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Physicochemical Characteristics and Stability of Antioxidant Extracts from Different Varieties of Purple Sweet Potato (*Ipomoea batatas* L.)

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ABSTRACT

Purple sweet potatoes are known to contain a natural pigment and antioxidant called anthocyanins, whose stability is affected by pH and temperature. This study aimed to determine the physicochemical characteristics of extracts from different purple sweet potato (PSP) varieties and to evaluate the antioxidant stability of the extracts under various pH and temperature conditions. The PSP powders from three varieties—Bogor, Cilembu, and Murasaki (Japan) were extracted using the maceration method with 70% and 96% ethanol. The stability of the selected extract was tested at pH levels of 1, 3, 5, 7, and 9, and temperatures of 20, 40, 60, and 80°C. Results showed that variety significantly affected extract yield, water content, antioxidant activity, and total anthocyanin, phenolic, and flavonoid contents. The Bogor variety extracted with 96% ethanol yielded the best results, with 15.70±1.40% yield, 14.10±0.15% water content, 185.23±3.95 mg Fe^{2+}/g antioxidant activity, 5.26±0.35 mg CyE/g anthocyanin, 40.35±3.87 mg GAE/g phenolic, and 5.12±1.05 mg QE/g flavonoid content. Increasing pH enhanced antioxidant activity and lightness, while color intensity decreased. Increasing temperature raised anthocyanin content and color parameters but reduced antioxidant activity. Under pH 1 and 80°C, the extract showed the highest anthocyanin content (6.01±0.44 mg CyE/g), a (12.57±0.63), b* (0.73±0.06), and chroma (12.59±0.63) values.*

1. INTRODUCTION

Purple sweet potato (PSP) is a tuber commonly found in Indonesia. Its purple coloration is attributed to the presence of anthocyanin pigments. As the predominant secondary metabolite in PSPs, anthocyanins serve both as natural colorants and as antioxidants capable of scavenging free radicals (Zahroh & Agustini, 2021).

Extraction is the process of releasing soluble chemical compounds from insoluble materials using a liquid solvent (Ramlan, 2021). Maceration, a commonly employed extraction technique, is frequently used to obtain bioactive compounds from natural materials (Mukhriani, 2014). In addition to the type of solvent, its concentration can also affect the characteristics of the resulting extract. Varying the ethanol-to-water ratio alters the solvent's concentration and polarity. The extraction process follows the principle of "like dissolves like," whereby solvents with polarity values closer to that of the solute facilitate more efficient and rapid dissolution from natural material samples (Hakim & Saputri, 2020).

The color stability of anthocyanin pigments is influenced by factors such as pH, temperature, and light exposure. Anthocyanins remain stable when stored at 4–25 °C, but elevated temperatures can cause pigment degradation and structural damage. Conversely, anthocyanins exhibit higher stability under acidic conditions, whereas increased pH levels promote degradation, typically manifested as visible color changes (Almajid *et al*., 2021).

This study presents a novel comparative assessment of three PSP varieties and two ethanol extraction concentrations, elucidating the influence of pH and temperature on the physicochemical and antioxidant stability of their extracts. In this study, PSP powder from Bogor, Cilembu, and Murasaki (Japan) varieties was extracted via maceration using 70% and 96% ethanol. The extract with the most favorable physicochemical properties was subsequently evaluated for antioxidant stability at pH 1, 3, 5, 7, and 9, and temperatures of 20, 40, 60, and 80 °C. This study aimed to determine the physicochemical characteristics of extracts from different PSP varieties and to evaluate the antioxidant stability of the extracts under various pH and temperature conditions.

2. MATERIALS AND METHODS

2.1. Plant Materials & Chemicals

The materials used in this research included Bogor PSP, Cilembu PSP, and Murasaki (Japan) PSP, 70% food grade ethanol, 96% food grade ethanol, citric acid crystals, aluminum foil, TPTZ powder, $FeCl_3$ crystals, $CH_3COONa.3H_2O$ crystals, glacial CH_3COOH solution, distilled water, 37% HCl solution, $FeSO_4.7H_2O$ crystals, ethanol pro analysis, KCl crystals, Folin-Ciocalteu reagent, Na_2CO_3 crystals, gallic acid crystals, $AlCl_3$ crystals, CH_3COONa crystals, quercetin powder, buffer solution pH 1, 3, 5, 7, and 9.

2.2. Experimental Design

The first stage of the study employed a Completely Randomized Design (CRD) with two factors—PSP variety and ethanol concentration—and four replications. The second stage, for the pH treatment, used a CRD with one factor (*p*H level) and three replications. The third stage, for the temperature treatment, also used a CRD with one factor (temperature) and three replications. Data were analyzed using ANOVA ($\alpha = 0.05$) followed by Duncan's multiple range test.

2.3. Research Method

2.3.1. Preparation of PSP Powder

PSP powder was prepared by first sorting 500 g of each variety of PSP. The tubers were peeled and thoroughly washed with clean water. Subsequently, they were sliced into thin pieces approximately 1 cm thick. The slices were then dried in a cabinet dryer at 50 °C for 24 h. After drying, the slices were ground using a grinder and sieved through a 60-mesh screen to obtain a fine powder.

2.3.2. Extraction of PSP

In the initial stage of the study, extracts from three varieties of PSPs were obtained using the maceration method. Two solvent systems were employed: 70% and 96% ethanol, each supplemented with 2% citric acid. The PSP powder was combined with the solvent at a sample-to-solvent ratio of 1:5 (w/v) and stirred using a magnetic stirrer for 30 min. The maceration process was conducted over 48 h (2×24 h) in the dark, with the flasks wrapped in aluminum foil to prevent light exposure, following the method described by Pham *et al*. (2019) with modifications. Subsequently, the mixture was filtered using a Buchner funnel and Whatman No. 1 filter paper under vacuum to obtain the filtrate. The solvent in the filtrate was then evaporated using a rotary vacuum evaporator at 50°C, yielding the PSP extract.

2.3.3. Effect of pH and Temperature on the Antioxidant and Color Stability of PSP Extract

In the second stage of the study, the extract selected from the first stage was subjected to treatments at varying temperatures (20 °C, 40 °C, 60 °C, and 80 °C) and pH levels (1, 3, 5, 7, and 9). The antioxidant and color stability of the PSP extract was assessed based on analyses of antioxidant activity, total anthocyanin content, total phenolic content, total flavonoid content, UV–Vis color spectrum, and color measurements via a chromameter.

2.3.3.1. Effect of pH on the Antioxidant and Color Stability of PPSP Extract

Exactly 0.5 g of the selected PSP extract was dissolved in a 50 mL volumetric flask, and buffer solution (pH 1, 3, 5, 7, or 9) was added up to the calibration mark.

2.2.3.2. Effect of Temperature on the Antioxidant and Color Stability of PSP Extract

Exactly 0.5 g of the selected PSP extract was dissolved in a 50 mL volumetric flask using the buffer solution—with the pH level chosen from the previous stage of the study—and diluted to the calibration mark. The solution was then heated in a water bath at 20 °C, 40 °C, 60 °C, and 80 °C for 15 min.

2.4. Analysis

Moisture content was determined using the oven method (AOAC, 2005). Yield analysis and antioxidant activity analysis were carried out using the FRAP (Ferric Reducing Antioxidant Power) method (Franková *et al*., 2022; Ramlan *et al*., 2021; Siregar T.M & Miarsa, 2024). Total anthocyanin content was analyzed using the pH differential method (Mahmudatussa'adah *et al*., 2014; Siregar T.M & Miarsa, 2024). Total phenolic content was determined using the Folin–Ciocalteu method (Siregar T.M & Miarsa, 2024), and total flavonoid content was analyzed using the colorimetric method (Suhendy *et al*., 2022). UV-Vis color spectrum analysis followed the method described by Almajid *et al*., (2021), and color intensity analysis using a chromameter followed Hasbullah & Umiyati (2017).

3. RESULTS AND DISCUSSION

3.1. Yield of PSP Powder

As shown in Table 1, the yield of PSP powder ranged from 31.60±1.01% to 33.28±0.38%, which is consistent with the findings of Rendowaty (2018), who reported an average yield of 30.16%.

Table 1. Physical characteristics of PSP extract

Variety	Type of Solvent	Yield (%)	Moisture Content (%)
Bogor	Ethanol 70%	22.82±2.17^{c}	13.99±0.50^{bc}
	Ethanol 96%	15.70±1.40^{ab}	14.10±0.15^{cd}
Cilembu	Ethanol 70%	17.46 ±3.21^{ab}	9.82±1.18^{a}
	Ethanol 96%	16.44±1.31^{ab}	12.64±0.01^{b}
Japan Murasaki	Ethanol 70%	18.56 ±1.52^{b}	10.41±0.41^{a}
	Ethanol 96%	14.46±1.13^{a}	15.43±0.09^{d}

Note: Different superscripts within the same column indicate significant differences ($p < 0.05$) based on DMRT

3.2. Moisture Content of PSP Powder

The moisture content of powders from the three PSP varieties, as shown in Table 1, ranged from 5.07 ± 0.45% to 5.28 ± 0.25%. These values comply with the Indonesian National Standard (SNI 3751-2009), which specifies a maximum moisture content of 14.5% for powdered products (BSN, 2009).

3.3. Effect of Variety and Ethanol Concentration on the Physicochemical Characteristics of PSPE

The effects of variety and ethanol concentration on the physicochemical characteristics of PSP extract were evaluated based on yield, moisture content, antioxidant activity, total anthocyanin content, total phenolic content, and total flavonoid content.

3.3.1. Physical Characteristics of PSPE

Based on the results presented in Table 1, both the variety and ethanol concentration had a significant effect on the yield of PSP extract ($p < 0.05$). Variations in yield are attributed to differences in the suitability of the ethanol concentrations used (70% and 96%), which influence the efficiency of secondary metabolite extraction (Hakim & Saputri, 2020). Additional factors such as maceration time, solvent evaporation time, acid addition, and sample particle size may also affect the yield of the extract. Similar to yield, the moisture content of the extract is influenced by factors such as maceration time, solvent evaporation time, acid addition, and sample particle size.

3.3.2. Chemical Characteristics of PSP Extract

As shown in Table 2, variety had a significant effect on the antioxidant activity of PSP extract ($p < 0.05$), whereas ethanol concentration had no significant effect ($p > 0.05$). Differences in antioxidant activity are attributed to variations in the physicochemical characteristics of PSP varieties (Montilla *et al*., 2010). Such variations may be influenced by environmental and genetic factors, including sunlight exposure, rainfall, soil conditions, humidity, temperature, and plant genetics (Esteban *et al*., 2015). Ethanol concentrations of 70% and 96% did not significantly affect the antioxidant activity of the extract, indicating that the secondary metabolites in PSP are readily soluble in polar solvents of both concentrations. While both are classified as polar solvents, 70% ethanol exhibits a higher degree of polarity than 96% ethanol (Solikah *et al*., 2023). Antioxidant activity is largely determined by the presence of phenolic compounds containing hydroxyl (-OH) groups, which can donate hydrogen atoms to free radicals, thereby inhibiting their propagation (Siregar & Amadea, 2021).

Table 2. The chemical characteristic of PSP extract

Variety	Antioxidant Activity (mg Fe^{2+}/g)	Total Anthocyanin (mg CyE/g)	Total Phenolic (mg GAE/g)	Total Flavonoid (mg QE/g)
Bogor	179.26±7.73^{a}	4.99±0.39^{a}	39.91±4.19^{a}	4.48±0.88^{a}
Cilembu	115.27±15.98^{b}	3.98±0.45^{b}	29.23±2.82^{b}	2.95±1.63^{b}
Japan Murasaki	168.31±10.49^{a}	2.50±0.21^{c}	37.83±3.58^{a}	3.22±0.52^{b}

Note: Different superscripts within the same column indicate significant differences ($p < 0.05$) based on DMRT

The physicochemical characteristics of PSP, including color and phenolic content, can be influenced by the variety (Montilla *et al*., 2010). In contrast, ethanol concentration did not significantly affect these characteristics, indicating that the secondary metabolites in PSP are soluble in polar solvents such as 70% and 96% ethanol. The solubility of a compound is determined by solvent polarity; the closer the polarity of the solvent to that of the compound, the greater its solubility (Sani & Kunarto, 2017). A positive association was observed between anthocyanin content and antioxidant activity, consistent with the fact that anthocyanins are flavonoid compounds that dissolve readily in polar solvents such as water and ethanol (Zahroh & Agustini, 2021). Anthocyanins, which belong to the flavonoid group, are part of the larger class of phenolic compounds, and higher phenolic and flavonoid contents are generally associated with stronger antioxidant capacity against free radicals. However, in the Murasaki (Japan) variety, total anthocyanin content did not correlate with antioxidant activity, phenolic content, or flavonoid content, as observed in the Bogor and Cilembu varieties. This suggests that the high antioxidant activity in the Murasaki (Japan) variety may be attributed to phenolic and flavonoid compounds other than anthocyanins, such as flavones (Widyawati *et al*., 2018). The theoretical maximum absorbance wavelength of anthocyanins ranges from 505 to 545 nm; in this study, it varied between 505 and 535 nm, consistent with the absorbance of cyanidin-3-glucoside (Zahroh & Agustini, 2021).

Total phenolic content tends to increase with higher antioxidant activity. Ethanol contains a hydroxyl group that can interact with the hydrogen atom of the hydroxyl group in phenolic compounds, thereby enhancing their solubility in ethanol (Suhendra *et al*., 2019). Chayati *et al*. (2019) reported that purple corn extract obtained using a 3% ethanol–citric acid solvent contained 5615±71.9 mg GAE/L phenolics, which was markedly higher than the 2747±71.9 mg GAE/L obtained using distilled water with 3% citric acid.

Based on the results, 96% ethanol was the selected solvent for the Bogor variety of PSP, yielding the highest flavonoid content. The hydroxyl group (-OH) of ethanol can interact with the hydroxyl groups of flavonoids, enhancing their solubility. Ethanol concentrations above 70% are generally less effective for dissolving low–molecular–weight flavonoids; therefore, the findings suggest that the flavonoid compounds in PSP in this study are of relatively high molecular weight, making them more effectively extracted at ethanol concentrations above 70% (Riwanti *et al*., 2018).

3.3.3. Determination of the Selected PSPE

The maceration of Bogor variety PSP powder using 96% ethanol was identified as the optimal treatment, yielding an extract with the following characteristics: yield, 15.70±1.40%; moisture content, 14.10±0.15%; antioxidant activity,

185.23±3.95 mg Fe^{2+}/g; total anthocyanin content, 5.26±0.35 mg CyE/g; total phenolic content, 40.35±3.87 mg GAE/g; and total flavonoid content, 5.12±1.05 mg QE/g. Therefore, the 96% ethanol extract of the Bogor variety PSP was used in the second stage of the study.

3.4. pH Effects on the Antioxidant and Color Stability of PSP Extract

The effects of pH on the antioxidant and color stability of the Bogor variety PSP extract were evaluated based on antioxidant activity, total anthocyanin content, UV-Vis color spectrum, and chromameter color intensity.

3.4.1. Antioxidant Activity

Based on the results presented in Table 3, pH had a significant effect on the antioxidant activity of PSP extract ($p < 0.05$). At pH 3 and 5, the PSP extract exhibited the highest stability, as indicated by antioxidant activity, compared with pH 1, 7, and 9. This may be due to the interference of buffers used in the pH treatments—particularly at pH 1, 7, and 9—with the effectiveness of acetate buffers, which are only effective within the pH range of 3.6–5.5 (Rachmayanti *et al*., 2021) The higher antioxidant activity observed at pH 3 and 5 corresponds to this optimal buffer range for the FRAP assay. Buffers function to maintain stable pH conditions, thereby enabling the optimal reduction of the Fe^{3+}–TPTZ complex to Fe^{2+}–TPTZ, which is favored under acidic conditions (Rachmayanti *et al*., 2021; Yuliawati *et al*., 2022).

Table 3. Effect of pH on the antioxidant activity, maximum wavelength, and absorbance of the PSP extract

pH	Antioxidant Activity (mg Fe^{2+}/g)	Anthocyanin (mg CyE/g)	λ max (nm)	Absorbance
1	162.62±1.44^{c}	4.62±1.18	520	0.360
3	246.07±4.38^{d}	4.34±1.04	525	0.169
5	264.70±2.60^{e}	4.25±0.50	535	0.060
7	145.00±3.48^{a}	4.17±0.80	565	0.072
9	152.02±3.54^{b}	3.14±0.43	600	0.167

Note: Different superscripts indicate significant differences ($p < 0.05$)

3.4.2. Total Anthocyanin Content

Based on the measurement results presented in Table 3, pH had no significant effect on the total anthocyanin content of PSP extract ($p > 0.05$). Across the pH treatments, total anthocyanin content ranged from 3.15±0.42 to 4.62±1.18 mg CyE/g, with the highest stability observed at pH 1. Although the stability decreased with increasing pH, the differences were not statistically significant. This finding is consistent with Zahroh & Agustini (2021), who reported that more acidic conditions increase anthocyanin content. Under acidic conditions, the red anthocyanin pigment is predominantly in the flavylium cation form, which contains more hydroxyl groups than the quinonoidal structure found at alkaline pH, thereby enhancing free radical scavenging capacity (Enaru *et al*., 2021). Furthermore, highly acidic pH promotes the breakdown of vacuolar cell walls due to membrane denaturation, facilitating greater anthocyanin extraction. As pH increases, the stability of the extract, based on total anthocyanin content, tends to decline (Zahroh & Agustini, 2021).

3.4.3. UV-Vis Color Spectrum

Selected PSP extracts at five different pH levels were subjected to stability tests, with maximum absorbance measured across wavelengths of 400–700 nm using a UV-Vis spectrophotometer. The results of the pH-based stability measurements are presented in Table 3. Based on the data, the maximum absorbance wavelengths of PSP extract at pH 1, 3, and 5 were 520, 525, and 535 nm, respectively. These values align with the theoretical wavelength range of anthocyanins (505–545 nm) as reported by Zahroh & Agustini (2021). Among these, pH 1 exhibited the highest absorbance, consistent with the findings of Fendri *et al.* (2018), which indicated that lower pH values enhance anthocyanin absorbance, as reflected by a stable red coloration. In contrast, extracts at pH 7 and 9 did not fall within the theoretical range due to anthocyanin degradation and consequent wavelength shifts (Fendri *et al*., 2018).

These results also agree with the observations of Chen *et al*. (2019), who reported a gradual color change in PSP extract from red at low pH to faded red, purple, and blue at higher pH levels. At pH 1, anthocyanins predominantly exist as the red-colored flavylium (oxonium) cation, the most stable form under strongly acidic conditions (pH 1–2). At pH 3–5, partial conversion to colorless carbinol pseudobases results in a faded red hue, which diminishes further in weakly acidic conditions. At pH 6–7, some colorless carbinols transform into blue quinonoidal bases, yielding a purple coloration. At pH 7–9, the quinonoidal form becomes dominant, producing a blue color, while at pH values above 9, the yellow chalcone form prevails, resulting in a green appearance (Mahmudatussa'adah *et al*., 2014; Kunnaryo & Wikandari, 2021).

3.4.4. Chromameter Color Intensity

The stability of color intensity of PSP extract under various pH was evaluated using a chromameter, based on five parameters: lightness (*L*), *a** value, *b** value, chroma (*C*), and hue angle (°Hue). The results are presented in Table 4.

Table 4. Effect of pH on the chromameter color intensity of PSP extract

pH	Lightness (*L**)	*a** Value	*b** Value	Chroma Value (C)	°Hue	Color Categories
1	54.74±0.58^{a}	9.34 ±1.76^{d}	0.49±0.10^{d}	9.36±1.76^{c}	3.02±0.13 ^{a}	Reddish purple
3	56.48±0.11^{b}	5.42±0.52^{c}	-0.02±0.01^{c}	5.42±0.52^{b}	359.79±0.10^{d}	Reddish purple
5	57.89±0.09^{b}	1.70 ±0.15^{b}	0.03±0.01^{c}	1.70±0.15^{a}	0.98±0.45 ^{a}	Reddish purple
7	57.24±0.25^{a}	1.14±0.21^{b}	-0.39±0.25^{b}	1.21 ±0.28^{a}	342.41±7.78^{c}	Reddish purple
9	54.44±1.90^{a}	-0.47±0.53^{a}	-1.65±0.25^{a}	1.76 ±0.28^{a}	254.92±16.60^{b}	Blue

Note: Different superscripts within the same column indicate significant differences ($p < 0.05$)

a. Lightness (*L**)

A lightness value of 0 indicates a completely dark color (black), whereas a value approaching 100 represents an increasingly bright color (white) (Widyawati *et al*., 2018). Based on the measurement results shown in Table 4, pH had a significant effect on the lightness value of PSP extract ($p < 0.05$). The lightness values at pH 1 and pH 9 were the lowest, indicating more intense colors. In contrast, pH 5 and pH 7 showed the highest lightness values, suggesting faded or nearly transparent colors. The deep red color at pH 1 corresponds to anthocyanins in the form of a stable red flavylium cation, while the deep blue color at pH 9 corresponds to anthocyanins in the form of a stable blue quinonoidal base (Mahmudatussa'adah *et al*., 2014).

b. Red-Green (*a**) Value

The *a** value represents the chromaticity of red and green reflected light, with positive values (0 to +100) indicating increasing redness and negative values (0 to −80) indicating increasing greenness (Widyawati *et al*., 2018). Based on the measurement results shown in Table 4, pH had a significant effect on the *a** value of PSP extract ($p < 0.05$). As pH increased, the *a** value decreased. The red coloration in anthocyanins originates from the flavylium cation structure, which undergoes transformation with increasing pH. At pH 3–5, the red flavylium cation is partially converted to colorless carbinols, while at pH 7–9, it shifts to blue quinonoidal forms. At pH 1–7, the *a** value remained positive, indicating the persistence of some flavylium cation structures, with pH 1 showing the highest *a** value. In contrast, at pH 9, the *a** value became negative, indicating the absence of red and the presence of green. At this pH, anthocyanins predominantly exist in the blue quinonoidal form (Mahmudatussa'adah *et al*., 2014).

c. Yellow-Blue (*b**) Value

The b value represents the chromaticity of yellow and blue reflected light, with positive values (0 to +70) indicating increasing yellowness and negative values (0 to −70) indicating increasing blueness (Mahmudatussa'adah *et al*., 2014). As shown in Table 4, pH had a significant effect on the b value of PSP extract ($p < 0.05$). An increase in pH generally resulted in a decrease in the *b** value. At pH 1 and pH 5, positive *b** values indicated the presence of yellow, with no detectable blue coloration. However, at pH 3, the *b** value was slightly negative (−0.02±0.01), suggesting the unexpected presence of blue in the sample. At pH 9, the *b** value was distinctly negative, reflecting the dominance of blue coloration due to anthocyanins in the blue quinonoidal form (Mahmudatussa'adah *et al*., 2014).

d. Chroma Value (*C*)

The chroma value (*C*) represents the color intensity of a sample, calculated as $(a^2 + b^2)^{1/2}$. A higher chroma value indicates a more vivid and saturated color, whereas a lower value reflects fading color intensity (Hasbullah & Umiyati, 2017). As shown in Table 4, pH had a significant effect on the chroma value of PSP extract ($p < 0.05$). The highest chroma value was observed at pH 1, corresponding to the presence of anthocyanins in the form of stable red flavylium cations. As pH increased, the chroma value decreased due to the transformation of the red flavylium cations into colorless carbinol forms, resulting in progressively faded coloration. In weakly acidic conditions, the fading effect became more pronounced. At pH 9, the chroma value increased again, which can be attributed to the conversion of the colorless carbinol structure into the blue quinonoidal form, yielding a strong blue color intensity (Mahmudatussa'adah *et al*., 2014; Hasbullah & Umiyati, 2017).

d. °Hue Value

As shown in Table 4, pH had a significant effect on the °Hue value of PSP extract ($p < 0.05$). The pH values of 1, 3, and 5 are classified as reddish-purple (342°–18°), with °Hue values of 3.02±0.13, 359.79±0.10, and 0.98±0.45, respectively. At pH 7, the anthocyanin color was also categorized as reddish-purple, with a °Hue value of 342.41±7.78, although it should have been classified as purple. At pH 9, the anthocyanin color tended toward blue, with a °Hue value of 254.92±16.60. Based on these °Hue results, pH 1, 3, and 5 can be categorized as stable, non-degraded anthocyanin color groups, specifically reddish-purple (Mahmudatussa'adah *et al*., 2014).

3.4.5 Antioxidant and Color Stability of PSP Extract under Different pH Conditions

The antioxidant stability of PSP extract remained stable at pH values of 1, 3, and 5, with pH 1 showing a significant difference compared to pH 3 and pH 5. The extract at pH 1 was selected based on the following parameters: total anthocyanin content of 4.62±1.18 mg CyE/g, lightness (*L*) of 54.74±0.58, *a** value of 9.34±1.76, *b** value of 0.49±0.10, chroma value (*C*) of 9.36±1.76, and °Hue of 3.02±0.13. Additionally, the maximum absorbance value was 0.360 at a wavelength of 520 nm, representing the highest absorbance among all tested pH conditions.

3.5. Temperature Effects on the Antioxidant and Color Stability of PSP Extract

The effects of temperature on the antioxidant and color stability of the Bogor variety PSP extract were evaluated based on antioxidant activity, total anthocyanin content, UV-Vis color spectrum, and chromameter color intensity. The reults are presented in Table 5.

Table 5. Effect of Temperature on the antioxidant activity of PSP extract

Temperature (°C)	Antioxidant Activity (mg Fe^{2+}/g)	Total Anthocyanin Content (mg CyE/g)	λ max (nm)	Absorbance
20	169.98±4.57^{b}	4.48±0.26^{a}	520	0.356
40	165.11±4.42^{b}	5.34±0.46^{bc}	520	0.363
60	153.13±6.39^{a}	5.06±0.33^{ab}	520	0.397
80	147.89±6.39^{a}	6.01±0.44^{c}	520	0.434

Note: Different superscripts indicate significant differences ($p < 0.05$)

3.5.1. Antioxidant Activity

Based on the results presented in Table 5, temperature has a significant effect on the antioxidant activity of PSP extract ($p < 0.05$). At 20°C, the extract exhibited the highest stability based on antioxidant activity. Dwiyanti *et al*. (2018) reported that the antioxidant activity of PSP extract and juice decreases with increasing heating temperatures (70 °C, 80 °C, 90 °C). This reduction is likely due to the degradation of anthocyanins, a key secondary metabolite in PSPes responsible for antioxidant activity. Anthocyanins are highly sensitive to heat, which can lead to irreversible structural changes and brownish-red discoloration. Upon heating, the glycone (sugar) moieties attached to anthocyanins are released, forming the aglycone anthocyanidin. Subsequent cleavage of the C-ring separates the A and B rings, resulting in the formation of two new compounds, phloroglucinaldehyde and 4-hydroxybenzoic acid. This cyanidin

cleavage process causes discoloration and reduces the ability of anthocyanins to scavenge free radicals, thereby decreasing antioxidant activity (Nasrullah *et al*., 2021; Suzery *et al*., 2020).

In the present study, heating for 15 min reduced antioxidant activity by 2.80–12.99%. Longer heating durations led to increased degradation and structural changes, resulting in a brownish color.

3.5.2 Total Anthocyanin Content

As presented in Table 5, temperature significantly affects the total anthocyanin content of PSP extract ($p < 0.05$). These results do not correspond with the measurements of antioxidant activity. Fendri *et al*. (2018) reported that anthocyanins at pH 1 experience solution concentration, characterized by increased color intensity, which leads to higher absorbance values. The observed increase in absorbance may be due to the presence of compounds other than anthocyanins, as heating can enhance the apparent concentration, reflected in the increased absorbance (Enaru *et al*., 2021; Nasrullah *et al*., 2021). Additionally, heating can cause the evaporation of volatile compounds, such as water and other constituents, resulting in a reduced sample volume and further concentration (Purwanti *et al*., 2019).

Heydari *et al*. (2014) stated that a relatively short heating time minimizes decreases in anthocyanin content and thermal browning degradation. In this study, a short heating duration of 15 min was applied, which limited browning, as indicated by only a slight darkening of the sample. The anthocyanin measurement is based on absorbance readings at pH 1 and pH 4.5 at their maximum wavelengths and at 700 nm, followed by calculation of the difference. Therefore, a more intense red color at pH 1 indicates a higher anthocyanin content.

3.5.3. UV-Vis Color Spectrum

Selected PSP extract at pH 1 was subjected to stability testing under four different temperature conditions by measuring the maximum absorbance at wavelengths of 400–700 nm using a UV-Vis spectrophotometer. The results of the temperature stability measurements are presented in Table 5. As shown in the table, PSP extract at pH 1 exhibited the same maximum wavelength, while the absorbance value increased with rising temperature. This observation is consistent with Fendri *et al*. (2018) who reported that anthocyanin extract from PSP peel at pH 1 did not show a shift in maximum wavelength but exhibited increased absorbance. This indicates that anthocyanins at pH 1 undergo color concentration, characterized by intensified color, resulting in higher absorbance values. Furthermore, compounds other than anthocyanins may form due to heating, contributing to increased color intensity and, consequently, higher absorbance readings when measured using a UV-Vis spectrophotometer (Nasrullah *et al*., 2021).

3.5.4. Chromameter Color Intensity

The color intensity stability of PSP extract under various temperature conditions was evaluated using a Chromameter based on five parameters: lightness (*L*), *a* value, *b** value, chroma (*C*), and °Hue. The reults are presented in Table 6.

Table 6. Effect of temperatures on the chromameter color intensity of PSP extract

Temperature (°C)	*a** Value	*b** Value	Chroma Value (*C*)	°Hue	Color Categories
20	8.77 ±0.84^{ab}	0.52±0.01 ^{ab}	8.79 ±2.30 ^{ab}	3.65±1.20	reddish-purple
40	11.29±0.60 ^{bc}	0.66±0.10 ^{bc}	11.31±0.60 ^{bc}	3.37±0.56	reddish-purple
60	6.82±2.28 ^{a}	0.43±0.10 ^{a}	6.83±2.28 ^{a}	3.74±0.59	reddish-purple
80	12.57±0.63 ^{c}	0.73±0.06 ^{c}	12.59±0.63 ^{c}	3.33±0.40	reddish-purple

Note: Different superscripts within the same column indicate significant differences ($p < 0.05$)

3.5.4.1. Lightness (*L**)

Based on the measurement results, temperature had an insignificant effect on the lightness of PSP extract ($p > 0.05$). These results are consistent with the total anthocyanin content, where 80 °C exhibited the most favorable condition, followed by 40 °C, 60 °C, and 20 °C. Lower Lightness values indicate a darker red color. This effect is likely due to the relatively short heating duration of 15 min, which minimizes thermal browning degradation, as evidenced by only a slight darkening of the color (Heydari *et al*., 2014).

3.5.4.2. *a** Value

Based on the measurement results presented in Table 6, temperature has a significant effect on the *a** value of PSP extract ($p < 0.05$). The measured *a* values are consistent with the Lightness values, with 80 °C and 40 °C exhibiting the highest *a** values, indicating a deep red color. The decrease in redness at 60 °C is attributed to unstable temperature conditions for anthocyanins and damage to the pigment chromophore group responsible for red coloration (Ani & Awaliyah, 2015; Nasrullah *et al*., 2021).

3.5.4.3. *b** Value

Based on the measurement results presented in Table 6, temperature has a significant effect on the *b** value of PSP extract ($p < 0.05$). As shown in Table 10, all *b** values are positive, indicating the absence of blue coloration. This finding is consistent with the measured *a** values, where the highest *b** value was observed at 80 °C, followed by 40 °C, 20 °C, and 60 °C. Temperature influences the *b** value, suggesting that heating can increase the concentration of yellow anthocyanins even at low levels (Mahmudatussa'adah *et al*., 2014).

3.5.4.4. Chroma Value (*C*)

Based on the measurement results presented in Table 6, temperature has a significant effect on the Chroma value of PSP extract ($p < 0.05$). The Chroma values are consistent with the measured a and b values, with the highest value observed at 80 °C, followed by 40 °C, 20 °C, and 60 °C. Temperature affects the color intensity of anthocyanins at pH 1, where heating at 40 °C and 80 °C results in increased color concentration. This intensification is likely due to the relatively short heating time of 15 min, which minimizes thermal degradation and browning, leading to slightly darker coloration and higher measured color intensity (Heydari *et al*., 2014).

3.5.4.5. °Hue

Based on the measurement results, temperature had a non-significant effect on the °Hue of PSP extract ($p > 0.05$). Anthocyanins at pH 1 under temperature conditions of 20, 40, 60, and 80 °C were classified as reddish-purple (342°–18°), with °Hue values ranging from 3.33±0.40 to 3.74±0.59, respectively. These results are consistent with the measurements of *a**, *b**, and Chroma values, where the highest values were observed at 80 °C, followed by 40 °C, 20 °C, and 60 °C.

3.5.5 Antioxidant and Color Stability of PSP Extract under Different Temperature Conditions

The antioxidant stability of PSP extract at temperatures ranging from 20 to 80 °C was evaluated based on total anthocyanin content (4.48±0.26 to 6.01±0.44 mg CyE/g), Lightness (*L*) (52.61±2.25 to 54.61±0.84), *a** value (12.57±0.63), *b** value (0.43±0.10 to 0.73±0.06), Chroma value (6.83±2.28 to 12.59±0.63), and °Hue (3.33±0.40 to 3.74±0.59). The maximum absorbance under these temperature conditions ranged from 0.356 to 0.434 at a wavelength of 520 nm. PSP extract remained stable up to 80 °C, indicating its potential application in the food industry as a natural colorant and antioxidant for pasteurized beverages and baked goods.

4. CONCLUSION

The maceration of Bogor variety PSP powder using 96% ethanol was identified as the optimal treatment, yielding an extract with a yield of 15.70±1.40%, moisture content of 14.10±0.15%, antioxidant activity of 185.23±3.95 mg Fe^{2+}/g, total anthocyanin content of 5.26±0.35 mg CyE/g, total phenolic content of 40.35±3.87 mg GAE/g, and total flavonoid content of 5.12±1.05 mg QE/g. Increasing pH led to higher antioxidant activity and Lightness (*L*) of the extract, whereas the UV-Vis absorbance, a value, *b** value, Chroma (*C*) value, and °Hue decreased. In contrast, increasing temperature resulted in higher total anthocyanin content, UV-Vis absorbance, *a** value, *b** value, and Chroma value, while antioxidant activity decreased. Among all treatments, the extract at pH 1 and 80°C exhibited the highest values, with a total anthocyanin content of 6.01±0.44 mg CyE/g, *a** value of 12.57±0.63, *b** value of 0.73±0.06, and Chroma value of 12.59±0.63. Extracts from Bogor variety PSP using 96% ethanol, at pH 1 and 80 °C, show high anthocyanin and antioxidant content, suitable as natural colorants and functional food ingredients. Further study on the application and stability of PSP extract in food products.

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AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
TMS	✓	✓		✓		✓	✓			✓		✓		
FK		✓		✓	✓	✓	✓	✓	✓					

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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