Proximate composition and functional properties of banana flour at different ripening stages

Kandungan proksimat dan sifat fungsional tepung pisang pada berbagai tingkat kematangan buah

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ABSTRACT

Bananas commonly grow in tropical areas and have many health benefits derived from both the inner and outer parts of the fruit. The proximate composition and functional properties of banana flour with varying ripening stages of plantain banana fruit (green, green-yellow, yellow-green) were studied in this research. Banana was peeled prior to drying and milling into flour followed by starch extraction. Besides proximate analysis, the yields of the obtaining banana flour and starch, as well as the functional properties of starch such as solubility, swelling power, and pasting properties, were also determined. The total carbohydrate, crude fiber, and ash content tended to decrease with the ripening process, in contrast, fat, protein, and moisture content tended to increase over ripening. The amylose/amylopectin content of banana starch influenced the functional properties such as solubility, swelling, and pasting profiles. However, there were no significant differences in the chemical compositions and functional characteristics of banana flour compared with its ripening stage ($P>0.05$) based on Kruskal-Wallis non-parametric statistical tests. Indeed, the information about chemical characteristics and functional properties of banana flour and starch during fruit ripening is important for the banana fruit processing and their product quality assurance.

ABSTRAK

Pohon pisang merupakan tanaman yang banyak tumbuh di daerah tropis dan buah pisang baik bagian dalam maupun luar memiliki banyak manfaat terhadap kesehatan. Kandungan proksimat dan sifat fungsional tepung pisang pada berbagai tingkat kematangan pisang kepok (hijau, hijau-kuning, kuning-hijau) dipelajari dalam penelitian ini. Buah pisang dikuliti sebelum dikeringkan dan ditepungkan serta diekstraksi untuk pengambilan patinya. Di samping analisa proksimat, dilakukan pula pengujian terhadap rendemen dari tepung serta pati pisang, serta sifat fungsional pati pisang seperti kelarutan, daya pembengkakan, dan sifat pasta. Kandungan karbohidrat total, serat kasar, dan abu cenderung menurun seiring dengan peningkatan kematangan buah, sedangkan kandungan lemak, protein, dan kadar air cenderung meningkat dengan meningkatnya kematangan buah. Kandungan amilosa/ amilopektin pada pati pisang mempengaruhi beberapa sifat fungsional seperti kelarutan, daya pembengkakan, dan profil pasta. Tidak ada perbedaan nyata terhadap komposisi kimia serta karakteristik fungsional tepung pisang pada berbagai tingkat kematangan buah (P>0.05) berdasarkan uji non-parametrik Kruskal-Wallis. Karakteristik kimia dan sifat fungsional tepung dan pati pisang berdasarkan tingkat kematangan buah sangat penting untuk proses pengolahan buah serta penjaminan mutu dari produk-produk buah pisang kepok.

1. Introduction

Banana (*Musa* spp.) has been widely cultivated and grows abundantly in tropical regions, such as Indonesia. There have been many banana varieties grown in Indonesia such as raja banana, kepok banana, ambon banana, and so on. According to Statistics Indonesia, (2023), the banana production in 2021 reached 8,741,147 tons or about 33.65% of the total fruit production in Indonesia. Kepok banana which is belong to plantain banana is amongst the superior cultivars which grows everywhere in Indonesia and has been commercially marketed for their processed banana products. This productivity is relatively high but their utilization has been limited to food applications. Little has been used for industrial purposes.

Bananas are a widely consumed fruit when adequately ripe. However, bananas perish easily due to enzymatic activity. Banana shelf life is about 3-5 days, after which it becomes soft and the color changes to dark brown and deterioration due to the overripening process. This occurs since banana belongs to climacteric fruit which ripens during storage. To prevent huge banana loss during the process of large-scale production and storage, bananas could be further processed into banana flour or banana starch during their unripe stage. This could be stored for quite a long time and be practically used as food ingredients for processed foods or food additives. The immature banana pulp contains between 70-80% starch (dry basis) which is comparable to starch in the endosperm of corn grains and potato pulps (Alcázar-Alay and Meireles, 2015).

Starch is the most abundant and important digestible polysaccharide and in fact, it provides 70-80% of the calories consumed by humans worldwide (Alcázar-Alay and Meireles, 2015). Furthermore, the current demands of versatile uses of starch in non-food industries such as pharmaceutical, biodegradable plastics, textile, adhesive, paper and many other chemicals have been increasing (Alcázar-Alay and Meireles, 2015; Khlestkin et al., 2018). In Indonesia, starch is generally supplied from cassava, corn or wheat. Besides being used as a raw material for starch production, corn has been used as the feedstock. With population growth, demand for corn for other applications increases. Therefore, an alternative source for starch production must be considered. The utilization of unripe banana as a resource for starch production is very promising due to its abundance while diminishing the losses of rejected or perished overripe banana.

However, the attempt for making banana starch is still lacking. The unripe banana indicated by its green color should contain the highest concentration of starch. Starch will be depolymerized into glucose as the banana ripens. There has been very little investigation into chemical composition changes during the ripening process of bananas in Indonesia. Genitha I (2014) compared the characteristics of unripe and ripe Cavendish bananas in India. Unripe bananas contained higher amounts of starch and less moisture compared to the unripe ones. Kookal and Thimmaiah (2018) compared the nutritional composition of three banana cultivars in Southern India associated with the unripe and ripe stages of the banana fruit. The findings indicated the ripening effect on the proximate composition, mineral contents, phytochemical content, and anti-nutrient factors of the flours. Iliyasu and Ayo-Omogie (2019) from Nigeria studied the effects of ripening and pretreatment on the proximate composition and functional properties of Cardaba banana flour. The proximate and functional properties of the flours were greatly affected by ripening and pretreatment. Overall, the chemical changes that occur during ripening would definitely affect the processing of banana flour or banana starch and the overall quality of the product. The objective of this research was to determine the carbohydrate, crude fiber, fat, protein, ash, and moisture content by conducting proximate analysis of unripe/ semi-ripe kepok banana of different ripening stages, as well as to determine amylose and amylopectin content of its corresponding starch. Some functional properties of the starch such as solubility, swelling power, and viscosity were analyzed. The yields of both banana flour and starch were also determined. These results would be very useful to study how the physicochemical changes during ripening of kepok bananas influenced the characteristics of both the banana flour and starch which may in turn affect their applications in food industries.

2. Methods
2.1. Materials

Unripe/semi-ripe plantain bananas ("kepok" banana/ *Musa paradisiaca L.*) of white variety were obtained from a local supermarket in Surabaya, Indonesia at three different ripening stages as indicated by different peel colors, i.e. green (stage 1), green-yellow (stage 2), and yellow-green (stage 4) according to Banana Ripening Guide, color index numbers for banana ripening [1: green; 2: light green (breaking toward yellow); 3: yellowish; 4: greenish (more yellow than green); 5: yellow with green tips; 6: yellow; 7: yellow, flecked with brown], Agricultural Marketing Service (AMS), United States Department of Agriculture (USDA) (2023).

2.2. Preparation of banana flour and banana starch

The banana was peeled, transversely cut and dried at 50°C for 2 days in an oven (Memmert, Germany) to reach the moisture content of less than 10% prior to size reduction in a blender (Miyako BL 101 GS, Indonesia). The banana flour was then sieved into 200 mesh. The banana flour, mainly containing starch, was then analyzed for its yield and proximate composition.

Banana starch was extracted from banana fruit with water by a maceration process. The banana was peeled, transversely cut and then soaked in water for 30 min at ratio of 1:2 (w/v) for green and green-yellow banana and 1:10 (w/v) for yellow-green banana. The banana to water ratio has been increased since the glucose content was higher compared to the less ripened banana, thus more water was required to dissolve the water-soluble components to obtain starch with high purity. Afterwards, the mixtures were blended and filtered. The filtrate was collected and kept at room temperatures for

12 h until the precipitates were obviously seen. Starch was precipitated at the bottom of the flask while other components, which were water soluble such as glucose, moved to the aqueous phase. The precipitates were separated from the liquid and dried in an oven (Memmert) at 50°C for 12 h in order to get the starch powder with moisture content of below 10%. High purity starch was indicated by their white color. The yield and amylose/amylopectin content of dried banana starch as well as some of their functional properties were determined.

2.3. Determination of Yield and Proximate Analysis

The yields of both banana flour and banana starch were determined gravimetrically and were calculated according to equation (1) and equation (2), respectively.

$$Flour\ Yield = \frac{mass\ of\ dried\ banana\ flour}{mass\ of\ wet\ banana} \times 100\% \qquad (1)$$

$$Starch\ Yield = \frac{mass\ of\ dried\ starch}{mass\ of\ dried\ banana\ flour} \times 100\% \qquad (2)$$

The proximate analysis of banana flour containing mostly starch was determined. These included a determination of total carbohydrate, crude fiber, fat, protein, ash, and moisture content. Total carbohydrate was determined based on the method described in SNI 01-2892-1992 (National Standardization Agency of Indonesia, 1992). Glucose content was calculated using Luff Schoorl method which was then converted into total carbohydrate using a conversion factor of 0.9. Crude fiber content mainly attributed to pentosan was determined using the method described in Sudarmadji et al. (2010). Fat content was determined by the Soxhlet extraction method using diethyl ether as a solvent, whereas protein content was determined using Kjehdahl method (Sudarmadji et al., 2010). Destruction process was carried out in Kjehdahl flask equipped with heating mantle (Thermolyne, UK). Ash content was determined gravimetrically after 3 g of sample weighed using a balance (Mettler-Toledo AL 204, Switzerland) was thermally heated in a furnace (Ney VULCAN D-550, DentsplyCeramco, USA) at 550°C for 5 h. Moisture content was determined gravimetrically according to Sudarmadji et al. (2010).

2.4. Determination of Amylose/ Amylopectin and Functional properties analysis

It has been known that amylose and amylopectin content of the banana starch strongly influence the functional properties of the starch which is the main ingredient of banana flour. The amylose content in banana starch was determined using iodine solution. Starch-iodine complex were formed, indicated by the blue color of which intensity was measured using UV-VIS spectrophotometer (Lamda EZ 150, Perkin Elmer, USA) at the wavelength of 624 nm (Gao et al., 2016). The intensity of the blue color was linearly correlated with the amylose concentration. The amylopectin was then calculated as sum of amylose and amylopectin fractions are 100%.

Determination of additional functional properties of the banana starch such as solubility, swelling power and pasting properties was only applied to starches derived from green and green-yellow kepok banana since the starch derived from yellow-green banana was sticky and showed very low yield. The starch solubility and swelling power tests at 95° were conducted based on procedures of Chel-Guerrero et al. (2016). The pasting properties of 14% banana starch suspension were determined using a Rapid Viscosity Analyzer at PT. ISM Bogasari Flour Mills, Surabaya. Parameters measured were peak viscosity, trough viscosity, final viscosity, breakdown (peak viscosity– trough viscosity), and setback (final viscosity–trough viscosity), as well as time to reach peak viscosity.

2.5. Statistical analysis

All tests were conducted in duplicates. Statistics were applied using Kruskal-Wallis non-parametric tests. The comparisons were deemed to be significantly different if P<0.05. The statistics tests were carried out using MINITAB® Release 14.12.0.

3. Results and discussions
3.1. Yields and proximate compositions of banana flours

The kepok banana flour yields for green, green-yellow, and yellow-green banana were 39.06, 37.48, and 21.04%, respectively. The yield of banana flour was calculated based on the mass ratio of dried banana flour to wet banana. As could be seen in Table 1, the yields tended to decrease as the banana was getting ripened although no significant differences amongst the samples were found. This occurred due to the increase of water content during the ripening process as would be discussed later on. The drying process of banana flour preparation led to a decreased yield.

The carbohydrate contents in green, green-yellow, and yellow-green banana were 55.98, 52.29, and 51.15% respectively. It could be observed that carbohydrate contents were decreased as the banana ripened, as shown in Table 1. However, no significant differences were found amongst the samples. There have been a lot of biochemical changes during the ripening process involving the changes in structure, texture, colour, and taste. It was obvious that bananas were getting sweeter as they ripened due to the increased amount of sugars as a result of starch hydrolysis (Zhu et al., 2021). The decrease of total carbohydrate during the banana ripening process was then furthermore attributed to the catabolism of sugars into other organic products. The carbohydrate content in previous investigation was about 80% (Salawu et al., 2014). The differences were possibly due to the chief differences in banana variety, the ripening stages of bananas, and the analysis techniques.

Crude fiber content also tended to decrease with the increase of ripening stage of banana as seen in Table 1 though the differences were not significant. The crude fiber contents were found to be 2.75% in green, 2.48% in green-yellow, and 2.28% in yellow-green banana. The decrease of crude fiber during the ripening process was

due to the hydrolysis of hemicelluloses and breakdown of pectic substances (Wills et al., 1984). The range of crude fiber contents found in this experiment was in the same range with previous findings (Wills et al., 1984).

Green banana which contained the highest amount of crude fiber proved potentially useful as a dietary fiber source in processed food (Kim et al., 2020).

Table 1.
Flour yields and proximate compositions of kepok banana at different ripening stages

Trait	Green	Green-yellow	Yellow-green
Flour Yield (%)	39.06 ± 0.40[a]	37.48 ± 0.27[a]	21.04 ± 0.38[a]
Carbohydrate (%)	55.98 ± 1.42[a]	52.29 ± 0.83[a]	51.15 ± 1.49[a]
Crude fiber (%)	2.75 ± 0.13[a]	2.48 ± 0.06[a]	2.28 ± 0.10[a]
Fat (%)	1.80 ± 0.06[a]	2.04 ± 0.21[a]	2.15 ± 0.14[a]
Protein (%)	8.61 ± 0.50[a]	9.79 ± 0.17[a]	12.15 ± 0.17[a]
Ash (%)	3.00 ± 0.02[a]	2.89 ± 0.02[a]	2.55 ± 0.10[a]
Moisture (%)	8.22 ± 0.01[a]	9.69 ± 0.01[a]	10.04 ± 0.02[a]

Note: [a,b] Means within the same row without a common letter are significantly different ($P>0.05$)

On the other hand, fat content surged slightly with increased ripening stages (Table 1). There were no significant differences in fat content among the samples. The fat content seemed constant within the range of 1.80 to 2.15%. The similar trends were found during the ripening process in unripe bananas in the previous investigation (Kookal and Thimmaiah, 2018). Dotto et al. (2019) found out the increased fat content (~0.6 to ~ 2.3%) as the banana ripened. Presumably, there was a conversion of carbohydrate into fat during the ripening process (Campuzano et al., 2018). It has been known that the major fatty acids found in banana pulp were palmitic acid, linolenic acid, linoleic acid, and stearic acid (Shivashankara, 2016).

Furthermore, as the banana ripened, the protein content increased (Table 1). The protein contents in green, green-yellow, and yellow-green banana were 8.61, 9.79, and 12.15%, respectively. No significant differences were found amongst the samples. The increase in protein content during ripening following the peak in ethylene production has been mainly correlated with the esters syntheses which are responsible for aroma compounds formation and phenolic compounds during the ripening (Alsmairat et al., 2018; Hu et al., 2020). Amino acids such as valine, leucine, and cysteine as well as aromatic amino acids such as phenylalanine, tyrosine, and tryptophane as the precursors of phenolic compounds formation were steadily accumulated throughout ripening (Alsmairat et al., 2018; Hu et al., 2020). Protein content was rather constant during the ripening process of banana according to previous investigation (Wills et al., 1984). On the other hand, the protein content tended to be significantly increased with the increasing ripening stages (Campuzano et al., 2018; Kookal and Thimmaiah, 2018). The protein contents from the previous investigation were found to be 11.72% in unripe banana flour (Salawu et al., 2014) and 4.76% in banana flour (Zhang and Hamaker, 2012). The differences were due to different banana varieties and ripening stages of those used during the experiment.

The ash contained inorganic residue of mostly minerals and tended to slightly decrease with the banana ripening stage (Table 1). The decreasing trend as the banana ripened was similar to the previous investigation (Iliyasu and Ayo-Omogie, 2019). The ash contents in green, green-yellow, and yellow-green bananas were 3.00, 2.89, and 2.55%, respectively. The value was similar with the ash content of about 3% from the previous finding (Zhang and Hamaker, 2012). The ash content of banana from other investigations was within the range of 0.4–1.5% (Wills et al., 1984; Valérie Passo Tsamo et al., 2014; Dotto et al., 2019). The ash content tended to be decreased as the moisture content decreased (Valérie Passo Tsamo et al., 2014). The high ash content of banana flour indicated high level minerals in the bananas which would be quite useful for the fortification of food products. There could be several elements present in the ash according to previous investigation, such as K, Mg, Ca, P, Si, Fe, Zn, Se (Dotto et al., 2019; Vega-rojas et al., 2021). Moisture content was closely related to the product quality. Low moisture content was desirable to prolong the product shelf-life. As banana ripening stages increased, the moisture content likewise increased (Table 1). However, no significant differences were found amongst the samples. This tendency confirmed the previous investigation (Genitha I, 2014) resulting in the softening texture of the bananas as they ripened. Furthermore, the increase of water content was caused by the increasing respiration activity during the ripening process leading to water as the end product and also could be due to water movement from the peel to the pulp (Wills et al., 1984; Adi et al., 2019). In this experiment, water content was increasing from 8.22% in green banana to 10.04% in yellow-green banana flour. The range of moisture content in banana flour obtained from this experiment was similar with that obtained from the previous investigation (Zhang and Hamaker, 2012). The increase of water content in ripe bananas would definitely affect the processing of banana flour and the quality of the final products.

3.2. Yields, amylose/ amylopectin contents, and functional properties of banana starches

Starch is the principal component of banana flour, which mostly determines its functional properties. The

banana starch yield tended to decrease as the banana ripened, as shown in Table 2. The green banana contained the highest starch yield of 44.14% while the yellow-green banana contained the lowest starch yield of 20.30% although no significant differences were found amongst the sample (*P*>0.05). The decrease of starch content correlated with the increase of ethylene concentration during the ripening process, leading to starch conversion into sugars as the banana ripened (Hu et al., 2017). Green banana flour could be used as ingredients for bakery products, cookies and for the development of food and medical products (Falade and Oyeyinka, 2015).

Table 2.
Starch yields and amylose/ amylopectin contents of kepok banana starches at different ripening stages

Trait	Green	Green-yellow	Yellow-green
Starch yield (%)	44.14 ± 0.38[a]	35.75 ± 0.39[a]	20.30 ± 0.35[a]
Amylose (%)	37.04 ± 0.38[a]	24.42 ± 0.44[a]	17.12 ± 0.44[a]
Amylopectin (%)	62.96 ± 0.40[a]	75.58 ± 0.34[a]	82.88 ± 0.41[a]

Note: [a,b] Means within the same column without a common letter are significantly different (*P*>0.05)

As the banana ripened, the amylose content decreased and the amylopectin content increased, as can be seen in Table 2. However, there were no significant differences in amylose/amylopection content found amongst the varying ripening stages of banana samples (*P*>0.05). The decrease in amylose during ripening was also seen in Cavendish and plantain banana in previous studies (Campuzano et al., 2018). The decrease of amylose during the ripening was mainly due to hydrolysis in the amorphous part of the starch granule (Campuzano et al., 2018) which was mainly catalyzed by β-amylase (Gao et al., 2016).

The amylose content decreased from 37.04% in green banana to 17.12% in yellow-green banana, whereas the amylopectin content increased from 62.96% in green banana to 82.88% in yellow-green banana. The amylose contents found in starch flour from previous findings ranged from 1.67 – 50.79 (Zhang and Hamaker, 2012; Gao et al., 2016; Campuzano et al., 2018). The differences were due to different banana varieties and ripening stages as well as the method used for the analysis during the experimentation. Additional functional properties of starches derived from green and green-yellow banana, including solubility, swelling power and pasting properties, were also determined. These properties were greatly influenced by the amylose/ amylopection content as well as the molecular structure of the starch (Zhang and Hamaker, 2012; Sarawong et al., 2014; Yadav et al., 2016). The solubility values of green and green-yellow banana starches were 26.3% and 19.6% respectively, while their corresponding swelling power were 3.9 and 6.7 g water/g starch, respectively (Table 3).

Both solubility and swelling power were measured at 95°C, whereby gelatinization occurred due to the temperature exceeding 70°C (Pandey et al., 2021). In hot water, the crystalline region in the amylopectin melted and water molecules became linked by hydrogen bonding to the exposed hydroxyl groups of amylose and amylopectin, leading to granule swelling followed by rupture. Simultaneously, the soluble matters such as amylose were leached out of the granules into the surrounding water.

The solubilization of green-yellow banana starch was lower compared with the green banana starch. This was corroborated by the previous findings (Genitha I, 2014; Iliyasu and Ayo-Omogie, 2019). The solubilization was correlated with water absorption capacity whereby it was higher for unripe banana flour, since its moisture content was lower than the ripe one. It could therefore uptake more water to reach the equilibrium water content (Genitha I, 2014). Additionally, the unripe banana starch contained a higher amount of amylose which readily dissolved in hot water, unlike amylopectin which was largely insoluble (Yadav et al., 2016).

Table 3.
Solubility, swelling power, and pasting characteristics of green and green-yellow banana starches

Trait	Green	Green-yellow
Solubility (%)	26.3 ± 0.42[a]	19.58 ± 0.68[a]
Swelling power (g water/g starch)	3.9 ± 0.08[a]	6.68 ± 0.25[a]
Peak viscosity (cP)	5294.04	5835.96
Trough viscosity (cP)	5214	3810
Breakdown viscosity (cP)	80.04	2025.96
Final viscosity (cP)	8132.04	6381
Setback viscosity (cP)	2918.04	2571
Peak time (minute)	7	4.6

Note: [a,b] Means within the same column without a common letter are significantly different (*P*>0.05)

The swelling power of the unripe banana flour was lower than the ripe one, which was confirmed the previous investigation (Iliyasu and Ayo-Omogie, 2019). Amylopectin was generally considered to contribute to water absorption, while an inverse correlation was found between amylose content and swelling power (Cai et al., 2015). It was obvious that the green-yellow banana starch contained more amylopectin than the green one, which contributed to the more pronounced swelling power. The swelling power was dependent on the capacity of the starch molecules to hold water via hydrogen bonding. After complete gelatinization, the hydrogen bonds between the starch molecules were broken and replaced by hydrogen bonds with water (Li et al., 2020). Starch granule continued to swell as the temperature of the suspension increased above the gelatinization range. This occurred even more rapidly after amylose had first been exuded, starting at the hilum and swelled rapidly to the periphery. As temperature increased, so did the crystallinity disruption and swelling, followed by the rupture of the starch granule. Small amylose molecules leached out from the granule and the remaining amylose and amylopectin molecules were dispersed in the solution, becoming a sol coupled with an increase in viscosity, reaching peak viscosity (Cornejo-Ramírez et al., 2018).

The temperature attained at peak viscosity represented the gelatinisation temperature as seen in Figure 1 and Figure 2. It turned out that the gelatinisation temperature of green-yellow banana starch (~95°C) was much higher than that of green banana starch (~80°C). This was again confirmed by the higher amylose content or lower branched chains of green banana starch which resulted in gelatinisation temperature decrease (Zhang and Hamaker, 2012).

The peak viscosity obtained at holding temperature of 95°C for green and green-yellow banana starch was 5294 and 5836 cP respectively (Table 3). The lower peak viscosity of green banana starch in comparison to that of green-yellow banana starch was due to its higher amylose content. Increased amylose content displayed decreased peak viscosity (Blazek and Copeland, 2008; Yadav et al., 2016). Peak viscosity was associated with the water binding capacity, as well as the maximum swelling degree of starch granule during heating (Yadav et al., 2016). The peak time measured for green-yellow banana starch was shorter than the green banana starch (Table 3). This indicated a shorter cooking time required by the green-yellow banana starch to reach peak viscosity. This was due to a higher content of amylopectin present in green-yellow banana starch which attributed to an increased water absorption and swelling during the cooking period. With the continuation of cooking at 95°C, starch granule began to rupture and viscosity tended to decrease. Interestingly, the viscosity of green banana starch remained high during cooking at 95°C with low or no obvious peak observed in the pasting profile in contrast to that of the green-yellow banana starch (Figure 1 vs. Figure 2).

The green banana starch demonstrated a higher trough viscosity compared to that of the yellow-green banana starch. This resulted in a very low breakdown viscosity of the green banana starch showing the high stability of the starch flour against shear and high temperatures while cooking. This profile was in line with the previous investigation (Zhang and Hamaker, 2012) which resembled the pasting profile of a chemically lightly cross-linked starch (Zhang and Hamaker, 2012). This remarkable properties could be contributed by the presence of resistant starch which has been known to be abundantly present in green plantain banana (Gao et al., 2016). In contrast, the green-yellow banana starch showed a higher breakdown value due to disintegration of the gelatinized starch granule structure during the continuation of stirring and heating (Yadav et al., 2016). Furthermore, the swollen and ruptured starch granules started to re-aggregate during the cooling period. This is reflected by the setback value.

A much higher setback viscosity of green banana starch with higher amylose content indicated a higher degree of retrogradation of the starch which confirmed the previous investigation (Sarawong et al., 2014). The pronounced setback (retrogradation) of banana starch during cooling agreed with the previous finding (Zhang and Hamaker, 2012). The higher setback viscosity of the green banana starch likewise reflected its higher final viscosity that was the result of the gel viscosity that formed after retrogradation (Sarawong et al., 2014). This greater final viscosity indicated a higher degree of starch molecules aggregation (Sarawong et al., 2014). The final gel viscosity increased at a faster rate in green banana starch because there was more amylose available for network formation (Blazek and Copeland, 2008). Green-yellow banana starch, which consisted of a higher amount of amylopectin, could produce highly gelatinous dispersions when cooked. They could also form soft and runny gels, in contrast to amylose, which contributed to gel strength and firmness, along with less sticky starch gels (Blazek and Copeland, 2008). Moreover, the final viscosity of banana starch was significantly higher than the other starches, such as that found in wheat and corn (Zhang and Hamaker, 2012). Both green and green-yellow banana starch demonstrated higher final viscosities, compared to their peak viscosities, suggesting their potential for use as a thickener or texture modifier of various food applications.

Kepok banana starch demonstrated unique pasting properties, along with quite high pasting viscosities. Green-yellow banana starch with higher amylopectin content displayed higher peak viscosity, higher breakdown value, and lower final viscosity; while the unripe green banana starch containing a higher amount of amylose, showed lower peak viscosity but a higher final viscosity and setback value. The pasting profile of banana starch with varied amylose/amylopectin contents confirmed the previous investigation (Blazek and Copeland, 2008; Zhang and Hamaker, 2012; Yadav et al., 2016). These unique pasting properties were due to differences in swelling power and solubility, influenced by the amylose/amylopectin content of the banana starches, despite their statistical differences not being significant. Interestingly, banana starch especially that derived from unripe green banana could replace chemically cross-linked starch as a native starch thickener, since it demonstrated high stability and restricted swelling under both high shear and high

temperature (Zhang and Hamaker, 2012; Yadav et al., 2016).

The green banana starch, that demonstrated high setback value, correlated with the formation of retrograded starch that belonged to resistant starch and thus could be considered as a functional food (Sarawong et al., 2014; Zhang and Hamaker, 2012). Moreover, the ability of starch to absorb water at high temperatures was considered an essential quality of the starch in obtaining the desirable functional properties to maximize a wide

range of utilization in food industry. However, the functional properties of banana flour and starch were largely influenced by many factors such as the origin of raw materials, growth condition, granule structure and size, amylopectin chain length distribution, starch molecule distribution, and so on which would require further investigation to ensure the desirable functional properties for their suitable use as novel and functional food ingredients.
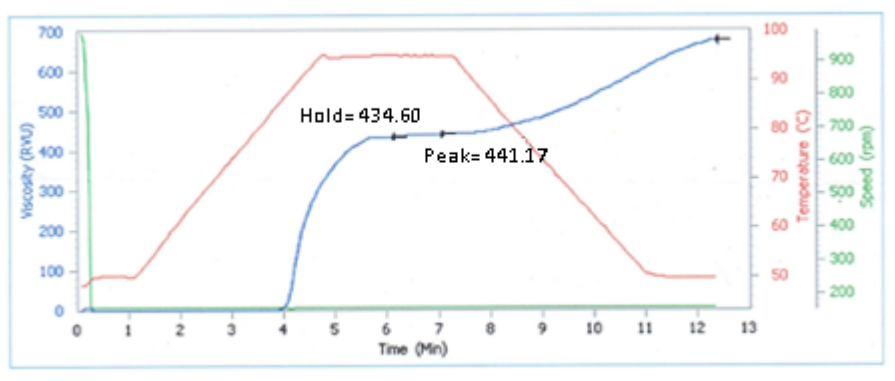

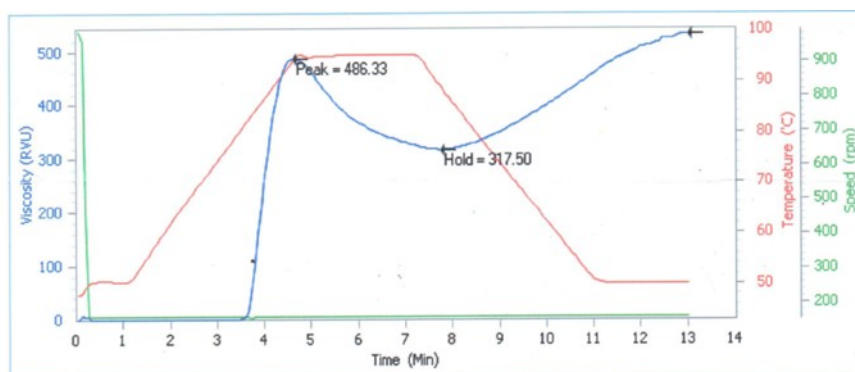Figure 1. Representative viscoamylograph of pasting profile of green banana starch

Figure 2. Representative viscoamylograph of pasting profile of green-yellow banana starch

4. Conclusions

There were many biochemical processes that occurred during the ripening process leading to the various changes in the proximate analysis of banana flour with starch as the main ingredient. Fat, protein, and moisture content tended to increase, in contrast to carbohydrate, crude fiber and ash which were shown to decrease as the banana ripened. However, there were no significant differences found in the banana samples tested in regards to all their properties throughout the ripening stages ($P>0.05$). The highest yield of both banana flour and banana starch of about 40 and 44%, respectively was obtained from the unripe green banana. Furthermore, where the amylose content decreased, the amylopectin content was increased during the ripening stage. The highest amylose content of about 37% was obtained from green banana while the highest amylopectin content of about 83% was present in yellow-green banana. The amylose/amylopectin content affected some functional properties of starch such as solubility, swelling power, and pasting properties. Solubility was higher while swelling power was lower in

green banana starch as compared to those of green-yellow banana starch. The green-yellow banana starch demonstrated a higher peak viscosity, lower final viscosity, and lower setback compared to the green banana starch. The ripening stages of banana played a role in determining the overall properties of banana flour that might influence the characteristics and nutritional composition of the final products when banana flour was used as food ingredients. Furthermore, it seems that unripe green banana has the potential to become the bioresource for starch production that could be widely used in both food and non-food industries. The ripening stages of banana determined the amylose/amylopectin composition that might significantly influence the starch processing and functional properties of the final products.

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