Austria). Each dried sample was mounted onto a stub with double-sided tape and sputter-coated with gold (Balzers sputter coater; SCD 040; Germany). Finally, the samples were observed using a scanning electron microscope (JSM-IT500 HR; JEOL; Japan) operating at 10 kV. Micrographs of samples were taken at 500× and 2,000× magnifications.

Sensory evaluation

The chicken meat analog samples were selected based on a different group of texture characteristics (hardness and chewiness) for sensory evaluation by 50 panelists. Samples (15 mm × 15 mm × 20 mm) were assessed by asking the panelists to rate the liking of quality attributes according to appearance, fibrousness, color, flavor, taste, texture and overall acceptability using a 9-point hedonic scale (1 = dislike extremely to 9 = like extremely). A three-digit code number was assigned to each sample and water was served to each panelist between the samples to be tested.

Statistical analysis

A randomized complete block design was performed for physicochemical analysis and sensory testing. Each result was reported as mean ± SD. Analysis of variance and statistical differences were analyzed using Duncan's new multiple range test method at the significance level of $p < 0.05$ with the SPSS for Windows software (version 24; SPSS Inc; USA).

Ethics statements

This study was approved by the Ethics Committee of Thammasat University (Approval no. 099/2565).

Results and Discussion

Macrostructural

Images of the chicken meat analogs with different formulations, mock chicken and steamed chicken are presented in Fig. 1. The inner surfaces the samples were inspected and the observed characteristics of chicken meat analog samples differed by varying the level of the composition following the mixture design. Among the seven chicken meat analogs, the sample with the highest level of YJ (Fig. 1A) showed soft and moist characteristics, containing more pores. The sample containing the highest level of WG (Fig. 1B) displayed dense, streaky and layered characteristics. The sample with the highest level of SPI (Fig. 1C) was smooth with no layers. The mock chicken (Fig. 1H) had a dense structure with no pores, whereas the steamed chicken (Fig. 1J) had a layer of muscle fibers.

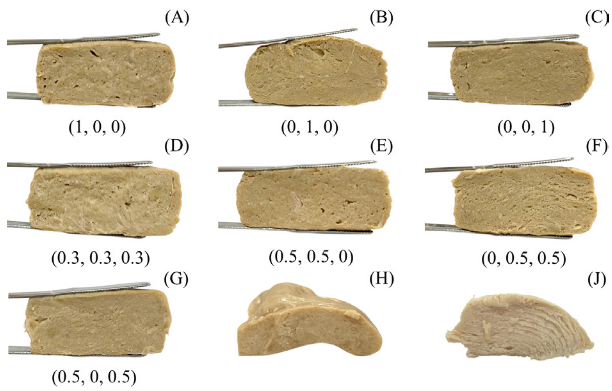

Fig. 1 Visual observation of chicken meat analogs with different formulations: (A–G) formulas 1–7 respectively; (H) mock chicken; (J) steamed chicken, where three bracketed amounts represent levels of YJ, WG and SPI, respectively

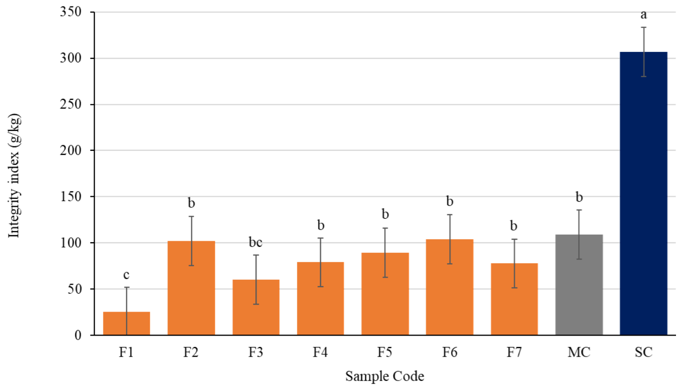

Fig. 2 Integrity index of chicken meat analogs with different formulations, where F1–F7= formulas 1–7 respectively (See Table 1 for more details); MC = mock chicken; SC = steamed chicken; data are presented as means and error bars represent SD; different lowercase letters on each bar indicate significant ($p < 0.05$) differences

Moisture content

The moisture contents of the chicken meat analogs with different formulations, mock chicken and steamed chicken are shown in Table 2. The moisture contents of the chicken meat analogs with different formulations were in the range 74.76–65.82%, which was more than for the mock chicken. The levels of YJ, WG and SPI had significant effects on the moisture content of the chicken meat analogs. The chicken meat analogs in samples F2 and F6 were not significantly different compared to steamed chicken. From the response contour plot (Fig. 3A), when the level of YJ increased, the moisture content of the chicken meat analog also increased. This could have been the result of YJ having the highest moisture content compared to the other products. An increase in WG resulted in a decrease in the moisture content of the analogs. This may have been due to WG having a lower water binding capacity compared to SPI (Peters et al., 2017), making free water in the lattice of the protein network more prone to syneresis. For the chicken meat analogs, an increased level of SPI resulted in less change in the moisture content compared to WG. Roccia et al. (2009) observed the same results for a mixture of SPI and WG, where syneresis increased with WG addition, while the mixture with the added SPI substitution showed decreased syneresis.

Table 2 Moisture content of chicken meat analogs with different formulation, mock chicken and steamed chicken

Sample	Variable level			Moisture content (%)
	X_1	X_2	X_3	
F1	1	0	0	74.76±0.61^{a}
F2	0	1	0	65.82±0.82^{e}
F3	0	0	1	68.38±1.21^{d}
F4	0.3	0.3	0.3	69.76±0.59^{c}
F5	0.5	0.5	0	70.57±0.33^{c}
F6	0	0.5	0.5	67.04±0.55^{e}
F7	0.5	0	0.5	72.74±0.71^{b}
Mock chicken				55.29±1.97^{f}
steamed chicken				66.86±1.54^{e}

F = Formula (see Table 1 for more details); X_1 = young jackfruit; X_2 = wheat gluten; X_3 = soy protein isolate.
Mean values (± SD) in each column with different lowercase superscript letters are significantly ($p < 0.05$) different.

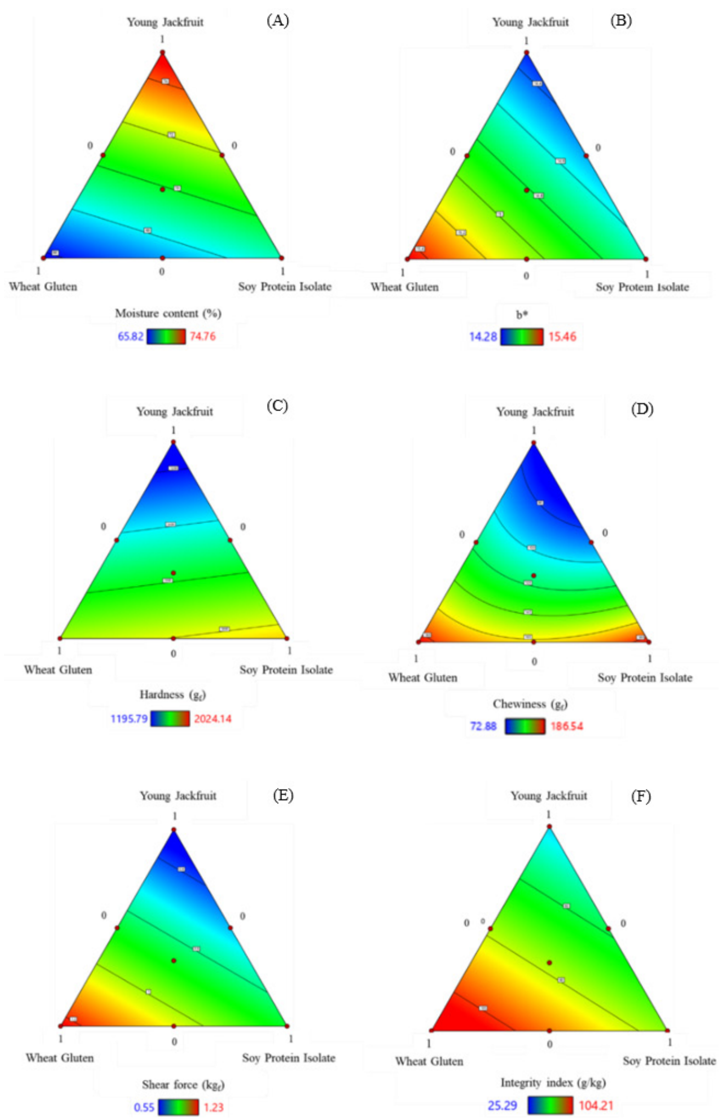

Fig. 3 Response contour plot showing effect of YJ (X_1), WG (X_2) and SPI (X_3) on: (A) moisture content; (B) b*; (C) hardness; (D) chewiness; (E) shear force; (F) integrity index, where g_f = gram force and kg_f = kilogram force

Color and browning index

The color and browning index of chicken meat analogs with different formulations, mock chicken and steamed chicken are shown in Table 3. The color values of the chicken meat analogs with different formulations had lightness (L*) values in the range 56.09–59.01, greenness–redness (a*) values in the range 2.47–2.87 and blueness–yellowness (b*) values in the range 14.28–15.46. BI, defined as brown color purity, is one of the most common indicators of browning reactions (Lunadei et al., 2011). The BI values of the chicken meat analogs were in the range 30.86–33.75. The levels of YJ, WG and SPI had significant effects on the b* value and a lesser (but still significant) effect on the L* values of the chicken meat analogs, while there were no significant effects on the a* and browning index of the chicken meat analogs. Compared to the mock chicken and steamed chicken, the integrity index and color values (L*, a*, and b*) of the chicken meat analogs differed significantly. Among the seven formulas of chicken meat analogs, the sample F1 had the highest L* and the lowest browning index values which corresponded to its high moisture content, as shown in Table 2. This finding was in accordance with Palanisamy et al. (2019), Zhang (2020) and do Carmo et al. (2021) in that the effect of increased feed water content caused the increase in the lightness of the meat analogs, indicating that moisture content affected the browning reactions (Palanisamy et al., 2019). From the response contour plot (Fig. 3B), as the level of YJ increased, the b* value decreased because the high moisture content of YJ resulted in a decrease in the total solids-to-liquid content of the product, leading to a decrease in the Maillard reaction that produces the brown pigments, called melanoidins (brown compound) (Kumar et al., 2017). In contrast, as the WG level increased, the b* value increased, and likewise, as the SPI levels increased, the b* value increased slightly. This may have been due to a higher proportion of WG proteins than SPI in the recipe, although the experimental design indicated that the level of SPI was as high as the level of WG (Table 1). However, the highest percentage in the study range of SPI was only 2% which was approximately 10 times lower than the highest WG content (15%). Thus, WG can lead to a greater browning reaction than SPI, (an increase in WG had a greater effect on b* than an increase in SPI). This could indicate that the browning reactions of chicken meat analogs were promoted by WG.

Textural properties

The textural properties of the chicken meat analogs with different formulations, mock chicken and steamed chicken are shown in Table 4. The textural properties of the chicken meat analogs were based on TPA. The results indicated that hardness was in the range 1,195.79–2,024.14 gram force (g_f) and chewiness was in range 72.88–186.54 g_f. The levels of YJ, WG and SPI had significant effects on the hardness and chewiness of the chicken meat analogs. The hardness and chewiness of chicken meat analogs were significantly different to the mock chicken and steamed chicken, except for the chewiness of the samples F2, F3 and F6, which were not significantly different to steamed chicken. Fig. 3C shows that as the level of SPI increased, the hardness greatly increased, compared to the level of WG, due to SPI forming firm, hard, brittle and resilient gels (Chiang et al., 2021). Fig. 3D shows that as the level of SPI and WG increased, the chewiness increased, where the percentage proportion of SPI in the formulation of the chicken meat analogs was less than for WG. It can be concluded that SPI had a greater effect on chewiness than WG. In addition, Chiang et al. (2021) reported that the hardness and chewiness of the chicken meat analogs increased as

Table 3 Color and browning index of chicken meat analogs with different formulation, mock chicken and steamed chicken

Sample	Variable level			Color			Browning index
	X_1	X_2	X_3	L*	a*	b*	
F1	1	0	0	59.01±3.09^{c}	2.87±0.46^{b}	14.44±0.16^{d}	30.86±2.53^{b}
F2	0	1	0	57.66±3.22^{cd}	2.59±0.65^{b}	15.46±0.65^{b}	33.75±4.41^{b}
F3	0	0	1	56.09±2.49^{d}	2.49±0.55^{b}	14.71±0.26^{cd}	32.78±2.21^{b}
F4	0.3	0.3	0.3	57.70±1.09^{cd}	2.51±0.38^{b}	14.84±0.33^{bcd}	31.98±0.68^{b}
F5	0.5	0.5	0	57.08±2.07^{cd}	2.56±0.62^{b}	14.83±0.17^{bcd}	32.49±2.16^{b}
F6	0	0.5	0.5	56.53±2.71^{d}	2.53±0.68^{b}	15.13±0.27^{bc}	33.57±3.25^{b}
F7	0.5	0	0.5	57.12±1.50^{cd}	2.47±0.59^{b}	14.28±0.34^{de}	31.02±1.19^{b}
Mock chicken				61.68±2.67^{b}	3.88±0.27^{a}	18.36±0.92^{a}	39.01±4.05^{a}
Steamed chicken				73.80±1.42^{a}	0.08±0.39^{c}	13.70±0.83^{e}	19.91±1.63^{c}

F = Formula (see Table 1 for more details); X_1 = young jackfruit; X_2 = wheat gluten; X_3 = soy protein isolate.
Mean values (± SD) in each column with different lowercase superscript letters are significantly ($p < 0.05$) different.

Table 4 Textural properties of chicken meat analogs with different formulation, mock chicken and steamed chicken

Sample	Variable level			Textural property		
	X_1	X_2	X_3	Hardness (g)	Chewiness (g)	Shear force (kg)
F1	1	0	0	1195.79±179.35[e]	72.88±34.61[c]	0.55±0.05[e]
F2	0	1	0	1716.58±243.26[bcd]	186.54±39.37[b]	1.23±0.13[c]
F3	0	0	1	2024.14±430.79[b]	186.34±62.57[b]	0.84±0.13[d]
F4	0.3	0.3	0.3	1433.99±208.78[de]	114.46±52.03[c]	0.81±0.11[d]
F5	0.5	0.5	0	1575.57±239.64[cd]	116.12±52.49[c]	0.81±0.12[d]
F6	0	0.5	0.5	1810.11±266.77[bc]	161.90±20.18[b]	1.15±0.17[c]
F7	0.5	0	0.5	1219.02±170.09[e]	86.85±43.23[c]	0.66±0.09[de]
Mock chicken				3667.71±683.33[a]	263.23±137.51[a]	2.22±0.40[b]
steamed chicken				3454.93±897.86[a]	184.52±130.05[b]	2.64±0.92[a]

F = Formula (see Table 1 for more details); X_1 = young jackfruit; X_2 = wheat gluten; X_3 = soy protein isolate.
Mean values (± SD) in each column with different lowercase superscript letters are significantly ($p < 0.05$) different.

the ratio of SPI increased. It was found that the hardness and chewiness values of the samples F1 and F7 were lower than in the other formulas, as these two samples had high moisture contents (Table 2). *T*he high level of YJ compared to the other formulas was consistent with Figs. 3C and 3D, showing that as the level of YJ increased, the hardness and chewiness decreased because the high moisture content of YJ resulted in a loose and soft product that did not provide much resistance in the compression test. This finding was in accordance with Hamid et al. (2020) that hardness and chewiness decreased as the YJ content in the formula increased. Additionally, Lin et al. (2000) reported that when the moisture content decreased, the hardness and chewiness of meat analogs increased. In the current study, the shear force values of the chicken meat analogs with different formulations were in the range 0.55–1.23 kilogram force (kg_f). The levels of YJ, WG and SPI had significant effects on the shear force values of the chicken meat analogs. The shear force values of the chicken meat analogs were significantly different to the mock chicken and steamed chicken. Fig. 3E shows that as the levels of WG increased, the shear force also increased. This could be explained by the fact that WG has the ability to form a cohesive, viscoelastic network linked by both intra-and intermolecular disulfide bonds (Wieser, 2007). As a result, the chicken meat analogs had toughness, elasticity and resistance to the blade's cutting shear forces.

Integrity index

The integrity index refers to the residue texture after the meat analogs had been hydrated, autoclaved, homogenized and dried (Samard et al., 2019). The integrity index values of the chicken meat analogs with different formulations, mock chicken and steamed chicken are shown in Fig. 2. The integrity index values of the chicken meat analogs were in the range 25.29–104.21 g/kg. The levels of the three components (YJ, WG and SPI) had no significant effects on the integrity index values of the chicken meat analogs, except for sample F1. Steamed chicken had the highest integrity index, while the samples F2 and F6 of chicken meat analogs had higher integrity index values than the other chicken meat analog formulas. The response contour plots showed the effect of YJ, WG and SPI on the integrity index (Fig. 3F). When the level of YJ increased, the integrity index decreased, whereas when the level of WG increased, the integrity index increased. The effect of WG was more influential than SPI due to the unique ability of WG to form a cohesive and compact structure, which mainly involved the formation of both within-glutenin and between-glutenin and gliadin molecules formed by disulfide bonds (Samard et al., 2019). Samard et al. (2019) reported that the integrity index values for meat analogs with added WG were noticeably higher than those for meat analogs without WG extruded under the same conditions.

Microstructure

A model of the mixture design points in this study was taken into consideration when selecting the chicken meat analog samples for microstructure observation. Fig. 4 shows the chicken meat analogs with four representative formulations that were chosen from three points of the highest leverage point of each component and one point of all three components having the same level, compared to mock chicken and steamed chicken. The microstructure of the chicken meat analogs was very different from those of the control samples; the chicken meat analogs were complex and had no directional structure, which could have been due to differences in their manufacturing processes compared to mock chicken. The sample F1 (Figs. 4A and 4B), having the highest level of YJ, showed fiber-like characteristics, containing some pores among the fiber strands, which might be the reason for its lowest hardness and chewiness values (Table 4). The sample F2 (Figs. 4C and 4D), having the highest level of WG, showed a layered structure. The highest level of SPI, in sample F3 (Figs. 4E and 4F), had a dense structure without any layer. The sample F4 (Figs. 4G and 4H), which had moderate levels of YJ, WG and SPI, resembled the F1 sample in appearance but did not clearly reveal visible jackfruit fibers. This may have been caused by the fibers of YJ being covered by other components around the fibers. In contrast, mock chicken (Figs. 4I and 4J) exhibited a fibrous structure formed by numerous thin filaments and more fiber arrangements than the chicken meat analog samples. Such findings suggested that this characteristic is often observed in extrudate with shear structural characteristics from the high moisture extrusion process, while steamed chicken (Figs. 4K and 4L) showed typical muscle fibers enwrapped in connective tissue.

Sensory evaluation

The textural characteristics, hardness and chewiness were taken into consideration when selecting the chicken meat analog samples for sensory evaluation. The seven formulas of chicken meat analogs were categorized into four groups: group 1 (samples with low hardness and chewiness, F1 and F7); group 2 (samples with moderate hardness and chewiness, F4 and F5); group 3 (samples with moderate hardness and high chewiness, F2 and F6); and group 4 (samples with high hardness and chewiness, F3). The formula with the lowest proportion of SPI in the group of formulas with more than one was chosen for sensory evaluation (F1, F2, F3, and F5). As seen in Table 5, the results showed that the chicken analogs from the different groups of texture characteristic were significantly different regarding texture, taste and overall acceptability. The sample F2 (40.64% YJ, 20.32% WG and 1.35% SPI), which had moderate hardness and high chewiness, received the highest overall acceptability score of 6.32 (like slightly to like moderately).

The results of this study revealed that the addition of young jackfruit, wheat gluten and soy protein isolate significantly affected the physical, chemical properties, and microstructure of chicken meat analogs. This study showed that it is possible to produce chicken meat analogs from young jackfruit that improved the microstructure of the chicken meat analogs and provided better texture characteristics when used in combination with wheat gluten and soy protein isolate. Future research or production, or both, could use these valuable findings for the development of desired properties in meat analog products.

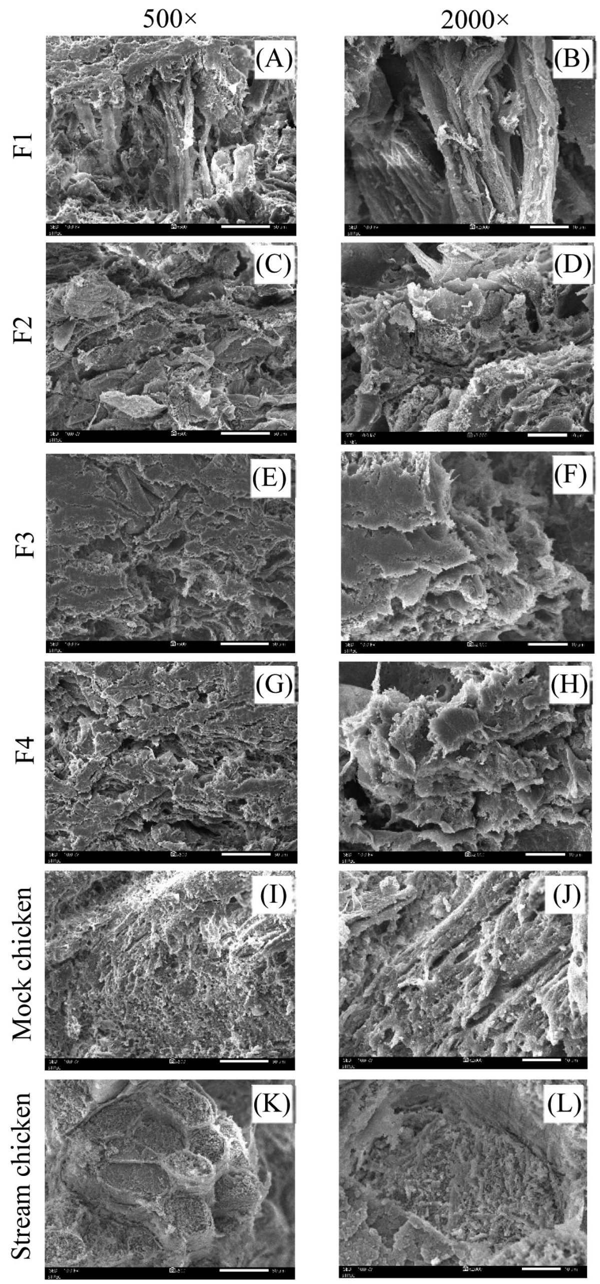

Fig. 4 Scanning electron micrographs of chicken meat analogs with different formulations at different magnifications: (A and B) formula 1; (C and D) formula 2; (E and F) formula 3; (G and H) formula 4; (I and J) mock chicken; (K and L) steamed chicken, where scale bars =50 µm for 500×magnification and 10 µm for 2,000× magnification and F = formula

Table 5 Sensory evaluation of chicken meat analogs with different formulations

Attribute	Score (Mean ± SD)			
	F1	F2	F3	F5
Appearance [ns]	7.00±1.161	7.08±1.307	7.16±1.490	6.94±1.361
Fibrous [ns]	6.30±1.810	6.82±1.548	6.64±1.711	6.52±1.876
Texture	6.26±1.915[b]	6.78±1.595[a]	6.44±1.752[ab]	6.16±1.963[b]
Color[ns]	7.10±1.607	6.72±1.715	6.70±1.515	6.82±1.625
Flavor [ns]	5.62±1.894	6.06±1.778	5.92±1.787	5.90±1.876
Taste	5.38±1.806[b]	5.86±1.678[a]	5.96±1.702[a]	5.62±2.059[ab]
Overall acceptability	5.76±1.685[c]	6.32±1.596[a]	6.18±1.758[ab]	5.88±2.007[bc]

F = Formula (see Table 1 for more details)

ns = not significantly ($p > 0.05$) different

Mean values (± SD) in each row with different lowercase superscript letters are significantly ($p < 0.05$) different.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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