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Effects of Boiling and Steaming Time on Physicochemical Properties of Unripe Banana Pulp and Flour

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Abstract

The effects of boiling and steaming times on physicochemical properties of unripe banana (*Musa* ABB cv. Kluai Namwa) pulp and unripe banana flour were investigated. Unripe bananas were boiled or steamed by using boiling water for 15, 30 and 45 min and compared unheated (raw) banana acted as a control. The hardness of unripe banana pulp significantly decreased with boiling and steaming times from 36.73 N to 24.29 and 22.97 N, respectively ($p < 0.05$). However, pulp brightness (L^*) from both processes decreased with heating time ($p < 0.05$). Ash and soluble dietary fiber of unripe banana flour showed markedly increases with heating time. Whereas fat, protein, total dietary fiber, insoluble dietary fiber content and resistant starch content of the pulp decreased inversely with the boiling and steaming time. The boiling and steaming process caused the decreased pasting temperature (from about 87.23 to 67.70°C). While, breakdown and setback viscosity of unripe banana flour increased to 37.46 and 56.13 RVU, respectively. Total phenolic content (TPC) and antioxidant activity (2,2-diphenyl-1-picrylhydrazyl, DPPH; and Ferric reducing antioxidant power, FRAP) of the flour increased directly with boiling and steaming time. Results indicated that the increase in antioxidant activity shown by DPPH and FRAP values of heated banana flour corresponded to an increase in phenolic compounds. Finally, boiled banana flour had higher TPC, DPPH and FRAP values than steamed banana flour. The findings can promote the application of boiled and steamed banana flour as a beneficial ingredient in the food industry.

Introduction

Banana (*Musa* sp.) is an important food crop that is widely cultivated in Southeast Asia, South Asia and West Africa, alongside rice, wheat, maize and tapioca (Aurore et al., 2009; Chaipai et al., 2018). In Thailand, common banana varieties include Kluai Hom, Kluai Namwa, Kluai Hakmuk and Kluai Khai. Kluai Namwa

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(*Musa* ABB) is the most extensively grown, accounting for 70% of the total production (Suvittawat et al., 2014). Bananas are rich sources of important nutrients including carbohydrates, vitamins and minerals, as well as functional components, such as dietary fibers and polyphenols, which all play important roles in promoting health and well-being (Singh et al., 2016). The 100 g of Kluai Namwa contains 91.71-96.01% carbohydrates, 0.05-5.56% protein, 0.00-0.79% fat and 7.98-10.39% total dietary fiber (Vatanasuchart et al., 2015). Ripe bananas have a high amount of sugar and are eaten raw as a sweet fruit or used as a dessert ingredient. On the other hand, unripe bananas are a good source of starch, accounting for 70-80% of the total composition (Chaipai et al., 2018). Bananas are processed into starch and flour, then used as culinary ingredients or as a drug with beneficial properties, such as the treatment of peptic ulcers (Jirukkakul & Rakshit, 2011). Unripe banana flour is rich in resistant starch (RS) about 49-65% (Menezes et al., 2011; Rodríguez-Damian et al., 2013) and has been evaluated as a functional ingredient that plays an important role in decreasing the glycemic index (Detchewa et al., 2021). Several studies indicated that the polyphenol content of bananas had high potential as a food source with preventive health benefits. Total phenolic content (TPC) in unripe bananas ranges from 0.90% to 3.0% (dry weight), mainly as tannin components, polymeric catechins and flavonoids (Jannoey et al., 2021; Sulaiman et al., 2011).

Unripe bananas are generally cooked (e.g., boiling, steaming, frying, or roasting) before consumption. However, when the unripe are fruit is cooked, the physicochemical qualities changed and natural RS becomes digestible (Muyonga et al., 2001; Rodríguez-Damian et al., 2013; Chaipai et al., 2018; Tsamo et al., 2015). The way different varieties and ripening stages impact banana properties have been recently reported in the literature, but to the best of our knowledge changes in the physicochemical properties, rheology and health-promoting benefits of unripe bananas after heat processing, such as boiling and steaming, have yet to be clearly defined. Better use of bananas might be obtained by examining how various types of processing and process conditions influence the quality of heated bananas. Therefore, the effects of boiling and steaming duration time on the properties of the pulp and flour from unripe bananas were investigated.

Materials and methods

1. Materials

Unripe or green bananas (*Musa* ABB cv. Kluai Namwa) with 90 days of age, counted from the time the banana blossom produced. The bananas were obtained from a farm in Khlong Luang District, Pathum Thani, Thailand.

2. Boiling and steaming process

Banana fingers were separated from the hand, washed in cleaned water at room temperature and then heated by boiling and steaming. For the boiling process, unripe bananas (22 fruits) were submerged in 3,000 mL of boiling water (100°C) for 15 min (BB15), 30 min (BB30) and 45 min (BB45). Steaming (~110 °C) was carried out by placing unripe bananas in a steamer and steamed with boiling water for 15 min (SB15), 30 min (SB30) and 45 min (SB45). The temperature at the center of boiled and steamed bananas varied from 88°C to 96°C and from 83°C to 90°C, respectively. The heated unripe bananas were immediately soaked in cold water at 4°C for 30 min to reduce the temperature.

3. Banana flour preparation

The raw, steamed and boiled banana fruits were peeled, cut into 0.5 cm thick slices and then freeze-dried (Home freeze dryer, FD4L model, Epsilon Co. Ltd., Thailand). The dried samples were grounded by using a grinder (Fritsch, Pulverisette16, Germany), sifted through a 177 µm (80 mesh) filtered sieve (Fritsch, Analysette 3 Spartan, Germany), packaged in plastic bags and stored in a desiccant jar for further analyses. Consequently, the flours were obtained from raw bananas that had been boiled and steamed at 15, 30 and 45 min resulting as BBF15, BBF30, BBF45, SBF15, SBF30 and SBF45, respectively.

4. Determination of pulp properties

4.1 The moisture content of banana pulp

The moisture content of banana pulp was determined by gravimetric heating at 105°C using a 3-5 g sample according to the AOAC (2004) method in triplicate.

4.2 Hardness analysis of banana pulp

Analysis of hardness was performed by using a Texture Analyzer (TA.XT plus Texture Analyzer, Stable Micro Systems Ltd., UK). The measurement was performed using a penetration probe (6 mm diameter). The texture analyzer was set in return-to-start mode with a pre-test speed of 1.0 mm/s, test speed of 2.0 mm/s and post-test speed of 10 mm/s. Banana pulp samples were positioned in the middle of the texture analyzer platform and penetrated 50% of the sample height.

4.3 Color analysis of banana pulp

Color scales were determined by using a colorimeter (Color Flex 4510, Hunter Lab, VA, USA). The scales L*, a* and b* indicating in terms of lightness, redness/greenness and yellowness/blueness of banana pulp, respectively. The parameters were L* (L* = 0 (black) and L* = 100 (white)), a* (–a= greenness and +a = redness) and b* (–b = blueness and +b = yellowness).

5. Determination of flour properties

5.1 Protein, fat and ash content of banana flour

The banana flour was analyzed for chemical composition (protein, fat and ash content) according to the AOAC (2004) method in triplicate. Protein content was determined by the Kjeldahl method. Soxhlet extraction was used for total crude fat content. Ash content was estimated after incinerating 1 g of the sample in a muffle furnace at 525°C and calculated as follows:

$$\text{Crude ash (\%)} = \left(\frac{W_1 - W_2}{\text{Weight of sample}}\right) \times 100$$

where: W_1 is the weight of the crucible with ash and W_2 is the weight of the empty crucible.

5.2 Dietary fiber

The total, insoluble and soluble dietary fiber contents were measured using a Megazyme test kit (Megazyme International Ltd., Ireland) following AACC (2012) Method 32-05.01: total dietary fiber (TDF) and method 32-21.01: soluble/insoluble dietary fiber. To remove starch and protein, 1.00 g of flour was exposed to sequential enzymatic digestion by heat-stable α-amylase, protease and amyloglucosidase. The sample solution was filtered to remove insoluble dietary fiber (IDF) and the filtrate was treated with 95% (w/v) ethanol to precipitate the soluble dietary fiber (SDF). IDF and SDF residues were dried for the final estimation of dietary fiber content.

5.3 Resistant starch

Resistant starch (RS) was determined by using the Megazyme assay kit (Megazyme International Ltd.) following AOAC (2011) Method 2002.02: resistant starch. Flour samples were digested overnight with α-amylase and amyloglucosidase. To remove soluble starch, the flour suspension was consecutively washed with 95% and 50% ethanol. The pellet was then dissolved in potassium hydroxide (KOH) solution, hydrolyzed with amyloglucosidase and spectrophotometrically quantified using a glucose oxidase-peroxidase (GOPOD) reagent.

5.4 Pasting viscosity

The pasting properties of banana flour were determined by using a Rapid Visco Analyzer (RVA-Super3, Newport Scientific Pty Ltd., Warriewood, Australia). Briefly, 2.5 g of flour, corrected to dry weight basis, was dispersed in 25 mL of water in an aluminum can. The suspension was then heated at 50°C for 1 min with a rotation of 160 rpm. The temperature was raised to 95°C at a constant rate (14°C/min) and held at 95°C for 4 min. Finally, the samples were cooled to 50°C (14°C/min) and held at 50°C for 2 min. Variations in the viscosity of the flour suspension including peak viscosity (PV), minimum viscosity (MV), breakdown (BD), final viscosity (FV), setback (SB) and pasting temperature (PT) were recorded.

5.5 Total phenolic content and antioxidant activity

Banana flour extraction was performed following the procedure of Moongngarm et al. (2014) with some modifications. Two grams of banana flour were placed in 25 mL of 80% ethanol and extracted in an ultrasonic bath (CREST, 2600D model, Malaysia) at 35-37°C for 1 hr. After one hour of extraction, the extract was filtered through Whatman No. 1 paper. A rotary evaporator (Heidolph,Vakuumbox Hei-VAP,Germany) was used to concentrate the filtrate at 40°C and the weight of each extract was recorded. The extract was then re-dissolved in 80% ethanol to a final volume of 25 mL and used for phenolic content and antioxidant analyses.

Total phenolic content (TPC) of banana flour were determined according to the method described by Fatemeh et al. (2012) with some modifications. The sample extract (100 μL) was mixed with 750 μL of Folin-Ciocalteu's phenol reagent and 500 μL of distilled water and allowed to stand for 5 min. Then, 750 μL of 6% (w/v) sodium carbonate (Na_2CO_3) solution was added to the mixture. The absorbance was measured after 90 min of reaction at 765 nm using a spectrophotometer (Gene quant 1300, Harvard Bioscience, Inc., Kista, Sweden). Total phenolic content (TPC) was calculated using the gallic acid calibration curve within the dilutions of 0-0.1 mg/mL and TPC values were expressed as mg gallic acid equivalent (GAE) per 100 g of dry matter. All experiments were performed in triplicate.

The radical scavenging ability of the flour samples was evaluated using a DPPH free radical scavenging assay, following the modified modification method of Fatemeh et al. (2012). Briefly, 100 μL of the diluted extract was mixed with 750 μL of 0.025 g/L DPPH methanolic solution and allowed to stand in darkness for 15 min. The absorbance of the resulting solution was measured at 517 nm using a UV-visible spectrophotometer. Dilutions of different concentrations (0.01-0.05 mg/L) of ascorbic acid were used to plot a calibration curve, with results expressed as milligrams of ascorbic acid equivalent (AAE) per gram of sample dry basis.

The FRAP assay was performed following the method of Benzie and Strain (1999). In brief, FRAP reagent was prepared using a volume ratio of 10:1:1 of 300 mmol/L sodium acetate buffer (pH 3.6), 10 mmol/L 2,4,6-Tris(2-pyridyl)-s-triazine (TPTZ) solution (40 mmol/L hydrochloric acid (HCl) as solvent) and 20 mmol/L iron (III) chloride ($FeCl_3$) solution. The FRAP reagent was warmed in a water bath to 37°C before use. A 30 μL aliquot of banana flour extract was added to 2.7 mL of the FRAP reagent and allowed to stand for 20 min. The absorbance was then measured at 615 nm using a spectrophotometer. Ferrous sulfate ($FeSO_4$) solution (100–500 μmol) was used to construct the standard curve, with results expressed as mmol FeSO4 per gram of sample dry basis.

6. Statistical analysis

All measurements were performed in triplicate, with results presented as mean values and standard deviation (SD). Data were subjected to analysis of variance (ANOVA), with comparison among means determined according to Duncan's new multiple range test using IBM SPSS Statistics v.20 (International Business Machines (IBM) Corporation, Armonk, NY, USA). The significance between means was determined by the least significant difference values at the 5% level.

Results and discussion

1. Physicochemical properties of boiling and steaming banana pulp

The effects of boiling and steaming on changes in moisture content, hardness and color of the banana pulp are shown in Table 1. The results showed that the heating process significantly ($p<0.05$) affected the pulp moisture content that increased directly with boiling and steaming time but no significant difference in moisture content was recorded for samples heated for 30 and 45 min. This might be due to the boiling and steaming process providing large amounts of water and vapor, causing the transfer of water into the banana pulp throughout the process (Tsamo et al., 2015). However, water diffuses into banana pulp continuously with boiling and steaming duration until maximum, resulting in no further water diffusion. As a result, no difference in moisture content was found between boiled or steamed samples heated for 30 and 45 min. At the same boiling and steaming duration, the steamed samples had less moisture than the boiled samples. This occurred because boiling delivered more water to bananas than steaming, consequently, boiling bananas in plenty of water increased their water content due to osmotic exchange (Gafuma et al., 2018).

The boiling and steaming process had a significant ($p<0.05$) effect on the textural characteristic of unripe banana pulp, resulting in a decrease in hardness. Independent of the boiling and steaming process, the textural hardness of all heated banana pulp decreased with increasing boiling and steaming time from 15 to 45 min. Boiling and steaming reduced hardness rapidly in the first 15 min and slightly decreased thereafter. The initial hardness of raw unripe bananas was 36.73±1.66 N. After heat processing, hardness decreased by 22.90, 28.07, and 33.87% for BB15, BB30 and BB45, respectively and by 26.35, 28.61 and 37.46% for SB15, SB30 and SB45, respectively. This phenomenon was also observed by Gafuma et al. (2018) with boiled bananas and occurred due to an increase in the water content of unripe bananas after boiling and steaming. Excess water promotes starch swelling and gelatinization while also promoting the breakdown and solubilization of other intercellular components such as pectin, resulting in structural separation.

Boiling and steaming time significantly ($p<0.05$) affected the color of unripe bananas by decreasing the lightness (L*) and yellowness (b*) of banana pulp. BB45 had the least lightness (65.01±0.44), followed by SB45 (67.22±1.02). The L* and b* values of boiled and steamed unripe bananas decreased because the banana pulp absorbed pigment from the banana peel while being heated. Moreover, the redness (a*) of banana also increased from 1.2 to 2.7 and 3.5 from boiling and steaming, respectively. There was no significant change in the redness (a*) of the boiled and steamed samples compared to a raw banana, except for BB45 and SB45.

Table 1 Physical properties of raw, boiled and steamed unripe banana pulp

Processing	Moisture content (%)	Hardness (N)	Color		
			*L**	*a**	*b**
Raw banana	66.26±0.25[d]	36.73±1.66[a]	86.26±0.29[a]	1.17±0.18[bc]	16.71±0.49[a]
BB15	68.22±0.21[b]	28.32±0.30[b]	71.72±1.77[b]	0.85±0.53[bc]	16.64±2.75[a]
BB30	68.66±0.21[a]	26.42±0.06[c]	67.95±0.66[cd]	1.48±0.47[bc]	12.22±1.37[b]
BB45	68.92±0.30[a]	24.29±0.32[d]	65.01±0.44[d]	2.69±0.80[a]	12.27±0.32[b]
SB15	67.04±0.09[c]	27.05±0.65[bc]	69.17±2.27[bc]	0.56±0.03[c]	13.43±0.28[b]
SB30	68.20±0.17[b]	26.22±0.87[c]	68.16±2.91[c]	1.63±0.79[bc]	11.92±1.65[b]
SB45	68.30±0.10[b]	22.97±0.11[d]	67.22±1.02[cd]	3.52±0.29[a]	12.19±0.32[b]

Remark: a – d = Means ± SD (n = 3) with different lowercase superscript letters within a column are significantly different ($p < 0.05$)
*L** = Lightness, *a** = redness, *b** = yellowness according to the CIE system
BB = Unripe bananas heated by boiling
SB = Unripe bananas heated by steaming
15,30,45 = boiling and steaming time of unripe bananas (min)

2. Physicochemical properties of boiling and steaming banana flour

2.1 Chemical compositions

The heated banana flour compositions (ash, fat and protein) compared to unheated banana flour are presented in Table 2. Raw banana contained 2.70±0.02% (db) ash, 0.51±0.02% (db) fat and 2.61±0.02% (db) protein. Boiling and steaming processes significantly ($p<0.05$) affected the ash content of unripe banana flour. Boiling and steaming unripe bananas for longer periods (45 min) markedly increased the ash content of the banana flour up to 3.02 and 3.37% (db), respectively. These results concurred with Tsamo et al. (2015) who found that the total ash content of plantain banana (*Musa* sp.) pulp decreased after boiling without peel, whereas it remained stable or increased after boiling with peel. An increase in ash content induced by boiling and steaming whole bananas (with peel) was attributable to the migration of minerals such as potassium (K), sodium (Na), calcium (Ca), magnesium (Mg) and phosphorus (P) which are contained in the banana peel and transferred to the pulp. At the same boiling and steaming time, the ash content of steamed banana flour was higher than boiled banana flour. This might be due to some minerals in banana peel being leached into the boiling water, resulting in reducing the portion that migrated to the banana pulp. Conversely, the boiling and steaming processes decreased both the fat and protein contents of unripe banana flour. The fat content of raw unripe banana flour was 0.51±0.02% (db), while fat contents of boiled and steamed banana flours ranged from 0.11-0.23% and 0.13-0.18%, respectively. Low levels of fat in boiled and steamed banana flour were attributed to the formation of starch-lipid complexes during the heat process (Mohammed et al., 2009). As a result, the longer boiling and steaming time caused the lower fat content of the flour. Raw unripe banana flour had 2.61±0.02% (db) protein content, while boiled and steamed banana flour had protein content ranging from 2.47-2.53% and 2.45-2.56%, respectively. The protein content of heated unripe banana flour was slightly lower than raw banana flour because of protein denaturation by heat treatment. Likewise, Vongsumran et al. (2014) observed a decrease in the protein of 1-3% in cooked legume flour.

2.2 Dietary fiber

The effects of heat processing by boiling and steaming on SDF, IDF and TDF contents of unripe banana flour are shown in Table 2. Results revealed that heat processing noticeably modified the soluble and insoluble dietary fiber ratio. As a result, the IDF content of BBF and SBF decreased inversely with boiling and steaming times from 10.43 to 7.48 ($p<0.05$). Conversely, the SDF content of unripe banana flour markedly increased directly with the heating time. Boiling and steaming process increased the SDF content by 0.93, 1.01, 1.24, 1.52, 1.68 and 1.73% for BBF15, SBF15, SBF30, BBF45, BBF30 and SBF45, respectively. Results were consistent with Bader Ul Ain et al. (2019) who suggested that thermal processing including boiling, pressure cooking and roasting changed the SDF/IDF ratio of barley dietary fiber. Interestingly, the boiling process increased SDF by 51.2-53.9%, while decreasing IDF by 8.79-24.4% in barley varieties Haider-93 and Jau-87. The high temperature impacted change in SDF by destroying the glycosidic bonds of polysaccharides, allowing the release of oligosaccharides and thus, increasing the amount of SDF (Bader Ul Ain et al., 2019). Meanwhile, the TDF content of the flour was also decreased with heating time especially for the boiling process from 12.31 to 10.88% db. These findings indicated that heat treatment improved the functional properties of dietary fiber by increasing SDF. Boiling and steaming banana caused the decreasing of IDF. This might be due to IDF was hydrolysis by heating to short chain molecule. This caused IDF to become more soluble as a result of SDF increasing. Therefore, heated banana flour should be considered a promising source of SDF for use in therapeutic and health-promoting food products.

2.3 Resistant starch (RS)

Resistant starch (RS) can be neither hydrolyzed by human digestive enzymes nor absorbed in the small intestine, passing onto the colon (Englyst et al., 1992). RS can be classified into five different types RS1, RS2,

Table 2 Chemical properties of raw, boiled and steamed unripe banana flour

Samples	Ash (% db)	Fat (% db)	Protein (% db)	TDF (% db)	IDF (% db)	SDF (% db)	RS (% db)
Raw banana flour	2.70±0.02[d]	0.51±0.02[a]	2.61±0.02[a]	12.31±0.20[a]	10.43±0.89[a]	1.88±0.13[d]	53.17±3.46[a]
BBF15	2.85±0.13[cd]	0.23±0.11[b]	2.47±0.02[c]	12.28±0.48[a]	9.47±0.31[ab]	2.81±0.24[c]	18.93±0.18[c]
BBF30	2.90±0.04[bc]	0.14±0.04[bc]	2.53±0.01[bc]	11.75±0.42[b]	8.19±0.47[b]	3.56±0.17[a]	22.23±0.02[b]
BBF45	3.02±0.01[b]	0.11±0.01[c]	2.51±0.01[bc]	10.88±0.70[c]	7.48±0.08[d]	3.40±0.06[a]	23.69±1.31[b]
SBF15	2.70±0.09[d]	0.18±0.07[bc]	2.45±0.02[c]	12.44±0.33[a]	9.55±0.25[ab]	2.89±0.14[bc]	18.42±1.03[c]
SBF30	3.34±0.15[a]	0.13±0.02[bc]	2.53±0.01[bc]	12.27±0.29[a]	9.15±0.28[b]	3.12±0.07[b]	20.88±0.80[bc]
SBF45	3.37±0.06[a]	0.13±0.04[bc]	2.56±0.01[ab]	11.94±0.16[b]	8.33±0.29[c]	3.61±0.09[a]	22.56±1.14[b]

Remark: a – d = Means ± SD (n = 3) with different lowercase superscript letters within a column are significantly different ($p < 0.05$)
TDF = Total dietary fiber, IDF = Insoluble dietary fiber, SDF = Soluble dietary fiber, RS = Resistant starch, BBF = Unripe banana flour heated by boiling, SBF = Unripe bananas flour heated by steaming, 15, 30, 45 = boiling and steaming time of unripe bananas (min)

RS3, RS4 and RS5. Unripe banana flour is rich in RS2 which is characterized by native granular starch present in uncooked starchy foods (Detchewa et al., 2021; Vatanasuchart et al., 2009). RS2 is slowly hydrolyzed by α-amylase because of its high β-type granular structure (Jaiturong et al., 2020).

Table 2 shows RS content in raw and heated unripe banana flour. RS content of raw banana flour (53.17±3.46 g/100 g db) was consistent with previous reports, ranging from 32.26-58.10% (db) (Moongngarm et al., 2014; Vatanasuchart et al., 2012). Results revealed that heat processing significantly ($p<0.05$) reduced the RS content of unripe banana flour. After heating for 15 min, the RS content of boiled and steamed banana flour decreased to 18.93±0.18% (db) and 18.42±1.03% (db), respectively. These results concurred with Rodríguez-Damian et al. (2013) who found that boiling unripe banana flour decreased RS content from 65.6% (db) to 23.3% (db). The decline in RS2 was attributed to gelatinization of the starch during the autoclaved heating process, resulting in loss of crystallinity and other unreversible changes in starch characteristics (Aparicio-Saguilán et al., 2005). However, the RS content of boiled and steamed banana flour was increased to 22.23 and 20.88% after heating for 30 min. This might be due to the time of the boiling process which provided moist heat that enabled starch gelatinization and consequently, amylose was leached from the starch granules of banana (Chaipai et al., 2018; De la Rosa-Millan et al., 2014). Then, the leached amylose chains are associated to form hydrogen bonds and recrystallized to form RS3 (retrograded starch). Therefore, conditions that promoted gelatinization allowed the greater formation of RS3 in banana starch (Chaipai et al., 2018).

2.4 Pasting properties

The pasting properties of unripe banana flour were determined by gradually raising the temperature of moist starch to 95°C, maintaining this temperature for a period of time and then steadily reducing the temperature to 50°C. When the unripe banana flour was heated, amylose leached out of the swollen starch molecules, resulting in a rapid increase in viscosity with increasing temperature until PV was reached. Amylose leached out of the starch granules because the high temperature (95°C) and mechanical shear stress reduced the viscosity. The MV and BD were recorded. As the temperature of the mixture reduced, the starch molecules retrograded and formed a viscous gel network, resulting in an increase in FV (Amini Khoozani et al., 2020; Wang et al., 2017).

The pasting properties of raw and heated unripe banana flour are presented in Table 3. PT is the lowest temperature required to cook the sample. The highest PT was found in raw unripe banana flour (87.23±0.04°C). The boiling and steaming process affected the PT of the flour. For example, the PT of the BBF15 and SBF15 was decreased to 67.70 and 70.35°C, respectively. This behavior was caused by the type and amount of RS contained in the flour. Raw unripe banana flour is rich in RS2 which has strong resistance to gelatinization and high temperatures are necessary to gelatinize high-amylose starches. However, heated unripe banana flour contains RS3, a retrograded starch that easily gelatinizes in the presence of water at 60°C (Champ, 2004). As a result, a longer heating duration could cause the re-increase PT of the flour, especially the flour treated by steaming process such as SBF45 showed 82.07°C of PT. Other viscosity values including PV, MV and FV gave comparable results; as boiling and steaming time increased, the viscosity significantly ($p<0.05$) increased. This occurred because the longer heating time increased the quantity of RS (RS3) in the boiled and steamed banana flour, making the flour more resistant to high temperature and shear stress, resulting in an increase in viscosity. BD is defined as the difference between peak and hold viscosity, explaining hydration, starch swelling power and shear resistance of starch paste during boiling and steaming. Low BD is often related to poor hydration and swelling power and strong shear resistance (Shafie et al., 2016). BD values of BBF15 and SBF15 were not different from raw banana flour; however, there were notable increases in BD of boiled and steamed samples heated for 30- and 45-min. BD values of steamed unripe banana flour were lower than the boiled samples for the same heating time.

SB viscosity is the difference between the final and lowest viscosity, indicating starch retrogradation tendency after gelatinization and cooling. Viscosity changes while cooling was mainly due to amylose molecular reassociation, resulting in the formation of new structures (Shafie et al., 2016). SB values of the BBF30 and SBF45 were higher than for BBF15 and SBF15 because with longer boiling and steaming time, more banana pulp granules were gelatinized, and more amylose was destroyed. When the gelatinized starch cooled, the structure rapidly rearranged with the formation of intermolecular hydrogen bonds, resulting in high starch retrogradation.

steamed banana flour at the same heating time. These results concurred with Ebun and Santosh (2011), who found that boiling impacted the phenolic compounds in plantain banana (*Musa paradisiaca*). Plantain boiled with skin had higher TPC values than raw plantain banana. Similarly, Tsamo et al. (2015) observed an increase in TPC in the pulp of boiled plantain banana (*Musa* sp.) with peel. These phenomena can be explained because heat processing weakens the cell wall and enhances the release of bound phenolic compounds by breaking down the cellular constituents (Dewanto et al., 2002). An increase in the bound phenolic content is statistically significantly associated with both time and temperature of retorted heating (Dewanto et al., 2002). A result of a preliminary experiment indicated that the temperature at the center of boiled bananas was 88°C and 96°C for BB15 and BB45, respectively, compared with 83°C and 90°C for SBF15 and SBF45, respectively. In addition, BBF45 contained the highest TPC values.

The antioxidant activity of boiled and steamed banana flour increased markedly with increasing the heating duration, especially in samples heated by boiling. As a result, DPPH and FRAP values of raw banana flour

Table 3 Pasting properties of raw, boiled and steamed unripe banana flour

Samples	PT (°C)	PV (RVU)	MV (RVU)	BD (RVU)	FV (RVU)	SB (RVU)
Raw banana flour	87.23±0.04^{a}	188.77±0.56^{e}	178.82±0.15^{c}	9.96±0.71^{d}	219.92±1.18^{d}	41.11±1.33^{d}
BBF15	67.70±2.26^{d}	180.32±1.92^{f}	145.13±1.17^{e}	9.21±1.12^{d}	186.15±3.15^{e}	41.03±1.97^{d}
BBF30	69.01±0.04^{cd}	228.83±3.31^{c}	171.38±7.14^{d}	50.33±2.48^{b}	216.21±4.65^{d}	44.83±2.48^{c}
BBF45	69.88±0.67^{c}	251.21±1.12^{a}	200.88±1.35^{a}	57.46±3.83^{a}	257.00±0.35^{a}	56.13±1.00^{a}
SBF15	70.35±0.01^{c}	191.42±2.83^{e}	182.08±3.54^{bc}	9.33±0.71^{d}	227.38±3.60^{c}	38.34±2.24^{d}
SBF30	70.33±0.04^{c}	219.46±0.18^{d}	187.00±2.36^{bc}	32.46±2.18^{c}	225.33±0.12^{c}	45.29±0.06^{c}
SBF45	82.07±0.26^{b}	235.00±2.83^{b}	199.42±0.94^{a}	35.59±1.89^{c}	248.00±2.12^{b}	48.59±1.18^{b}

Remark: $^{a-d}$ = Means ± SD (n = 3) with different lowercase superscript letters within a column are significantly different ($p < 0.05$)
PT = Pasting temperature, PV = Peak viscosity, MV = Minimum viscosity, BD = Breakdown, FV = Final viscosity, SB = Setback viscosity, RVU= Rapid Visco Analyzer units, BBF = Unripe banana flour heated by boiling, SBF = Unripe banana flour heated by steaming, 15, 30, 45 = boiling and steaming time of unripe bananas (min)

2.5 TPC and antioxidant activity

The TPC values of unripe banana flour and antioxidant activity determined by FRAP and DPPH assays are presented in Table 4. Results indicated that the boiling and steaming processes impacted antioxidant activity and TPC values of unripe banana flour. The TPC values of boiled flour samples ranged from 8.25 to 9.42 mgGAE/g (db) and those of steamed flour samples ranged from 7.53 to 8.46 mgGAE/g (db). While, the lowest TPC value of 1.80 mgGAE/g (db) was obtained from raw unripe banana flour. The TPC values significantly ($p < 0.05$) increased with increasing the boiling and steaming time. TPC values of boiled banana flour were higher than

were 3.99±0.04 mg AAE/g (db) and 9.25±0.12 mmol FeSO4/g (db), respectively. While DPPH values of BBF15, BBF30 and BBF45 samples increased by 28.3, 48.6 and 58.9%, respectively. Comparing, SBF15, SBF30 and SBF45 exhibited increases in DPPH values by 5.5, 24.3 and 35.8%, respectively. Similarly, FRAP of heated samples increased as boiling and steaming time increased. For the same treatment time, steamed banana flour had lower FRAP values than boiled samples. Results indicated that the increase in antioxidant activity shown by DPPH and FRAP values of heated banana flour corresponded to an increase in phenolic compounds. Previous studies reported that the antioxidant activity of a food is linearly and positively correlated with the phenolic content (Başyiğit et al., 2018; Ruengdech et al., 2019). The Pearson correlation coefficients were calculated between the means of TPC, DPPH and FRAP (Table 5). Results showed high correlation between TPC and DPPH (r=0.762, p<0.01) and TPC and FRAP (r=0.890, p<0.01); DPPH and FRAP (r=0.792, p<0.01) were also observed.

Table 4 Phenolic content and antioxidant activity of raw, boiled and steamed unripe banana flour

Samples	TPC (mg GAE/g db)	DPPH (mg AAE/g db)	FRAP (mmol FeSO4/g db)
Raw banana flour	1.80±0.02[g]	3.99±0.04[g]	9.25±0.12[g]
BBF15	8.25±0.01[d]	5.12±0.02[d]	17.38±0.18[f]
BBF30	9.14±0.03[b]	5.93±0.03[b]	26.42±0.13[b]
BBF45	9.42±0.03[a]	6.34±0.05[a]	30.39±0.31[a]
SBF15	7.53±0.04[f]	4.21±0.03[f]	20.80±0.18[e]
SBF30	8.12±0.03[e]	4.96±0.01[e]	24.46±0.22[d]
SBF45	8.46±0.03[c]	5.42±0.03[c]	25.71±0.07[c]

Remark: a – g = Means ± SD (n = 3) with different lowercase superscript letters within a column are significantly different ($p < 0.05$)
TPC = Total phenolic content, DPPH = 1,1-Diphenyl-2-picrylhydrazyl radical scavenging activity, FRAP = Ferric reducing antioxidant power, BBF = Unripe banana flour heated by boiling, SBF = Unripe banana flour heated by steaming, 15,30,45 = boiling and steaming time of unripe bananas (min)

Table 5 Pearson correlation coefficients of phenolic content and antioxidant activity of raw, boiled and steamed unripe banana flour

	TPC	DPPH	FRAP
RaTPC	1	0.762**	0.890**
DPPH	0.762**	1	0.792**
FRAP	0.890**	0.792**	1

Remark: ** Correlation was significant at $p < 0.01$, TPC = Total phenolic content, DPPH = 1,1-Diphenyl-2-picrylhydrazyl radical scavenging activity, FRAP = Ferric reducing antioxidant power

Conclusions

Results demonstrated that boiling and steaming unripe bananas for 15 to 45 min significantly caused the physicochemical properties alternation of pulp and flour banana. Boiling and steaming caused the soft texture of the unripe banana pulp because of starch gelatinization so it was simpler to eat and increased SDF and antioxidant levels. Results revealed that boiling had a stronger impact on the qualities of banana flour than steaming, particularly, pasting properties and antioxidant activity. Meanwhile, the resistant starch content of unripe banana flour was reduced about 30% by steaming and boiling process. Boiled banana flour showed higher TPC, DPPH and FRAP than steamed banana flour. These findings can assist researchers to determine the optimal nutritional advantages and disadvantages of consuming cooked bananas and to promote the application of boiled and steamed banana flour as a beneficial ingredient in the food industry.

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