Effect of different drying methods on the nutritional and physicochemical properties of unpeeled banana flour

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ABSTRACT

This work was conducted to evaluate the effect of drying methods on the nutritional values and physicochemical properties of unpeeled banana flour. Proximate, amylose content, phenolic compound, resistant starch, total dietary fibre, functional properties, pasting properties, and thermal properties of dried banana flour samples were evaluated. Three different drying methods of whole banana with the intact peel were studied including 1) hot-air unpeeled flour (HAU) (dried at 60°C for 2 h in hot-air chamber), 2) microwave-vacuum unpeeled flour (MVU) (36,000 W under vacuum -600 mmHg for 15 min in a pilot microwave-vacuum dryer), and 3) infrared unpeeled flour (IRU) (600 W for 15 min in infrared channel dryer). The HAU and MVU showed the highest yield. Drying methods did not affect the compositions of the flour but significantly affected the total dietary fibre, resistant starch, amylose content and phenolic compound of the flour. Among samples, HAU contained the highest nutritional values with outstanding functional properties, and pasting properties. The unpeeled banana flour can be utilized in various food products such as noodle, bakeries, snack or used as functional ingredients for nutritional purposes.

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1. Introduction

Banana is used popularly among all classes of people due to its widely available, cheap with great nutritive and medicinal values. In recent times, interest in using banana at the green stage as a food ingredient has been aroused because of its high carbohydrate content, especially resistant starch which is considered as a functional food (Mastro et al., 2007; Mohapatra et al., 2010). The banana peel has been reported to contain a high amount of dietary fibre, minerals, vitamins and polyphenolic compounds (Anjum et al., 2014). Consequently, banana peel is a great potential material that could be considered and developed for further application. However, banana production has been excessive, causing a large amount of bananas to be reduced in price or wasted due to the lack of well-organized and proficient preservation techniques (Maskan, 2000); and banana peel is mostly discarded to be used as fertilizer in landfills, animal feed or waste. Therefore, preservation technique should be investigated to extend the shelf-life and the utilization of banana peel is necessary to maximize the benefit of banana and increase the productivity of banana production.

Hot-air drying is a conventional drying method which has low energy efficiency and a long drying time (Adu & Otten, 1996; Feng & Tang, 1998). For this reason, it may cause substantially undesirable impact on quality of dried products (Lin et al., 1998; Drouzas et al., 1999). Microwave-vacuum and infrared heating are characterized by rapid and uniform heating which could be the alternative for hot-air drying.

In this study, hot-air drying chamber,

microwave-vacuum chamber and infrared channel were investigated as preservation techniques for prolonging the shelf-life of unpeeled banana by lowering its moisture content. Proximate, total dietary fibre, resistant starch, amylose content and phenolic compound were analyzed to figure out the effect of the three different drying methods on nutritional value of banana flour. Functional properties, thermal properties, pasting properties and colour were also evaluated among the three drying methods to understand the physical properties of banana flour.

2. Materials and Methods

2.1. Banana flour processing

The first ripeness stage of banana Pisang Awak Musa obtained from Phitsanulok Province, Thailand was chosen based on the standard ripeness chart (Kader, 1996) for producing banana flour. The preparation of banana flour was made by using the method of Arisa et al. (2013) with a slight modification. Individual banana fruits with intact peel were obtained from banana bunches by cutting and washing. After that, they were sliced into 2 mm thickness using a kitchen slicer and immediately soaked into sodium metabisulfite 0.1% for 5 min. Then, they were separated into 3 parts for being dried using 3 different drying methods including 60°C for 2 h in hot-air chamber (HAU), 36,000 W under vacuum -600 mmHg for 15 min in a pilot microwave-vacuum dryer (MVU), and 600 W for 15 min in infrared channel dryer (IRU). The dried banana slices were ground into powder using a grinder DXFill model DXM 2000 and then screened through a 60 mesh sieve. The banana flour was packed in an aluminium pack and stored at -18^{0}C.

2.2. Analysis

2.2.1. Production yield

Production yield was determined by dividing the weight of the obtained banana flour (dry basis) by the weight of the fresh banana fruit, and then multiply by 100.

2.2.2. Water activity

Water activity of samples was measured using Lab swift water activity meter.

2.2.3. Proximate

Proximate in terms of moisture, protein, crude fat and ash was analysed by the method described in AOAC (1990).

2.2.4. Amylose content

The amylose content measurement was done according to the method of Almeida et al. (2010) with a slight modification. Briefly, a total of 100 mg sample was homogenized with 1 mL of 95% ethanol and 9 mL of 1 M NaOH. The sample was heated for 10 min in a boiling-water bath to gelatinize the starch. After cooling, it was transferred into a volumetric flask and the volume was made up to 100 mL with water. Then 1 mL of 1 M acetic acid and 2 mL of iodine solution (0.2% I2, 2% KI) was added to a 5 mL aliquot. The solution was made up to 100 mL with water and allowed to stand for 10 min. Spectrophotometric quantification was performed at 620 nm, with a UV-Vis spectrophotometer Shanghai Metash Instrument. The apparent amylose content was calculated using an equation obtained from the standard curve using purified amylose and amylopectin extracted from potato tubers.

2.2.5. Phenolic compound

Phenolic compound was measured using the method of Yang et al. (2014) with a slight modification. Briefly, the sample (5 g) was extracted twice with 50 mL of 80% (v/v) aqueous ethanol for 30 min at ambient temperature and centrifuged at 6000 r/min for 15 min at 20°C. The supernatants were collected, combined, and then evaporated under vacuum -300 mbar at 40°C in Evaporator apparatus (Büchi Rotavapor R-114; Büchi Waterbath B-480, Büchi Vacuum-System B-169) to dry and reconstituted in 100 mL of distilled water. Phenolic compound was measured using Folin-Ciocalteu method.

2.2.6. Resistant starch

Resistant starch was determined by using the method of Megazyme International Ireland. Briefly, the sample was incubated in 4.0 mL of pancreatic α-amylase solution at 37°C with continuous shaking for 16 hours. Ethanol (99% v/v) of 4 mL was added and vigorously stirred on the vortex mixer. The tubes were centrifuged at 3,000

rpm for 10 min (non-capped). The supernatants were carefully decanted and the pellets were re-suspended in 2 mL of 50% ethanol and vigorously stirred on the vortex mixer. Accurately 6 mL of 50% IMS was further added and the solution was centrifuged again at 3000 rpm for 10 min using centrifuge universal 320. The supernatants were decanted. These suspension and centrifugation steps were repeated once more. The pellets were re-suspended in 2 mL of 2 M KOH and stirred for approximate 20 min in an ice/water bath. Accurately 8 mL of 1.2 M sodium acetate buffer (pH 3.8) was added. The mixture was incubated in 0.1 mL of AMG at 50°C for 30 min. To measure resistant starch, accurately 0.1 mL aliquots (in duplicate) was mixed with 3.0 mL of GOPOD reagent, the mixture was incubated at 50°C for 20 min. The absorbance of the mixture was measured at 510 nm against the reagent blank.

2.2.7. Total dietary fibre

Total dietary fibre was determined by using the method of Megazyme International Ireland. Briefly, duplicate of samples were mixed with 10ml MES-TRIS solution using magnetic stirring bar. After that, the mixture was incubated in 50 μL thermostable α-amylase solution at 98 - 100°C for 30 min and 100 μL protease solution at 60°C for 30 min successively with continuous agitation. Accurately 5 mL of 0.561 N HCl was dispersed into the mixture and the pH was adjusted with additional 5% NaOH solution. The mixture was incubated in 200 μL amyloglucosidase solution at 60°C for 30 min with continuous agitation. The insoluble fibre in the mixture was filtrated using filter paper Whatman number 4. The soluble fibre in the filtrate was precipitated by incubating in EtOH 95% at 60°C for 60 min. The soluble fibre was filtrated using filter paper Whatman number 4. Each replicate of the insoluble and soluble fibre filter paper was measured for protein and ash. Dietary fibre is the sum of insoluble and soluble fibre.

2.2.8. Functional properties

The water absorption index (WAI), water solubility index (WSI) and swelling power index (SPI) were determined according to a reported method of Tong et al. (2015) with a slight modification. Briefly, about 0.1 g of sample was dispersed in 20 mL deionized water and agitated at 25°C and 100°C for 30 min using shaking water bath JSR model JSSB-30T, respectively. After centrifuging the dispersion at 15,000 g for 30 min using a Hermle Z206A centrifuge, the supernatant was dried in a hot-air oven SNOL at 105°C until a constant weight was obtained. WAI, WSI and SPI were calculated by the following formulas:

$$\text{Water absorption index} = \frac{\text{wet sediment weight}}{\text{dry sample weight}}$$

$$\text{Water solubility index (\%)} = \frac{\text{dried supernatant weight}}{\text{dry sample weight}} \times 100$$

$$\text{Swelling power index} = \frac{\text{wet sediment weight}}{\text{dry sample weight x (1-WSI)}}$$

The oil absorption index (OAI) was determined based on the protocol developed by Kraithong et al. (2018) with a slight modification. The sample of 1 g was mixed with 10 mL of soybean oil bought from Lotus supermarket. The mixture was centrifuged at 4000 rpm for 20 min using a Hermle Z206A centrifuge. After that, the supernatant was decanted while the residue was weighed. The calculation of OAI was as follows:

$$\text{Oil absorption index} \left(\frac{\text{g}}{\text{g}}\right) = \frac{\text{weight of residues(g)-weight of sample(g)}}{\text{weight of dry sample (g)}}$$

2.2.9. Thermal properties

Thermal properties in terms of onset temperature, peak temperature, enset temperature and enthalpy were measured using a Mettler Differential Scanning Calorimetry (DSC). The method was followed a procedure of Nimsung et al. (2007). Approximately 5 mg of the sample (dry basis) was weighed directly in a tared stainless pan at temperature of 20°C and distilled water was added to get the starch:water ratio of 1:2 (5 mg:10 μL). The pan containing the sample was hermetically sealed and allowed to equilibrate for 1 hour at room temperature to complete starch hydration before the analysis. After that, the pan was placed in the DSC and heated from 10 to 130°C at the rate of 10°C/min. An empty pan was used as a reference. The onset (T_o), peak (T_p), completion temperature (T_c), and energy of enthalpy (ΔH) were recorded and computed

using computer software supplied with the instrument.

2.2.10. Pasting properties

The pasting properties in terms of peak viscosity, hot paste viscosity, breakdown, cold paste viscosity, set back, peak time and pasting temperature were determined using a Rapid Visco Analyzer 4500 (Newport Scientific). The method was followed procedure of Nimsung et al. (2007) with a slight modification. The sample of 3 g (dry basis) was weighed into a disposable aluminium RVA canister, and distilled water was added to obtain a total sample weight of 28 g. The sample was held at 50°C for 1 min and heated to 95°C for 4 min and held at 95°C for 2 min, and then cooled from 95°C to 50°C and held at 50°C for 9 min. The RVA parameters including the peak viscosity, hot paste viscosity, breakdown, cold paste viscosity, setback, and pasting temperature were all recorded. All measurements were performed in duplicates.

2.2.11. Statistical analysis

An analysis of variance (ANOVA) was performed. The data were expressed as the mean ± SD and analysed by SPSS (version 19 for windows, SPSS Inc., Chicago, IL, USA) using Duncan's Multiple-Range Test at a significant level of $P < 0.05$.

3. Results and Discussion

3.1. Production yield and water activity

Production yield obtained from 3 drying methods of peeled and unpeeled banana flour is presented in Table 1. There was a small difference in production yield among the drying methods except for MVU and HAU which show higher production yield (25.73% and 25.5%, respectively) than that of IRU. These results were similar to the production yield of green banana flour obtained from 4 types of banana reported by Yani et al. (2013) (*Janten* 35 - 36%, *Kepok Manado* 19 - 20%, *Muli* 16 - 17% and *Raja Nangka* 20 - 21%). Yani et al. (2013) stated that the difference of production yield might be due to the maturity stages of bananas which is related to the starch content and properties. Microwave-vacuum drying and hot-air drying could be considered to apply for producing unpeeled banana flour regarding the economic benefit and production yield.

In general, the water activity of banana flour dried by the 3 drying methods was lower than 0.6 which is the safe level for preserving the product. MVU exhibited the lowest water activity (0.326) and there were not significant differences in the water activity between HAU (0.482) and IRU (0.469). As a result, the most effective drying method for reducing water activity was microwave-vacuum.

Table 1. Production yield (% dry basis) and water activity of banana flour

Samples	Production yield	Water activity
HAU	25.50	0.482 ± 0.060^{a}
MVU	25.73	0.326 ± 0.017^{b}
IRU	22.68	0.469 ± 0.001^{a}

Values are shown as mean ± SD; $^{a-b}$Different letters in the same column are significantly different ($P < 0.05$); HAU: Hot-air unpeeled; MVU: Microwave-vacuum unpeeled; IRU: Infrared unpeeled.

3.2. Proximate analysis

Proximate of banana flour including moisture content, protein, crude fat, ash and carbohydrate is presented in Table 2. The moisture content was highest in IRU (12.14%) and lowest in MVU (5.38%). It might be due to the high processing temperature and shallow depth effect of infrared which caused the cake hardening phenomenon which prevents moisture from diffusion and evaporation; and in microwave vacuum drying, the heat created by ionic polarization or dipole rotation transfer within the food by conduction or convection so that the inner and outer parts of food receive the same energy or the moisture content is removed thoroughly.

Protein ranged from 2.80% in IRU to 3.03% in MVU and there were not significant differences in protein content among different drying methods. The results were close to the range of 2.55 - 3.41% in banana flours reported by Yani et al., (2013), 2.50 - 3.0% reported by Mota et al. (2000) and 1.88 - 4.47% reported by Nimsung et al. (2007). The variance of protein content in banana flour was caused by some factors such as weather, soil nutrient and varieties (Yani et al., 2013) and matuirty stage (Emaga et al., 2007).

The range of 0.23% in IRU and 0.26% in MVU for crude fat were in agreement with Liao & Hung

Table 2. Proximate of banana flour (% dry basis)

Method	Moisture	Protein^{ns}	Crude fat^{ns}	Ash^{ns}	Carbohydrate^{ns}
HAU	9.50 ± 0.20^{b}	2.84 ± 0.18	0.24 ± 0.02	1.94 ± 0.16	94.98 ± 0.33
MVU	5.38 ± 0.27^{c}	3.03 ± 0.33	0.26 ± 0.01	1.68 ± 0.35	95.04 ± 0.07
IRU	12.14 ± 0.13^{a}	2.80 ± 0.11	0.23 ± 0.02	1.52 ± 0.16	95.45 ± 0.23

Values are shown as mean ± SD; $^{a\text{-}c}$Different letters in the same column are significantly different ($P < 0.05$); ^{ns}Non-significant; HAU: Hot-air unpeeled; MVU: Microwave-vacuum unpeeled; IRU: Infrared unpeeled.

(2015) and Nimsung et al. (2007) who found that the fat content of banana flour was 0.25% and 1.56 - 4.88%, respectively. The three drying methods did not have an effect on the fat content of banana flour.

The ash was in the range of 1.52% in IRU and 1.94% in HAU. The results also showed that there were not significant differences among the three drying methods ($P > 0.05$). These results were lower than the range of 2.24 - 3.03% and 2.6 - 3.5%, which were reported by Yani et al. (2013) and Mota et al. (2000), respectively. The differences in the ash content might be due to the soil, varieties and planting weather.

Carbohydrate was in the range of 94.98% in HAU and 95.45% in IRU and there were not significant differences among 3 drying methods in the carbohydrate content ($P > 0.05$).

3.3. Total dietary fibre, resistant starch, amylose content and phenolic compound

Total dietary fibre, resistant starch, amylose content and phenolic compound are shown in Table 3. Total dietary fibre ranged from 15.75% in IRU to 18.38% in HAU, these values compared reasonably well with the 6.0 - 15.5% total fibre reported by Mota et al. (2000).

The highest and lowest amounts of resistant starch were found to be in HAU (60.21%) and IRU (34.26%) respectively. The values were well comparable with those of 48.99% reported by Menezes et al. (2011) who followed the method of AOAC 2002.02 and 30.3% reported by Liao & Hung (2015) whose method was based on the approved method 32 - 40 (AACC, 2000). This difference might be caused by the high temperature and temperature fluctuation in infrared drying that reduced the amount of resistant starch.

Amylose content was found to be highest and lowest in HAU (37.95%) and IRU (32.17%) respectively. The difference in amylose content among 3 drying methods might be due to the differences in moisture contents, drying rates, drying temperatures and drying mechanisms. The result shows that there might be a relationship between resistant starch and amylose content since the higher the amylose content, the higher the resistant starch content.

The highest and lowest phenolic compounds were found to be in HAU and IRU respectively. The phenolic content in banana flour was obtained from 20.22 mg GAE/100 g in IRU to 62.66 mg GAE/100 g in HAU. The phenolic content in HAU and MVU was closely and IRU was pretty lower compared to 50.65 mg GAE/100 g reported by Menezes et al. (2011). The difference might be due to the high and inconsistence of the temperature of different drying systems.

The total dietary fibre, resistant starch and amylose content might be sensitive to high temperature and the temperature fluctuation since they were lowest in the flour produced by infrared drying. The impact of hot-air drying on nutritional value of banana flour was the least comparing to microwave-vacuum drying and infrared drying, even though these 2 drying methods were evaluated to be less undesirable on quality of banana flour. It is appeared that optimization of drying condition of microwave-vacuum and infrared drying should be investigated in order to altarnate the traditional drying method.

3.4. Functional, thermal and pasting properties

The functional properties of banana flour including WAI (Water Absorption Index), WSI (Water Solubility Index), SPI (Swelling Power Index) and OAI (Oil Absorption Index) are shown in Table 4. Water Absorption Index (WAI) ranged from 3.15 g/g in MVU to 3.59 g/g in HAU. WAI exhibits the ability of flour to absorb water molecules (Shafi et al., 2016). It is supported by the hydrophilic groups within the starches, which provide the viscosity, smoothness, and softness in the products (Aprianita et al., 2014). The polar side chains in carbohydrates and proteins could

Table 3. Total dietary fibre, resistant starch, amylose content and phenolics of banana flour (dry basis)

Samples	Total dietary fibre (%)	Resistant starch (%)	Amylose (%)	Phenolics (mg GAE/100 g)
HAU	18.38 ±0.03^{a}	60.21 ± 0.13^{a}	37.95 ± 0.98^{a}	62.66 ± 0.04^{a}
MVU	17.34 ± 0.16^{b}	56.48 ± 0.90^{b}	35.07 ± 1.09^{b}	57.55 ± 1.82^{b}
IRU	15.75 ± 0.12^{c}	34.26 ± 0.49^{c}	32.17 ± 1.01^{c}	20.22 ± 0.34^{c}

Values are shown as mean ± SD; $^{a\text{-}c}$Different letters in the same column are significantly different ($P < 0.05$); ^{ns}non-significant; HAU: Hot-air unpeeled; MVU: Microwave-vacuum unpeeled; IRU: Infrared unpeeled.

Table 4. The functional properties of banana flour (dry basis)

Samples	WAI (g/g)	WSI (%)	SPI (g/g)	OAI (g/g)
HAU	3.59 ± 0.04^{a}	5.92 ± 0.15^{a}	3.82 ± 0.04^{a}	2.02 ± 0.01^{a}
MVU	3.15 ± 0.02^{c}	5.13 ± 0.30^{b}	3.32 ± 0.02^{c}	1.91 ± 0.04^{b}
IRU	3.43 ± 0.01^{b}	5.83 ± 0.21^{a}	3.65 ± 0.02^{b}	2.02 ± 0.03^{a}

Values are shown as mean ± SD; $^{a—c}$Different letters in the same column are significantly different ($P < 0.05$); HAU: hot-air unpeeled; MVU: microwave-vacuum unpeeled; IRU: Infrared unpeeled; WAI: Water Absorption Index; WSI: Water Solubility Index; SPI: Swelling Power Index; OAI: Oil Absorption Index.

support the hydrogen bonding of the rice flour (Prasad et al., 2012). The water binding capacity is also encouraged by the negative charges of phosphate groups within amylopectin (Wang et al., 2016). The large particle size could reduce the WAI value (Otegbayo et al., 2013). The amylose-lipid and amylose-protein complexes inhibit the polar and charges group from water binding, which reduce the value of WAI (Falade & Christopher, 2015).

Water Solubility Index (WSI) was obtained in the range of 5.13% in MVU and 5.92% in HAU. It is not significantly different between HAU and IRU. The WSI represents the amount of soluble components which disperse in the aqueous solution during cooking (Shafi et al., 2016). The higher the WSI, the higher adhesive and sticky in the products, however, the lower consistent in the food structure (Wang et al., 2016). Junction zone formation by amylose encourages a rigid structure of starch granules, providing low WSI (Chung et al., 2011). The starch-protein and starch-lipid complexes could reduce the value of WSI because the soluble parts are reduced within the starch molecules (Keawpeng & Meenune, 2012). As a result, the low WSI value is desirable as it indicates the consistent structure of food during cooking (Kraithong et al., 2018).

Swelling Power Index (SPI) was in the range of 3.32 g/g in MVU and 3.82 g/g in HAU. The starch granules absorb water when it is heated to a critical temperature in the presence of excessive water. The starch granules then swell and a part of starch leaches out into the solution. The extend of swelling and leaching are determined by the strength of chemical bonding within the granules. The strong intermolecular bonds and high amylose content create an extensive network which can reduce the extent of swelling. The complete swelling is reached only after amylose has been leached out of the granules, therefore amylose is believed to restrict swelling. Furthermore, swelling index is also affected by the structure of starch granules. The high open structure of waxy starches allows rapid water penetration, swelling, and solubility. The swelling capacity of the starch granules is restricted by the increase of amylose content which can limit the amount of starch exudates leaching into solution. However, there are other factors affecting the swelling and solubility of starch granules (Bhattacharya et al., 1999).

Oil Absorption Index (OAI) was obtained from 1.91 g/g in MVU to 2.02 g/g in HAU and IRU. OAI was the highest and not significant different in HAU and IRU. The OAI value exhibits the ability to retain oil in the starch granules (Kraithong et al., 2018). It is supported by the hydrophobic groups within the starch molecules (Tharise et al., 2014). The flour with high OAI value promotes the mouth-feel, palatability, and flavour retention in the products. However, the rancidity is increased due to high value of OAI (Falade & Christopher, 2015).

The pasting properties including peak viscosity, hot paste viscosity, breakdown, cold paste viscosity, setback, peak time and pasting tem-

perature are presented in Table 5. The pasting profile could be related to the molecular characteristics of the starch components such as lipid and amylose. Furthermore, the morphology of the starch granules could affect the starch property (Nimsung et al., 2007). The variations in pasting properties are accounted by the differences in flour composition (Oko & Ugwu, 2011). The amylose is considered to reduce peak, hot paste, and breakdown viscosities, however, increase the setback, cold paste viscosities, and pasting temperature (Ye et al., 2016). However, the results in this study shows that amylose content had a tendency to increase peak viscosity, hot paste viscosity, breakdown, cold paste and speed up the peak time. The result also demonstrated that resistant starch and total dietary fibre showed the same relationship as amylose content with pasting properties. Protein and lipid also affect the pasting properties. The setback and cold paste viscosities are increased while the peak and breakdown viscosities are reduced by the formations of amylose-protein complex or amylose-lipid complex (Alcazar-Alay & Meireles, 2015). The protein with hydrophilic groups could increases the peak viscosity of rice flour (Hsu et al., 2015). The pasting properties of the flour are determined by the rigidity of starch granules which affects the granule swelling potential.

Peak viscosity values of HAU, MVU and IRU were 404, 313 and 263 RVU respectively and were significantly different ($P < 0.05$). The peak viscosity presents the water binding ability of the starch granule via hydrogen bonds (Otegbayo et al., 2013). The amylopectin content is responsible for high peak viscosity due to its high water holding capacity (Ye et al., 2016). Furthermore, small particle size with large surface area also increases the viscosity (Prasad et al., 2012). Higher peak viscosity is caused by higher breakdown because less heat and shear stress resistance during cooking (Hsu et al., 2015). Hot paste viscosity values of HAU, MVU and IRU were 267, 243 and 222 RVU, respectively. The Hot paste viscosity presents for the minimum viscosity at constant temperature. Breakdown viscosity of HAU, MVU and IRU were 137, 70, and 40, respectively. The high breakdown viscosity is resulted of the composition such as protein, lipid and amylose content. Cold paste viscosity of HAU, MVU and IRU were 408, 385, and 363, respectively. The cold paste viscosity presents for the stability of cooked paste and ability to form gel after cool-

Table 5. Pasting properties of banana flour

Sample	Peak viscosity (RVU)	Hot paste viscosity (RVU)	Breakdown (RVU)	Cold paste viscosity (RVU)	Setback^{ns} (RVU)	Peak Time (min)	Pasting Temp^{ns} (°C)
HAU	404 ± 1^{a}	267 ± 2^{a}	137 ± 3^{a}	408 ± 3^{a}	141 ± 0	5.00 ± 0.00^{c}	82.73 ± 0.60
MVU	313±0^{b}	243 ± 2^{b}	70 ± 2^{b}	385 ± 2^{b}	142 ± 0	5.20 ± 0.09^{b}	82.83 ± 0.60
IRU	263 ± 1^{c}	222 ± 2^{c}	40 ± 1^{c}	363 ± 0^{c}	140 ± 2	5.33 ± 0.00^{a}	83.13 ± 0.04

Values are shown as mean ± SD; ^{a}—^{c}Different letters in the same column are significantly different ($P < 0.05$); ^{ns}Non-significant; HAU: hot-air unpeeled; MVU: microwave-vacuum unpeeled; IRU: Infrared unpeeled.

Table 6. Thermal properties of banana flour

Samples	Onset (°C)	Peak (°C)	Endset (°C)	Enthapy (J/g)
HAU	74.04	77.83	82.68	4.18
MVU	74.18	77.83	81.49	2.40
IRU	74.74	78.74	83.64	3.14

HAU: hot-air unpeeled; MVU: microwave-vacuum unpeeled; IRU: Infrared unpeeled.

ing. Setback viscosity of HAU, MVU and IRU were 141, 142 and 140, respectively. The setback viscosities of banana flour were not significantly different ($P > 0.05$) among 3 drying methods. The high setback during cooling represents the high retrogradation which is due to the effect of amylose and amylopectin (Nimsung et al., 2007). The retrogradation process occurs faster in the starch which has higher amylose content (Suwonsichon et al., 2011). The increase in setback value is due to the amylose re-association upon cooling which creates a 3-dimensional gel network (Jamal et al., 2016). The peak time was in the range of 5.00 - 5.33 min and the pasting temperature was in the range of 82.73°C - 83.13°C in HAU and IRU respectively.

Table 6 shows the thermal properties of banana flour including onset temperature, peak temperature, endset temperature and enthalpy. The overall gelatinization temperature range of banana flours was 74.04 - 83.64°C, which was comparable to the range (70.70 - 86.18°C) reported by Nimsung et al. (2007) and the range (62.3 - 86.9°C) reported by Mota et al. (2000). The mean onset temperature was 74.32°C, ranging from 74.04°C in HAU to 74.74°C in IRU. The peak temperature ranged from 77.83°C in HAU and MVU to 78.74°C in IRU, with the mean of 78.13°C, while the final temperature showed an average of 82.60°C, ranging from 81.49°C in MVU to 83.64°C in IRU. There was a negative relation between gelatinization and pasting properties in terms of peak viscosity, hot paste viscosity, breakdown and cold paste viscosity. The enset temperature was close to the value of pasting temperature measured by Rapid Visco Analyzer. Gelatinization enthalpy varied from 2.40 J/g in MVU to 4.18 J/g in HAU, with the mean of 3.24 J/g, which was much lower than the values of 10.8 - 13.3 J/g reported by Mota et al. (2000) and 15.16 - 19.62 J/g reported by Nimsung et al. (2007).

The differences in gelatinization temperature were accounted by the differences in amylose content, the distribution, size and form of starch granules as well as the internal arrangement of starch fractions within the granules (Singh et al., 2003). As shown in this study, the amylose content, total dietary fibre and resistant starch were negatively related to gelatinization temperature. The enthalpy represents the melting of amylopectin crystallites. The differences in enthalpy appear to be attributed to the differences in bonding forces between the double helices that form amylopectin crystallites, resulting in different alignment of hydrogen bonds within starch molecule (McPherson & Jane., 1999). The higher values of DSC parameter are encouraged by large amylopectin branches (crystallinity) (Kraithong et al., 2018). According to Alcazar-Alay & Meireles (2015), high energy is required for disrupting the large crystalline regions of high amylopectin rice flour. Besides, amylose-lipid and amylose-protein complex formations also can increase the gelatinization temperature due to their structures (Morales-Martínez et al., 2014). In contrast, the gelatinization of flour with high amorphous regions (high amylose) is accomplished easily because of weak hydrogen bonds (Jamal et al., 2016). The small particle size of rice flour advocates low gelatinization temperature because of large surface areas for binding water molecules (Ye et al., 2016).

4. Conclusion

Productivity was highest in hot-air drying and microwave vacuum drying. Drying method did not have any significant effects on proximate of unpeeled banana flour. Total dietary fibre, resistant starch, amylose content and phenolic compound of the flour produced by microwave-vacuum drying were fairly high, however, these were less than those contained in the flour produced by hot-air drying. Therefore, hot-air drying was still the superior method for preserving those nutritional values. The flour produced by hot-air drying exhibited the highest functional properties such as WAI (3.59 g/g), WSI (5.92%), SPI (3.82 g/g) and OAI (2.02 g/g). Pasting properties of

the flour were also highest for hot-air drying. The gelatinization was highest in infrared drying and the enthalpy was highest in hot-air drying.

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