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MEATBALL PROPERTIES AS AFFECTED BY SUBSTITUTION OF TAPIOCA WITH PURPLE SWEET POTATO

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Abstract
This research investigated the effects of substituting tapioca flour with purple sweet potato flour (PSPF) on the physicochemical properties, antioxidant activity, and microstructure of chicken meatballs during cold storage. Purple sweet potato is rich in anthocyanins, which act as natural antioxidants and colorants, potentially enhancing the functional properties of meat products. Chicken meatballs were formulated with different levels of PSPF substitution (0%, 5%, 10%, and 15%) and evaluated for cooking loss, water holding capacity (WHC), gel strength, pH, color, total anthocyanin content, lipid oxidation, and scavenging activity over 15 days at 4 °C. Results showed that PSPF substitution significantly influenced cooking loss, WHC, gel strength, and color. The addition of PSPF increased total anthocyanin content and antioxidant activity, contributing to enhanced oxidative stability by inhibiting lipid oxidation. Microstructural analysis revealed that PSPF substitution led to a more homogeneous and compact matrix, reducing the porous nature of the meatballs. However, excessive substitution (≥10%) resulted in a decline in WHC and gel strength. The findings suggest that incorporating PSPF in chicken meatballs at a substitution level of up to 10% improves antioxidant properties while maintaining acceptable texture and physicochemical characteristics. This approach could serve as a natural alternative to synthetic antioxidants like butylated hydroxytoluene (BHT), aligning with the growing demand for healthier and functional meat products.

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Introduction

Minced meat-based food products such as burgers, sausages, and meatballs are very popular products at this time. In the manufacturing process, these products use non-meat ingredients as binders and fillers. Many non-meat ingredients are added to various meat products to increase the nutritional value and product quality. Many types of binders and fillers such as tapioca flour, potatoes, rice flour, barley flour, and corn flour [1], and sweet potato powder are used in sausages or meatballs production [2,3].

Traditionally, meatball formulations incorporate tapioca flour as a binder due to its ability to improve texture and water retention [4]. However, to enhance elasticity and cohesiveness, synthetic additives such as sodium tripolyphosphate (STPP) are frequently included [5]. Additionally, butylated hydroxytoluene (BHT) is commonly used as an antioxidant to prevent lipid oxidation and maintain product stability during storage. However, recently, a lot of studies have been directed to produce functional meat products by modifying binders and fillers, especially to produce healthier meat products. Much research has been focused on the use of binders and fillers that function as antioxidants, such as corn flour [6] and sorghum [7].

This is in line with the consumers' demands who desire functional food, especially foods with health benefits [8]. The use of natural antioxidants can preserve essential characteristics of a product [9] and maintain shelf life. Long shelf life can be achieved by the addition of antioxidants to prevent rancidity due to oxidation of unsaturated fatty acids and to retain nutritional value. In addition, antioxidants are used not only as preservatives but also as compounds that have important effects on biochemical reactions in the human body, suppressing oxidation processes and preventing chronic diseases associated with oxidative stress [10].

One of the ingredients that can be used as a binder/filler and is rich in antioxidants is Purple Sweet Potato Flour (PSPF) [11]. Purple sweet potato has been greatly acknowledged for its health benefits for humans. It is rich in vitamins including A and C, dietary fiber and some minerals including manganese [12]. This kind of purple sweet potato cultivar (Ipomoea batatas (L.) Lam.) is high in the anthocyanin content (13.73 ± 0.13 mg/100 g), which contributes to the purple color and natural antioxidants [13].

Some studies indicate that when purple sweet potato is incorporated into confectionaries and yoghurt products, anthocyanins show surprising nutraceutical properties, such as antioxidant, antimicrobial, anticancer properties, and improve cardiovascular and sight health [14]. Chemical compositions of PSPF consist of 6.91% moisture, 5.82% protein, 0.39% fat, 88.15% carbohydrate, 3.07% ash in dry basis and 380 cal [15].

Substitution of tapioca flour with PSPF is expected to improve the quality of chicken meatballs. However, the substitution of fillers can affect the physical and sensory properties of sausages. Filler and binder also play an essential role in functional properties of meat processed products such as emulsification, and water-binding capacity, and textural properties [16]. In addition, many non-meat ingredients used as fillers can affect the appearance, taste, and texture of food products [17].

Based on this description, it is necessary to conduct research to determine an influence of the substitution of tapioca flour with purple sweet potato (*Ipomea batatas* L.) flour (PSPF) on the physical, chemical, microstructure, and sensory properties of chicken meatballs. The purpose of this study was to determine the effect of substitution of tapioca with PSPF on the physicochemical properties, antioxidant activity, and microstructure of chicken meatballs stored at a low temperature of 4±1°C for 15 days.

Objects and methods

Meatball preparation

Fresh chicken meat and other ingredients were purchased from a local market. The meat was transported to the laboratory in ice boxes. The purple sweet potato was purchased from Tangerang, Indonesia. To prepare meatballs, chicken meat was sliced into small pieces and excess fat and visible connective tissue were trimmed. Then, chicken meat was ground with a meat grinder (grinder-model MK-MG1300, Panasonic Manufacturing Malaysia Berhad), using an 8 mm plate, divided randomly into five groups, and mixed with purple sweet potato used at different levels, tapioca, salt, fresh garlic, pepper, seasoning, and sodium tripolyphoshate (STPP) in Table 1. Each mixture from five treatment groups was chopped for 5 min. The batter was shaped into balls (approximately 11 g) and cooked in 80°C water for 15 min. The core temperature of sampled meatballs was checked using a digital thermometer — thermometer food grade –40 to 280°C, Krisbow 10106736 (Krisbow, Indonesia). All samples were kept in the refrigerator (4±1°C) and analyzed on the 1st, 5th, 10th, and 15th day of storage.

Table 1. Formulation of chicken meatballs prepared with BHT and substitution of tapioca flour with PSPF

Ingredients, g	Treatment				
	P_0	P_1	P_2	P_5	P_7
Chicken meat	400	400	400	400	400
Tapioca	80	80	60	40	20
PSPF	0	0	20	40	60
Ice cube	120	120	120	120	120
Garlic fresh	4	4	4	4	4
Pepper	4	4	4	4	4
Salt	7.2	7.2	7.2	7.2	7.2
Seasoning	4	4	4	4	4
STPP	0.12	0.12	0.12	0.12	0.12
BHT 0.01%	—	0.04	—	—	—

BHT = butylated hydroxytoluene.
Treatments: P_0, tapioca flour 20%; P_1, tapioca flour 20% + 0.01% BHT; P_2, tapioca flour 15%: PSPF 5%; P_5, tapioca flour 10%: PSPF 10%; P_7, tapioca flour 5%: PSPF 15%.

Proximate composition

The proximate composition was determined by referring to according to AOAC [18] and carbohydrate was calculated by difference.

Cooking loss measurement

Cooking loss was calculated as the difference between the uncooked sample weight and cooking weight divided by uncooked weight. Cooking loss is expressed as a percentage.

Water holding capacity (WHC)

The water holding capacity was determined according to Jung and Joo [19]. Briefly, 10 grams of minced samples were homogenized with 40 ml distilled water and then incubated in a water bath at 30°C for 30 min. The homogenized sample was centrifuged at 3000 rpm for 30 min. The supernatant formed was removed and then the mixture was re-incubated for 10 min and the supernatant was removed again. The *WHC* was calculated as follow:

$$WHC\left(\%\right) = \frac{A}{B} \times 100, \quad (1)$$

WHC is water holding capacity, *A* is weight of the sample after removing supernatant, and *B* is the weight of the sample mixed with distilled water.

Gel strength measurement

The gel strength was evaluated following the method adapted from Yusof et al. [20] using a texture analyzer (TAXTplus Stable Micro System Texture Analyzer, Goldamig, Surrey, UK), equipped with a 5-kg load cell and a crosshead speed of 1 mm/s. The test was performed in triplicate using a flat-bottomed plunger with a diameter of 27 mm (0.5 inch) to ensure accuracy.

Folding test

The folding test was determined according to Nurul et al. [21]. Briefly, a meatball was shaped into a 3-mm-thick piece and then was tested by folding a sample using the thumb and forefinger. The sample condition after folding was expressed on a numerical scale as follows: score 1 if the sample was broken by, score 2 if the sample cracked immediately when folding into half, score 3 if the sample cracked gradually when folding into half, score 4 indicated the sample without cracking after folding in half, and score 5 if the sample showed no cracks after folding twice.

pH value

The pH was measured using a digital portable pH-meter (HI 99163, Hanna Instruments, Eibar, Spain) by injecting the probe into 15-g meatballs and for 10 s to obtain the pH value.

Color determination

Color analysis of meatballs was carried out using a Tes-135A color meter (Test Electrical Electronic Corp, Taipei, Taiwan). The color was measured at room temperature (23 ± 2 °C) in triplicate. The color meter was calibrated with a standard plate before use.

Total anthocyanin content (TAC)

The total anthocyanin content in chicken meatballs was quantified spectrophotometrically as monomeric anthocyanin by the pH differential method according to Lee et al. [22]. The extract of the sample was diluted with 25 mM NaCl buffer (pH 1) and another extract with 0.4 M sodium acetate buffer (pH 4.5) with a dilution factor of 1:4 for extract: buffer. The solution absorbance was measured at 700 and 516 nm wavelengths after 15-min equilibrium time. The TAC was calculated using equations 2 and 3.

$$A = (A_{516} - A_{700})\ \text{pH } 1.0 - (A_{516} - A_{700})\ \text{pH } 4.5. \qquad (2)$$

Monomeric anthocyanin pigment

$$(\text{mg/L}) = (A \times MW \times DF \times 1000) / (\varepsilon \times 1) \qquad (3)$$

where MW: molecular weight (449.2), DF: dilution factor, and ε: molar absorptivity (26,900), 1: diameter of the optical path (1 cm).

Scavenging activity

The 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging assay was done according to Hajrawati et al [23]. One gram of the meatball was extracted with 5 mL of methanol for 24 h at room temperature. After that, 400 µl of the extract was reacted with 3.6 mL of 0.1 µM DPPH, then homogenized and allowed to react for 30 minutes in a dark place. The percent inhibition against DPPH was calculated as the percentage reduction in absorbance at a wavelength of 517 nm.

Lipid oxidation (TBARS assay)

The 2-thiobarbituric acid reactive substances (TBARS) assay was performed to evaluate lipid oxidation of meatballs, following the method described by Sørensen and Jorgensen [24]. The results were expressed as 2-thiobarbituric acid-reactive substances (TBARS) in malonaldehyde/kg samples. The concentrations were determined at 532 nm. A standard curve was prepared using 1,1,3,3-tetra ethoxy propane (TEP).

Statistical analysis

The data were analyzed by ANOVA and the differences among treatment means were assessed using Tukey's test. Means were considered significantly different at $p < 0.05$. The results are presented as means ± SD. Analysis was performed using SAS statistical software, NC, USA.)

Results and discussion

Proximate composition

The chemical or nutritional properties of the chicken meatballs in this study are shown in Table 2. In general, the moisture, protein, and fat contents of meatballs were not significantly different ($P > 0.05$) among treatments with an average of 70.51%, 18.04%, and 2.14%, respectively. Meanwhile, the substitution of tapioca flour with PSPF had a significant effect ($P < 0.05$) on the ash content and crude fiber of meatballs. The ash and crude fiber of the meatballs were higher with the greater proportion of PSPF. The comparison of tapioca flour with PSPF 10:10% (P_5) and 5:15% (P_7) resulted in meatballs with significantly higher ash content ($P < 0.05$) compared to other treatments. The results indicated that at the proportion of 10:10 and 5:15, the ash content increased because purple sweet potato contains higher ash than tapioca flour. The addition of BHT in chicken meatballs did not affect the proximate composition of chicken meatballs ($P > 0.05$). Sweet potatoes from various varieties contain ash levels ranging from 2.22% to 4.34% [25], whereas cassavas contain ash levels between 1.01% and 2.06% [26]. The inclusion of these ingredients will augment the overall ash content in the products.

Data in Table 2 also shows that PSPF contains higher crude fiber than tapioca flour. It can be seen that with a ratio of 15:5 (P_2) to 5:15 (P_7) chicken meatballs contain significantly different percent of crude fiber compared to meatballs without PSPF substitution. It was due to the

Table 2. Proximate composition of chicken meatballs with addition of BHT and substitution of tapioca flour with PSPF

Formula	Chemical composition, (%)				
	Moisture	Ash	Protein	Fat	Crude fiber
P_0	70.69 ± 0.91	1.65 ± 0.06^{c}	17.98 ± 0.74	2.17 ± 0.16	0.22 ± 0.04^{d}
P_1	70.65 ± 0.43	1.67 ± 0.06^{c}	17.94 ± 0.61	2.09 ± 9.15	0.26 ± 0.04^{d}
P_2	70.66 ± 0.77	1.74 ± 0.03^{bc}	18.15 ± 0.73	2.08 ± 0.24	0.41 ± 0.03^{c}
P_5	70.58 ± 1.06	1.82 ± 0.03^{ab}	18.05 ± 0.81	2.20 ± 0.12	0.61 ± 0.16^{b}
P_7	69.96 ± 0.21	1.93 ± 0.02^{a}	17.96 ± 1.00	2.15 ± 0.28	0.79 ± 0.10^{a}
Average	70.51 ± 0.31^{ns}	1.76 ± 0.11	18.04 ± 0.07^{ns}	2.14 ± 0.05^{ns}	0.46 ± 0.24

A different letter following the data in the same row or column indicates a significant difference ($P < 0.05$); ns indicates a non-significant difference ($P > 0.05$). Ratios between tapioca and PSPF were 20:0% (P_0), 20:0% + 0.01% BHT (P_1), 15:5% (P_2), 10:10% (P_5) and 5:15% (P_7).

higher content of crude fiber in sweet potatoes compared to the crude fiber content in cassava. The crude fiber in sweet potatoes from various varieties ranges between 1.74% and 4.81% [25], whereas the crude fiber in cassava ranges from 0.15% and 0.37% [27]. The high content of ash and crude fiber in meatballs containing PSPF was associated with the levels of these two components in PSPF. The nutritional characteristics of the meatballs from this study were in agreement with the criteria of the Indonesian National Standard (SNI). SNI meatballs 3818–2014 states that the moisture content of meatballs is max. 70%, ash is 3% max, protein content is 11% max, and fat is a maximum of 10% [28].

Cooking loss, gel strength, WHC, folding test

The physical properties of chicken meatballs with or without substitution with PSPF are presented in Table 3. Substitution with a ratio of 5:15% (P_7) caused a significantly higher cooking loss ($P < 0.05$) compared to other treatments. This result is also in line with other physical properties, where the gel strength decreased at the substitution ratio of 10:10% (P_5) and 5:15% (P_7), WHC and the results of the folding test decreased at the substitution ratio of 5:15% (P_7) ($P < 0.05$). These data indicate that the substitution of tapioca with 10:10% PSPF (P_5) causes the physical quality of chicken meatballs to decrease. However, 15:5% substitution led to the results with characteristics equivalent to those without substitution. Meanwhile, the addition of BHT in chicken meatballs did not affect the physical properties ($P > 0.05$).

A decrease in the physical characteristics of the meatballs at P_5 and P_7 is most probably caused by several physical properties of the two types of flour. One of the important physical properties is the pasting properties of flour. These properties are closely related to the nature of the suspension during the cooking process, which is affected by the viscosity of the flour. Shittu et al [29] reported that the viscosity of sweet potato is lower than tapioca. It influences the cooking loss, gel strength, WHC, and folding test. Viscosity properties affecting the physical properties of the product are peak viscosity, breakdown viscosity, setback viscosity, and final viscosity. The peak viscosity is closely related to the maximum swelling and breakdown of starch granules at the equilibrium stage [30]. The low viscosity parameter causes the product to have a low cooking loss, gel strength, WHC, and folding test.

Another factor that may affect the physical properties of meatballs based on the flour used is the proportion of amylose and amylopectin in the starch [31]. Tapioca flour contains more amylopectin (about 87%) than other flour [31]. Meanwhile, sweet potatoes of various varieties contain amylopectin at a level of 76.2–78.1% [32,33]. Amylopectin has a high viscosity, which causes the starch in tapioca flour to be more sticky and viscous [32]. Amylose has properties that cause a product to become more solid or stiff [34]. This may have caused an increase in cooking loss and a decrease in gel strength, WHC, and folding test of meatballs that received a high proportion of purple sweet potatoes.

pH value and color

The pH values and color characteristics of chicken meatballs with and without substitution of tapioca flour with PSPF during cold storage for 15 days are presented in Table 4. The pH of meatballs was not affected by either substitution or storage time ($P > 0.05$). The pH of the meatballs obtained was in the range of 6.06 to 6.11. The results of this study were in line with Al-Mamun et al. [6], who reported that the pH value of meatballs was not affected by the substitution of corn flour with tapioca. The similar pH value of all meatballs is probably because the pH value of tapioca flour and PSPF is also the same. The pH value of tapioca flour from several varieties and ages varied from 5.07 to 6.64 [35], and the pH value of PSPF from several varieties was 5.77–6.21 [36].

Each of the color characteristics of meatballs (lightness, redness, and yellowness) showed a different response (Table 4). The lightness and yellowness of the meatballs were affected by the tapioca substitution with PSPF and storage time, although there was no interaction between both ($P > 0.05$). Meanwhile, the level of redness of the meatballs was influenced by the interaction between the substitution treatment and storage time ($P < 0.05$).

Changes in the color characteristics of the meatballs are in sync with the increasing proportion of PSPF in the ingredients for making meatballs. The purple color in PSPF causes the redness level of the meatballs to increase and is accompanied by a decreased yellowness level. However, during storage, the redness and yellowness decreased. The brightness level of the meatballs began to decrease on the 10th day of storage. This is in line with the research by Jin et al. [37], who showed a decrease in the brightness level of sausages with additional PSPF. The purple color in PSPF changes after the meatball cooking process due to heating [38].

Table 3. Physical properties of chicken meatballs with addition of BHT and substitution of tapioca flour with PSPF

Formula	Cooking loss, %	Gel strength, g/cm^2	WHC,%	Folding test
P_0	3.85 ± 0.94^b	$1042.33 \pm 82.57_a$	31.34 ± 2.76^a	5.00 ± 0.00^a
P_1	3.92 ± 0.33^b	1009.55 ± 22.84^a	30.72 ± 0.75^a	5.00 ± 0.00^a
P_2	4.11 ± 0.34^b	1013.93 ± 55.68^a	30.66 ± 1.13^{ab}	5.00 ± 0.00^a
P_5	4.38 ± 0.46^b	899.53 ± 29.52^b	30.42 ± 1.99^{ab}	4.67 ± 0.58^{ab}
P_7	6.03 ± 0.31^a	797.21 ± 72.65^c	27.47 ± 1.47^b	4.00 ± 0.00^b

A different letter following the data in the same column indicates a significant difference ($P < 0.05$). Ratios between tapioca and purple sweet potato flour were 20:0% (P_0), 20:0% + 0.01% BHT (P_1), 15:5% (P_2), 10:10% (P_5), and 5:15% (P_7).

Table 4. Effect of BHT addition and substitution of tapioca flour with PSPF on the pH and color values of the chicken meatball

	Formula	Storage, day				Average
		0	5	10	15	
pH	P0	6.11 ± 0.05	6.09 ± 0.04	6.07 ± 0.07	6.09 ± 0.03	6.09 ± 0.02^{ns}
	P1	6.10 ± 0.03	6.10 ± 0.06	6.11 ± 0.05	6.11 ± 0.02	6.11 ± 0.00^{ns}
	P2	6.12 ± 0.03	6.08 ± 0.03	6.08 ± 0.02	6.09 ± 0.04	6.09 ± 0.02^{ns}
	P5	6.11 ± 0.02	6.08 ± 0.06	6.05 ± 0.06	6.05 ± 0.02	6.07 ± 0.03^{ns}
	P7	6.11 ± 0.06	6.09 ± 0.06	6.07 ± 0.11	6.09 ± 0.04	6.09 ± 0.02^{ns}
	Average	6.11 ± 0.01^{ns}	6.06 ± 0.01^{ns}	6.07 ± 0.02^{ns}	6.09 ± 0.02^{ns}	—
Ligthness	P0	73.57 ± 0.31	73.07 ± 0.06	72.17 ± 0.45	70.70 ± 0.66	72.38 ± 1.26^{b}
	P1	73.77 ± 0.57	73.43 ± 0.90	73.03 ± 1.01	72.53 ± 1.50	73.19 ± 0.53^{a}
	P2	59.13 ± 1.23	58.83 ± 1.38	58.43 ± 1.50	57.80 ± 0.95	58.55 ± 0.58^{c}
	P5	54.30 ± 0.96	53.83 ± 1.01	53.37 ± 1.16	53.30 ± 1.82	53.70 ± 0.47^{d}
	P7	51.30 ± 0.56	50.83 ± 0.45	50.20 ± 0.66	49.63 ± 0.84	50.49 ± 0.73^{e}
	Average	62.41 ± 10.6^{a}	62.00 ± 10.66^{ab}	61.44 ± 10.6^{b}	60.79 ± 10.3^{c}	—
Redness	P0	0.13 ± 0.06^{i}	0.17 ± 0.06^{i}	0.21 ± 0.40^{i}	0.40 ± 0.30^{i}	0.23 ± 0.12
	P1	0.13 ± 0.06^{i}	0.17 ± 0.06^{i}	0.23 ± 0.06^{i}	0.27 ± 0.10^{i}	0.20 ± 0.06
	P2	4.80 ± 0.10^{g}	4.30 ± 0.26^{gh}	4.20 ± 0.35^{gh}	3.87 ± 0.39^{h}	6.08 ± 0.41
	P5	6.53 ± 0.06^{cd}	6.27 ± 0.12^{de}	5.90 ± 0.30^{ef}	5.60 ± 0.50f	7.20 ± 0.52
	P7	7.70 ± 0.10^{a}	7.50 ± 0.17^{ab}	7.07 ± 0.35^{bc}	6.53 ± 0.20^{cd}	3.30 ± 0.22
	Average	3.86 ± 3.55	3.68 ± 3.40	3.52 ± 3.18	3.33 ± 2.90	—
Yellownes	P0	13.70 ± 1.08	12.87 ± 1.10	12.67 ± 1.08	12.40 ± 1.23	12.80 ± 0.32^{a}
	P1	13.60 ± 1.13	13.33 ± 1.18	13.13 ± 1.10	12.87 ± 1.24	13.23 ± 0.31^{a}
	P2	7.07 ± 0.64	6.87 ± 0.72	6.67 ± 0.91	6.27 ± 0.76	6.69 ± 0.35^{b}
	P5	6.40 ± 0.20	6.00 ± 0.30	5.60 ± 0.31	5.47 ± 0.35	5.87 ± 0.42^{c}
	P7	6.33 ± 0.15	6.00 ± 0.46	5.73 ± 0.46	5.57 ± 0.51	5.91 ± 0.33^{c}
	Average	9.31 ± 3.73a	9.01 ± 3.75ab	8.74 ± 3.82^{bc}	8.51 ± 0.82^{c}	

A different letter following the data in a row and column in the same variable indicates a significant difference (P < 0.05). Ratios between tapioca and purple sweet potato flour were 20:0% (P_0), 20:0% + 0.01% BHT (P_1), 15:5% (P_2), 10:10% (P_5) and 5:15% (P_7).

Anthocyanin content

Measurement of total anthocyanins was carried out on the 0th and 15th days of storage. The results for total anthocyanins in meatballs are presented in Figure 1. Figure 1 shows that P_0 and P_1 meatballs, both with the use of tapioca flour, did not contain anthocyanins. In the meatballs with PSPF substitution, the anthocyanin content was significantly different (P < 0.05) and it was in line with an increase in the proportion of substitution with PSPF. However, during 15 days of storage, the total anthocyanin content in the meatballs decreased significantly (P < 0.01).

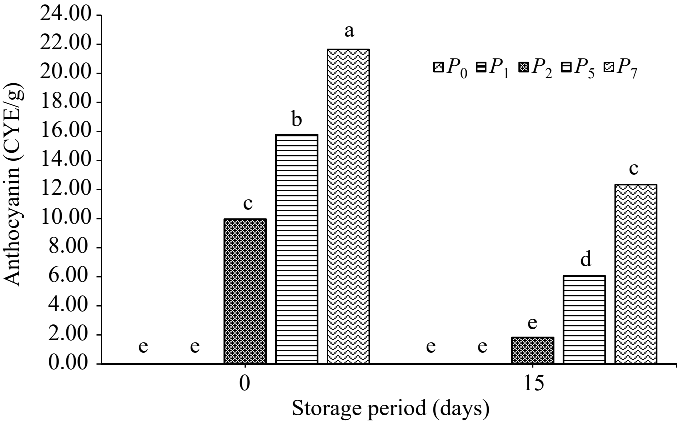

Figure 1. Anthocyanin content of chicken meatballs with addition of BHT and PSPF substitution

A different letter following the bars indicates a significant difference (P < 0.05). Ratios between tapioca and purple sweet potato flour were P_0, P_1, P_2, P_5, P_7.

The appearance of anthocyanins in the meatballs was due to the contribution of PSPF. Several studies have revealed that PSPF from various cultivars contains high levels of anthocyanins [11,12]. However, it is presumed that the total anthocyanin content in of meatballs decreased compared to the PSPF. This is because anthocyanins are less stable during heating [39]. However, a decrease in anthocyanins did not eliminate the anthocyanins in meatballs, so they continued playing a role in the color development and antioxidant properties in meatballs.

During storage, the anthocyanin content decreased. However, this decrease was accompanied by an increase in the color value since during storage anthocyanins were extensively polymerized [39]. A decrease in the anthocyanin content during storage could be influenced by several factors, such as enzyme residues or condensation reactions of anthocyanins with other phenolic compounds [40]. This led to a reduction of the total anthocyanin content on the 15th day of storage compared to the 0th day.

Scavenging activity

Scavenging activity in meatballs illustrates the ability of meatballs to scavenge free radicals, which in this case are DPPH radicals. The percentage of ability to scavenge DPPH radicals for each meatball is presented in Figure 2. Figure 2 shows that the scavenging activity of meatballs is influenced by the presence of antioxidants and storage time (P < 0.05). The antioxidants here are BHT and PSPF.

Meatballs that did not receive additional BHT and without substitution of tapioca flour with PSPF had the lowest scavenging activity. The interesting thing here was that PSPF substituting tapioca flour at 5–15% had a higher scavenging activity than tapioca with addition of BHT (P_1). Figure 2 also indicates that the higher the substitution proportion, the higher its ability to scavenge DPPH radicals. The longer the storage, the lower the ability to scavenge free radicals.

The results of the study indicate that PSPF plays an essential role in contributing antioxidants to meatballs. The antioxidants given by PSPF were presumed to be due to the phenolic compounds in PSPF, mostly anthocyanins [11]. Anthocyanins in PSPF play an important role as compounds with the antioxidant, anti-inflammatory, and anticancer properties [12]. Their presence causes an increase in the scavenging activity of meatballs with a higher PSPF proportion.

Figure 2 also shows that meatballs containing PSPF have a higher percentage of scavenging activity than meatballs containing BHT. It indicates that the anthocyanins in PSPF have a higher ability to scavenge DPPH radicals than BHT. This was in line with the results of the research by Jiao et al. [41], who stated that the scavenging ability of PSPF against DPPH radicals was higher than that of BHT. This is also indicated by the IC_{50} value of PSPF, which is lower than that of BHT [41].

Lipid oxidation (TBARS assay)

The TBARS value indicates the oxidation in meatballs expressed in mg malondialdehyde (MDA) per kg of meatballs. It can be seen from Figure 3 that meatballs without BHT and without replacement of tapioca flour with PSPF showed a significantly higher MDA level ($P < 0.05$) than other meatballs. The levels of MDA were not significantly different in meatballs with BHT and substitution of PSPF in all proportions. The meatballs without the addition of

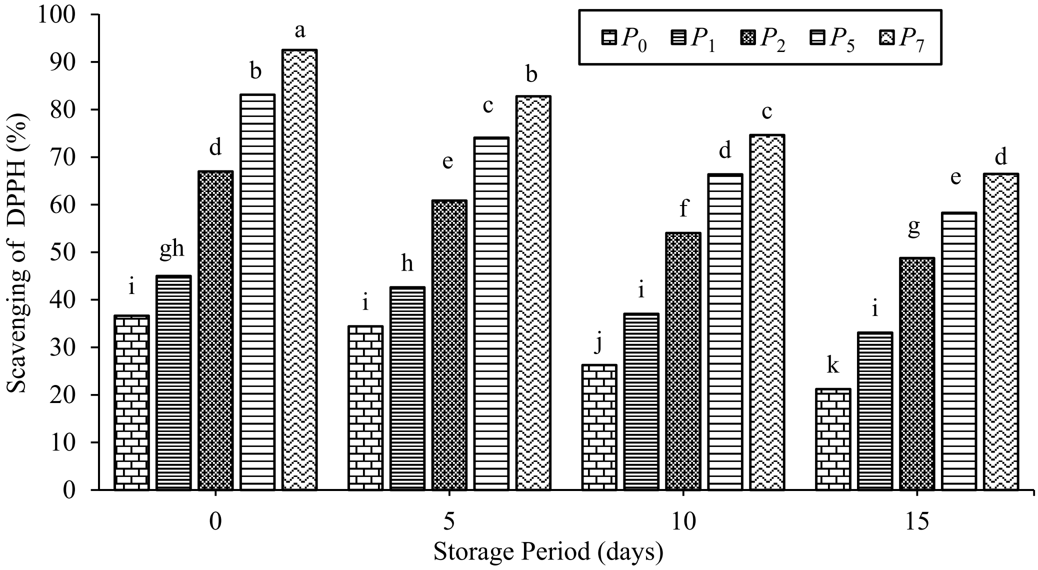

Figure 2. Scavenging activity against DPPH of chicken meatballs with addition of 0.01% BHT and PSPF substitution
A different letter following the bars indicates a significant difference ($P < 0.05$). Ratios between tapioca and purple sweet potato flour were P_0, P_1, P_2, P_5, P_7.

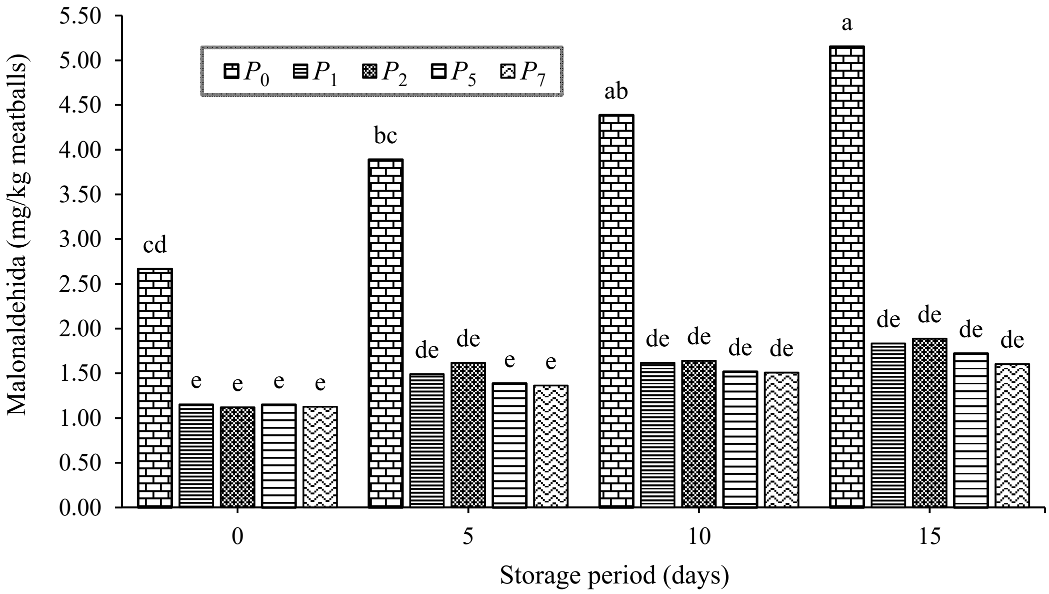

Figure 3. The MDA of chicken meatballs with addition of BHT and PSPF substitution
A different letter following the bars indicates a significant difference ($P < 0.05$). Ratios between tapioca and purple sweet potato flour were P_0, P_1, P_2, P_5, P_7.

BHT and PSPF substitution showed a significant increase in the amount of MDA during storage for up to 15 days, while the amount of MDA in meatballs with BHT and PSPF substitution remained stable, suggesting that PSPF has the antioxidant properties. The antioxidant properties are also shown by its ability to scavenge DPPH radicals as shown in Figure 2. The replacement of tapioca flour with PSPF at ratios of 15:5, 10:10, and 5:15 led to an antioxidant capacity equivalent to 0.01% BHT by weight of meat.

The ability of PSPF to suppress the TBARS value of chicken meatballs was strongly anticipated because of the phenolic compounds in PSPF, especially anthocyanins. Anthocyanins in addition to acting as dyes or pigments in purple sweet potatoes, also have antioxidant properties [11,12]. In addition to anthocyanins, non-anthocyanin phenolic compounds in PSPF are also found and act as antioxidants [12]. The results of this study indicate that the substitution of tapioca flour with PSPF with a proportion of 15:5 exerted effects that were similar to the addition of 0.01% BHT in the manufacture of chicken meatballs.

Meatballs microstructure

Figure 4 shows the results of the descriptive analysis of the microstructural character of the meatballs upon substitution of tapioca flour with PSPF by comparing the structure visually using 500× magnification. The SEM results showed that meatballs with tapioca flour as a filler both with and without 0.01% BHT had large cavities and tended to be inhomogeneous (P_0 and P_1). Usually, tapioca granules are seen as solid granules that form aggregates with each other [42]. The combination of tapioca flour with PSPF resulted in homogeneous and dense-looking cavities (P_2, P_5, and P_7). The higher the proportion of substitution, the denser the texture as shown in Figure 3. (P_7, 5:15%). The denser the microstructure, the lower the water binding capacity and gel value. This value is in line with the resulting physical properties (Table 2). It can be seen in Table 2 that with a high proportion of tapioca flour substitution with PSPF, the physical characteristics of the meatballs decreased.

The denser and more compact meatballs with a high proportion of PSPF were probably obtained due to differences in the characteristics of the type of flour and the proportion of the type of starch. PSPF can produce a compact texture due to heating [43], and the process of making meatballs involves heating (cooking). Tapioca flour contains a lower proportion of amylose than PSPF [32,33], and vice versa for amylopectin. High amylose makes starch easy to form starch-lipid conjugates and usually will easily undergo gelatinization [44]. The gelatinization process easily occurs when the amylose content increases or the amylopectin content decreases [45]. Therefore, the microstructure of food that is high in amylose is coarser than that of a product that contains little amylose [43]. The condition causes the meatballs from tapioca flour to have more and larger cavities than the meatballs with the addition of PSPF.

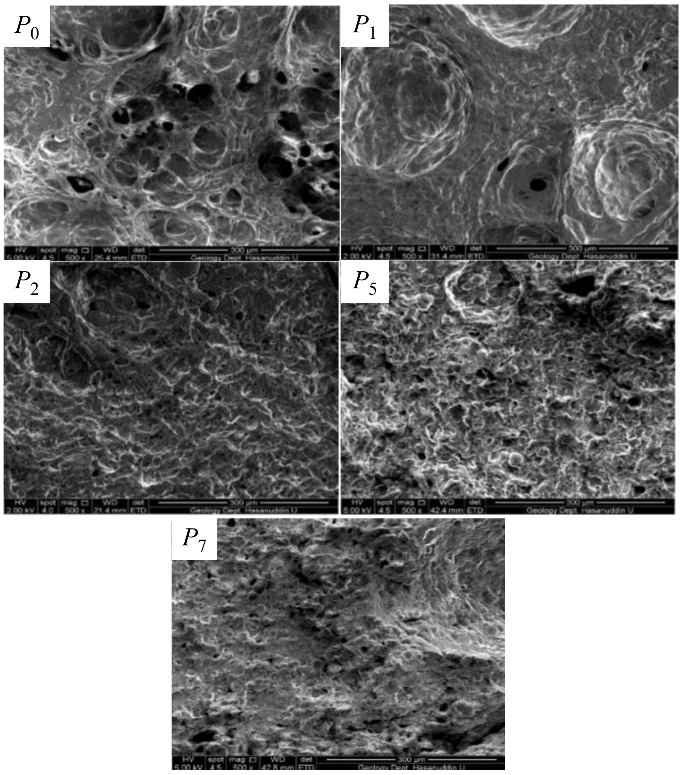

Figure 4. Chicken meatball microstructure with filler combination of tapioca and PSPF. Ratios between tapioca and purple sweet potato flour were P_0, P_1, P_2, P_5, P_7

Conclusion

The substitution of tapioca flour with purple sweet potato flour in chicken meatballs causes changes in fiber content, cooking loss, *WHC*, gel strength and folding test and meatball color. In addition, the substitution of purple sweet potato flour significantly increased the anthocyanin content, scavenging activity and the ability to inhibit fat oxidation. The ability of purple sweet potato flour at a ratio of 10:10 to inhibit fat oxidation in chicken meatballs was equivalent to 0.01% BHT.

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