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Physicochemical, Phytochemical and Antioxidant Properties of Organic Sweet Potato Flour and Its Application in Breadstick

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Abstract

Sweet potato flour (SPF) is used to produce food products worldwide due to good biological activity in the human diet and low cost. In this experiment, sweet potato tubers were processed into flour including purple-SPF, yellow-SPF and orange-SPF and applied in breadsticks. The proximate, physical, phytochemical and antioxidant properties of flour and breadsticks were investigated. The carbohydrate, moisture, ash, fat, protein and fiber contents of SPF ranged from 82.19 - 85.21, 4.12 - 5.78, 1.30 - 2.46, 0.32 - 0.86, 4.07 - 4.74 and 3.58 - 5.65 %, respectively. The water activity (a_w) of SPF ranged from 0.2277 - 0.2695. The phytochemical analysis showed that purple-SPF and purple-SPF based breadstick products exhibited the highest total phenolic contents (TPC), total flavonoid contents (TFC) and total anthocyanin contents (TAC), while total carotenoid contents (TCC) was observed in both orange-SPF and breadstick made from orange-SPF. In addition, purple-SPF and breadstick produced from purple-SPF had the highest antioxidant activity against ABTS, FRAP, DPPH and metal chelating activity. The X-ray diffraction patterns of SPF samples showed a C-type crystal structure, with a crystallinity ranging from 19.43 - 31.05 %. The scanning electron micrographs of SPF granules revealed that they were mostly round and spherical, with a size range between 5 - 28 μm. The viscosity characteristics of yellow-SPF had the highest peak viscosity (307.97 ± 9.87 RVU), trough viscosity (200.81 ± 10.07 RVU), breakdown (108.42 ± 3.13 RVU), final viscosity (277.75 ± 8.60 RVU) and setback (76.95 ± 4.03 RVU). The physical quality showed breadstick from yellow-SPF had the highest hardness and fracturability with values of 11,537.67 ± 190.58 g and 11,143.33 ± 161.97 g, respectively. These results indicate that sweet potato flour composite breadstick has high phytochemical and antioxidant potential and may be applied in the food industry.

Keywords: Antioxidant activity, Breadstick, Pasting viscosity, Sweet potato flour, Texture analysis

Introduction

The most valuable member of the Convolvulaceae family is *Ipomoea batatas* L. or sweet potato (SP). It is commonly believed to have originated in Central and South America. The cultivation of the SP was later spread to Asia, Africa and Europe in the 16^{th} century [1]. Currently, more than 100 countries in the world cultivate SP in tropical, subtropical and temperate regions [2]. After rice, wheat, maize and cassava, SP is ranked as the 5th-most important food crop in poor nations based on fresh weight because of its value as an energy source [3]. The flesh color of SP can range from white to several shades of cream, yellow, orange, or even purple [4]. SP is a good source of carbohydrates, dietary fiber, protein, ascorbic acid, B vitamins, minerals such as K, P, Ca, Mg, Na and other minerals such as Fe, Zn [5]. In addition, SP contains antioxidants such as phenolic acids, anthocyanins and carotenoids. These compounds in SP lead to a variety of beneficial health-promoting activities such as antimutagenic, antioxidant, antimicrobial, anticarcinogenic, hepatoprotective, cardioprotective and anti-inflammatory activities. Additionally, SP can help with neurological, cognitive and metabolic disorders [6,7]. Purple-fleshed SP is an abundant source of anthocyanins, which are natural pigments that give fruits and vegetables their blue, red, or purple colors [8]. Anthocyanins offer protection against diseases such as cardiovascular disease, cancer and inflammation. Cyanidin 3-sophoroside-5-glucoside and peonidin 3-sophoroside-5-glucoside are the 2 main anthocyanins specifically found in purple-SP [9]. While SP cultivars with lighter flesh tend to be higher in phenolic compounds, those with stronger yellow coloring tend to be higher in β-carotene, a kind of carotenoid [10]. Orange-fleshed SP is high in β-carotene, which is a precursor to vitamin A. Moreover, it exhibits significant antioxidation, anti-cancer, protection against liver injury and lipid peroxidation properties, all of which represent the ability of this compound to protect the body [11]. Therefore, SP is considered a very interesting nutrient-rich and high-value food product because it has significant levels of secondary metabolites that are beneficial to health. However, SP tubers are difficult to store and can hardly keep longer than a few weeks post-harvest. For that reason, processing SP tubers into flour creates a more stable form that can be kept longer [12].

SPF can be used in various products, such as noodles, bakery foods, snack foods, confectionery, alcohol and in brewing industries [13,14]. SPF can also enhance the natural sweetness, color and flavor of processed foods. Ngoma *et al*. [15], reported that the chemical properties of flour derived from different SP varieties influence the physicochemical properties of their SPF and the quality of the SPF-based food products. Therefore, knowledge of the chemical and physical properties of SPF is useful in developing appropriate products and industrial applications. In addition, using SPF incorporated with wheat flour to produce baked products could reduce wheat flour, sugar and increase the value of SP.

Breadsticks are crispy products with low moisture content, A_w and long shelf-life. The basic formulation of breadsticks is wheat flour and high amounts of lipid, which have a low nutritional value (lack of protein, iron, calcium and vitamins). For this reason, the incorporation of SPF in breadsticks could improve the nutritional value and antioxidant activity of the products. Therefore, this research aimed to determine the chemical composition, phytochemical, antioxidant and physical properties of 3 different varieties of SPF (purple, yellow and orange). Furthermore, the physical, phytochemical and antioxidant activities of breadstick made from all 3 SPF were also investigated.

Materials and methods

Preparation of SPF

Three varieties of organic sweet potato: Purple color (SR003/21), yellow color (SR010/21) and orange color (SR007/21) were purchased from Patchareeya sweet potato farm (Tha Sawang, Mueang Surin District, Surin province, Thailand). SPF was prepared according to the methods described by Jangchud *et al*. [16] with slight modifications. All of the fresh sweet potatoes were washed, peeled and sliced into 3 - 4 mm pieces with a fruit slicer peeler. The sweet potato slices were first soaked in 1 % NaCl solution with a subsequent soaking in anti-browning agent solution containing 1 % potassium metabisulfite (KMS) and 0.5 % citric acid for 30 min, then dried at 60 °C for 24 h in an electric oven (FNB, HB-12A, Thailand). The dried sweet potato slices were finely ground, and sieved through 80 mesh. The flours were packaged in polypropylene bags and stored at 4 °C until further analysis.

Chemical and physical properties

Chemical compositions analysis

The proximate composition such as moisture, protein, fat, carbohydrate, ash and fiber content were determined using the AOAC method [17].

Physical property determinations

Color and water activity (a_w) were done according to the methods of Musika *et al*. [18]. Color values of sample were determined in terms of CIE L*, a*, b* values using a color measurement device (Hunter Lab, Color flex 4510, USA). The a_w of samples was evaluated by water activity meter (AQUA LAB 4TE dew point, Pullman, WA, USA).

Phytochemical properties

A mixture of 0.5 g SPF and 10 mL distilled water was prepared. Then, the samples were homogenized (IKA T25 Digital Ultra Turrax, Staufen, Germany), and centrifuged (HERMLE Labortechnik GmbH, Wehingen, Germany) at 6,000×g for 10 min. The supernatants were collected and the total phenolic, flavonoid, anthocyanin and carotenoid contents and antioxidant activity were measured [19].

Total phenolic contents (TPC)

TPC of samples was studied by using the Folin-Ciocalteu method [20]. Briefly, 100 µL of sample was mixed with 2 mL of 2 % Na_2CO_3. After 2 min, 100 µL of Folin-Ciocalteu reagent was added and the mixture was incubated for 30 min. UV-vis spectrophotometer was used to measure absorbance at 750 nm, and the results were expressed as mg gallic acid eq./g sample.

Total flavonoid contents (TFC)

TFC of samples was measured by a colorimetric assay [21]. Briefly, 250 µL of sample was mixed with 1.25 mL of deionized (DI) water and incubated with 75 µL of 5 % $NaNO_2$ for 6 min. The mixture was then incubated with 100 µL of 10 % $AlCl_3.6H_2O$ for 5 min. After that, 500 µL of 1M NaOH and 275 µL of DI were added and incubated for 10 min and the absorbance read at 510 nm. The TFC of sample was expressed as mg catechin eq./g sample.

Total anthocyanin contents (TAC)

TAC of samples was evaluated by the pH-differential method [22]. Briefly, 2 samples of 500 µL were prepared: One was incubated with 4.5 mL of potassium chloride buffer, pH 1.0, and the other with sodium acetate buffer, pH 4.5. After incubation for 15 min, the absorbance was measured at 510 and 700 nm. The TAC of sample was expressed as mg cyanidin-3-glucoside eq./g sample. The absorbance of sample (A) was calculated as follows:

$$\mathrm{A} = (\mathrm{A}_{510} - \mathrm{A}_{700})\mathrm{pH}1.0 - (\mathrm{A}_{510} - \mathrm{A}_{700})\mathrm{pH}4.5 \quad (1)$$

Total carotenoid contents (TCC)

The method of extraction was based on that of Davey *et al*. [23] with slight modifications. One g of the samples was mixed with 25 mL of absolute ethanol for 1 min. The supernatant was collected by centrifugation at 6,000×g for 10 min. On the other hand, the residual was re-extracted twice with absolute ethanol. The supernatant was evaporated and the absorbance read at 450 nm. The TCC of sample was expressed as mg β-carotene eq./g sample.

Determination of antioxidant activities

ABTS radical scavenging assay

ABTS radical scavenging assay was conducted following the method described by Wiriyaphan *et al*. [24]. Briefly, 20 µL of sample was incubated with 1980 µL of ABTS working solution in the dark for 5 min and the absorbance measured at 734 nm. Results were expressed as mg Trolox eq./g sample.

Ferric reducing ability power (FRAP)

The FRAP assay was estimated using the method described by Benzie and Strain [25]. FRAP reagent was freshly prepared by mixing 10 parts of 300 mM sodium acetate buffer solution at pH 3.6, 1 parts of 20 mM $FeCl_3$ solution and 1 parts of 10 mM 2,4,6-tripyridyl-s-triazine (TPTZ) in 40 mM HCl. Briefly, 100 µL of sample were incubated with 1 mL of FRAP reagent at 37 °C for 10 min. The absorbance was read at 593 nm and data were expressed as mg trolox eq./g sample.

DPPH radical scavenging activity assay

DPPH assay was estimated according to the method described by Musika *et al*. [26] with slight modifications. Briefly, 50 µL of samples was incubated with 1.95 mL of 40 mg/L methanolic $DPPH^{\bullet}$ solution for 20 min in the dark. The absorbance was measured at 515 nm and results were expressed as mg trolox eq./g sample.

Metal chelating activity

Metal chelating activity was measured according to the method described by Decker and Welch [27]. Briefly, 100 µL of samples was mixed with 50 µL of $FeCl_2$ and 100 µL of 5 mM ferrozine. After incubation for 20 min, the absorbance was recorded at 562 nm and results were expressed as mg EDTA eq./g sample.

X-ray diffraction of SPF

XRD patterns of SPF were investigated by an X-ray diffractometer (LabX-XRD-6100, Shimadzu, USA). The measurements were obtained at room temperature with a diffraction angle in range of 10 to 40 ° (2θ), 40 kV, and 30 mA following the method of Li *et al*. [28] with slight modifications. The relative crystallinity (RC) of SPF was calculated as the ratio of the crystalline peak area to the total area (crystalline and amorphous of diffraction peaks).

Structural characterization of SPF

Morphology of SPF was carried out following the method of Yong *et al*. [29]. The SPFs were installed on an aluminum stub using double-sided adhesive tape, after that, gold coating was applied to the upper side of the stub. Then, the samples were examined by using scanning electron microscope (SEM) (TESCAN, VEGA LMU, Czech Republic) at an acceleration voltage of 15 kV. The structural characterization of SPF was observed under microscope (500×, 1000× and 1,500× objective, respectively).

Pasting viscosity

The pasting properties of the SPF were examined by the methods of Li *et al*. [28] with slight modifications. The samples (3.5 g) were mixed with 25 g of distilled water and then the samples were analyzed using a Rapid Visco analyser (RVA Visco Analyser, RVA Tecmaster, Australia). The SPF slurry was pasted with a temperature range of 50 to 95 °C, beginning with an initial hold at 50 °C for 1 min, and then a linear increase to 95 °C for 4.7 min, a further hold at 95 °C for 7.2 min, a linear cooling to 50 °C for 11 min, and a final hold at 50 °C for 13 min. The viscosity was measured in Rapid Visco Units (RVU).

Breadsticks production from SPF

The breadsticks were prepared following the procedure of Thumrongchote *et al*. [30] with some modifcations. The exact measurements of the ingredients used are illustrated in **Table 1**. All-purpose flour, corn starch, vanilla powder and SPF were sieved and mixed into a batter. Salted butter and butylated hydroxytoluene (BHT) were mixed at medium speed by using KitchenAid 5 L (St. Joseph, Michigan, USA). The other ingredients including icing sugar, iodized salt and eggs were added. The mixed batter and water were poured into the mixture and mixed until the ingredients were well combined at a constant speed for 10 min. The dough was kneaded to a sheet and cut into bar shapes with the size of 11 cm length × 0.7 cm width × 0.5 cm height then frozen for 10 min. These were transferred in the oven (YCD-2-4D, Pathumthani, Thailand) and baked at temperature of 170 - 176 °C for 30 min. The cooled breadsticks were packaged in PET plastic container with an oxygen absorber and silica gel for further analysis.

Table 1 The ingredients for breadsticks prepared from sweet potato flour.

Ingredient	Baker's percentage (%)	Gram (g)
All-purpose flour	60	120
Purple-, orange- and yellow-SPF	40	80
Corn starch	2.2	4.4
Icing sugar	30	60
Salted Butter	50	100
Egg yolk	5.4	10.8
Egg	5.4	10.8
Iodized salt	1	2
Vanilla powder	1.3	2.6
Water	15.0	30
Butylated hydroxytoluene (BHT)	0.035	0.07
Total	210.34	420.67

Note: The baker's percentage (%) based on a total flour weight (200 g) was used in this formula.

Phytochemical and antioxidant activities of breadstick

Two g of breadstick was mixed with 20 mL of DI water. The mixture was vortexed and then centrifuged at 6,000×g for 10 min. The supernatants were kept and the phytochemical and antioxidant properties were determined [19].

Texture evaluation of breadstick

Texture properties of breadstick from SPF were measured using texture analyzer (TA-TX plus model, Stable Microsystems, Godalming, UK). The samples were tested by texture profile analysis (TPA) mode using a TA11/1000 probe with a speed at 2 mm/s following the method of Korese *et al*. [31]. The hardness, adhesiveness, cohesiveness, chewiness and fracturability of the products were measured using a sample with the size of 6 mm length × 8 mm width × 5 mm height.

Statistical analysis

Data were statistically analyzed by one-way ANOVA using SPSS 19.0. Duncan's multiple range test (DMRT) was used to determine significant differences, at 95 % confidence level.

Results and discussion

Chemical and physical properties

The chemical compositions of SPF are presented in **Table 2**. The main composition of the 3 varieties of SPFs was carbohydrate, which ranged from 82.19 - 85.21 % (w.b.). The carbohydrate content of purple-SPF and orange-SPF was not significantly different, but both had higher carbohydrate content than that of yellow-SPF. This could have been due to the high moisture and fiber content in yellow-SPF. The carbohydrate content of SPFs obtained from our studies was higher than those reported by Hasmadi *et al*. [32], which ranged from 69.89 - 74.16 %. On the other hand, Olatunde *et al*. [33] suggested that carbohydrate content of SPF from 10 varieties of SP ranged from 74.55 - 94.22 %. Different carbohydrate contents in flour might be attributed to the differences in variety, harvest age and growing environmental conditions of sweet potatoes. Moisture content of yellow-SPF was the highest with a value of 5.78 ± 0.05 %, followed by orange-SPF and purple-SPF, respectively (**Table 2**). Generally, flours and starches contain approximately 12 % moisture content [34]. The maximum allowable moisture content in the flour is 14 % [32]. The moisture content of untreated (control) *Ndou* sweet-SPF, citric acid-pretreated SPF and sodium metabisulphite-pretreated SPF was 6.50, 5.54 and 7.70 %, respectively [15]. Differences in moisture content of flour may be due to variety peculiarities, preparation method and storage practices. In this study, the moisture content of SPFs was below the maximum specified for flour and previous reports. Therefore, the SPFs could resist microbial growth, resulting in improved shelf stability. The ash content of purple-SPF was 2.46 ± 0.21 %, which was higher than that of yellow- and orange-SPF. This implies that the total amount of minerals on purple-SPF was higher than that of yellow-SPF and orange-SPF. Ash content of flour from SP pretreated with sodium metabisulphite was 2.54 ± 0.13 % [15]. Ash content of SPF from *Jepun*, *Kairot* and *Kaladi* varieties ranged from 2.34 - 2.76 % [32]. The ash content observed in purple-SPF was similar to previous reports, however, the ash content of yellow-SPF and orange-SPF were lower [32,15]. Protein content of orange-SPF (4.74 ± 0.50 %) was higher than that of purple-SPF (4.07 ± 0.12 %) but was not significantly different from yellow-SPF (4.47 ± 0.21 %). The SPF contained protein content ranged between 3.02 - 5.30 % [32], 1.08 - 3.09 % [28] and 0.55 - 5.87 % [33]. Differences in protein may be due to varietal differences. Protein is essential in the human diet for growth. Therefore, orange-SPF and yellow-SPF have good biological value due to their high protein. Fat content in purple-SPF (0.86 ± 0.09 %) was higher than in yellow-SPF (0.36 ± 0.07 %) and orange-SPF (0.32 ± 0.01 %). Similar results were also reported by Hasmadi *et al*. [32] who observed that the fat content of SPF ranged between 0.49 - 0.87 %. Different varieties of purple-SPF had 0.17 - 0.41 % of fat [35]. Fat content of purple-, orange- and white-SPF was 2.11, 1.87 and 1.04 %, respectively [36]. Yellow-SPF contained the highest fiber content with value of 5.65 ± 0.36 % (**Table 2**). The crude fiber content of SPF ranged from 1.95 - 2.70 % [32]. SPF contained 0.08 - 5.54 % of fiber [33]. The difference in chemical composition of SPF could be due to the variety, growing locations, pretreatment and drying methods.

The a_w of the 3 SPFs ranged from 0.2277 - 0.2695 (**Table 2**). Generally, dried foods contain a_w value of less than 0.60, which is an indication of shelf-stable product. Therefore, the 3 SPFs could be classified as dried foods, which are microbiologically stable. a_w of 12 SPF ranged between 0.52 - 0.60 [12]. Differences in a_w may be due to variety peculiarities. L*, a* and b* values indicate the lightness, redness and yellowness, respectively. The color values of SPF in this study are presented in **Table 2**. L* values of yellow-SPF (91.13 ± 0.52) was found to be the highest, followed by orange-SPF (77.53 ± 0.60) and purple-SPF (65.53 ± 0.28). The a* value of purple-SPF was the highest, followed by orange-SPF and yellow-SPF. An increase in L* value was correlated with a decrease in a* value. This indicates that yellow-SPF was the brightest while purple-SPF was the darkest due to its high content of anthocyanins and phenolic acid. Therefore, due to its high L* values, yellow-SPF would be appropriate for products with whiter appeal. b* value of orange-SPF was the highest (17.10 ± 0.41), followed by yellow-SPF (1.18 ± 0.08) and purple-SPF (–1.78 ± 0.05). This indicates that the orange-SPF was yellowish due to its high content of β-carotene. The range of values for all SPF was L* of 79.90 - 101.48, a* of –0.27 - 3.54 and b* of 9.89 - 27.94 [33]. Flour from the purple-fleshed SP had brightness (L*) of 40.32, redness (a*) of 10.35 and yellowness (b*) of –5.21 [37]. The color of SPF is derived from natural pigments in the crops such as, carotenoids, anthocyanins and phenolic acid, which affect the red-yellow index of the flour [12]. Color values of SPF are affected by variety, pretreatment and drying methods [33].

Table 2 Chemical and physical properties of SPF.

Chemical and physical properties	**SPF**		
	Purple	**Yellow**	**Orange**
Moisture)%w.b.)	4.12 ± 0.02^{c}	5.78 ± 0.05^{a}	4.8 6 ± 0.07^{b}
Ash)%w.b.)	2.46 ± 0.21^{a}	1.56 ± 0.30^{b}	1.30 ± 0.08^{b}
Fat)%w.b.)	0.86 ± 0.09^{a}	0.36 ± 0.07^{b}	0.32 ± 0.01^{b}
Protein)%w.b.)	4.07 ± 0.12^{b}	4.47 ± 0.21^{ab}	4.74 ± 0.50^{a}
Fiber)%w.b.)	3.87 ± 0.43^{b}	5.65 ± 0.36^{a}	3.58 ± 0.22^{b}
Carbohydrates)%w.b.)	84.62 ± 0.78^{a}	82.19 ± 0.53^{b}	85.21 ± 0.81^{a}
a_w	0.2277 ± 0.0300^{b}	0.2695 ± 0.0100^{a}	0.2373 ± 0.0100^{ab}
Color			
L*	65.53 ± 0.28^{c}	91.13 ± 0.52^{a}	77.53 ± 0.6^{b}
a*	15.84 ± 0.10^{b}	4.39 ± 0.08^{c}	20.13 ± 0.31^{a}
b*	–1.78 ± 0.05^{c}	1.18 ± 0.08^{b}	17.10 ± 0.41^{a}

Note: Different letters ($^{a, b, c}$) in the same row indicate significant differences ($p \leq 0.05$).

Phytochemical analysis

Phytochemical properties of different varieties of SPF samples exhibited significant differences ($p \leq 0.05$) in their TPC, TFC, TAC and TCC values (**Table 3**). The measured values of TPC in purple-SPF, yellow-SPF and orange-SPF were 8.80 ± 0.14, 2.73 ± 0.05 and 3.19 ± 0.05 mg gallic acid eq./g, respectively. The highest amount of TPC was found in purple-SPF, exceeding the values reported by Zhang *et al*. [38], who found that the TPC of free and bound fractions of SPF ranged between 0.13 - 0.90 mg GAE/g and between 0.05 - 0.24 mg GAE/g, respectively. Similarly, the TFC of SPF sample was from 0.60 - 3.20 mg catechin eq./g. The result showed that purple-SPF had the highest TFC while yellow-SPF had the lowest TFC ($p \leq 0.05$). According to Shaari *et al*. [39], the TFC of unpeeled, peeled and skin tuber SPF was from 0.014 - 0.09 mg quercetin eq./g. The specific phenolic contents detected in the SPF belonged to the phenolic acids and flavonoids groups, such as p-coumaric acid, feruloyl-D-glucose and gallic acid [40]. The TAC of SPF samples is illustrated in **Table 3**. The results showed that a significant ($p \leq 0.05$) and the highest amount of TAC was exhibited in purple-SPF (3.28 ± 0.01 mg C-3-G eq./g), while yellow-SPF and orange-SPF showed the lowest amounts. There was no significant difference in the TAC value found between yellow-SPF and orange-SPF. This result agreed with the study by Abidin *et al*. [41], where anthocyanin was found in only purple-SPF, whereas it was not detected in both yellow- and white-SPF. In addition, the previously reported amount of TAC in purple sweet potato were 0.17 mg/g [42], 0.65 mg/g [43] and 0.83 mg/g [44]. The TAC findings from this study differ from that of previous investigations, which may be due to several of factors, including the variety of the raw materials, the quantity of cultivars investigated and the anthocyanin extraction techniques. The TCC of SPF samples are shown in **Table 3**. Orange-SPF had the highest carotenoid content with the value of 1.05 ± 0.02 mg β-carotene eq./g sample. This finding was supported by Tang *et al*. [10] and Islam *et al*. [45], who found that the carotenoid contents were detected in orange- and yellow-SP. β-carotene is provitamin A compound that was found as the major carotenoid in orange-SP and may be utilized as a food supplement for reducing vitamin A deficiency. These results reveal that the levels of phytochemicals composition in SPF depend on several factors, such as SP cultivars and extraction methods.

Table 3 Phytochemical properties of SPF.

Phytochemical properties	SPF		
	Purple	Yellow	Orange
Total phenolic content (mg gallic acid eq./g sample)	8.80 ± 0.14^{a}	2.73 ± 0.05^{c}	3.19 ± 0.05^{b}
Total flavonoid content (mg catechin eq./g sample)	3.20 ± 0.07^{a}	0.17 ± 0.01^{c}	0.60 ± 0.01^{b}
Total anthocyanin content (mg C-3-G eq./g sample)	3.28 ± 0.01^{a}	0.01 ± 0.00^{b}	0.00 ± 0.00^{b}
Total carotenoid content (mg β-carotene eq./g sample)	0.00 ± 0.00^{b}	0.01 ± 0.00^{b}	1.05 ± 0.02^{a}

Note: Different letters ($^{a, b, c}$) in the same row indicate significant differences ($p \leq 0.05$).

Table 4 displays a summary of the phytochemical constituents of the breadsticks made using the SPF from all 3 different varieties. The breadstick prepared from the purple-SPF had the highest amounts of TPC, TFC and TAC, whereas orange-SPF breadstick had the highest amounts of TCC compared to the other samples. These results were correlated with the phytochemical properties of SPF. The TPC, TFC and TAC in breadstick from purple-SPF were 1.84 ± 0.02 mg gallic acid eq./g, 0.53 ± 0.01 mg catechin eq./g and 0.8 5 ± 0.03 mg C-3-G eq./g, respectively, while the TCC in breadstick from orange-SPF was 0.19 ± 0.03 mg β-carotene eq./g.

Table 4 Phytochemical properties of breadstick from SPF.

Phytochemical properties	Breadstick made from SPF		
	Purple	Yellow	Orange
Total phenolic content (mg gallic acid eq./g sample)	1.84 ± 0.02^a	0.80 ± 0.04^c	0.68 ± 0.02^b
Total flavonoid content (mg catechin eq./g sample)	0.53 ± 0.01^a	0.06 ± 0.01^c	0.11 ± 0.01^b
Total anthocyanin content (mg C-3-G eq./g sample)	0.85 ± 0.03^a	0.11 ± 0.04^b	0.16 ± 0.02^b
β-carotene content (mg β-carotene eq./g sample)	0.00 ± 0.00^b	0.01 ± 0.00^b	0.19 ± 0.03^a

Note: Different letters ($^{a, b, c}$) in the same row indicate significant differences ($p \leq 0.05$).

Antioxidant activity

The antioxidant activity of SPF is presented in **Table 5**. The highest scavenging activity of SPF sample was found in the purple-SPF ($p \leq 0.05$), while the lowest amount was observed in the yellow-SPF. Purple-SPF possessed the highest $ABTS^{\bullet+}$ scavenging activity compared to other samples. The ABTS value of purple SP was between 6.10 - 7.66 mg TEAC/g dry weight (DW) [46] and the SPF made from 7 New Zealand SP varieties was 270 µmol Trolox/100 g DW against ABTS [47]. Many researchers have reported SP to be rich in antioxidant properties by scavenging $ABTS^{\bullet+}$ [38,48,49]. As a measure of antioxidant capacity, the ferric reducing ability power (FRAP) is based on the integrated reducing ability of the sample. FRAP of the SPF sample ranged from 2.24 - 15.58 mg Trolox eq./g. Purple-SPF also showed the highest ferric reducing activity. This result agreed with the study by Tang *et al*. [10], who found the FRAP values of 5 different varieties of raw SP were between 274.02 - 52.93 mmol FE/g. The highest antioxidant capacity was observed in raw deep purple, followed by light purple, orange, white and yellow sweet potatoes. Chen *et al*. [42], found that purple SP also reduced Fe^{3+} to Fe^{2+} at 40 mg/mL. Purple-SPF exhibited the highest scavenging activity on DPPH radicals with value of 9.19 mg Trolox eq./g. This result was supported by Abidin *et al*. [41], who reported that purple-SPF showed higher antioxidant capacities against DPPH than yellow- and white-SPF. The free and bound fractions of whole meal flour from 7 SP varieties on DPPH assay ranged from 56.14 - 284.55 and 6.54 - 87.61 µmol Trolox equivalent/100 g, respectively [31]. Additionally, the DPPH value of purple SP ranged from 11.63 - 12.23 mg TEAC/g DW [40]. The purple-SPF exhibited the highest chelating activity on ferrous ions among the SPF samples, with a value of 0.61 ± 0.02 mg EDTA eq./g (**Table 5**). The chelating effect of different SPF had the EC_{50} values between 0.18 - 0.78 mg/mL [50] and 6.7 - 15.3 mg/mL [51]. This finding indicates that the chelating effect of SPF is influenced by the genotype of the SP and different methods of extraction. The SPF exhibited antioxidant activity and phytochemical properties. Most notably, the purple SPF contained anthocyanins, which have physiological effects on hepatitis and hypertension in as well as antihyperglycemic and antiatherosclerosis properties. Orange-SPF contained carotenoids, which showed antioxidative activities that could prevent various diseases as well as being effective strategy for reducing vitamin A deficiency in sensitive populations.

Table 5 Antioxidant activity of SPF.

Antioxidant activities	SPF		
	Purple	**Yellow**	**Orange**
ABTS radical scavenging activity (mg trolox eq./g sample)	21.97 ± 1.99^{a}	4.21 ± 0.06^{c}	6.24 ± 0.16^{b}
Ferric reducing antioxidant power (mg trolox eq./g sample)	15.58 ± 0.45^{a}	2.24 ± 0.03^{c}	4.27 ± 0.24^{b}
DPPH radical scavenging activity (mg trolox eq./g sample)	9.19 ± 0.13^{a}	1.27 ± 0.08^{c}	3.05 ± 0.14^{b}
Metal chelating activity (mg EDTA eq./g sample)	0.61 ± 0.02^{a}	0.00 ± 0.00^{c}	0.13 ± 0.03^{b}

Note: Different letters ($^{a, b, c}$) in the same row indicate significant differences ($p \leq 0.05$).

The antioxidant activity of the breadstick products made from SPF is presented in **Table 6**. The highest antioxidant property was observed in purple-SPF breadstick ($p \leq 0.05$), while yellow-SPF breadstick exhibited the lowest antioxidant activity. The antioxidant activity of purple-SPF samples was 3.62 ± 0.06, 2.35 ± 0.07 and 1.47 ± 0.02 mg trolox eq./g against ABTS, FRAP and DPPH, respectively. The purple-SPF-based biscuit products were found to possess the highest DPPH and FRAP values [41,10]. Purple-SPF breadstick showed the highest chelating effect with value of 0.73 ± 0.04 mg EDTA eq./g, followed by orange-SPF and yellow-SPF breadsticks with 0.45 ± 0.01 and 0.22 ± 0.03 mg EDTA eq./g, respectively. Oloniyo *et al*. [52], found that iron chelating activity of orange SP composite-based bread had EC_{50} values range of 0.43 - 2.01 mg/mL. The iron chelating values of cookies made from orange-SPF ranged between 42.3 - 67.67 % [53]. The antioxidant activity of breadstick products might be as a result of high anthocyanins in purple-SPF (3.28 ± 0.01 mg C-3-G eq./g sample, **Table 3**) and carotenoids in the orange-SPF (1.05 ± 0.02 mg β-carotene eq./g sample, **Table 3**). The SPF-based breadsticks could be considered functional foods as they contain phytochemical and antioxidant compounds that possess the ability to chelate, prevent or inhibit free radicals in the body.

Table 6 Antioxidant activity of breadstick from SPF.

Antioxidant activities	Breadstick from SPF		
	Purple	**Yellow**	**Orange**
ABTS radical scavenging activity (mg trolox eq./g sample)	3.62 ± 0.06^{a}	1.85 ± 0.08^{c}	2.05 ± 0.06^{b}
Ferric reducing antioxidant power (mg trolox eq./g sample)	2.35 ± 0.07^{a}	0.42 ± 0.01^{c}	0.66 ± 0.01^{b}
DPPH radical scavenging activity (mg trolox eq./g sample)	1.47 ± 0.02^{a}	0.19 ± 0.02^{c}	0.45 ± 0.12^{b}
Metal chelating activity (mg EDTA eq./g sample)	0.73 ± 0.04^{a}	0.22 ± 0.03^{c}	0.45 ± 0.01^{b}

Note: Different letters ($^{a, b, c}$) in the same row indicate significant differences ($p \leq 0.05$).

Crystalline structure analysis

The X-ray diffraction patterns and relative crystallinity (RC) of SPF samples are presented in **Figure 1**. All of the SPF samples demonstrated a C-type crystalline structure with 2θ angles at 15.5, 17.5, 18.25 and 23.25. These were consistent with a previous report, which suggested that SP was a C-type starch [54]. Li *et al*. [28] reported that SP from 44 varieties had A-, C_A-, C_C- and C_B-type starches. A-type had strong diffraction peaks at 2θ 15 °, double peaks at 17 and 18 ° and single peak at 23 °. B-type had strong diffraction peaks at 2θ 5.6 and 17 °, double peaks at 22 and 24 °. C_A-type starch exhibits significant shoulder peaks at 2θ 18 °. C_B-type starch has significant shoulder peaks at 2θ 22 and 24 °. C_C-type starch has diffraction peaks at 2θ 5.6, 15, 17 and 23 °. Based on the XRD patterns, the SPF samples were likely a C_A type. The RC of orange-SPF was the highest (31.05 %) followed by yellow-SPF (25.00 %) and purple-SPF (19.43 %). The RC of C-type starches from different sweet potato varieties ranged between 21.96 - 25.93 % [28]. These indicate that, compared to a previous report by Li *et al*. [28], yellow-SPF had a similar RC while the orange-SPF had higher RC, and purple-SPF had lower RC.

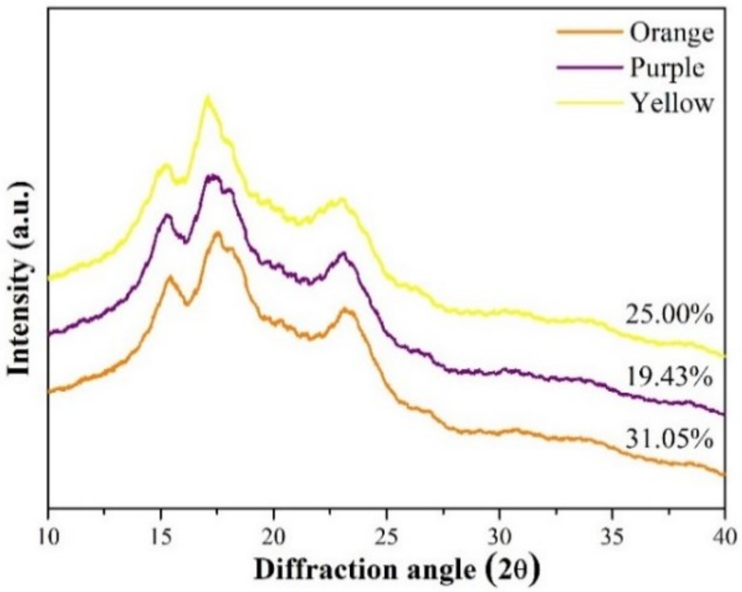

Figure 1 X-ray diffraction pattern of SPF.

Scanning electron microscope (SEM)

The microstructures of SPF are shown in **Figure 2**. The morphology of SPF granules was observed to be mostly round and spherical, with sizes ranging from 5 - 28 µm. The result agreed with the study by Yadav *et al*. [55], who found that SPF starch granules were mainly round, hexagonal and spherical, with sizes between 4 - 26 µm. In addition, the starch granules in SPF in a previous study were found to be also round and spherical [56]. Babu *et al*. [57] reported that although the majority of the SP starch granules were polygonal in shape, round and irregular shapes were also identified, and the granule sizes ranged between 8.0 - 8.9 µm. There are reportedly some functional qualities and physiological functions that are impacted by granule size [56].

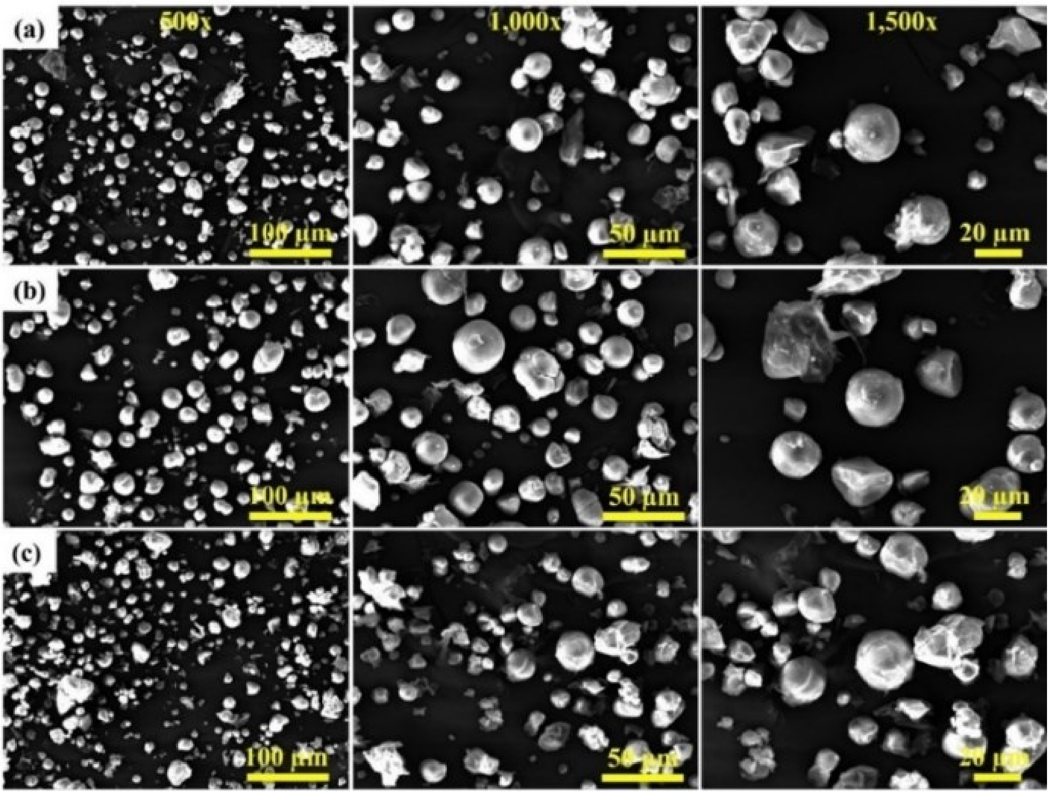

Figure 2 Scanning electron microscopy images of SPF granules at magnifications of 500×, 1,000× and 1,500×: (a) purple-SPF, (b) yellow-SPF and (c) orange-SPF.

Pasting viscosity

The viscosity characteristics of the 3 SPFs are presented in **Table 7**. The pasting temperature of orange-SPF (80.20 ± 0.48 °C) was the highest, followed by purple-SPF (79.08 ± 0.06 °C) and yellow-SPF (77.55 ± 0.05 °C). The higher pasting temperature observed in orange-SPF suggested that the granules were resistant to swelling and would thus need more energy to cook. This agreed with their X-ray diffraction patterns (**Figure 1**), which showed that orange-SPF had higher RC (31.05 %) than the others. This also implied that yellow-SPF is easier to cook, compared to the orange-SPF and purple-SPF. Santi *et al*. [58] reported that the pasting temperature of all 3 SPF ranged between 78.50 - 79.75 °C. The pasting temperature of SPF observed in this study were closely related to those reported by Santi *et al*. [58]. The yellow-SPF had the highest peak viscosity (307.97 ± 9.87 RVU), followed by purple-SPF (129.92 ± 26.12 RVU), and orange-SPF (63.58 ± 0.47 RVU) (**Table 7**). The highest peak viscosity of yellow-SPF was correlated with its lowest pasting temperature. Yellow-SPF had higher fiber than orange-SPF and purple-SPF, which might have contributed to higher water binding capacity and swelling during heating in water, resulting in higher peak viscosity. In addition, purple-SPF contained higher fat and ash contents while orange-SPF contained higher protein content and RC, which might have contributed to restricting the swelling of starch granules and reducing the peak viscosity. In our study, the peak viscosity of yellow-SPF and purple-SPF was in the range of 90.7 - 318.8 RVU similar to the report of Zhang *et al*. [59], however, the peak viscosity of orange-SPF was lower. Flours with high peak viscosity are suitable for products that require high gel strength [60]. Therefore, yellow-SPF could be applied to products with high gel strength and elasticity while purple-SPF and orange-SPF may be appropriate for products with low viscosity. The peak time of the 3 SPFs was from 3.89 - 4.75 min (**Table 7**). It has been reported that peak time of SPF ranged between 3.3 - 9.76 min [61].

A high peak time indicates a longer time to reach peak viscosity, which is not desired in baking industries due to high energy input [62,63].

Therefore, the 3 SPFs obtained from this study were suitable for application in baking industries due to the short peak time values. Trough viscosity of yellow-SPF was the highest, with a value of 200.81 ± 10.07 RVU, followed by purple-SPF (96.50 ± 16.11 RVU) and orange-SPF (10.42 ± 0.17 RVU). Flour with high viscosity may indicate low cooking losses, a superior eating quality, and would be appropriate for products with high flour consistency requirements for prolonged cooking [64]. SPF from different varieties obtained by different drying methods had trough viscosity in the range of 4.33 - 139.96 RVU [65]. The purple-SPF had the lowest breakdown viscosity of 33.42 ± 10.02 RVU, followed by orange-SPF (53.17 ± 0.30 RVU) and yellow-SPF (108.42 ± 3.13 RVU). The breakdown viscosity of the 3 SPFs was in the range of 11.00 - 125.33 RVU as reported by Olatunde *et al*. [33]. Flours with high breakdown viscosity values have a lower ability to resist heating and shear stress during cooking [62]. This indicated that purple-SPF had higher paste stability under hot conditions than others. Final viscosity of yellow-SPF was the highest, with a value of 277.75 ± 8.60 RVU, followed by purple-SPF (126.89 ± 19.86 RVU) and orange-SPF (14.42 ± 0.17 RVU) (**Table 7**). SPF prepared from different varieties, pretreatments and drying methods had final viscosity ranging from 10.21 - 225.50 RVU [33]. The final viscosity of yellow-SPF from this study was higher than the one reported by Olatunde *et al*. [33]. The final viscosity represents the ability of a material to form a gel or viscous paste after cooking or cooling.

The setback value was correlated with final viscosity where yellow-SPF had the highest setback value (76.95 ± 4.03 RVU), followed by purple-SPF (30.39 ± 3.76 RVU) and orange-SPF (4.00 ± 0.00 RVU). Higher setback and final viscosity values in yellow-SPF might have been due to a higher fiber content compared to the others. The lower setback value in orange-SPF might have been due to the higher protein content in the orange-SPF compared to the others. These suggest that orange-SPF had the lowest tendency for retrogradation. It has been reported that the setback viscosity of SPF from different varieties ranged between 9.83 - 117.22 RVU [12], and 1.90 - 80.13 RVU [65]. Flours with high setback values are appropriate for bread making whereas those with low viscosity may be appropriate for products requiring low elasticity and gel strength [66]. Thus, yellow-SPF might be applicable in the bread industry.

Table 7 RVA parameters of SPF.

SPF	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (min)	Pasting Temp (°C)
Purple	129.92 ± 26.12^b	96.50 ± 16.11^b	33.42 ± 10.02^c	126.89 ± 19.86^b	30.39 ± 3.76^b	4.75 ± 0.04^a	79.08 ± 0.06^b
Yellow	307.97 ± 9.87^a	200.81 ± 10.07^a	108.42 ± 3.13^a	277.75 ± 8.60^a	76.95 ± 4.03^a	4.15 ± 0.04^b	77.55 ± 0.05^c
Orange	63.58 ± 0.47^c	10.42 ± 0.17^c	53.17 ± 0.30^b	14.42 ± 0.17^c	4.00 ± 0.00^c	3.89 ± 0.03^c	80.20 ± 0.48^a

Note: Values of RVA parameters are means of 3 determinations; different letters ($^{a, b, c}$) within a column indicate with significant differences ($p \leq 0.05$).

Physicochemical properties of breadstick

Generally, baked products should contain low moisture content (< 5 %) and a_w (< 0.6) [31]. In this study, breadstick from all SPF contained moisture content of 3.13 - 4.87 % and a_w of 0.2598 - 0.3601, which were within the recommended limits (**Table 8**). The moisture content and a_w observed in our study were similar to the values reported by Korese *et al*. [31], who found that the moisture content and a_w of cookies from orange-fleshed SPF ranged from 2.16 - 3.57 and 0.23 - 0.33 %, respectively. The lowest L* and highest a* values were observed in the breadstick from purple-SPF, with values of 31.71 ± 0.87 and 9.98 ± 1.55, respectively, due to the high anthocyanins content of the flour (3.28 ± 0.01 mg C-3-G eq./g sample, **Table 3**). On the other hand, the highest b* was observed in the breadstick from orange-SPF (17.70 ± 2.35) due to the high β-carotenes content of the flour (1.05 ± 0.02 mg β-carotene eq./g sample, **Table 3**). Besides, not only natural pigments but also Maillard and caramelization reactions during baking affected the color of breadsticks. Textural properties play a crucial role on quality and consumer acceptability of breadsticks. As shown in **Table 8**, the hardness of breadstick from yellow-SPF was the highest, with a value of 11,537.67 ± 190.58 g. This could be due to the higher final viscosity and setback values in yellow-SPF, which resulted in a product with dense texture. The fracturability of purple-SPF and yellow-SPF breadsticks was not significantly different ($p > 0.05$), but it was higher than that of orange-SPF breadsticks. The lower hardness and fracturability in the breadstick from orange-SPF could be a result of its higher moisture content compared to the others. The results agreed with the findings of Korese *et al*. [31], who reported that hardness and fracturability of cookies from orange-fleshed SPF decreased when moisture content increased. In addition, this could be due to lower final viscosity and setback values in orange-SPF compared to the others. These indicate that breadstick from orange-SPF had a higher crispiness due to lower fracturability. However, adhesiveness was not significantly different among the samples. The cohesiveness of the breadstick from orange-SPF was higher than that of purple-SPF but was not significantly different from yellow-SPF breadstick. The higher cohesiveness of orange-SPF breadsticks might be attributed to the higher moisture content of orange-SPF than purple-SPF and yellow-SPF, resulting in stickier orange-SPF breadsticks. This value was correlated with the highest chewiness in breadstick from orange-SPF, which had a value of 2.37 ± 0.38 mJ. The variations in the internal structure of cookies could further be attributed to variations in the chemical and functional properties of the flour [67]. Therefore, the difference in texture properties of breadstick from orange-, purple- and yellow-SPF might be attributed to the differences in chemical and functional properties of the flour.

Table 8 Physicochemical properties of breadstick from SPF.

Physicochemical properties	**Breadstick from SPF**		
	Purple	**Yellow**	**Orange**
Moisture content (%)	3.13 ± 0.05^{c}	4.34 ± 0.06^{b}	4.87 ± 0.17^{a}
Water activity (a_w)	0.2598 ± 0.0117^{b}	0.3061 ± 0.0390^{b}	0.3601 ± 0.0734^{a}
Color			
L*	31.71 ± 0.87^{b}	43.39 ± 3.64^{a}	41.06 ± 1.38^{a}
a*	9.98 ± 1.55^{a}	4.74 ± 0.63^{c}	6.54 ± 0.62^{b}
b*	-3.05 ± 0.39^{c}	10.89 ± 2.38^{b}	17.70 ± 2.35^{a}
Hardness (g)	$9{,}059.67 \pm 371.37^{b}$	$11{,}537.67 \pm 190.58^{a}$	$9{,}084.00 \pm 416.70^{b}$
Adhesiveness (mJ) ^{ns}	0.57 ± 0.12	0.43 ± 0.31	0.40 ± 0.20
Cohesiveness	0.01 ± 0.01^{b}	0.02 ± 0.00^{ab}	0.03 ± 0.01^{a}
Chewiness (mJ)	0.90 ± 0.10^{b}	0.70 ± 0.01^{b}	2.37 ± 0.38^{a}
Fracturability (g)	$10{,}169.67 \pm 644.20^{a}$	$11{,}143.33 \pm 161.97^{a}$	$8{,}295 \pm 680.62^{b}$

Note: Different letters ($^{a, b, c}$) in the same row indicate significant differences s ($p \leq 0.05$); ns means not significantly different in the same row ($p > 0.05$).

Conclusions

Flour from 3 different varieties of organic sweet potatoes (purple, yellow and orange) had different chemical compositions, phytochemicals, relative crystallinity and viscosity characteristics, which had further effect on the physicochemical and antioxidant properties of the breadsticks. Purple-SPF and breadstick made from purple-SPF contained the highest TPC, TFC, TAC and antioxidant activities. The results obtained from this study suggest that the purple-SPF could be useful in the manufacture of highly antioxidative breadstick. In addition, the SPF from the 3 different varieties demonstrated C-type starches with granule ranging in size from 5 - 28 µm and had mostly round, and spherical shape. Furthermore, yellow-SPF exhibited the highest peak, trough, breakdown, final and setback viscosity, which could be applied to products requiring high gel strength and elasticity while purple-SPF and orange-SPF may be suitable for products with low viscosity.

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