



Quality evaluation of noodles partially substituted with white- and purple-fleshed sweet potato flours

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ABSTRACT

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In this study, noodles were produced by replacing a portion of wheat flour with a combination of white-fleshed sweet potato (WFSP) flour at 3%, 4.5%, 6%, 7.5%, and 9%, and purple-fleshed sweet potato (PFSP) flour at 10%, 12.5%, 15%, 17.5%, and 20%. The results indicated that the noodles exhibited the highest quality in terms of physicochemical properties and nutritional composition when formulated with WFSP and PFSP flour contents of 7.5% and 17.5%, respectively, which involved partial substitution of wheat flour. The cooking quality of the noodles was assessed through parameters such as weight increase, volume increase percentage, and cooking loss, all of which showed favorable outcomes under these conditions. The noodles contained high levels of anthocyanins and total polyphenols, measuring 82.80 mg/100 g and 18.94 mg GAE/g, respectively, along with the characteristic purple coloration derived from PFSP. When sweet potato flour was used to partially replace wheat flour, the estimated potential renal acid load (PRAL) score was reduced to 4.38 compared to the control sample, which was made entirely of wheat flour and had a PRAL score of 11.75. Nutritional analysis revealed that the noodles contained protein at 8.19%, carbohydrates at 16.45%, fat at 1.17%, moisture at 63.32%, fiber at 2.52%, ash at 0.65%, and resistant starch at 4.11%. Therefore, incorporating sweet potatoes, which are rich in nutrients, into product processing is significant for nutrition, economic benefits, and sustainable development.

Contribution/Originality: This work represents an innovation in the use of sweet potato's bioactive component-rich resources in noodle production. This not only improves the product's color and nutritional value but also introduces various health-beneficial components and opens up new possibilities for the country's abundant and readily available agricultural resources.

1. INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is an essential food crop that contains a high concentration of carbohydrates, fiber, protein, vitamins A, C, and B group, as well as minerals such as potassium, iron, zinc, and calcium, all of which provide several health benefits to humans (Grace et al., 2014). In addition, sweet potatoes are rich in biological compounds such as carotene, phenolics, and anthocyanins, which offer health benefits including antioxidants, anti-inflammatory effects, support for diabetes treatment, and cancer prevention (Oki et al., 2002). Among the existing

varieties of sweet potatoes, purple-fleshed sweet potatoes (PFSP) possess a characteristic, vibrant, and eye-catching color due to the presence of anthocyanin compounds, a group of natural pigments belonging to the flavonoid family. Anthocyanins are highly bioactive compounds with strong antioxidant properties, providing numerous health benefits. The vivid color of this compound indicates its potential to replace synthetic colorants currently widely used in food processing (Truong & Avula, 2010). This demonstrates that purple sweet potatoes can be utilized to improve food quality through their color and rich nutritional components, which also influence human hunger, food selection, and enjoyment (Auvray & Spence, 2008). Besides, WFSPs are nutritious, starchy roots with a sweet flavor, easy to prepare into many dishes. They are also an abundant source of polyphenols and exhibit high antioxidant activity (Thuy et al., 2024). However, large-scale harvesting of sweet potatoes presents numerous challenges throughout the country. Sweet potatoes are often stored in warehouses awaiting export, causing losses for garden owners who lose revenue and are forced to lower prices, which leads to declining business. Additionally, many sweet potatoes are damaged before they can be sold. Most of Vietnam's agricultural products are exported in raw, unprocessed forms; the export market depends heavily on China, but mainly through small quotas, resulting in low value (Vietnam National University of Agriculture, 2020). Consequently, this industry faces a difficult situation, with large quantities of potatoes still unexploited, low economic value, and a recurring call for support. For example, sweet potato powder has the potential to be used in food processing, especially in the production of popular daily meal products such as noodles, vermicelli, rice noodles, and bread.

Among popular foods, noodles are a widely consumed dish in many countries due to their simple production process, high nutritional value, convenience, and ability to meet the needs of consumers in developed societies (Zhang & Ma, 2016). Noodles have long been integral to culinary traditions worldwide and play a significant role in human nutrition (Fu, 2008). With their low-calorie and fat content and appealing flavor, noodles have become a staple in daily diets (Hou, 2010). Recently, there has been increasing interest in adding vegetable ingredients to noodles to enhance natural color and nutritional value in both domestic and international markets. For example, replacing 15% of wheat flour with purple sweet potato flour, which has an attractive red-pink hue, improves both the color and nutrients of the product (Shan, Zhu, Peng, & Zhou, 2013).

Uthai, Suktanarak, Chetyakamin, and Thumrongchote (2022) found that substituting 20% of wheat flour with sweet potato flour enhanced the nutritional profile of noodles and was well received by consumers. Hu et al. (2023) reported that reducing the particle size of purple sweet potato flour improved dough uniformity and surface compactness, enhanced cooking quality, and promoted anthocyanin retention and diffusion stability in noodles. Previous research indicates that using purple-fleshed sweet potato as a raw material can enhance both the nutritional and visual qualities of noodle products (Ginting, Utomo, & Restuono, 2021). Despite its potential and excellent nutritional qualities, relatively few studies have explored the use of white sweet potato flour in noodle production. Most investigations focus on the combined use of purple-fleshed and white sweet potato flours in noodle formulations. The aim of this study was to evaluate the physicochemical properties of noodles when a portion of wheat flour was substituted with white and purple sweet potato flours, with the goal of effectively utilizing sweet potatoes rich in natural colors and bioactive compounds. Additionally, incorporating these ingredients not only improves the color, texture, and nutritional content of the products but also supports the sustainable use of the country's abundant agricultural resources.

2. MATERIALS AND METHODS

2.1. Sample Preparation

WFSP and PFSP are collected from the farming areas in Vinh Long province and then transported to the laboratory. Tubers that are damaged or show signs of pathology are removed. WFSP and PFSP were prepared according to the method developed by Thuy et al. (2024).

2.2. Materials and Experimental Design for the Noodle Preparation Process

Several ingredients were weighed consistently, including 65 g of egg, 63 g of water, 50 g of semolina flour, 50 g of potato starch, 15 g of modified starch, 1.5 g of konjac flour, 6 g of xanthan gum, and 2 g of salt. Various types of flour, such as wheat flour, PFSP, and WFSP flour, were weighed using the experimental setup. The total weight of one batch was 452.5 grams. In this investigation, the control recipe A0 contained 100% wheat flour, while five formulas (A1 to A5) replaced wheat flour with WFSP flour (3% to 9%) and PFSP flour (10% to 20%) (Table 1). The product was prepared using an automatic noodle maker (Philips, HR2365/01, Japan).

Table 1. Noodle recipes that replace a portion of the wheat flour with WFSP and PFSP flours.

Ingredients (g)	A0	A1	A2	A3	A4	A5
Wheat flour	200	174	166	158	150	142
WFSP flour	0	6	9	12	15	18
PFSP flour	0	20	25	30	35	40

2.3. Physicochemical Properties Analysis

The color of the samples was measured using a Hunter Lab colorimeter (Color Flex, USA), based on L*, a*, and b* values. The L* value indicates lightness, ranging from black (0) to white (100). The a* value represents the color spectrum from green (negative values) to red (positive values). The b* value reflects the color from blue (negative values) to yellow (positive values). Each sample was measured five times, and the average value was calculated to ensure accuracy and reliability of the results.

The samples' hardness was assessed using a TA.XTplusC Texture Analyser (Stable Micro Systems, England). Five boiling noodles were placed on a flat metal plate and squeezed horizontally to 70% of their original height with a 3.175 mm metal blade at a rate of 1 mm/s (Sudha, Rajeswari, & Venkateswara Rao, 2012).

The cooking quality of the sample was assessed based on weight increase (%), volume increase (%), and cooking loss (%), following the AACC 66-50 technique (AACC International, 2000).

The nutritional properties of noodles, including moisture, protein, fat, carbohydrate, fiber, and ash content, were assessed using the AOAC (2005) method. The resistant starch (RS) concentration was determined following the protocol outlined by McCleary, McNally, and Rossiter (2002). Additionally, bioactive substances such as total polyphenols (TPC), expressed in mg GAE/g, and anthocyanins, measured in mg per 100 g, were quantified using the Folin-Ciocalteu method (Teixeira et al., 2013) and the pH differential method (Giusti & Wrolstad, 2001), respectively.

2.4. Estimation of Potential Renal Acid Load (PRAL)

The PRAL score of meals is used to determine their acidifying or alkalizing potential (Equation 1).

$$\text{PRAL}/_{100\text{ g}} = 0.0366 \times \text{Phosphorus (mg)} + 0.4888 \times \text{Protein (g)} - [0.0205 \times \text{Potassium (mg)} + 0.0125 \times \text{Calcium (mg)} + 0.0263 \times \text{Magnesium (mg)}] \quad (1)$$

2.5. Scanning Electron Microscopy

A scanning electron microscope (SEM) was used (Hitachi S-4800, Japan), as described by Zambelli et al. (2018).

2.6. Statistical Analysis

The trials were conducted three times, and the results are presented as mean $\pm$ standard deviation (STD). The data were analyzed using one-way ANOVA tests with Statgraphics Centurion XV.I software (USA).

3. RESULTS AND DISCUSSION

3.1. Physicochemical Properties of Noodles

Replacing part of the wheat flour with a mixture of WFSP and PFSP flours in the recipes resulted in noodles with higher hardness compared to the control sample (Table 2).

Table 2. Physicochemical properties of noodles with varying ratios of white and purple sweet potato flours.

Parameters	Formula					
	A0	A1	A2	A3	A4	A5
Hardness (g force)	55.30 ^a ±0.05	57.15 ^b ±0.09	59.29 ^c ±0.35	60.78 ^d ±0.22	61.39 ^e ±0.15	63.70 ^f ±0.22
L*	69.56 ^d ±0.04	60.29 ^c ±0.13	60.65 ^c ±0.97	59.89 ^c ±0.69	56.24 ^b ±0.02	44.73 ^a ±1.29
a*	18.60 ^c ±0.58	16.66 ^b ±0.36	16.45 ^b ±1.08	15.99 ^b ±0.95	13.77 ^a ±1.08	14.55 ^a ±1.02
b*	-3.18 ^a ±0.21	-2.99 ^a ±0.14	-2.35 ^b ±0.31	-1.62 ^c ±0.21	-1.57 ^{cd} ±0.91	-1.22 ^d ±0.14
Weight increase (%)	58.54 ^a ±0.41	60.55 ^b ±0.45	61.77 ^c ±0.46	63.65 ^d ±0.39	66.20 ^e ±0.82	68.06 ^f ±0.09
Volume increase (%)	50.58 ^a ±0.54	55.33 ^b ±1.53	64.33 ^c ±1.15	69.67 ^d ±0.58	74.33 ^e ±1.05	79.33 ^f ±1.15
Cooking loss (%)	2.82 ^a ±0.07	3.57 ^b ±0.16	4.23 ^c ±0.30	4.88 ^d ±0.10	5.65 ^e ±0.28	6.14 ^f ±0.10
TPC (mg GAE/g)	1.21 ^a ±0.22	7.55 ^b ±0.01	11.32 ^c ±0.02	15.11 ^d ±0.01	18.94 ^e ±0.03	22.66 ^f ±0.02
Anthocyanin content (mg/100 g)	0.00 ^a ±0.00	47.17 ^b ±0.14	59.25 ^c ±0.12	70.37 ^d ±0.10	82.80 ^e ±0.27	94.32 ^f ±0.34

Note: Values are expressed as mean±STD. Values with different superscripts (a, b, c, d, e, f) in the same row are significantly different according to LSD test ($P < 0.05$).

The lowest hardness value is observed in sample A0 (55.30 g-force), while the highest is recorded in sample A5 (63.70 g-force). The increased hardness can be attributed to the high insoluble fiber content, combined with the significant RS present in sweet potato flour. When these powders are incorporated into the dough, the hardness of the noodles increases due to the fibers competing with the flour for water absorption. Pu et al. (2017) found that adding potato starch to the formulation increased the hardness of the noodles while enhancing the product's durability. Li, Huang, Yang, and Wang (2012) discovered that incorporating purple yam starch into the noodle formulation improved the product's hardness.

Color is regarded as an important quality characteristic because it is the first feature of a product. Flavor and color are also primary criteria used by customers to assess product quality (Adejuwon, Jideani, & Falade, 2020). The brightness of white and purple sweet potato powder-added noodle samples decreased as the quantity increased; the L* value dropped from 69.56 (control sample) to 44.73 (sample A5) (Table 2). Substituting wheat flour with WFSP and PFSP flours resulted in more intense purple noodles but also significantly lowered brightness (L-value) ($P < 0.05$). This change is primarily due to the presence of anthocyanin, a natural pigment responsible for the distinctive purple hue of purple sweet potatoes. The variations are more pronounced in samples A1–A5 (Figure 1). The values a* and b* both indicate significant changes in the white and purple sweet potato dough replacement ratio. The a* value tends to decrease compared to the control sample (light yellow), inversely proportional to the increased rate of white and purple sweet potato powder. However, the a* value did not differ significantly in models A1 (16.66), A2 (16.45), and A3 (15.99), but began to decrease in models A4 (13.77) and A5 (14.55). These two models also do not show meaningful differences. Conversely, b* values increased from sample A0 (-3.18) to sample A5 (-1.22). The observed b* values were all negative, indicating a progressive decline in blue color towards neutrality on the color axis. Rodríguez-Mena et al. (2023) found that the anthocyanin-rich natural colorant from purple sweet potatoes can be used as a food additive, maintaining color stability comparable to artificial colorants and providing numerous health benefits.

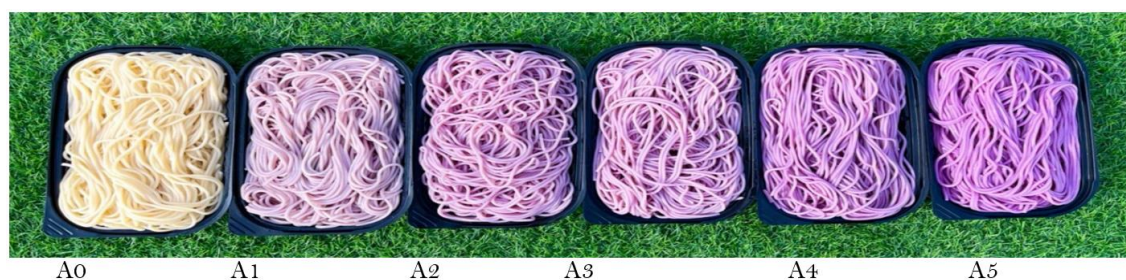


Figure 1. Noodle color at varying ratios of white and purple sweet potato flours.

Note: A0: control sample (100% wheat flour); the ratios of white sweet potato flour: Purple sweet potato flour: Wheat flour (%): A1 (3.0: 10: 87), A2 (4.5: 12.5: 83), A3 (6.0: 15: 79), A4 (7.5: 17.5: 75), A5 (9.0: 20: 71).

The cooking quality of noodles was assessed based on the percentage increase in weight and volume, as well as the loss of dry matter during cooking (Özyurt et al., 2015). The results demonstrated that the percentage increase in weight and volume of noodles ranged from 58.54% to 68.06% and 50.58% to 79.33%, respectively. Noodles prepared with varying amounts of white and purple sweet potato flour showed increased weight and volume compared to the control sample, likely due to the high water-holding capacity of sweet potato flours. Additionally, the high levels of soluble fiber, pectin, and RS in sweet potato flour enhanced water absorption and retention, which significantly extended the starch structure after heating. The inclusion of sweet potato flour also disrupted the gluten network in wheat flour, facilitating greater water penetration. These factors collectively contributed to the increased weight and volume of noodles after cooking. Several previous studies (Santiago et al., 2016; Taneya, Biswas, & Ud-Din, 2014) have indicated that adding sweet potato flour improves water absorption capacity, as well as the weight and volume of noodles after cooking. The research findings also revealed that the dry matter loss ratio of noodles substituted with WFSP and PFSP flours increased from 3.57% to 6.14% compared to the control sample (2.82%) (Table 2). This increase might be due to the disintegration or decomposition of the protein-starch matrix during cooking, or it could be owing to a decrease in gluten content in the flour after replacing the protein with WFSP and PFSP flours. Chen et al. (2002) reported that the cooking loss percentage of sweet potato starch-added noodles ranged from 1.9% to 5.2%. All noodle samples had a cooking loss ratio of less than 8%, which is considered technologically acceptable (Dick & Youngs, 1988). In contrast, increasing the replacement ratio of white and purple sweet potato flour resulted in higher TPC and anthocyanin concentration in noodle products (Table 2). Sample A0 showed low levels of TPC (1.21 mg GAE/g), while sample A5 contained higher levels of TPC and anthocyanins (22.66 mg GAE/g and 94.32 mg/100 g, respectively). This increase is due to the fact that white and purple sweet potato flours (WFSP and PFSP) have high levels of TPC and anthocyanins, whereas wheat flour has very low levels of TPC. The thermal processing also preserved the TPC and anthocyanin levels, which remained higher than in the control sample. This indicates that adding WFSP and PFSP flours to the noodle formulation enhances the anthocyanin and polyphenol content, which are associated with antioxidant properties. Ozgolet, Belkacemi, and Arici (2025) also found that replacing wheat flour with WFSP flour and corn starch increased the TPC of butter cookies by more than 50%. Noodles prepared from a combination of normal wheat flour, rye flour, or purple wheat flour showed significantly increased polyphenol and anthocyanin contents (Park, Cho, Kim, & Kweon, 2022). Santiago et al. (2016) reported that increasing the proportion of purple sweet potato powder improved the antioxidant and anthocyanin contents of noodles but also increased firmness and cooking loss when the addition exceeded 10%. Boonpichai and Sirivongpaisal (2019) also reported that higher substitution levels of purple sweet potato flour increased the anthocyanin content of noodles, while simultaneously affecting their textural properties.

3.2. Potential Renal Acid Load (PRAL) of Control and Chosen Noodle Samples

Table 3 demonstrates that WFSP and PFSP powders have estimated PRAL scores of -34.34 and -11.9, respectively, indicating alkaline material sources (PRAL < 0). Sample A0, which uses 100% flour, has an estimated PRAL value of 11.75, suggesting it is fairly acidic. Conversely, formula A4, containing a mixture of white and purple

sweet potato powders at a ratio of 7.5:17.5%, has an estimated PRAL of 4.38, indicating mild acidity. Therefore, replacing part of the flour with white and purple sweet potato flour in various proportions reduces the product's estimated PRAL value. In a typical diet, individuals do not consume foods that are entirely acidic or entirely alkaline; a balanced diet generally comprises approximately one-third acidic foods and two-thirds alkaline foods and beverages. To achieve this balance, consumers should incorporate vegetables and fruits into their diet, as these are alkaline foods (Adair & Bowden, 2020). After digestion, excess acid in the body must be filtered and eliminated through the kidneys. Consuming more alkaline foods reduces the acid load, thereby decreasing the strain on the kidneys. Consequently, replacing high-acid foods, such as formula A0 with 100% wheat flour, with lower-acid options like formula A4, which contains 7.5% WFSP flour and 17.5% PFSP flour, combined with vegetables, can help maintain a proper acid-alkaline balance and lessen the metabolic burden on the kidneys.

Table 3. Nutritional composition and estimated PRAL score of ingredients used in noodles.

Ingredients	Nutritional composition (per 100 g of edible portion)						PRAL**	
	Protein (g)	Phosphorus (mg)	Potassium (mg)	Calcium (mg)	Magnesium (mg)	*PRAL	A0	A4
Wheat flour	13	108	107	15	22	7.35	9.81	11.76
White sweet potato flour	0.94	42.57	1625	60.37	87.12	-34.34	0.00	-5.15
Purple sweet potato flour	2.35	21.71	561.21	47.56	66.20	-11.90	0.00	-4.16
Potato starch	6.9	168	1000	65	65	-13.50	-6.75	-6.75
Semolina	12.6	87	112	17	30	6.05	3.02	3.02
Salt	0	0	8	24	1	-0.49	-0.01	-0.01
Egg	12.5	198	176	56	12	8.73	5.68	5.68
Water	0	0	0	3	1	-0.06	-0.04	-0.04
Total							11.75	4.38

Note: *Data was calculated based on the ingredients' nutritional profile.

**Data was calculated using the following equation: PRAL = [PRAL ingredient (per 100 g) × amount of raw material (g)] / 100.

3.3. Nutritional Composition of the Selected Noodle Formulations

The results in Table 4 demonstrate that partially substituting white sweet potato and purple sweet potato flour for wheat flour enhances the quality of the noodles. The carbohydrate content of noodle products manufactured using formula A4 was tested at 16.45%, which is lower than that of formula A0 (20.53%). This indicates a tendency to reduce carbohydrate levels when wheat flour is partially replaced with white or purple sweet potato flour. This difference is attributable to the variations in the chemical composition of wheat flour and sweet potato flour, as noted by (Nawaz et al., 2023). Wheat flour generally contains more starch than sweet potato starch; however, sweet potato starch is rich in fiber, monosaccharides, pectin, and bioactive compounds such as polyphenols and anthocyanins, along with vitamins and minerals. Incorporating these compounds into noodle products can help lower the digestible carbohydrate content. Therefore, replacing some wheat flour with sweet potato flour not only reduces carbohydrate levels but also enhances health benefits by increasing fiber and other bioactive elements present in the sweet potatoes used in this study.

Table 4. Nutritional Composition of Noodles from Formulas A0 and A4

Nutritional Composition	A0 sample	A4 sample
Moisture Content, %	65.75 ^b ±0.02	63.32 ^a ±0.10
Carbohydrate, %	20.53 ^b ±0.15	16.45 ^a ±0.08
Ash, %	0.50 ^a ±0.05	0.65 ^b ±0.03
Lipid, %	1.21 ^b ±0.18	1.17 ^a ±0.11
Protein, %	11.90 ^b ±0.12	8.19 ^a ±0.13
Fiber, %	1.54 ^a ±0.02	2.52 ^b ±0.01
RS, %	3.22 ^a ±0.03	4.11 ^b ±0.05
TPC (mg GAE/g)	1.21 ^a ±0.22	18.94 ^b ±0.03
Anthocyanin content (mg/100 g)	0.00 ^a ±0.00	82.80 ^b ±0.27

Note: A0 (100% wheat flour); A4 (the ratio of WFSP:PFSP: Wheat flour is 7.5:17.5:75%).

Values are expressed as mean±STD. Values with different superscripts (a, b) in the same row are significantly different according to LSD test (P < 0.05).

The analysis results also revealed that sample A4 contained 1.64 times more fiber than sample A0 (Table 4), indicating that the addition of WFSP and PFSP flours enhanced the fiber content. The bran layer of wheat flour, which includes fiber, is often removed during the milling process. When sweet potato powder was used to replace some of the wheat flour in the noodle recipe, it retained both crude and soluble fiber content, leading to an increase in the fiber content of the noodle composition as the wheat flour was reduced and the sweet potato powder mixture increased. Nawaz et al. (2023) and Pakhare, Dagadkhair, Udachan, and Andhale (2016) reported similar findings. They discovered that adding sweet potato and soybean flour to noodles improved their fiber content. Fiber-rich foods offer numerous health benefits, including improved digestion, weight management, blood sugar regulation, and a reduced risk of cardiovascular disease and cancer. Sample A4 also had a higher RS content (4.11%) compared to sample A0 (3.22%) (Table 4), likely due to differences in composition and structure between wheat flour and sweet potato flour. Therefore, the addition of WFSP and PFSP flours resulted in positive trends for human health. Additionally, sweet potato flour contains higher proportions of amylose, fiber, and bioactive substances such as TPC and anthocyanins, which contribute to a stronger recovery of characteristics following starch gelatinization and the formation of more RS. Furthermore, sweet potatoes contain complex carbohydrates, such as RS, a form of starch that is indigestible in the small intestine and functions as dietary fiber (Rosell, Quizhpe, Ayuso, Peñalver, & Nieto, 2024). Kolarič, Minarovičová, Lauková, Karovičová, and Kohajdová (2020) observed that adding sweet potato starch increased the RS content in noodle products. Consumption of RS is believed to offer numerous health benefits, including the prevention of colon-related disorders, cardiovascular and diabetes complications, and prebiotic functions.

The noodles in the selected formulation exhibited higher TPC and anthocyanin levels (18.94 mg GAE/g and 82.80 mg/100 g, respectively) compared to sample A0, which had a TPC of 1.21 mg GAE/g (Table 4). This indicates that the inclusion of wheat flour supplemented with sweet potato flour (WFSP) and purple sweet potato flour (PFSP) significantly increased the product's TPC and anthocyanin content. Sweet potatoes are rich in phenolic compounds, such as anthocyanins and polyphenols, whereas refined wheat flour contains minimal amounts due to the removal of bran and germ during milling. Additionally, during dough mixing, noodle formation, and boiling, some polyphenols and anthocyanins bound within the starch structure of sweet potatoes can be released, further enhancing their content in the final product. Utilizing WFSP and PFSP flours in noodle production offers multiple benefits, including improved nutritional content and quality, characterized by high levels of natural polyphenols and anthocyanins. These bioactive compounds can also slow down digestion, leading to a more gradual release of nutrients and better blood sugar regulation. Consequently, incorporating these powders not only enhances the texture and natural color of noodles but also contributes positively to human health and increases the product's economic value (Giau, Van Hao, Van Tai, Minh, & Thuy, 2024).

3.4. Microstructural (SEM) Picture of the Control and Selected Noodles

Figure 2 shows scanning electron micrographs of two noodle samples: control A0 and sample A4. The SEM image clearly reveals the differences in surface structure between the control sample and the samples with WFSP and PFSP flours replacement. Sample A0 (100% wheat flour) (Figure 2a) exhibits a uniform, smooth, unbroken, densely organized noodle surface, indicating the production of a more developed and interconnected gluten network. This structure provides wheat noodles with their distinctive stiffness and flexibility. Gluten and starch form the backbone and filling of the conventional starch/protein system (Pu et al., 2017).

Sample A4 (Figure 2b), which replaced some wheat flour with white and purple sweet potato flour, had a more uneven surface with numerous small cracks, fewer voids, and a more heterogeneous structure. This was attributable to the lower gluten level, as sweet potato starch lacks proteins capable of forming gluten networks, causing a disruption in the binding structure of wheat flour. The gluten protein concentration decreased marginally, but it was

sufficient to establish the gluten-starch network (Pu et al., 2017). However, the gaps and slightly rough surface of the sample with partially replaced sweet potato flour may help improve water absorption and retention during cooking.

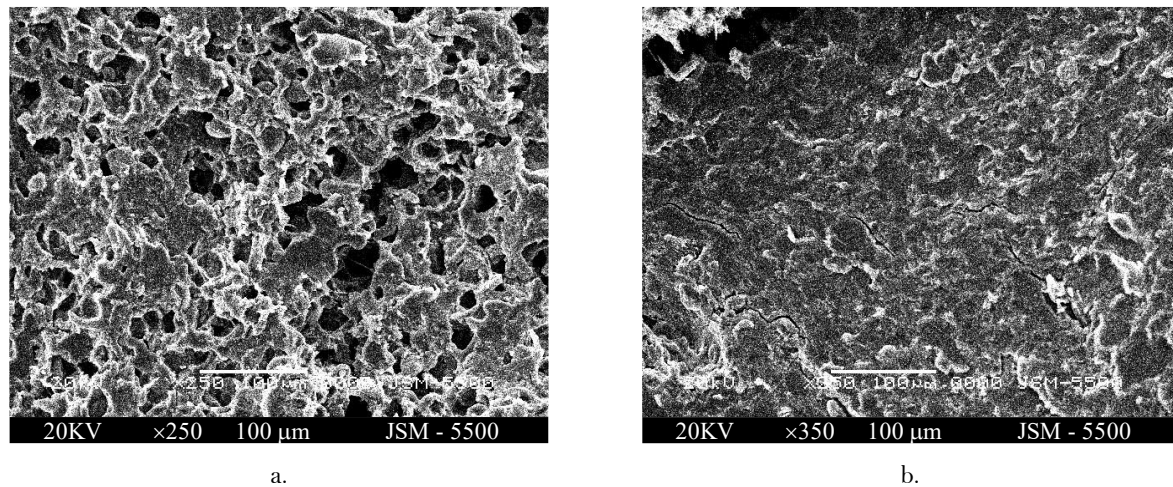


Figure 2. SEM (scale bar 100 µm) of noodle samples: (a) Sample A0 (magnification ×250) and (b) Sample A4 (magnification ×350).
Note: (A0 is control sample, A4 with 7.5% WFSP flour: 17.5% PFSP flour: 75% wheat flour).

4. CONCLUSION

Overall, the partial replacement of wheat flour with WFSP and PFSP flours improved the quality of noodles. A formulation was selected to produce high-quality noodles by combining 75% wheat flour with 7.5% white sweet potato flour and 17.5% purple sweet potato flour. This formulation yielded noodles with intermediate hardness, a pronounced purple color, enhanced weight and volume, and low dry matter loss. The product also contained higher levels of total polyphenols, anthocyanins, ash, fiber, and RS compared to the control sample. Conversely, carbohydrate, moisture, fat, and protein contents were decreased. SEM images of noodle samples revealed significant microstructural variations among the tested samples. The estimated PRAL scores of the noodles with the selected formulation were lower than those of the control, suggesting that when consumed with vegetables, these noodles may have a positive health impact. Therefore, substituting a portion of wheat flour with WFSP and PFSP flours can be an effective strategy to enhance the economic value of common domestic raw materials, which are both inexpensive and of high quality. Specifically, using sweet potatoes particularly varieties with natural colors supports the trend toward green, healthful foods and reduces reliance on imported materials, aligning with the goal of establishing a circular economy in agriculture. Future research will focus on evaluating shelf-life stability, industrial-scale processing parameters, and the economic feasibility of this formulation to facilitate large-scale application and commercialization.

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Competing Interests: The authors declare that they have no competing interests.

Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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