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RESEARCH ARTICLE

Characteristics of flour plantain: use of fruit peels and ripening fruit stages

Riyanti Ekafitri[1]*, Rima Kumalasari[1], Yani Suryani[2], Nana Sutisna Acahyadi[2], Dewi Desnilasari[1], Nur Kartika Indah Mayasti[1], Diki Nanang Surahman[1]

[1]Research Center for Appropriate Technology - National Research and Innovation Agency-IndonesiaJl. K.S. Tubun No. 5 Subang 41213, West Java, Indonesia, [2]Departement of Food Technology, Faculty of Engineering- Pasundan University Jl. Dr. Setiabudi No.193, Bandung 40154, West Java, Indonesia

ABSTRACT

Tanduk plantain cultivar is one of the famous banana types in Indonesia and can be processed into plantain flour. The use of peels in raw and ripe plantain affects the characteristics of the flour. This research evaluates changes in the physic-chemical properties (starch, amylose, dietary fiber, antioxidant activity, color), functional properties (WAI, OAI, SC, solubility, hygroscopicity), thermal, pasting, and crystalline properties, and also FTIR spectra affected by the ripening stage and peel use. *Tanduk* plantain flour is made in ripening stages 1, 4, and 6 through peeling and unpeeling processes. The higher the ripening stage, the lower the starch, amylose, and dietary fiber of plantain flour, yet its antioxidant activity increases. In terms of its pasting properties, the higher the ripening stage, the lower the value of plantain flour's peak viscosity, breakdown viscosity, and setback viscosity. Meanwhile, the unpeeled plantain flour has higher starch, amylose, dietary fiber, antioxidant activity, breakdown viscosity, and setback viscosity but lower T_O and T_P values. The *Tanduk* plantain flour in the ripening stages 1, 4, and 6 through the peeling and unpeeling process has the same crystalline properties (type C) and functional group in structure. The physicochemical, pasting, and crystalline properties of plantain flour at each ripening stage through the peeling or unpeeling process allow better selection depending on the industrial application.

Keywords: Peel; Plantain flour; Ripening stage

INTRODUCTION

Plantain is a type of banana that is widely used as flour (Elvis, 2014; Falade and Oyeyinka, 2015; Inyang et al., 2017). Plantain contains 73.4% starch, 21-24% amylose, 17% sugar, and is not easy to brown when processed, low in protein and fat, high in vitamins, minerals, dietary fiber, and resistant starch (Juarez-Garcia et al. 2006; Soares et al. 2011; Oladele 2013; Eleazu CO 2014; Anyasi et al. 2017; Olatunde et al. 2017). Starch is an important component in the flour process. The ripening stage of the fruit determines the characteristics of the flour produced. Raw plantain flour is high in resistant starch and dietary fiber, suitable for human health (Juarez-Garcia et al. 2006). Ripe plantain flour is high in sugar content, suitable for food products that require solubility, sweetness, and energy content. Ripe plantain flour has a good sensory (better in taste and flavor) and easy to digest than raw one (Ekafitri et al. 2016; Kumalasari et al. 2020). Plantain peel flour is a source of dietary fiber and antioxidant components. According to (Agama-Acevedo et al. 2016), plantain peel flour contains 376.4 g/kg of dietary fiber, 7.71 to 30.98 mg of GAEs/g polyphenols, and 49.65 to 84.73 µmol Trolox eq/g of antioxidant capacity.

Researches on the manufacture of plantain flour at various ripening levels using the peels (whole plantain) is still limited, especially (*Musa acuminata x Musa balbisiana (AAB) cv. Tanduk*), or Indonesian people usually call it *Pisang Tanduk*. *Pisang Tanduk* is a popular cultivar in Indonesia, with yellowish-white pulp, sweet-and-sour taste, soft texture, slightly thick peel, and yellowish-green to light yellow. *Tanduk* plantain can be processed into flour since it has high starch content (29.16%) (Kumalasari et al., 2021). This cultivar was also recommended by Mayasti et al. (2021) to be used as ripe plantain flour, because it produced the highest yield (15.22%) and the most preffered organoleptic. Based on the starch content of the *Tanduk* cultivar, it is recommended to use stage 1-3 for unripe flour and stage 4-5 for ripe flour (Kumalasari et al, 2021).

***Corresponding author:**
Riyanti Ekafitri, Research Center for Appropriate Technology - National Research and Innovation Agency-Indonesia Jl. K.S. Tubun No. 5 Subang 41213, West Java, Indonesia. **E-mail:** riyantisyahryan@gmail.com

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Generally, plantain flour processing in Indonesia still uses the peeling stage. Desnilasari et al. (2020) have used the whole *Tanduk* plantain pulp to make flour, which shows high mineral content (912.14mg/100g of potassium, 198.16 mg/100g of magnesium, and 24.84mg/100g of iron). Therefore, it is necessary to research plantain flour manufacturing from *Tanduk* plantain cultivar and peel use to compare its characteristics.

The object of this research are to evaluates changes in the physic-chemical properties, functional properties, thermal pasting, and crystalline properties, and also functional groups forms affected by the ripening stage and peel use of *Tanduk* plantain flour. Consequently, the research results are expected to provide recommendations for the intended processed product.

MATERIALS AND METHODS

Materials

The primary materials used in this research were *Tanduk* plantain cultivar (*Musa acuminata x Musa balbisiana* (AAB) cv. *Tanduk*) at ripening levels of stages 1, 4, and 6 (Fig 1). The stages were determined based on peel color changes, referred to Inyang et al. (2017). The plantains were obtained from Subang, West Java, in ripening stage 1 (the whole peel is green). The observation process was carried out by looking at the peels color changes every morning and evening. When the plantains had reached stage 4 (the peel is more yellow than green) and stage 6 (the whole peel is yellow), the plantains were separated and then processed to be flour. Sodium sulfite was used as supporting raw material in flour processing to reduce the plantains' browning. The general diagram of the experiment is shown in Fig. 2.

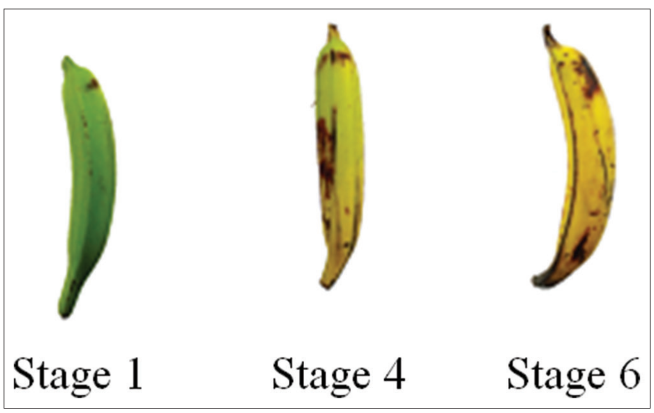

Fig 1. *Tanduk* plantain cultivar (*Musa acuminata x Musa balbisiana* (AAB) cv. *Tanduk*) at ripening levels of stage 1, 4, and 6 (Kumalasari et al. 2021)

Preparation of peeled and unpeeled plantain flour (Yani et al., 2013 with modifications)

The *Tanduk* plantains on stages 1, 4, and 6 were washed, peeled, a sliced thickness of 1 mm. Furthermore, the slices were immersed in a 0.3% sodium metabisulfite solution for 5 minutes, washed, then steamed for 10 minutes. Afterward, the slices were laid out on a tray and dried for 24 hours using a cabinet dryer at a drying temperature of 50°C. The dried slices were then milled and sieved with a 40-mesh sieve then the peeled plantain flour was obtained. There was no peeling process for the unpeeled plantain flour, and the way the flour was made was similar to how the peeled plantain flour was made.

Chemical analysis

The chemical analysis included moisture content, starch, amylose, dietary fiber, and antioxidant activity. The analysis of the starch contents was carried out according to the method of Sudarmadji (2003), the moisture content was according to the procedure of AOAC (2004), and the antioxidant activity analysis with the DPPH radical scavenging ability was carried out about the procedure of Fatemah et al., (2012). The procedure for the antioxidant activity analysis with the DPPH radical scavenging ability was carried out about the process of Fatemeh et al., (2012). The sample was first extracted using the maceration method (Anyasi et al. 2015). 1-gram plantain flour was extracted using the maceration method with 10-milliliter methanol for 30 minutes at room temperature in dark conditions. Later, run centrifugation at 6000 rpm for 10 minutes at 4°C. The extract resulted was

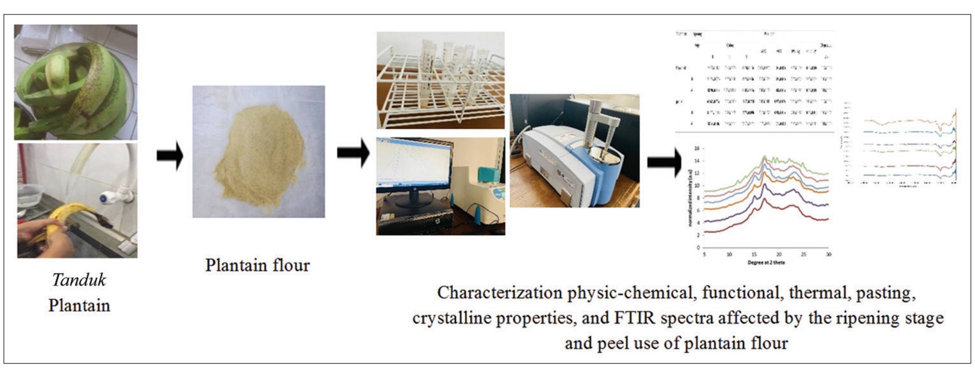

Fig 2. General diagram of experiment.

analyzed for its DPPH radical scavenging ability. A total of 5-milliliter DPPH solution with a concentration of 0.025 g/L in methanol solvent was reacted with 1 ml of 25 ppm sample extract in methanol solvent. The incubation was carried out for 30 minutes at room temperature in dark conditions. Next, the sample was measured at a 515-nanometer wavelength. The percentage of DPPH radical scavenging was calculated using the equation:

$$\%DPPH \frac{(Abs\,Control - Abs\,Sample)}{Abs\,Control} x\ 100 \quad (1)$$

Physical and functional analysis

Physical and functional analysis of plantain flour including color, WAI (water absorption index), OAI (oil absorption index), SC (swelling capacity), solubility, and hygroscopicity. The color measurement carried out on the flour sample using a Chroma Meter CR-300 (Konica Minolta Co., Osaka, Japan) with the observed color parameters of L, a, and b. WAI an OAI analysis refer to Julianti et al., (2017), SC and solubility was measured according method of Pranoto et al., (2014) with modification, and finally hygroscopicity determined using method of Suriyajunhom and Maradee et al., (2018).

Pasting properties (Campuzano et al., 2018)

The gelatinization profile test was carried out using a Rapid Visco Analyzer (RVA-TecMaster, Macquarie Park, Australia). The plantain flour sample was weighed 3.5 grams (based on 14-gram moisture per 100-gram flour) then mixed with 25-gram distilled water in an aluminum canister. The RVA setting used was the initial temperature of 50°C, which was maintained for 1 minute, and heated until the temperature reached 95°C at a speed of 12.2°C/minute, then held at 95°C for 2.5 minutes, and then cooled to a temperature of 50°C at 11.8°C/min. The paddle rotation speed was 960 rpm at the first 10 seconds, then decreased to 160 rpm, maintained during the analysis process. The recorded parameters included pasting temperature, peak viscosity, final viscosity, breakdown viscosity, setback viscosity, peak time, and temperature.

XRD (Campuzano et al., 2018)

The XRD Bruker D8 Advance 3kW with LynxEye XE-T detector and Cu K alfa radiation source was used at 30 mA and 40 kV, a diffraction angle (2θ) range of 5–40° with a 0.03° step size and measuring the time of 15 seconds. The relative crystallinity (RC) was determined through the equation:

$$RC\ (\%) = (Ac/(Ac + Aa))*100 \quad (2)$$

Whereas Ac is the crystalline area, and Aa is the amorphous area on the X-ray diffractogram. The areas were calculated by the Origin®2017 software (Origin Lab Corporation, Northampton, USA).

Differential scanning calorimetry (DSC)

Test using 214 Polyma (Netzsch, Germany) (Pragati et al. 2014). The samples were weighed (between 5 and 15-milligram samples, dry basis) in aluminum pans. The pans were hermetically sealed, pierced, and placed at the center of the sample chamber. The samples were heated from a baseline of 25 to 180°C, at a 10 K/min heating rate. Liquid nitrogen was purged at the 20 ml/minute flow rate with a pressure of 0.5 Kpa. The gelatinization or peak temperature (T_g), i.e., the glass transition temperature (T_g), or the so-called temperature at which the starch's glassy state changes into a rubbery state. The area covered was calculated as transition enthalpy (ΔH) onset, the end of the peak was also calculated to define the peak range. All calculations were obtained directly using the Proteus software.

FTIR analysis (Pragati et al., 2014)

The FTIR spectra of samples was assayed by using a FTIR Thermo-scientific Nicolet iS5 type iD5 ATR, USA with ZnSe (Zinc Selenide) crystal-coated by the diamond detector, in wavenumbers ranging from 4000 to 400 cm. All sample measurements were recorded at a temperature of 25°C. For each spectrum, 64 scans were acquired at a resolution of 3,8 cm^{-1}. The data analysis was carried out using the OMNIC Spectroscopy software.

Statistical analysis

The experimental design used a completely randomized design comparing the raw material preparation techniques (unpeeled and peeled) at three ripening levels (Stage 1, Stage 4, and Stage 6). Each treatment was repeated four times. The six treatments in this research were: P_1 = Unpeeled Plantain, Stage 1; P_2 = Unpeeled Plantain, Stage 4; P_3 = Unpeeled Plantain, Stage 6; P_4 = Peeled, Stage 1; P_5 = Peeled, Stage 4; and P_6 = Peeled, Stage 6. The experiment was carried out by repeating the experiment and replicating the analysis three times. The data obtained were then analyzed using variance (ANOVA) with Excel version 13 and Duncan's Test with the significance of $P < 0.05$.

RESULTS AND DISCUSSION

Chemical properties

Moisture content

The *Tanduk* plantain flour's moisture content ranges from 2.59% to 7.21% and is significantly different (P<0.05). The moisture content produced in this research is lower than the previous study at various ripening levels, namely 5.00% to 10.46% (Falade and Oyeyinka 2015), 6.96% to 12.25% (Abe et al., 2017), 4.46% to 9.47% (Amini et al., 2019), and slightly higher than the research of (Adeniji and Abdou 2008), which is 1.91% to 2.25%. Lower water content indicates that the product will have a longer shelf life due to the lower likelihood for microbial growth (low a_w) and is more stable to physical changes and chemical reactions (Amini et al., 2019). The moisture content of the flour produced from this research has met the Indonesian National Standard, a maximum of 12%. During 50°C for 20 hours of drying, the slices of raw and ripe plantains have a moisture loss of about 56%-57%. According to Onwuka and Onwuka (2005), the plantain slices dried at 60°C to 70°C will have a moisture loss of about 67% to 76.5%, respectively. In general, the moisture content produced by the unpeeled flour is lower than that of the peeled flour, and as the ripening level increases, there is a tendency for the moisture content of the flour to increase. According to, plantain's moisture content ranges from 60.01% (Stage 1) to 63.56% (Stage 7), meaning an increase in the moisture content during the ripening process. An increase in the fruit's moisture content results from the breakdown of carbohydrate groups used during the respiration process and the osmotic transfer from the peel to the pulp. This event causes differences in the peel and the pulp's osmotic pressure due to a rapid increase in the pulp's sugar content compared to the peel (Emaga et al., 2007). It is presumed that the water content in the unpeeled flour to be lower than that in the peeled flour.

Starch content

This research's starch content ranges from 44.69% to 74.84% and is significantly different (P<0.05). The starch content produced from the unpeeled flour tends to be higher than that of the peeled flour. The increasing ripening of plantain tends to make flour with decreasing starch content. The starch content of flour produced from the unpeeling treatment in stage 1 is significantly higher (P<0.05) than the other treatment. The starch content in the ripe flour decreases due to the plantain's natural ripening process that underwent enzymatic changes, which converted starch into sugar, flavor components, and energy (Gao et al. 2016). The peel also contains an amount of starch and degrades during ripening due to the respiration process. The starch content in the peel of several plantain cultivars ranges from 35.4% to 39.3% in stage 1 and decreases during the fruit ripening process from 0.1% to 3.2% in stage 7 of the total peel weight (Emaga et al. 2007). It causes the starch content of the unpeeled flour to be higher than the peeled flour.

Amylose

Table 1 shows that the amylose content of plantain flour ranges from 10.42% to 25.31% and is significantly different (P<0.05). These results are slightly higher than the 5-cultivar amylose of East African highland bananas, which range from 11.96 to 12.83% (Ssonko and Muranga 2017), which is equivalent to the *Karpuravalli* cultivar by 24.41% and lower than the *Nendran* cultivar by 36.87% (Ravi and Mustaffa 2013). According to (Reddy et al., 2015), the amylose percentage shows a significant difference between various plantain cultivars. These differences can be due to the growing site's climatological influence (Singh and Reddy 2006). Kossmann and Lloyd (2000) also state that the differences in amylose content can be caused by enzymes involved in linear biosynthesis and the branched-chain components. Table 1 shows a decreasing tendency for amylose content and the increasing stage of the ripening process, decreasing the value from around 12.05% to 12.95%. The amylose content in plantain and *Cavendish* bananas decreases significantly during the ripening process (Gao et al. 2016). In general, the amylose content in the unpeeled flour tends to be higher than that in the peeled flour. In line with Li et al. (2018), there are significant differences in the amylose content in plantain peel and pulp. The amylose content in the peel starch is higher (25.7%) than that in the peel starch (21.3%), and thus, the unpeeled flour has higher amylose content.

Dietary fiber

The DF of *Tanduk* plantain flour ranges from 10.15% to 18.67% and is significantly different (P<0.05). The DF content of *Tanduk* plantain flour tends to decrease during the ripening process (Table 1). In contrast to the research results conducted by (Ramli et al. 2010), the Total Dietary Fiber (TDF) of plantain peel flour (*Cavendish* and *Berangan* varieties) produced from the ripe peel is higher than that produced from the green peel. Similar to the research carried out by (Khoozani et al., 2019), the TDF increases in the yellow bananas (Stages 6 to 7). According to Emaga et al. (2007), the dessert-type bananas have higher TDF than the plantain type. *Cavendish* and *Berangan* are the dessert

Table 1: Chemical Properties of *Tanduk* Plantain Flour

Treatment	Ripening stage	Parameter				
		Moisture content (%)	Starch (%)	Amylose (%)	Dietary Fiber (%)	Antioxidant (%)
Unpeeled	1	3.50±0.05[b]	74.84±3.16[d]	25.31±0.17[b]	18.67±0.33[d]	37.05±0.71[a]
	4	4.47±0.09[c]	58.98±0.66[c]	17.41±0.15[d]	16.40±0.19[c]	180.38±4.19[c]
	6	4.31±0.32[c]	52.61±0.48[b]	12.36±0.34[f]	16.59±0.07[c]	182.84±9.85[c]
Peeled	1	2.59±0.00[a]	73.99±0.19[d]	22.47±0.39[e]	16.32±0.68[c]	34.82±1.54[a]
	4	4.46±0.37[c]	46.18±1.14[a]	13.36±1,00[c]	12.52±0.51[b]	37.25±2.18[a]
	6	7.21±0.34[d]	44.69±0.32[a]	10.42±0.38[a]	10.15±0.26[a]	123.00±0.37[b]

Mean values with different superscripts on the same column are significantly different (P < 0.05).

types, while *Pisang Tanduk* is the plantain type. The unpeeled plantains produce flour with DF content that tends to be higher than the peeled plantains flour (Table 1). The TDF value of unpeeled flour is higher due to the increase in the TDF from the peel. The research results conducted by (Garcia-Amezquita et al. 2018) show that the DF value in banana peel is higher than in the banana pulp. According to Zhang et al. (2005), the banana peel contains 20% DF, with the main components of hemicellulose, pectin, and lignin.

Antioxidant activity

The antioxidant activity increases during increasing the ripening stage (Table 1). The *Tanduk* plantain flour produced from the unpeeling treatment has higher antioxidant activity than the peeling treatment. The plantain flour made from the unpeeling treatment of ripening stage 6 has significantly increased antioxidant activity than other treatments (P<0.05)—the antioxidant activity of plantain flour in ripening stage 1 increases six times during the ripening stage 4. The increase in the antioxidant activity is caused by a biochemical reaction at stages 3 and 4 (Campuzano et al., 2018). The peels on several banana varieties contain a total antioxidant of 2.64 to 5.95 mM AAE/G (Baskar et al. 2011). The peeled plantain flour's high antioxidant activity can be caused by the peel's high total phenolic content. The peel's phenolic component is around 18.21 to 35.06 mg gallic acid/gr (Anal et al., 2014).

Physical and functional properties

Color

Color is an essential parameter in flour products since it can affect the consumers' acceptance. The colors of *Tanduk* plantain flour produced from the peeled and unpeeled plantains at several ripening levels are shown in Table 2. The values of *L, a,* and *b* of *Tanduk* plantain flour differ significantly (P < 0.05). In general, the unpeeled flour shows higher L (48.90 to 68.27), higher *a* (2.49 to 3.55), and lower *b* (11.48 to 18.24), so that the color of flour tends to be brighter than the peeled flour (*L* = 58.34 to 64.62, *a* = 2.29 to 3.89, and *b* = 12.75 to 21.72) which tends to be more yellow. The values of *L, a,* and *b* in the unpeeled are better than the unpeeled plantain flour by the research of Khoozani et al. (2019), which uses the methods of freeze dryer and oven dryer (*L* = 42.42 to 59.72, *a* = (−0.75) to 2.97, and *b* = 12.13 to 15.55). Meanwhile, peeled flour's L, a, and b values are better than Falade and Olugbuyi (2010) (*L* = 57.56 -67.45, *a* = 5.18-6.77, and *b* = 11.82-13.44). It is suspected that the cultivar and the preparation and drying methods cause this difference. According to Falade and Oyeyinka (2015), the cultivar, drying method, and maturity significantly influence the resulting plantain flour's L, a, and b values . In this research, the raw materials were blanched for 5 minutes for enzyme inactivation and dried using a cabinet dryer at 50^{o}C. Other research uses 0.05% sodium metabisulfite Falade and Oyeyinka (2015) and 0.5% citric acid (Khoozani et al. 2019). The drying method used a sun dryer, oven dryer at 60^{o}C, foam mat dryer at 60^{o}C (Falade and Oyeyinka 2015), freeze dryer at -30^{o}C to -10^{o}C, and oven dryer at 50^{o}C to 110^{o}C (Khoozani et al. 2019). It proves that the preparation and drying methods in this research produce better and more attractive colors. Table 2 shows that the higher the ripening level, the *L* value tends to decrease, the *a* value tends to increase, and the *b* value tends to decrease, indicating that the flour's color is getting brown. In line with previous research, more ripe bananas produce darker/brown colors (Falade and Oyeyinka 2015). The browning that occurs when maturity increases are associated with increased total solids and decreased starch. The sugar content in raw *Tanduk* plantain (Stage 1 to 3) ranges from 0% to 4.38%, while the ripe *Tanduk* plantain (Stage 4 to 7) ranges from 8.10% to 16.42% (Kumalasari et al. 2021).

WAI of the flour

WAI is the flour particle's ability to bind water when forming a dough. The WAI of flour produced in this research ranged from 1.75 to 2.60 and differed significantly (P < 0.01). The WAI made from the unpeeled flour was higher than the peeled flour. The increasing plantain maturity tends to produce flour with decreasing starch content. The WAI flour produced from the unpeeled treatment at Stage 1 was significantly higher than other treatments. The WAI value at ripening Level 6 was lower than the WAI produced by Kumalasari et al. (2020), which was 2.91, but comparable to the study of Onwuka and Onwuka (2005) for the peeled ripe *'false horn'* plantain, which was 2.00, and the peeled unripe

Table 2: Physical and Functional Properties of *Tanduk* Plantain Flour

Treatment	Ripening stage	Parameter							
		Colour			WAI	OAI	Swelling	Solubility	Hygroscopicity
		L	a	b					
Unpeeled	1	68.27±0.19^{f}	2.49±0.25^{a}	18.24±0.15^{e}	2.60±0.057^{c}	1.04±0.02^{b}	8.52±0.08^{d}	0.14±0,00^{a}	0.07±0.00^{a}
	4	51.58±0.27^{b}	3.55±0.01^{c}	13.25±0.04^{c}	2.27±0.26^{b}	1.05±0.01^{b}	7.57±0.29^{c}	0.32±0,00^{b}	0.10±0.00^{b}
	6	48.90±0.41^{a}	3.73±0.11^{cd}	11.48±0.05^{a}	2.17±0.02^{b}	1.08±0.01^{c}	6.62±0.34^{b}	0.35±0.00^{c}	0.11±0.00^{c}
Peeled	1	64.62±0.73^{e}	2.29±0.10^{a}	15.37±0.22^{d}	2.12±0.11^{b}	0.97±0.02^{a}	10.59±0.53^{e}	0.14±0.00^{b}	0.07±0.00^{a}
	4	61.57±1.16^{d}	2.76±0.05^{b}	12.75±0.09^{b}	2.07±0.27^{b}	0.98±0.01^{a}	9.14±0.67^{d}	0.35±0.01^{c}	0.10±0.00^{b}
	6	58.34±0.40^{c}	3.89±0.04^{c}	21.72±0.45^{f}	1.75±0.02^{a}	1.23±0.02^{d}	5.65±0.45^{a}	0.44±0.01^{d}	0.11±0.00^{c}

Mean values with different superscripts on the same column are significantly different (P < 0.05).

'false horn' plantain which was 2.5. The WAI value is higher in the unripe unpeeled flour treatment than the peeled ripe flour because the starch content in the unripe unpeeled flour treatment is higher than that of the peeled flour (Table 2). Starch is a more complex molecule and requires more water for the hydrolysis process than the sugar molecule, which is more plentiful in ripe flour (Onwuka and Onwuka 2005). Compared to the ripe peeled flour, the unripe unpeeled flour has a higher ability to bind water when forming a dough, so it is more suitable for bake food that requires dough compactness. Meanwhile, ripe flour is recommended for baby food products. Baby food products require less water to be absorbed/bound because it will reduce bulkily; thus, it is more palatable and easy to digest (Zakpaa et al. 2010).

OAI of the flour

OAI is the flour particles' ability to bind oil when forming a dough. Table 2 shows the OAI values of *Tanduk* plantain flour produced, ranging from 0.97 to 1.23, and significantly different ($P < 0.05$). This OAI value is still smaller than from the research by Kumalasari et al. (2020), which is 2.26, and also lower than the unripe *'false horn'* flour (5.33) and the firm ripe *'false horn'* flour (4.00) from the research by Onwuka and Onwuka (2005). The increase in ripening tends not to affect the OAI value. According to Rodríguez-Ambriz et al. (2008), OAI is related to starch's hydrophobic nature; the high OAI value has a high emulsion activity, which causes the emulsion in the dough to become more stable. The OAI value strongly correlates with emulsion stability (Khoozani et al. 2019). Besides, flour with a high OHC value can retain absorbed oil/fat. Therefore, it affects the texture and the 'mouth feel' of food products (Oluwamukomi and Oluwalana 2011). The high OAI value and high emulsion capacity value are needed for bakery products that require emulsion and creaming properties (Onwuka and Onwuka 2005), where oil/fat is an essential component in bakery products. The flour in this research with a low OAI value is recommended for products that do not require emulsifying properties.

The swelling capacity of the flour

Swelling capacity is the flour particles' ability to absorb water and expand when heated (Zakpaa et al. 2010). The flour swelling capacity (SC) produced in this research ranged from 5.65 to 10.59 and differed significantly ($P < 0.01$). The SC made from the unpeeled flour is lower than the peeled flour. The insoluble fiber, which is plentiful in the peel, prevents the starch from expanding when heated. The increasing plantain maturity tends to produce the flour with decreasing SC. During the ripening process, the starch in the plantain is broken down into sugar. The decreased starch content in the pulp causes the flour's ability to expand to decrease as well. The SC flour produced from the peeled treatment at Stage 1 is significantly higher than other treatments. The SC flour in this research was higher than from the study by Kumalasari et al. (2020), which was 3.41; more elevated than (Onwuka and Onwuka 2005), which was 3.00 (unripe) and 2.40 (ripe). The SC value is related to WAC. The higher the WAC, the higher the SC. SC is associated with the starch gelatinization process in which water is required (Oluwamukomi and Oluwalana 2011).

Solubility of the flour

Solubility is the material's ability to be absorbed in water so that no emulsion is formed. Solubility is a parameter used to indicate starch components damage (Reddy et al. 2015). Table 2 shows that the *Tanduk* plantain flour's solubility index value, ranging from 0.14 to 0.44%, differed significantly ($P < 0.05$). This research's solubility value is still lower than the study by Kumalasari et al. (2020). It was 29.67%, and the fermented modified *Tanduk* plantain flour, from 7.03 to 11.62% by Desnilasari et al. (2020). The use of peel on flour tends not to affect the solubility, yet the fruit ripening level tends to increase the solubility value. Solubility (carbohydrate leaching) value depends on the amylose ability from inside the starch granule to release. Heated starch granule will expand, causing amylose to release (Adebowale et al. 2005). The release of amylose into the water during heating occurs more in the pulp flour than in the peel flour (Alkarkhi et al. 2011).

Hygroscopicity of the flour

Hygroscopicity shows the product's final content after the flour/powder is left in an environmental condition with 79.5% Rh (Jaya et al. 2006). Meanwhile, according to Naknaen et al., (2016) Hygroscopicity is a material ability to engage and keep the water molecules from the surrounding environment. As seen in Table 2, the hygroscopicity of *Tanduk* plantain flour increases significantly with the increasing ripening level ($P < 0.05$). It is because the bananas' pulp and the peel contain types of sugars that have high Hygroscopicity. Bananas contain 5.8% sucrose, 3.8% glucose, and 6.6% fructose, where these three types of sugar have higher hygroscopicity than lactose and maltose (Davis 1995). The ripe banana peels also contain high amounts of dissolved sugars such as glucose and fructose, resulting from chlorophyll degradation during the ripening process (Yang et al. 2009). According to Jaya and Das (2004), sucrose, glucose, and fructose are responsible for strong interactions with the water molecules due to the polar terminals on these molecules. These sugars are hygroscopic in the amorphous phase and lose their ability to flow smoothly at high water content (clumping quickly). The sugars in the ripe plantain flour hold a large amount of water and are more robust than the starch ability. The increasing ripening level is causing the higher hygroscopic value of banana flour (Pragati et al. 2014). The *Tanduk* plantain flour's hygroscopic with peeling and unpeeling treatment at the same plantain ripening stage in the range of 0.065 to 0.105-gram ingredients/100 and do not significantly differ (P > 0.05), lower than Naknaen et al., (2016), and is also in between of gac powder (Suriyajunhom and Phongpipatpong 2018).

Pasting properties

Table 3 represents the pasting properties of *Tanduk* plantain flour. The higher the plantain flour ripening stage, the more decreases the values of peak viscosity, breakdown viscosity, and set back viscosity, significantly different ($p<0.05$). Meanwhile, the importance of peak time (PT) and Pasting Temperature are increasing and significantly different ($p<0.05$). This trend is similar to previous research (Agiriga, 2015; Campuzano et al., 2018). Due to the starch degradation during the ripening process resulting from the enzymatic activity of the β-amylase enzyme (Do Nascimento et al. 2006). The values of the peak viscosity in stage 1 in the plantain with peeling treatment are lower. However, the peak viscosity values of ripening stage 4 are higher than the plantain flour's peak viscosity values reported by Campuzano et al. (2018). This difference can be caused by the varieties of plantain used. According to Ragaee and Abdel-Aal (2006), the decrease in peak viscosity values and the ripening stage can be caused by reducing water absorption and starch granule swelling during the drying process. The plantain flour's viscosity breakdown values in the peeling treatment of ripening stage 1 are higher than the raw *Tanduk* plantain flour mentioned by Cheok et al. (2018).

Meanwhile, BD and SB values of plantain flour in ripening stage 6 are lower than the ripe plantain flour, according to Ng et al. (2014). The FV values of *Tanduk* plantain flour in stages 1,4, and 6 are lower than and in line with what is revealed by Campuzano et al. (2018) and Ng et al. (2014). The high values of breakdown set back and final viscosity on the *Tanduk* plantain flour in ripening stage 1, compared to those in stages 4 and 6, are led to firmer gels with a higher tendency to retrograde. The plantain gels obtained from stages 3 and 4 are more stable during heating, mixing, and cooling due to the decrease in the starch amount that can gelatinize (Bakare et al. 2017). The pasting temperature and peak time values tend to increase, along with the increasing ripening levels. The pasting temperature values are higher than the plantain flour revealed by Ayo-Omogie et al. (2010) at stages 1 to 7 ripening process. The sugar content increase due to the ripening is thought to be caused by the maturation (Ng et al. 2014). The ripe plantain flour has a high dissolved content, competing with the available water starch. Thus higher energy is required for gelatinization (Ng et al. 2014).

In ripening stage 4, the BD of the unpeeling treatment for plantain flour has lower BD values than the peeling treatment. It is influenced by the presence of fiber in the peels. The presence of fiber in starch paste causes a decrease in the BD values, indicating that the starch-fiber system's stability is better than the starch without fiber (Adamczyk et al., 2020). The final viscosity of the unpeeling plantain flour in stages 1 and 4 is lower than the peeling plantain flour's FV values in the same ripening stage. The low FV values can be caused by fiber in the plantain peels, causing the three-dimensional network to weaken (Yildiz et al. 2013). The SB values of plantain flour tend to be higher in the unpeeling treatment, ranging from 491.00 to 2653.00 cP, indicating a lower tendency of the plantain flour. The observed changes in the SV values concerning fiber type and concentration of plantain peel. The interaction between the fibers and leached amylose at the hydrophobic regions and binding them to amylopectin's side chains through hydrogen bonding and the Van der Waals force might affect the retro-gradation and re-association of the cooling period (Zhu et al. 2009). The peak time values of the unpeeling *Tanduk* plantain flour in ripening stage 1 are lower than ripening stages 4 and 6. It is similar to the tendency in composite flour and fiber in research conducted by (Yildiz et al. 2013), where the higher the fiber concentration, the lower the peak time values. *Tanduk* plantain flour's pasting temperature in the unpeeling treatment is lower than that of the peeling treatment. These research results indicate that the unpeeling plantain flour requires a lower temperature to undergo gelatinization than the peeling treatment of the plantain flour. It is thought to be due to each starch/fiber matrix's behavior, which is remarkably influenced by the fiber type and concentration during heating (Yildiz et al. 2013).

Table 3: Pasting Properties of Tanduk Plantain Flour

Treatment	Ripening stage	Peak viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	Peak Time (minute)	Pasting temperature (^{0}C)
Unpeeled	1	4863.00±320.82^c	1073.50±12.50^f	5598.00±393.00^d	2653.00±83.47^e	5.00±0.07^a	70.42±0.51^a
	4	1559.33±150.70^b	98.00±11.00^c	1845.50±233.50^c	646.54.500±^{c}	7.00±0.00^d	85.30±1.00^c
	6	741.00±107.06^a	64.00±13.00^b	1190.33±93.31^b	491.00±1.00^b	7.00±0.00^d	88.30±1.82^d
Peeled	1	4510.67±275.43^c	838.33±35.28^e	5705.50±115.50^d	2195.50±25.50^d	5.40±0.12^b	81.08±0.42^b
	4	1796.50±158.50^b	310.50±15.50^d	2079.00±98.00^c	487.50±60.50^b	6.02±0.19^c	86.00±0.45^c
	6	463.00±5.00^a	19.00±1.00^a	234.50±11.50^a	140.50±10.50^a	7.00±0.00^d	89.75±0.00^d

Mean values with different superscripts on the same column are significantly different ($p < 0.05$).

Thermal properties

The *Tanduk* plantain flour thermal result is shown in Table 4 using DSC. The results show that the *Tanduk* plantain flour at ripening stages 1 to 6 has an initial temperature (T_o) and a peak temperature (T_p) were tend to increase, the enthalpy (ΔH) and the final temperature (T_c) of gelatinization decrease with the increasing ripening stage. The plantain flour gelatinization enthalpy in this research is higher than the banana starch at ripening stages 1 and 3, as reported by Prachayawarakorn et al. (2016). However, it has the same tendency to decrease gelatinization enthalpy. This decrease is due to the loss of starch crystallinity as the ripening stage increases. According to Prachayawarakorn et al. (2016), the degree of crystallinity of plantain starch at Stage 1 is 25.8% decreasing to 12.6% at Stage 3. The XRD analysis results support the decrease in the starch crystallinity in this research (Fig 2). The higher the plantain ripening level, the starch content decreases and the increase in the sugar content. In sorghum starch, the sugar does not affect the enthalpy, while the sugar in potato starch increases the gelatinization enthalpy (Maaurf et al. 2001; Ronda and Roos 2008). This difference is due to starch sources, starch type, and other ingredients such as sugar, salt, water, and hydrocolloids (Elgadir et al. 2009).

T_O and T_P of the unpeeled plantain flour tends to be lower than the T_O and T_P of the peeled plantain flour. H and T_C's values of the unpeeled plantain flour are higher than those of the peeled plantain flour. The T_O and T_P values of all unpeeled banana flour at maturity Stage 1 in this research are lower (49.00 and 94.30°C) compared to the T_O and T_P reported by Nimsung et al. (2007), 73.44 to 76.27°C and 77.21 to 80.35°C with higher ΔH and T_C values (139.90 and 163.60). According to Singh et al. (2003), the difference is influenced by the amylose content, the shape and distribution of the starch granules, and the starch fraction's internal arrangement in the granules. Also, it can be caused by the differences in the strength of the double helix bonds that form amylopectin crystals, resulting in different hydrogen bonds in starch (McPherson and Jane 1999). The low T_0 and T_P in the unpeeled plantain flour are thought to be caused by the lower amylose content in the flour than the amylose content of the peeled banana flour.

The crystallinity of *Tanduk* plantain flour

Fig 3 shows the various X-ray diffraction patterns of *Tanduk* plantain flour with both unpeeling and peeling treatments at ripening stages 1, 4, and 6. The *Tanduk* plantain flour in the unpeeling treatment at stage 1, 4, and 6 has Type-C crystalline structure with the diffraction peaks at 2θ, which are 15.12, 17.2, 23.1, and 26.32° (Stage 1); 15.18, 17.3, 23.0, 26.0 (Stage 4); and 15.2, 17.2, 19.6, 21.9, 23, 24.2, and 26.1 (Stage 6). The XRD pattern shows a similar tendency and type to the plantain flour with the peeling treatment for the plantain flour with the peeling treatment. The plantain flour from the peeled plantain also has Type-C crystalline pattern as indicated by the prominent diffraction peaks at 14.8, 17.3, 23.15, and 25.5 (Stage 1); 15, 16, 17.4, 20.3, 22.3, 22.97, and 24.2 (Stage 4), and 8.5, 11.87, 15.49, 17.26, 18.99, 19.74, 20.99, 22.15, 24.87, and 24.44 (Stage 6). The research results are similar to those revealed by Prachayawarakorn et al. (2016).

Table 4: Thermal Properties of *Tanduk* Plantain Flour

Treatment	Ripening stage	T_O (°C)	T_P (°C)	H (J/g)	T_E (°C)
Unpeeled	1	49.00	94.30	139.90	163.60
	4	59.40	92.80	78.15	146.00
	6	60.1	94	65.21	126.3
Peeled	1	58.5	100.8	119.2	159.4
	4	52.7	86.8	56.39	126.8
	6	63.4	95.5	81.24	122.8

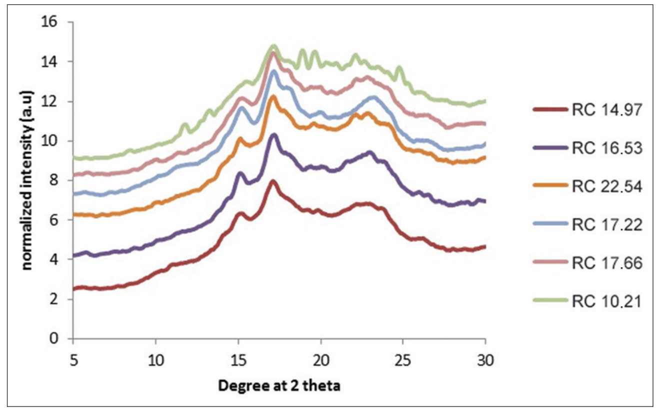

Fig 3. X-ray diffraction patterns of *Tanduk* plantain flour

The crystalline properties of plantain flour are the same as plantain starch, with lower relative values of crystallinity (Pelissari et al. 2012). The relative crystallinity values of the unpeeled plantain flour increase along with the increasing ripening stage. It is thought to be caused by the crystalline structure of the peels' fibers, which may interact with other existing components on the peel and the pulp (Xia et al. 2014). The peeled plantain flour shows many small peaks at stages 4 and 6, presumably due to the starch content's higher ripening level, accompanied by the high sugar content. It means that there are damages and changes in the starch crystals, accompanied by sugar crystals, which are seen as small peaks in the XRD pattern. Relative Crystallinity (RC) in the peeled plantain flour decreases along with the increasing ripening stage. The components in flour, such as ash, protein, fat, and crude fiber content, affect the granules' crystallinity (Pelissari et al. 2012).

The FTIR spectra of *Tanduk* plantain flour

The FTIR (Fourier Transform Infra-Red) test was conducted to determine the functional groups formed and changed in *Tanduk* plantain flour's structure. Fig 4 shows the IR FTIR absorbance pattern of *Tanduk* plantain flour

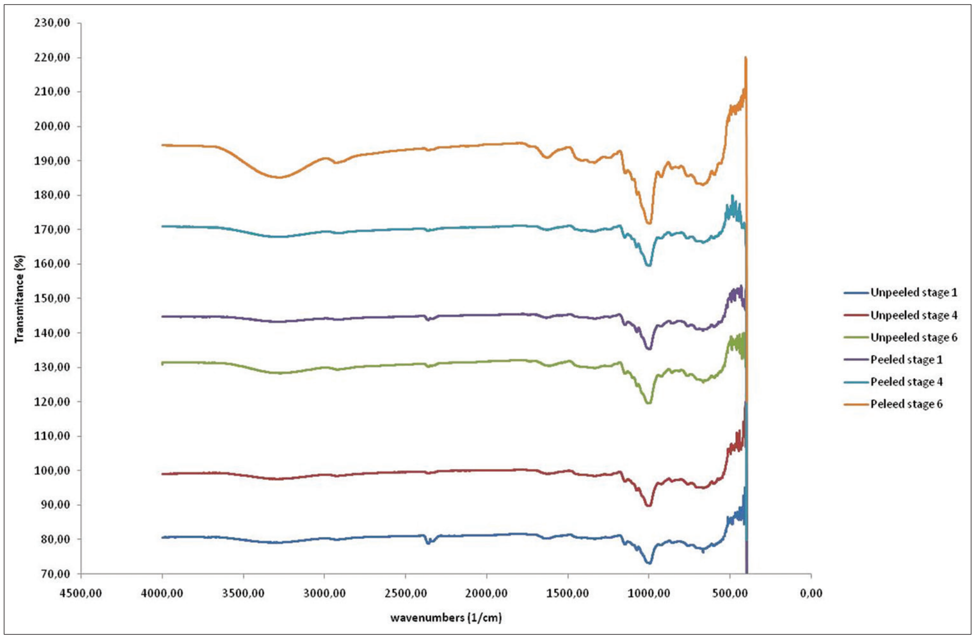

Fig 4. Fourier Transform Infra-Red patterns of *Tanduk* plantain flour

at ripening stages 1, 4, and 6 with peeled and unpeeled treatments, which are not much different. These results are similar to Khawas and Deka (2016), which stated that the IR spectra on the plantain peels at ripening stages 1 to 5 were almost identical. Li et al. (2018) also indicated that plantain's pulp and peel have the same FTIR spectrum. It is stated that pulp and peel starches have a similar short-range ordered structure in the granule's outer region.

All *Tanduk* plantain flour show bands at 3269.84 to 3294.53 cm^{-1} with a broader and sharper band on the unpeeling treatment (3269.84 cm^{-1}); the peeling treatment (3280.48 cm^{-1}) at the ripening stage 6 indicates symmetric and asymmetric stretching of the O-H bonds. The O-H bonds in this research are close to the O-H bonds in the plantain flour reported by Pelissari et al. (2012), 3289 to 3298 cm^{-1}. According to Khoozani et al. (2019), the unpeeled plantain flour at ripening stage 1 has IR spectra on the 3277.53 cm^{-1} bands. Meanwhile, the unpeeled plantain flour in this research has an O-H band at 3281.7 cm^{-1}. According to Derrick et al. (1999), O-H stretch generally occurs from 3600 to 3200 cm^{-1}. This region has a broadly rounded base that indicates the significant contribution of the water molecules.

The second band seen in the *Tanduk* plantain flour is located at the wave number 2359.42 to 2359.96 cm^{-1} which is sloping more along with the increasing ripening stage. According to Derrick et al. (1999), the absorption in these spectra is minimal. This area includes the window region (2800 to 1800 cm^{-1}), where the most visible band is atmospheric carbon dioxide (at 2340 cm^{-1}). According to Pelissari et al. (2012), the plantain flour has IR band spectra at wavenumbers at 2928 to 2931 cm^{-1}. Khoozani et al. (2019) found the spectra IR on the unpeeled plantain flour at the 2900 cm^{-1} band. The bands in this wave number would result from the stretching of C – H bonds. However, they were not found in the plantain flour in this research.

All plantain flour samples in this research have amide I and amide III bands located in the wavenumbers 1634.07 to 1632.21 cm and 1337.14 to 1334.84. The prominent bands are observed at 1634.07 to 1634.3 (Stage 1), 1632.21 to 1633.71 (Stage 4), and 1614.36 to 1633.47 (Stage 6), represent the bending mode of the absorbed water which might be related to the COO-stretching vibration in the carbohydrate group (Fan et al. 2012). According to Singh et al. (2003), The amide I band is found between 1600 and 1720 cm^{1}; this is the amide group of proteins and reflects the C– –O stretching. Another prominent band related to proteins is the amide III band, located between 1200 and 1350 cm^{1}. The existence of a peak in this wave number is thought to be caused by the plantain flour's protein content (Pelissari et al. 2012; Khoozani et al. 2019).

Like Khoozani et al. (2019), the plantain flour with the unpeeling treatment has a band around (996.55 to 998.82) cm-1 shows the carbohydrate biomolecules. According to Nasrin et al. (2015), the peak in the wavenumbers represents the properties of anhydrous glucose ring O-C stretching, which is also found in the plantain peel's flour and starch. The plantain flour at maturity Level 6 with peeling treatment shows a sharper peak at the wavenumbers around 800 to 1000 cm^{-1}, namely at 996.55 cm^{-1}, compared to other flours. Meanwhile, all plantain flour samples show the same pattern in other wavenumbers.

CONCLUSIONS

The peeled and unpeeled plantain flour in stages 1, 4, and 6 contains 44.69% to 74.84% starch content, respectively, indicating that they are essential starch resources. Based on its chemical properties, the unpeeled plantain flour provides higher dietary fiber content and antioxidant activity. Unpeeled plantain flour in stage 1 has a high peak and final viscosity in pasting properties as functional ingredients for bakery products. Meanwhile, peeled and unpeeled plantain flour at stages 4 and 6 show relative low final, setback viscosity, and WAI, which appropriates for developing weaning food. The peeled and unpeeled banana flour at stages 1, 4, and 6 have Type-C crystalline property, increase RC due to a higher ripening stage, and the same functional group in a structure according to IR FTIR absorbance pattern.

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AUTHORS' CONTRIBUTIONS

Riyanti E, Rima K, Yani S, and Nana SA designed and conducted field research. Riyanti E, Yani S, Dewi Desnilasari performed laboratory analysis. Riyanti E and Rima K, conducted statistical analysis. Riyanti E and Rima K wrote the manuscript with input from all co-authors. Diki Nanang S and Nur Kartika I M had written—reviewed, and editing the manuscript. Riyanti E had final responsibility for the content. All authors read and approved the final manuscript

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