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FULL PAPER

Sugar palm starch (*Arenga pinnata*) modification using microwave and acetylation: effect of moisture content and microwave power on physicochemical characteristics

Hehamahua, Z.N., Aziezah, E.A., Supriyadi, Ningrum, A. and *Ardhi, A.

Department of Food and Agricultural Product Technology, Faculty of Agricultural Technology, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

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Abstract

Sugar palm starch (*Arenga pinnata*) can be utilized for food and non-food products. The natural properties of native starch are high viscosity, fast retrogradation problems, unstable to heat and acid, and low paste resistance. Therefore, modifying sugar palm starch is necessary to improve its physicochemical characteristics. Microwave and acetylation are reported to be effective modification methods. In this research, modification using a microwave was carried out at 13%, 18%, 23%, and 28% moisture content, with a power of 200 W, 300 W, and 399 W. In general, increasing moisture content and microwave power could decrease starch, amylose content, and swelling power while solubility increases. The higher power applied reduced the starch granule size and changed the pasting properties. All the treatments in this research did not change the functional groups of the starch. The results showed that the starch with a moisture content of 13% and a microwave power of 300 W could most effectively reduce the granule size and swelling power. Subsequently, this condition opted for a combination modification method with acetylation. The combination of acetylation and microwave modification on sugar palm starch significantly decreased the starch and amylose content, swelling power, solubility, and granule size and changed the pasting properties of the starch. However, the combination of acetylation and microwave treatment had different effects on starch content and solubility compared to the single acetylation modification in particular. Overall, this result has demonstrated that dual modification of sugar palm starch could improve the limitation of its native characteristics in terms of granule size, swelling ability, gelatinization temperature, and retrogradation stability, which might be advantageous for specific purposes of food processing.

1. Introduction

Sugar palm (*Arenga pinnata*) is a plant with many benefits for humans, which can be utilized to produce industrial materials such as sap, sugar palm fruits, and sugar palm starch (Rahim *et al.*, 2016). The stem of the sugar palm plant has a starch content of approximately 26-37%. Today's use of palm starch in the food industry is a raw material for white noodles, vermicelli, meatballs, cendol, and bread. The selection of palm starch as a raw material for various types of food above is due to its very thick gelatinization nature (Pontoh, 2004).

Sugar palm starch has oval granules with pointed ends, which tend to be larger than other starch granules, a very high viscosity that is twice the viscosity of cassava starch, a high temperature required for gelatinization, and the resulting gel is thick (Pontoh, 2004). Heriawan *et al.* (2016) reported that the natural properties of sugar palm starch are its fast retrogradation, no resistance to acid conditions, low stability, and low resistance of the paste. In connection with the starch characteristics, it is necessary to have physical and chemical modifications to improve the physicochemical characteristics of sugar palm starch to be utilized optimally.

The modification using a microwave is one of the physical methods to improve the characteristics of sugar palm starch. This method runs using heat from microwave power, and the moisture content in food is regulated by around 10-40% (BeMiller, 2018). Controlling the moisture content in the microwave method will not cause gelatinization of native starch but

*Corresponding author.
Email: *aulia.ardhi@ugm.ac.id*

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change the conformation of the amylose and amylopectin molecules that are more compact (Sodhi and Singh, 2005). Hervelly *et al.* (2020) tested the interaction effect of moisture content and heating temperature on Hanjeli flour (*Coix lacryma* Jobi L.) using heat moisture treatment, where the higher the addition of moisture content, the higher the amylose content.

Acetylation is one of the chemical modification methods used to improve the undesirable characteristics of natural sugar palm starch on product texture and appearance. Acetylation is carried out by adding an acetyl group to affect the physicochemical characteristics of starch. The acetylated starch is reported to have lower viscosity and increased swelling power, solubility, paste clarity level, and starch gelatinization temperature (Heriawan *et al*., 2016). The acetylated starch performs better storage and better cooking stability when compared to the native starch (Raina *et al.*, 2006; Rahim *et al.*, 2015). The amylose, amylopectin, swelling power, and solubility of sago starch after acetylation tended to slightly increase compared to the native starch (Teja *et al.*, 2018).

The combination modification method can be an alternative to improve the functionality and physicochemical properties of native starch because when treated only with a single modification, the desired characteristics such as syneresis rate, shear stability, and retrogradation resistance have not been obtained (Cereda *et al.*, 2003; Oyeyinka *et al*., 2016; Babu *et al*., 2016; Moin *et al*., 2019). Combination modification processes commonly carried out are chemical combinations, such as cross-linking with esterification and substitution. Rahim *et al.* (2019) modified the combination of sugar palm starch with acetate and phosphate at various concentrations of sodium trimetaphosphate and sodium tripolyphosphate to produce starch with lower viscosity, swelling power, and solubility than its native. However, the modified sugar palm starch's moisture content and oil holding capacity were more remarkable than native starch. To date, there is still a lack of reports concerning the combination of physical starch modification in the form of microwave and acetylation as chemical modification carried out to sugar palm starch. Therefore, this study aimed to evaluate the effect of microwave power and moisture content and its combination with acetylation treatment on sugar palm starch's physicochemical characteristics.

2. Materials and methods

2.1 Materials

Sugar palm starch used in this study was obtained from a traditional market in Borobudur, Central Java, Indonesia. The starch was stored using a zip-lock plastic and placed at room temperature to maintain its quality. All chemicals used were purchased from Sigma-Aldrich.

2.2 Starch modification preparation

Sugar palm starch modification began with preparing 100 g of starch. Furthermore, starch was conditioned with four different moisture contents, which were 13, 18, 23, and 28%. The samples were heated using microwave (Sharp R242WW) heat for 60 s with a power of 200, 300, and 399 W. Afterward, the samples were stored in zip-lock plastic and stored in a cooling room with a temperature of 4°C to maintain the quality of palm starch until they were analyzed. After the selected microwave condition that produces the best starch characteristics was determined, dual modification involving acetylation and microwave was carried out. Modification by acetylation was carried out according to Chi *et al.* (2008). The samples were weighed with 100 g of sugar palm starch and added to 225 mL of distilled water. The 5% acetic acid was added dropwise as well as 3% NaOH to maintain the suspension pH at 8-8.5. To stop the reaction, 0.5 M HCl was added to obtain a pH of 4.5. The following process was the precipitation and washing of the starch acetate with distilled water three times, rinsing once with 96% ethanol, and drying in a cabinet dryer for 12 hrs. The dried starch acetate was then treated with a microwave. Furthermore, this dual-modified starch was analyzed for its physicochemical characteristics.

2.3 Physicochemical analysis

2.3.1 Starch

Analysis of starch content was carried out following the AOAC (2005) by adding 2.5 g of starch to 250 mL of distilled water. The solution was added 20 mL of 30% HCl, heated for 2.5 hrs, added 6 mL of 40% NaOH, diluted to 500 mL, and filtered using Whatman No. 1 filter paper. The solution's filtering results were taken at 10 mL and diluted to 100 mL. The subsequent treatment was the analysis of reducing sugar using dinitro salicylic acid.

2.3.2 Amylose

Analysis of amylose followed AOAC (2005) by preparing 0.01 g of starch and then adding 0.1 mL of 95% ethanol and 0.9 mL of 1N NaOH. The solution in the test tube was heated for 10 mins and diluted to 10 mL. The solution was taken as much as 0.5 mL and added 0.1 mL of 1 N acetic acid and 0.2 mL of 0.02% iodine, then diluted to 10 mL. The solution was allowed to stand for 20 mins and then measured using UV-VIS spectrophotometry (Genesys 105 Thermo Fisher, Germany) at 625 nm. Meanwhile, amylopectin is the difference between starch and amylose.

2.3.3 Swelling power and solubility

The swelling power and solubility of the starches were determined as described by Adebowale *et al*. (2005) with slight modification. Analysis of swelling power was conducted by preparing 0.1 g of sugar palm starch sample in a weighed centrifuge tube. The sample was added with 5 mL of distilled water and homogenized using a vortex. The starch mixture was heated using a water bath shaker at 90°C for 30 mins. After that, the starch solution was cooled to room temperature and centrifuged at 3500 rpm for 15 mins. The precipitate formed in the centrifuge tube is separated and weighed. The swelling power value was measured by dividing the weight of the sediment in the centrifuge tube by the weight of the initial sample (g/g). On the other hand, aliquots (5 ml) of the supernatant were dried to a constant weight at 110°C. The residue obtained after drying the supernatant represented the amount of starch solubilized in water. Solubility was calculated as g/100 g of starch on a dry weight basis. All determinations were triplicated.

2.3.4 Pasting properties

The pasting properties of sugar palm starch were measured using Rapid Visco Analyzer (RVA) Perkin Elmer RVA 4500 with Thermocline software for Windows (Version 3), according to Nakthong *et al*. (2017). Approximately 3.0 g sample was weighed in an RVA container. Water (25.0 g) was then added to the sample. Flour suspension was stirred at 160 rpm and heated from 50°C to 95°C at an increasing speed of 6°C/min. The temperature was then maintained at 95°C for 5 mins. Subsequently, the paste was cooled at a cooling speed of 6°C/min from 95°C to 50°C. The temperature was then maintained at 50°C for 2 mins.

2.3.5 Starch granule morphology

Starch granule was observed using an optical microscope (Olympus CX 21) at 400× magnification. As much as 1 g of sugar palm starch was dissolved in 20 mL of water and dripped using a pipette onto the object glass and closed (Chakraborty *et al*., 2020). After that, the images of the starch granules were obtained and recorded using Optilab Advance (Miconos). The granule size was measured using a scale ruler featured in the Optilab of 10 granule samples.

2.3.6 Functional group changes

Changes in functional groups in the starch structure were measured using Fourier Transformation Infra-Red Spectroscopy (FTIR) Thermo Nicolet i50 FTIR spectrometer (Waltham, MA) according to Ratnaningsih *et al*. (2016) at a wavelength of 400-4000 cm^{-1}. The sample was mixed with KBr crystals in a ratio of sample:KBr was 1:100 and put into a container to be inserted into the FTIR device.

2.4 Data analysis

This study applied a completely randomized design with two factorials. The results were expressed as the mean ± standard deviation (SD), and the statistical significance was analyzed by one-way analysis of variance (ANOVA). Post hoc Duncan's tests were used for comparisons amongst values. Differences were considered to be significantly different at $p<0.05$.

3. Results and discussion

Modification of starch caused changes in the chemical properties of starch, which would impact the characteristics and functional properties of the modified starch.

3.1 Starch

The starch content in the microwave-modified sugar palm starch is presented in Table 1. The difference in microwave powers showed fluctuating results, in which starch content in the microwave-modified starch was lower than the native starch ($p<0.05$). The microwave power affected the temperature inside the microwave. The higher the temperature, the lower the starch content because the higher temperature results in the leaching or destruction of the starch molecules due to gelatinization (Imanningsih, 2012). Variation in moisture content (MC) had significantly different starch content from the native starch, which increased MC and decreased the starch content. The results were similar to Putra *et al.* (2016) in that the higher MC caused a decrease in the starch content of taro *kimpul*.

3.2 Amylose

The difference in microwave power showed fluctuating amounts of amylose and amylopectin content. Amylose content showed a significant difference at 300 W ($p<0.05$), while there was no significant difference at 200 and 399 W ($p>0.05$). Starch modification using microwave decreased the amylose, which was in agreement with Nadiah *et al.* (2015), who obtained a decrease in tapioca starch after conventional and microwave heating. This result could be due to the leaching of amylose that occurred at the initiation of swelling and heating starch in the presence of water leading to an irreversible disruption of the granule structure. During microwave heating, a rapid increase in temperature around each granule resulted in a rapid

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Table 1. Starch and amylose content of microwave-modified sugar palm starch.

Parameters	Moisture Content (%)	Microwave Power (W)			
		Native	200	300	399
Starch (% db)	13	102.12±0.00^{Ad}	91.18±0.48^{Cc}	95.04±1.28^{Bc}	93.67±0.72^{Bc}
	18		92.961±0.64^{Bc}	94.09±0.66^{Bc}	91.11±0.45^{Cc}
	23		86.36±0.51^{Bb}	72.25±0.34^{Cb}	70.83±0.44^{Ca}
	28		67.73±2.52^{Ca}	66.66±0.88^{Ca}	78.32±1.12^{Bb}
Amylose (% db)	13	41.51±0.01^{Ad}	36.09±0.70^{Bb}	34.02±1.63^{Ba}	29.81±1.89^{Cc}
	18		39.01±0.37^{Bc}	38.75±0.55^{Bb}	28.32±1.91^{Cc}
	23		33.70±0.61^{Cb}	39.68±0.69^{Bb}	39.10±0.52^{Bb}
	28		35.25±1.20^{Bb}	40.73±1.35^{Ad}	22.78±1.07^{Cd}

Values are presented as mean±SD. Values with different uppercase superscripts within the same row are statistically significantly different while values with different lowercase superscripts within the same column are statistically significantly different.

increase in local viscosity, lowering the amylose leached out into the supernatant. The proportion of amylose in the supernatant decreased with increasing heating rates. However, there was also another opportunity that microwave energy absorption would damage the amylopectin chain and form linear amylose chains. Also, the higher the MC, the lower the amylose content because high MC and temperature make the amylose chain break (Cordeiro *et al.*, 2018).

3.3 Swelling power and solubility

Table 2 indicates that microwave treatment led to a decrease in the swelling power value of sugar palm starch when compared to the native. This finding followed Subroto *et al.* (2019), which reported that the higher the temperature of heat moisture treatment, the swelling volume decreased significantly to 110°C. Decreasing the swelling volume of starch granules can be caused by molecular rearrangement of granules, formation of amylose-lipid complex, degradation of amylopectin molecules, increased interaction between amylose chains, and changes in interactions between the morphous and crystalline matrix (Adebowale *et al.*, 2005). Swelling power is also mainly a role of amylopectin, while amylose acts as a diluting or inhibiting agent for amylopectin swelling (Liu *et al.*, 2015). However, the microwave modification treatment might cause the starch granule molecules to become more tightly packed, affecting the granules' ability to swell was limited or decreased. The decrease in swelling power could also be due to the lower amylopectin content (Jading *et al.*, 2011), which might be degraded during microwave heating. On the other hand, generally, the variation of MC did not affect the swelling power with the exemption found in MC of 13% with all microwave energies and MC of 28% in 200 and 300 W ($p<0.05\%$).

There was no significant difference in the samples' solubility at 200 W and 300 W, but not at 399 W (Table 2). The tendency to increase the solubility of modified starch might be caused by weathering starch granules during heating (Deka and Sit, 2016). Variations in MC affected the solubility of the native starch. The difference in MC gave the solubility value that was not significantly different in the MC of 13% and 23% as well as 18% and 28%. Solubility is closely related to the ease with which water molecules bind to molecules in starch granules and replace hydrogen bond interactions between molecules that lead to the increase in binding ability to water and

Table 2. Swelling power and solubility of microwave-modified sugar palm starch.

Parameters	Moisture Content (%)	Microwave Power (W)			
		Native	200	300	399
Swelling Power (g/g)	13	13.31±0.93^{Ba}	11.41±0.77^{Ab}	11.32±1.05^{Ab}	10.85±0.94^{Ab}
	18		12.69±1.26^{Aa}	13.58±0.85^{Aa}	12.77±0.88^{Aa}
	23		13.01±1.01^{Aa}	11.97±0.86^{Aa}	12.39±0.27^{Aa}
	28		9.25±0.95^{Ab}	11.01±0.46^{Ab}	12.25±0.10^{Aa}
Solubility (%)	13	1.10±1.06^{Ca}	3.77±1.02^{Ab}	2.47±0.05^{Ab}	2.49±0.69^{Bb}
	18		5.11±1.54^{Ac}	8.80±0.70^{Ac}	3.43±0.97^{Bc}
	23		3.47±1.14^{Ab}	2.33±0.34^{Ab}	3.00±0.50^{Bb}
	28		7.07±0.54^{Ac}	8.30±0.89^{Ac}	3.92±0.01^{Bc}

Values are presented as mean±SD. Values with different uppercase superscripts within the same row are statistically significantly different while values with different lowercase superscripts within the same column are statistically significantly different.

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swelling power. This expansion will suppress the starch granules from the inside, causing the starch granules to break and then the amylose to release the starch granules. Low amylose levels decreased molecular weight, and a high proportion of short chains and branching degree resulted in increased starch solubility (Li *et al.*, 2019).

3.4 Pasting properties

The microwave-modified sugar palm starch's pasting properties are depicted in Figure 1. This study showed that the initial gelatinization temperature in the native starch was 71.40°C, and in the modified starch ranged from 71-72°C, which was not significantly different in each modification. At the treatment of 23% MC with a power of 200 W, the highest initial gelatinization temperature was obtained at 72°C, while the lowest was 71°C found at 13% MC with a power of 399 W. Yusra *et al.* (2020) reported that starch granules of oil palm stem started to swell at a temperature of 71.55°C and followed by an increase in suspension viscosity during the heating phase. The initial temperature of gelatinization is the temperature range that causes the starch to reach its maximum swelling. An increase in the initial gelatinization temperature indicated that starch was more resistant to heat and required a higher temperature to start gelatinization.

The peak time of gelatinization explains the maximum viscosity during the heating process (Kusnandar, 2011). The results showed that each treatment of sugar palm starch had a different peak time. The highest gelatinization peak time (7.07 mins) was obtained at 23% MC and 200 W, and the lowest (6.33 mins) was found at 13% MC and 399 W. According to Imanningsih (2012), gelatinization and swelling properties of starch were determined by amylopectin structure, starch composition, and granule architecture.

The highest peak viscosity was obtained at 28% MC at 399 W and the lowest peak viscosity at 18% MC at 300 W. According to Nazhrah *et al.* (2014), peak viscosity values expressed the ability of the granules to bind water and maintain swelling during heating. The high viscosity indicates that amylose binds to other starch molecules to form a double-helical structure through hydrogen bonds and form a more robust structure (Kusnandar, 2011). The peak viscosity of modified starch tended to increase compared to the native starch because high water absorption ability would experience high swelling, resulting in a high peak viscosity of the paste.

Trough viscosity indicates the stability of starch paste during cooking, calculated from the difference in viscosity before and after holding at a temperature of 95°C (Kusnandar, 2011). Imanningsih (2012) reports that holding is a condition when the temperature increases, driving the starch granules to break and the amylose to come out of the granules into the liquid causing a decrease in viscosity. This study showed that the trough viscosity of the modified starch ranged from 1186-3488 cP, while the native starch was 2288 cP. The highest trough viscosity was obtained in a sample with an MC of

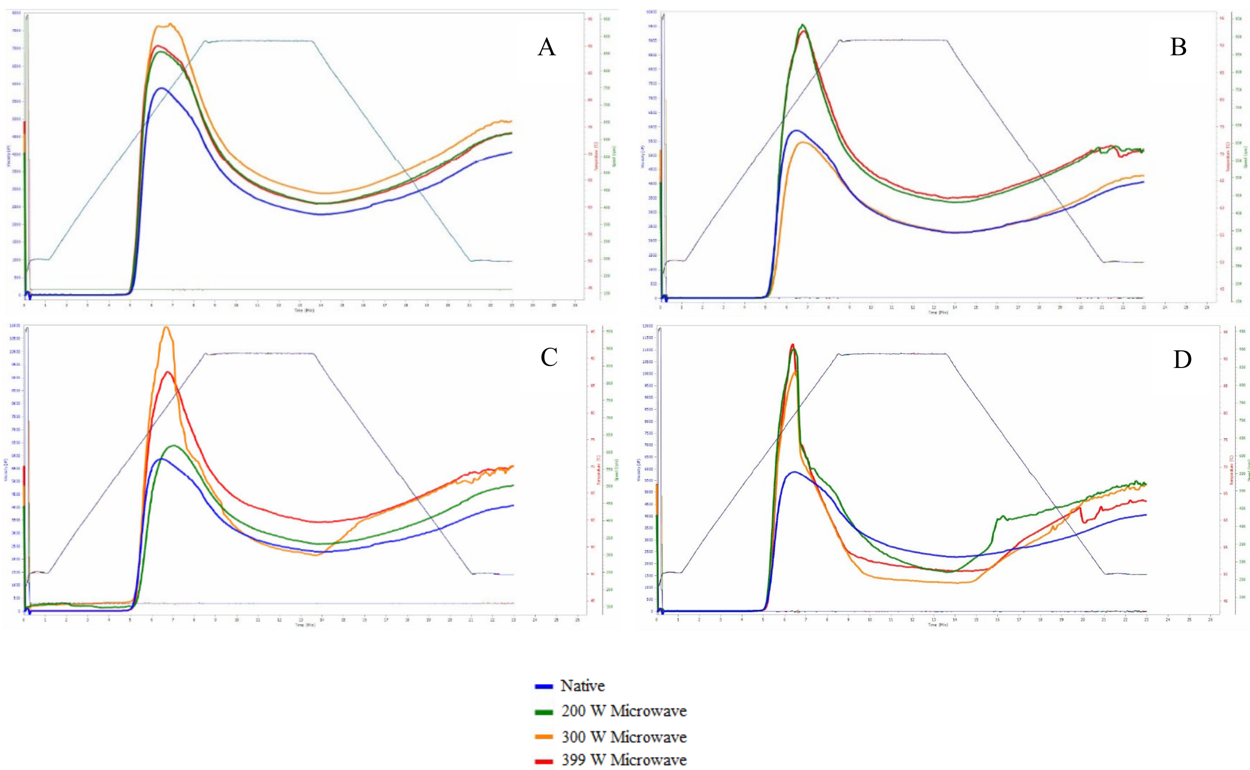

Figure 1. Pasting properties of microwave-modified sugar palm starch at moisture content of 13% (A), 18% (B), 23% (C), and 28% (D).

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18% at 399 W, while the lowest was found at an MC of 28% and 300 W.

The decrease in viscosity during the heating process indicates the stability of the starch paste during heating, where the lower the breakdown viscosity, the more stable the starch paste formed against heat (Lestari *et al.*, 2015). The highest modified starch breakdown viscosity was obtained at 28% MC at 399 W, and the lowest was obtained from starch with an MC of 18% at 300 W. According to Imam *et al.* (2014), the high breakdown value during the heating process indicates that the starch granules which have completely swelled have brittle properties and are not resistant to heating. The setback value indicates the ability of starch to undergo retrogradation. The setback viscosity in native starch was 1772 cp. Meanwhile, the sample with a moisture content of 28% and power of 300 W had the highest setback viscosity value of 4173 cP, and the sample with a moisture content of 18% and a power of 399 W had the lowest setback viscosity of 1664 cp. These results indicated that the modification tended to increase the setback value. According to Maulani *et al.* (2013), the higher the setback value, the higher the tendency to form a gel during cooling. Starch with low retrogradation indicates the ability to retain texture during storage. The difference in the setback value could occur due to differences in amylose content in starch. The higher the amylose content of starch, the higher the setback viscosity (Imam *et al.*, 2014). Syafutri (2015) suggested that starch with a high setback viscosity should not be used for cake, cake, or bread products because it creates hardness after the product has cooled, and it would be better to use it as a filler.

The final viscosity explains the stability of the starch viscosity against processing processes such as heating, stirring, and cooling (Nazrah *et al.*, 2014). Modified starch with an MC of 23% and 300 W had the highest final viscosity (5618 cP), while the modified starch with an MC of 18% and 300 W had a lower final viscosity (4279 cP), and native starch had the lowest final viscosity (4060 cP). According to Syafutri (2015), amylose and amylopectin can influence the final viscosity. Budijanto and Yuliyanti (2012) described that sorghum flour with high amylopectin had a high viscosity value, whereas those with a high amylose content had a low viscosity.

3.5 Functional group changes

The modification did not change the functional groups of the starch because there was no change in the peak and pattern of the FTIR results (Figure 2). FTIR spectra analysis on native and modified starches had a peak at a wavelength of 3332,391 cm^{-1}. Generally, peaks at wavenumbers 3000-3700 cm^{-1} are correlated to OH absorption and express the carbohydrate content (An *et al.*, 2011; Xing *et al.*, 2014; Hamid *et al.*, 2015; Wang *et al.*, 2015). The peak that appears at a wavelength of 2930 cm^{-1} indicates the presence of an aliphatic C-H group which is thought to come from the glucose unit that makes up starch (González-Cruz *et al.*, 2017). The wavelength range of 800-1500 cm^{-1} is the fingerprint area, which is vital in determining the difference in starch structure. The formation of new clusters or changes in the starch structure will be detected in the fingerprint area. The absorption at 800-1200 cm^{-1} is an infrared absorption of polysaccharides, a fingerprint of conformational and hydration in starch. In addition,

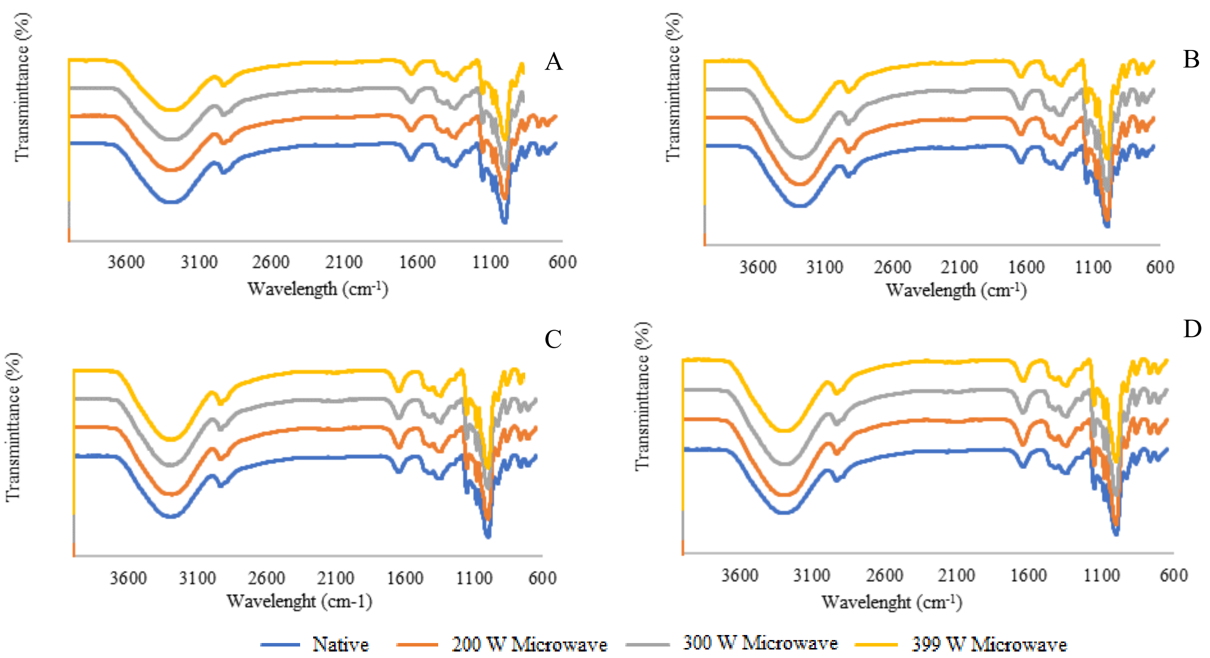

Figure 2. FTIR spectra of microwave-modified sugar palm starch at moisture content of 13% (A), 18% (B), 23% (C), and 28% (D).

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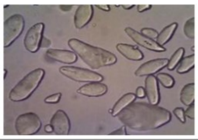
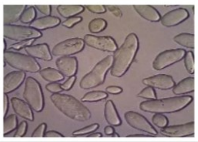
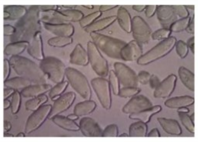
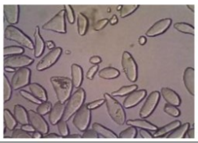
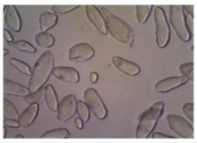
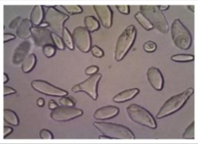
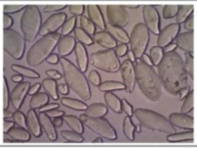
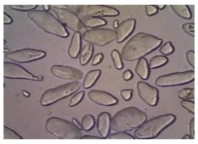
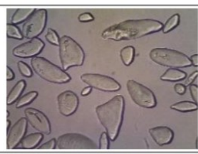
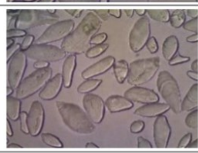
Table 3. Morphology of modified starch granules.

Treatment (Moisture Content, Microwave Power)	Granular Size (µm)	Granular Shape	Microscopic figures
Native	47.20±6.22	Oval, long, and pointed	
13%, 200 W	42.88±3.22	Oval, long, and the tip of the granule is not too sharp	
13% 300 W	37.21±3.20	Tended to be rounded, some parts of the granules were broken	
13% 399 W	37.85±3.03	Tended to be rounded, some parts of the granules were broken	
18% 200 W	44.42±2.80	Oval, long, the tip of the granule is not too sharp, some parts of the granules were broken	
18% 300 W	45.11±6.65	Oval, long, the tip of the granule is not too sharp, some parts of the granules were broken	
18% 399 W	42.19±4.25	Oval, long, the tip of the granule is not too sharp, some parts of the granules were broken	
23% 200 W	45.09±2.34	Oval, long, the tip of the granule is not too sharp, some parts of the granules were broken	
23% 300 W	44.22±2.62	Irregular oval, some parts of the granules were broken	
23% 399 W	44.76±3.76	Irregular oval, some parts of the granules were broken	
28% 200 W	43.26±2.11	Irregular oval, some parts of the granules were broken	
28% 300 W	45.35±3.58	Irregular oval, some parts of the granules were broken	
28% 399 W	45.74±7.35	Irregular oval, some parts of the granules were broken	

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absorption at 1022-1048 cm^{-1} indicates the presence of amorphous and crystalline regions in starch. Meanwhile, peaks at 930-500 cm^{-1} are absorptions originating from 1,4-glycosidic bonds (Dankar *et al.*, 2018).

3.6 Morphology of starch granules

Native sugar palm starch consisted of elongated or oval granules with tapered granule ends, with an average granule size was approximately 47 µm (Table 3). Pontoh (2004), in the previous research, showed that sugar palm starch granules were relatively larger than other starch granules, except for potato starch granules, which were reported to be 12 to 70 µm in size with an average size of 50 µm. The granule size can influence starch physicochemical properties such as crystallinity, pasting, enzyme resistance, and solubility, which larger-sized granules were reported to have higher amylose content, leading to more defects of the crystalline area, thus resulting in lower relative crystallinity (Zhang *et al.*, 2016; Ma *et al.*, 2017). The smallest granule size was obtained in the sample with 13% MC at 300 W. Modification using microwaves also tended to make starch granule size shrink and break because of the effect of microwaves that cause changes in starch rheology (Syamsir *et al.*, 2012). This result was by Xie *et al.* (2013), which found that potato starch's morphology and crystalline structure were damaged by microwave treatment. The large starch granules and a high degree of amylose starch polymerization made the gel hard after gelatinization. Therefore, it is one of the most important ways that the microwave treatment was used to change the physicochemical properties, especially regarding the granule size and viscosity, to make it suitable for instant food preparation. Meanwhile, the variation of MC did not tend to affect the granule size.

3.7 Dual modification with microwave and acetylation

Since the microwave modification at 300 W for the starch with 13% MC produced the smallest size, this condition has opted for the subsequent dual modification that combined microwave and acetylation to improve the physicochemical characteristics of sugar palm starch.

3.7.1 Starch

Modification by acetylation gives changes to the starch chain. Acid-modified starch chains break some of the glycosidic bonds in starch because the addition of acid will weaken the integration of the starch structure (Fitria *et al.*, 2018). In addition, microwave heating degraded the granules that initiate the starch coming out of the granules and dissolving into the wasted water during filtering. The combination of acetylation and microwave showed significantly different starch content from the native starch (Table 4). Dual modification yielded a higher starch content than single acetylation. However, both dual and single modifications decreased the starch content from the native starch.

3.7.2 Amylose

Dual modification showed significantly lower amylose than native and acetylated starch ($p<0.05$). This result followed Wani *et al.* (2015) that the amylose content of Indian black gram starch decreased after acetylation. It might be due to the introduction of acetyl groups in starch chains which impeded the formation of the helical structure of amylose in some areas by steric hindrance resulting in underestimation of amylose content (Gonzalez and Perez 2002).

3.7.3 Swelling power and solubility

The swelling power ability of dual-modified palm starch can be seen in Table 5. In general, both acetylated and dual-modified sugar palm starch had a lower welling power than the native starch. However, the swelling power of dual-modified starch was higher than acetylated starch. The decrease in swelling power was directly proportional to the decrease in amylopectin levels of dual-modified palm starch. The lower swelling power found in the modified starch occurred due to the disintegration of the structure due to the substitution of the hydroxyl group by the acetyl group, which causes the palm starch granules to be able to absorb water but

Table 4. Starch and amylose content of dual modified sugar palm starch.

Parameters	Treatment		
	Native	Acetylation	Acetylation and Microwave
Starch	102.12 ± 0.00^A	80.46 ± 0.00^C	91.56 ± 0.36^B
Amylose	41.51 ± 0.01^A	36.22 ± 0.02^B	33.33 ± 1.24^B

Values are presented as mean±SD. Values with different superscripts within the same row are statistically significantly different.

Table 5. Swelling power and solubility of dual modified sugar palm starch.

Parameters	Treatment		
	Native	Acetylation	Acetylation and Microwave
Swelling Power	13.31 ± 0.93^A	10.83 ± 0.14^B	8.60 ± 0.33^C
Solubility	1.10 ± 0.11^B	2.19 ± 0.14^A	0.87 ± 0.09^C

Values are presented as mean±SD. Values with different superscripts within the same row are statistically significantly different.

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cannot retain water during the centrifugation process (Fonseca *et al.*, 2015).

Sugar palm starch with dual modification had a lower solubility than acetylated starch and native starch. The results were similar to those of Sodhi and Singh (2005) regarding the acetylation of cornflour and potato starch. The substitution of acetyl groups weakened the hydrogen bonds in starch molecules facilitated water to penetrate more readily into the starch granules and caused amylose to come out of the granules, yielding the improvement in acetylated starch solubility.

3.7.4 Pasting properties

The pasting properties of single and double-modified palm starch are presented in Figure 3. The peak viscosity of acetylated modified starch was lower than that of the native starch. This result was in agreement with previous research, in which corn and rice-acetate starch performed a lower gelatinization temperature and a higher peak viscosity than unmodified starch (Raina *et al.* 2006; Colussi *et al.* 2014). This decrease in viscosity was due to an acetate group that substituted the hydroxyl group, thereby restricting the formation of water-binding strength (Lawal, 2004). Meanwhile, palm starch with dual modification performed an increase in a peak viscosity of 8280 cP with a lower gelatinization temperature due to high water absorption caused by the binding of amylose to other starch molecules to form a double-helical structure through hydrogen bonds (Kusnandar, 2011).

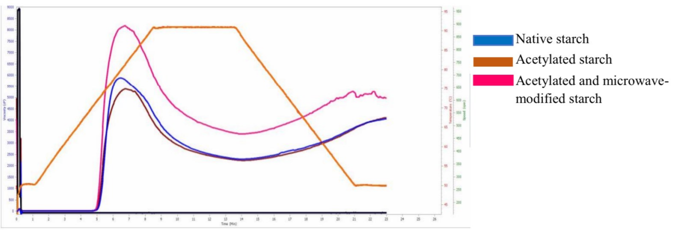


Figure 3. Pasting properties of dual modified sugar palm starch.

The breakdown value showed a decrease in acetylated sugar palm starch compared to the native starch. The results were similar to those reported by Colussi *et al.* (2017) in that the acetylation process reduced the breakdown of rice starch. The decrease in the breakdown value meant higher stability of the paste to heat. Acetylation treatment could increase the stability of sugar palm starch paste. Meanwhile, sugar palm starch with dual modification had a higher breakdown value than the native starch. At the breakdown, there were more swollen granules disrupting further and amylose molecules generally leached into the solution (Zaidul *et al.*, 2007). However, the starch with dual modification performed the lowest setback viscosity, which indicated that the starch was stable against retrogradation due to the leaching of amylose. When the amylose content was decreased, the setback viscosity of starch would diminish (Imam *et al.*, 2014).

3.7.5 Functional group changes

The acetylation and its combination with the microwave did not change the functional groups of the starch because there was no change in the peak and pattern of the FTIR spectra (Figure 4). Both native and modified starch exhibited a peak at a wavelength of 3332,391 cm^{-1}, which confirmed the presence of OH groups from starch molecules (An *et al.*, 2011; Xing *et al.*, 2014; Hamid *et al.*, 2015; Wang *et al.*, 2015).

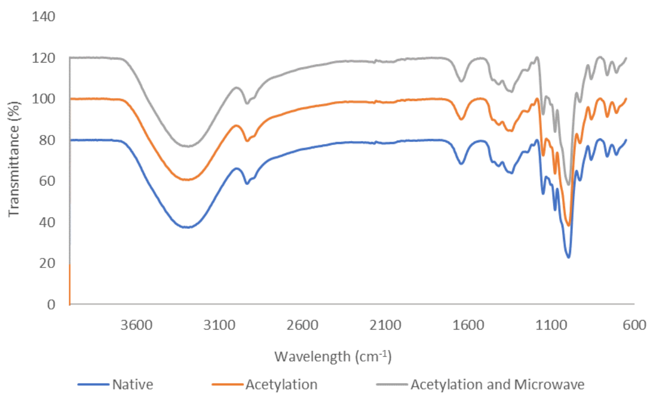
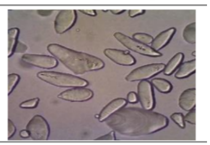
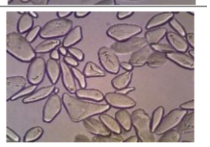


Figure 4. FTIR spectrum of dual modified sugar palm starch.

Table 6. Morphology of dual modified starch's granules.

Treatment	Granular Size (µm)	Granular Shape	Microscopic Figures
Native	47.20±4.11	Oval, long, and pointed	
Acetylation	45.75±2.61	Oval, long, the tip of the granule is not too sharp, some parts of the granules were broken	
Acetylated and Microwave	41.81±2.52	Oval, long, the tip of the granule is not too sharp, some parts of the granules were broken	

https://doi.org/10.26656/fr.2017.7(5).991

3.7.6 Morphology of starch granules

The shape and size of sugar palm starch granules modified by acetylation and a combination of acetylation and microwave are presented in Table 6. Acetylated sugar palm starch had a more uniform and smaller granule size than the native and microwave-modified palm starch. This finding was similar to that expressed by Sodhi and Singh (2005), in which the addition of acetate to acetylated palm starch causes the presence of acetyl groups in palm starch which causes the starch granule structure to be more robust when compared to the native starch.

4. Conclusion

To summarize, in general, increasing moisture content and microwave power could decrease starch, amylose content, and swelling power while solubility increases. The higher power applied reduced the starch granule size and changed the pasting properties. The results showed that the starch's moisture content of 13% and a power of 300 W could most effectively reduce the granule size and the swelling power. Thus, this treatment became the chosen condition for the subsequent combination modification method with acetylation. The combination of acetylation and microwave modification on sugar palm starch significantly decreased the starch and amylose content, swelling power, solubility, and granule size and changed the pasting properties of the starch. However, the combination of acetylation and microwave treatment particularly had different effects on starch content and solubility compared to the single acetylation modification. Overall, dual modification of sugar palm starch could improve the limitation of its native characteristics in terms of granule size, swelling ability, gelatinization temperature, and retrogradation stability, which might be advantageous for specific purposes of food processing.

Conflict of interest

The authors declare no conflict of interest.

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