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FULL PAPER

The effect of dual modification with annealing and Heat Moisture Treatment (HMT) on physicochemical properties of jack bean starch *(Canavalia ensiformis)*

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Abstract

In this study, the effect of the dual modification with annealing and Heat Moisture Treatment (HMT) on the physicochemical properties of jack bean starch was investigated. Native jack bean starch was modified by the annealing method with a moisture ratio of 1:2 and 1:3 at 50°C, 55°C, and 60°C for 24 hrs. Furthermore, the annealing method was combined with HMT at 30% moisture at 110°C for 16 hrs. The results showed that the dual modification process decreased the whiteness, amylose content, swelling power, solubility, setback viscosity, and breakdown viscosity of the jack bean starch. On the contrary, it led to an increase in the water adsorption, paste clarity, pasting temperature and stability ratio of the starch. The stability ratio of native jack bean starch, the sample treated by the single annealing, and the dual modification were 0.56, 0.62, and 0.86, respectively, indicating that the sample treated with dual modification was more stable at high temperature and shear stress. The dual modification did not affect the crystalline x-ray diffraction patterns. The findings emphasized the potential of using a dual modification to alternate the characteristic of jack bean starch.

1. Introduction

Starch, a polysaccharide that consists mainly of amylose and amylopectin stored in the form of granules, is widely used in the food industry (Cabrera-Canales *et al.,* 2020). It was reported that in 2018 the income from the starch industry was approximately 7.7 billion (Yao *et al.,* 2019). Thus, the exploration of the novel potential source of native starch is still being carried out by scientists (Sudheesh *et al.*, 2020). Jack bean *(Canavalia ensiformis)* is a potential source of starch and worth investigating due to its abundance and availability, particularly in Africa, Asia, the West Indies, Latin America, and India (Akande, 2016). Jack bean contains high carbohydrates (about 60%), making it a valuable source of starch for the industry. However, native starch is mostly unstable at high temperature or shear force, and also relatively easy to gelatinize and form a gel. These characteristics do not meet industrial needs (Yao *et al.*, 2019). Hence, modification of starch is required mainly to fine-tune its characteristic in order to use it for a specific purpose in the food industry, including as a thickener, gelling agent, binder, stabilizer, emulsifier, or encapsulation material (Cabrera-Canales *et al.*, 2020).

Hydrothermal modification using annealing and Heat Moisture Treatment (HMT) has been widely used to modify starch since these methods do not destroy the starch granule. Annealing is a physical modification in the presence of excess water at a temperature above the glass transition but below the gelatinization temperature, while HMT is a physical modification of the starch with a moisture content of 10-30% at a temperature above the gelatinization temperature (da Rosa Zavareze and Dias, 2011). According to Kittipongpatana and Kittipongpatana (2011), annealing can reduce the swelling power and solubility of the starch and improved starch stability at high temperatures and shear force. In the other study by Chung *et al.,* (2009), HMT improved paste properties of the starch, starch molecular interaction, and crystallinity of the starch.

Although many studies investigated the effect of annealing and HMT individually, there is still a lack of information about the effect of both combinations of annealing and HMT, particularly on jack bean starch. Thus, the objective of this study was to investigate the effect of the dual modification on the physicochemical

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properties of jack bean starch.

2. Materials and methods

2.1 Starch extraction

Jack beans were obtained from the local market in Surakarta (Central Java, Indonesia). The extraction of jack bean starch in this study followed the method of Ríos-Ríos *et al.* (2016) with minor modifications. Briefly, 500 g of jack beans were soaked in sodium metabisulfite at a concentration of 0.45% for 24 hrs at a ratio of 1 : 3 (w/v). Afterwards, it was peeled and milled to reduce particle size and form jack bean paste. The jack bean paste was then squeezed and precipitated for 24 hrs to obtain wet starch. The wet starch was washed three times with distilled water and then dried in a cabinet drier at 40°C for 24 hrs. The dried starch was crushed and sieved to 100 mesh size.

2.2 Hydrothermal modification

Starches were subjected to one-step annealing with the method of Ríos-Ríos *et al.* (2016) with slight modification. Native jack bean starch (60 g) was mixed with distilled water 120 mL (ratio 1:2), and 180 mL (ratio 1:3) in a sealed glass container. The samples were then incubated at 50°C, 55°C, and 60°C for 24 hrs in a water bath. After the incubation, the samples were decanted and air-dried at 40°C for 24 hrs. After that, the starches were crushed and sieved to 100 mesh size. The jack bean starch was obtained by only the annealing method and is considered single-annealed jack bean starch.

The modification process was then continued by the HMT method. HMT was performed based on the method of Chatpapamon *et al.* (2019). Accurately-weighed of annealed jack bean starch (40 g) were put into a petri dish. The moisture content of the starch was increased to 30% by adding the appropriate amount of distilled water. The petri dish was then sealed and incubated at 4°C for 24 hrs. Afterwards, it was placed in the oven at 110°C for 16 hrs. Finally, the samples were air-dried at 40°C for 24 hrs, milled and sieved to get 100 mesh size dual-modified jack bean starch.

2.3 Chemical analysis

The Standard Association of Official Analytical Chemistry method, AOAC (2012), was adopted for determining moisture, amylose, and amylopectin contents of native, single-annealed and dual-modified jack bean starch.

2.4 Colour analysis

The colour analysis method was carried out using a colour reader (CR-300, Kinoca Minolta, Japan). Based on the obtained L*, a*, and b* values, the whiteness index (WI) was calculated using Equation 1.

$$\mathrm{WI} = 100 - \sqrt{(100 - \mathrm{L}^*)^2 + \mathrm{a}^{*2} + \mathrm{b}^{*2}} \quad (1)$$

2.5 Swelling power and solubility

Swelling power and solubility analysis was conducted according to the protocol of Kittipongpatana and Kittipongpatana (2011). Briefly, 0.1 g of starches were placed on a test tube and then mixed with 10 mL of distilled water using a vortex for 1 min. The samples were then heated at 95°C for 10 mins in a water bath and then followed by air-cooling to reach room temperature. Afterwards, centrifugation at 3000 rpm was performed for 15 mins. Aliquots (5 mL) of the supernatant obtained from centrifugation were dried to a constant weight at 120°C. The swelling power of the samples was calculated using Equation 2 while the solubility was calculated using Equation 3.

$$\text{Swelling power} = \frac{(\text{Weight after centrifugation} - \text{weight of tube})}{\text{Weight of starch}} \quad (2)$$

$$\%\ \text{Solubility} = \frac{\text{Weight of dried sample}}{\text{Weight of sample}} \times 100 \quad (3)$$

2.6 Water adsorption

Water adsorption analysis was carried out following the method of Ríos-Ríos *et al.* (2016). Shortly, 0.1 g of starch was diluted with 10 mL distilled water and then incubated at room temperature for 30 mins. After that, the suspension was centrifuged at 2120 rpm for 15 mins and then weighed. The amount of water that was absorbed by starch is described as water adsorption.

2.7 Paste clarity

Paste clarity analysis was done referring to the method of Reddy and Seib (1999). Jack bean starches (0.5 g) were with 5 mL of distilled water in a test tube and followed by shaking at 1500 rpm for 30 secs using a vortex. The samples were placed in a water bath at 95°C for 30 mins. After cooling to an ambient temperature, the absorbance was measured at the wavelength of 650 nm using a spectrophotometer (Shimadzu model UV-3600, Shidmazu Corp, Kyoto, Japan).

2.8 X-ray diffraction

X-ray diffractogram of the native and modified starch was obtained from X-ray diffractometer D8 Advance, Bruker AXS, Billerica, MA, the USA at 40 kV at the scanning rate of 1°/min, at the diffraction of 2Θ = 10°- 30° (Wang *et al.*, 2014).

2.9 Pasting properties

Pasting properties were determined using a rapid visco-analyzer (RVA) Super 3 (Newport Scientific, Warriewood, Australia) following the protocol of Wang *et al.* (2014). Jack bean starch (3 g) was added into RVA canisters and then added with 25 mL of distilled water. Peak Viscosity (PV), Breakdown Viscosity (BD), Trough Viscosity (TV), Pasting temperature, Final Viscosity (FV), and Setback Viscosity (SB) were obtained from the RVA data.

2.10 Statistical analysis

Data were analysed statistically using analysis of variance (ANOVA) using SPSS V.20 (IBM, USA). The DMRT test, with a significance threshold of $\rho < 0.05$, was used to compare the difference among mean values.

3. Results and discussion

3.1 Colour properties

Table 1 and Figure 1 show the colour properties of the native and modified starch. Native starch exhibited L*, a*, b*, and whiteness values of 90.48, 0.53, 17.17, and 80.36, respectively. After single annealing and dual modification were performed, the whiteness and lightness substantially decreased. As shown in Table 1, this phenomenon is because the values of a* and b* substantially increased, and therefore significantly higher ($p < 0.05$) than native starch. Modification using the single annealing and the dual modification decreased the whiteness of jack bean starch to a range of 66.8 and 71.7. These results are consistent with the results reported by Suriya *et al.* (2019) who work with elephant foot yam starch. It was reported that the dual modification of jack bean starch resulted in significantly lower whiteness values than single annealing. A similar phenomenon has also been reported for sago and potato starch (Hrynets *et al.,* 2017).

According to Suriya *et al.* (2019), the decrease in the whiteness of modified starch may be due to the Maillard reaction during hydrothermal treatment. As jack bean starch contained amino acid, sugar reduction, and protein, the Maillard reaction was indeed possible (Kittipongpatana and Kittipongpatana, 2011). Furthermore, in the dual modification, Heat Moisture Treatment was also involved causing a nonenzymatic reaction between hydroxyl groups and amino acid, therefore resulting in the browning of the polymer. The heating process also induced a Maillard reaction, and thus an increase in heating temperature resulted in a decrease in the whiteness of the starch (Hrynets *et al.*, 2017). As colour is generally an important attribute in food (Muhammad *et al.,* 2020), the change of the colour of the jack bean starch during the modification process should be taken into account by the food industries.

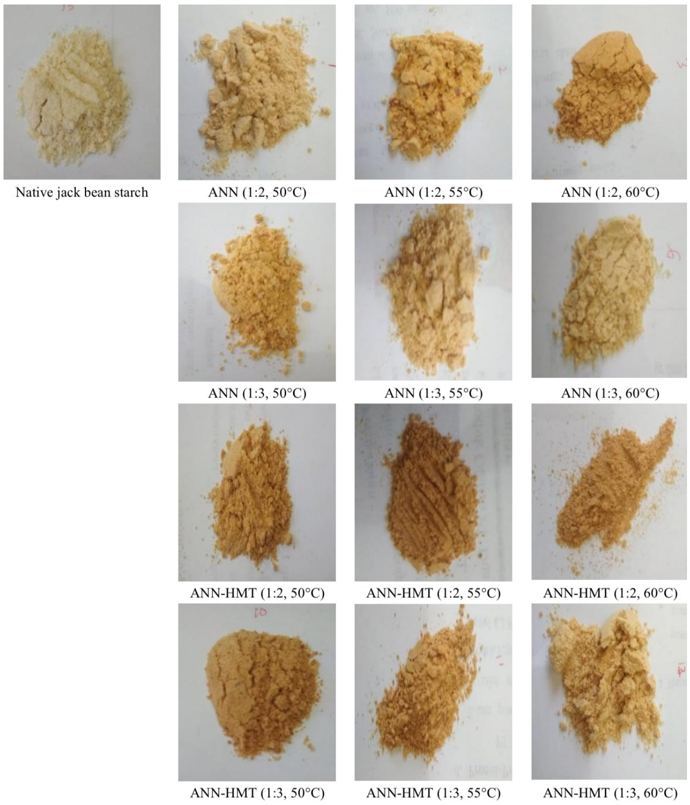

Figure 1. Native and modified jack bean starch is treated by single and dual modification methods with different ratios of jack bean starch and water at a temperature of 50°C, 55°C, and 60°C.

3.2 Chemical properties

As presented in Table 1, the moisture content of the native jack bean starch in this study was 10.56%. The result was lower than the moisture content of the native jack bean starch in the study of Lawal and Adebowale (2005), which was about 12.56%. The different moisture content of the starch might be affected by different geographical and starch sources and also the starch production method. Modification could reduce the moisture content of the jack bean starch. The application of dual modification resulted in significantly lower moisture content than a single annealing method. The dual modification resulted in moisture content in the range of 3.48-3.86%, while the single modification resulted in moisture content in the range of 9.57-9.83%. The high temperature during the modification process could have a significant impact on the reduction of moisture content during modification (Obi *et al.,* 2016).

In this study, the single and dual modification had just a limited effect on the amylose content and thus the amylopectin content of jack bean starch, which remained at around 25%. Notwithstanding the report of Chung *et al.* (2009), the modification could reduce the amylose content of corn starch by about 0.2-0.9% depending on the modification method. A decrease in the helical complex may cause a decrease in amylose content as a result of limited amylose that can form long helical from

Table 1. Colour and chemical properties of native and modified jack bean starch.

Sample	The ratio of native jack bean and water	Temperature (°C)	Colour properties				Chemical properties		
			*L**	a*	b*	Whiteness index	Moisture content	Amylose content (% db)	Amylopectin content (% db)
Native	-	-	90.5 ± 0.29^{l}	0.5 ± 0.05^{a}	17.2 ± 0.08^{a}	80.4 ± 0.13^{k}	10.6 ± 0.3^{c}	25.19 ± 0.0002^{g}	74.80 ± 0.0002^{a}
Single-modified jack bean starch (ANN)	1:02	50	81.4 ± 0.07^{i}	4.7 ± 0.08^{e}	22.7 ± 0.12^{c}	70.3 ± 0.11^{i}	9.7 ± 0.1^{b}	25.14 ± 0.0072^{d}	74.85 ± 0.0073^{d}
		55	79.5 ± 0.17^{h}	5.8 ± 0.05^{g}	25.4 ± 0.19^{f}	66.9 ± 0.08^{f}	9.6 ± 0.3^{b}	25.16 ± 0.0003^{ef}	74.83 ± 0.0003^{bc}
		60	79.2 ± 0.12^{g}	5.5 ± 0.05^{f}	24.4 ± 0.19^{e}	67.5 ± 0.12^{g}	9.6 ± 0.3^{b}	25.10 ± 0.0010^{a}	74.89 ± 0.0017^{g}
	1:03	50	83.1 ± 0.12^{k}	3.8 ± 0.08^{c}	22.3 ± 0.16^{b}	71.8 ± 0.16^{j}	9.8 ± 0.1^{b}	25.15 ± 0.0376^{de}	74.84 ± 0.0375^{cd}
		55	82.4 ± 0.05^{j}	4.1 ± 0.04^{d}	24.2 ± 0.16^{d}	69.8 ± 0.11^{h}	9.6 ± 0.2^{b}	25.11 ± 0.0020^{a}	74.88 ± 0.0020^{g}
		60	83.2 ± 0.10^{k}	3.6 ± 0.07^{b}	24.3 ± 0.10^{de}	70.3 ± 0.14^{i}	9.7 ± 0.4^{b}	25.11 ± 0.0026^{a}	74.88 ± 0.0025^{g}
Dual-modified jack bean starch (ANN-HMT)	1:02	50	64.3 ± 0.27^{b}	10.4 ± 0.23^{h}	30.6 ± 0.05^{g}	51.9 ± 0.26^{d}	3.5 ± 0.2^{a}	25.13 ± 0.0014^{c}	74.86 ± 0.0013^{e}
		55	63.6 ± 0.10^{a}	11.4 ± 0.05^{i}	30.6 ± 0.05^{g}	51.2 ± 0.08^{c}	3.9 ± 0.1^{a}	25.11 ± 0.0024^{ab}	74.88 ± 0.0024^{g}
		60	64.8 ± 0.07^{c}	13.4 ± 0.10^{j}	31.6 ± 0.05^{j}	48.3 ± 0.14^{a}	3.8 ± 0.2^{a}	25.16 ± 0.0015^{e}	74.83 ± 0.0015^{c}
	1:03	50	65.6 ± 0.16^{d}	10.3 ± 0.05^{h}	34.2 ± 0.08^{h}	52.2 ± 0.10^{e}	3.8 ± 0.1^{a}	25.13 ± 0.0039^{bc}	74.86 ± 0.0039^{ef}
		55	65.9 ± 0.04^{e}	12.9 ± 0.05^{j}	36.4 ± 0.05^{i}	50.0 ± 0.07^{b}	3.7 ± 0.1^{a}	25.18 ± 00003^{f}	74.81 ± 0.0003^{g}
		60	68.1 ± 0.05^{f}	12.9 ± 0.08^{k}	36.4 ± 0.05^{k}	50.0 ± 0.06^{b}	3.8 ± 0.3^{a}	25.12 ± 0.0003^{ab}	74.87 ± 0.0003^{fg}

Values are presented as mean±SD of triplicate measurement. Values with different superscripts within the same column are not significantly different (P>0.05). ANN: Annealing, ANN-HMT: Annealing-Heat Moisture Treatment, db: dry basis.

amylose-amylose or amylose-amylopectin.

3.3 Swelling power and solubility

Table 2 presents the swelling and solubility values of the native and modified jack bean starches. The result showed that the native starch had a swelling power value of 8.57 g/g. The single annealing and the dual modification caused a decrease in swelling power values. The dual modification resulted in a more pronounced swelling power reduction to around 3.67-4.33 g/g compared to the single modification (5.68-6.34 g/g). The modification is known to lower the swelling power of starch due to the interaction of amylose-amylose and amylose-amylopectin as well as crystalline perfection, which might decrease the swelling ability (da Rosa Zavareze and Dias, 2011). This result is in accordance with a study by Chung *et al.* (2009) reporting the reduction of swelling power of corn starch after modification using the combination of annealing and HMT.

Besides the swelling power, the modification resulted in a lower solubility. The solubility of native starch was recorded at 7.27%, while the single annealed and the dual modified starch had a solubility of about 5.1 -5.7% and 4-4.3%, respectively. This finding is in agreement with the previous reports on annealed corn starch, annealed rice starch, and the dual-modified corn starch (Chung *et al.,* 2009; Dias *et al.,* 2010; Ariyantoro *et al.,* 2018). Annealing caused a reorientation of the starch granules, and an increase in the interaction of amylose and amylopectin made starch granules more rigid, and thus decreased the solubility of the jack bean starch. The solubility of the starch is influenced by amylose content, amylose-lipid complex, amylose-amylose interaction, and amylose-amylopectin interaction. In the dual modification, HMT additionally led to a reinforcement interaction between amylose and the crystalline area, increasing the crystalline complex. HMT also caused an expansion of the amorphous region. The amorphous region caused by starch remains undissolved, and thus this situation can decrease the solubility of the starch (Lawal and Adebowale, 2005; Rafiq *et al.*, 2016).

3.4 Paste clarity

The clarity of the jack bean starch paste increased after the single annealing, and the dual modification treatment from 62.9% to around 74-77% (Table 2). This finding is in agreement with the previous studies focusing on the modified corn starch and the modified barley starch (Lawal and Adebowale, 2005; Ariyantoro *et al.*, 2018). Paste clarity of the starch is influenced by the water absorption capability (WAC). A high WAC value resulted in a high transmittance of the starch (Gani *et al.*, 2010). As also shown in this study, an increase in WAC was also directly proportional to an increase the paste clarity. The hydrothermal modification increased the paste clarity, which is strongly correlated with the solubility of the starch. The decrease in solubility caused an increase in paste clarity because of the limited granules leached out and also due to the interaction between amylose-amylose and amylose-amylopectin (Gani *et al.,* 2010). Swelling power also influenced the clarity of the jack bean paste. A decrease in swelling power led to a lower retrogradation, and subsequently, a higher transmittance of the starches (Mendes *et al.,* 2018).

Table 2. Physicochemical properties of native and modified jack bean starch.

Sample	The ratio of native jack bean and water	Temperature (°C)	Solubility (%)	Swelling Power (g/g)	Paste clarity (%)	Water adsorption (%)
Native	-	-	7.27±0.22^{f}	8.58±0.06^{g}	62.68±0.02^{a}	112.19±0.19^{a}
Single-modified jack bean starch (ANN)	1:02	50	5.16±0.36^{c}	6.26±0.03^{de}	74.31±0.05^{bd}	124.60±0.10^{b}
		55	5.24±0.04^{c}	6.34±0.02^{ef}	74.53±0.13^{c}	120.41±0.27^{c}
		60	5.63±0.06^{de}	5.60±0.08^{c}	75.78±0.21^{f}	148.56±0.20^{d}
	1:03	50	5.24±0.19^{c}	6.50±0.19^{f}	75.88±0.07^{f}	148.56±0.25^{d}
		55	5.78±0.04^{e}	6.09±0.30^{d}	74.44±0.30^{bc}	154.51±0.32^{e}
		60	5.15±0.18^{c}	5.68±0.12^{c}	75.25±0.35^{e}	155.38±0.21^{f}
Dual-modified jack bean starch (ANN-HMT)	1:02	50	5.57±0.05^{d}	3.67± 0.06^{a}	75.26±0.10^{e}	171.40±0.19^{g}
		55	4.24±0.03^{ab}	3.72±0.15^{a}	75.89±0.13^{f}	187.56±0.23^{j}
		60	4.25±0.08^{ab}	3.70±0.20^{a}	74.66±0.15^{d}	181.45±0.21^{i}
	1:03	50	4.39±0.08^{b}	3.87±0.11^{a}	75.18±0.04^{e}	171.62±0.21^{g}
		55	4.18±0.09^{a}	3.70±0.27^{a}	75.30±0.12^{e}	171.45±0.26^{g}
		60	4.08±0.09^{a}	4.33±0.19^{b}	77.16±0.03^{g}	173.66±0.19^{h}

Values are presented as mean±SD of triplicate measurement. Values with different superscripts within the same column are not significantly different (P>0.05).

3.5 Water absorption

Water absorption is defined to be the amount of water needed for starch to swell. It can also be defined as the percentage of water that could be absorbed by the starch (Takagi *et al.,* 2017). Modification with single annealing and combined annealing-HMT caused an increase in water absorption (Table 2). The water absorption of the starch obtained by the dual modification (171.40 - 187.56%) was higher than that of single annealing (120.41 - 155.38%) and native starch (112.19%). As afore-mentioned, annealing increased the crystalline complex on starch granules.

Interestingly, the increase in water ratio and temperature of the annealing process linearly increased the water absorption. This phenomenon occurred in both modified starch prepared by single annealing and dual modification. According to Adebowale *et al.* (2005), the increase in water absorption is correlated with the increase of binding sites and interaction between the amorphous region and the crystalline region Furthermore, in the dual modification, HMT caused an expansion of the amorphous region, broke the hydrogen bonds making the water easily penetrate, and thus increased the water absorption of the starch granules (Rafiq *et al.*, 2016). It has indicated that the hydrophilic tendency increased with hydrothermal modification annealing and HMT (Adebowale *et al.,* 2005).

3.6 X-ray diffraction pattern

Figure 2 illustrates the XRD patterns of the native and modified jack bean starches. The native and modified starches showed a characteristic C-type diffraction pattern, with a rate peak 2θ at 15.39° and 23.29° and a double peak at 2θ = 17.42° dan 18.23°. In general, the crystallinity of starch contained 10-20 glucose. The XRD pattern shows a double helix on crystalline polymorphs as A-type and B-type. The C-type starch is a combination of A-type and B-type. The crystallinity of the starch is influenced by size granule, double helix orientation, and double helix interaction (Wang and Copeland, 2015). The result obtained in this study indicated that annealing and HMT did not alter the diffraction pattern of jack bean starch. The C-type XRD of jack bean has also been previously reported in other studies (Lawal and Adebowale, 2005). As the XRD pattern of native and jack bean starches remained unaffected after treatment, this result confirms the study of Suriya *et al.* (2019), stating that HMT did not change the crystalline structures of starch. A similar result was also found on the dual modified -HMT corn starch studied by Chung *et al.* (2009). According to Singh *et al.* (2009), the XRD pattern is influenced by amylose-amylopectin chains, lipid content, amylose-lipid complex, and size granules.

3.7 Pasting properties

Table 3 presents the pasting properties of the native and modified jack bean starches. The native jack bean starch had a pasting point at 82.45°C. The temperature was slightly increased to about 83-87°C after the single annealing and dual modification were applied. The dual modification resulted in a higher temperature point than the single annealing modification and native starch. The Breakdown Viscosity (BV) value of native starch was observed at 749 cP, while the BV values of the starch were modified with annealing at native starch and a water ratio of 1:3 combined with HMT treatment was at the lowest point at 490 cP. This point was obtained by the annealing temperature at a temperature of 50 and 55°C. This result indicated that starch was more stable at high temperatures and shear force. The comparable results were also obtained in modified cassava, and pinhao starch (Klein *et al.,* 2013). This phenomenon could be possible because the dual modification could strengthen the interaction between amylose and amylopectin. This is also strongly correlated with the

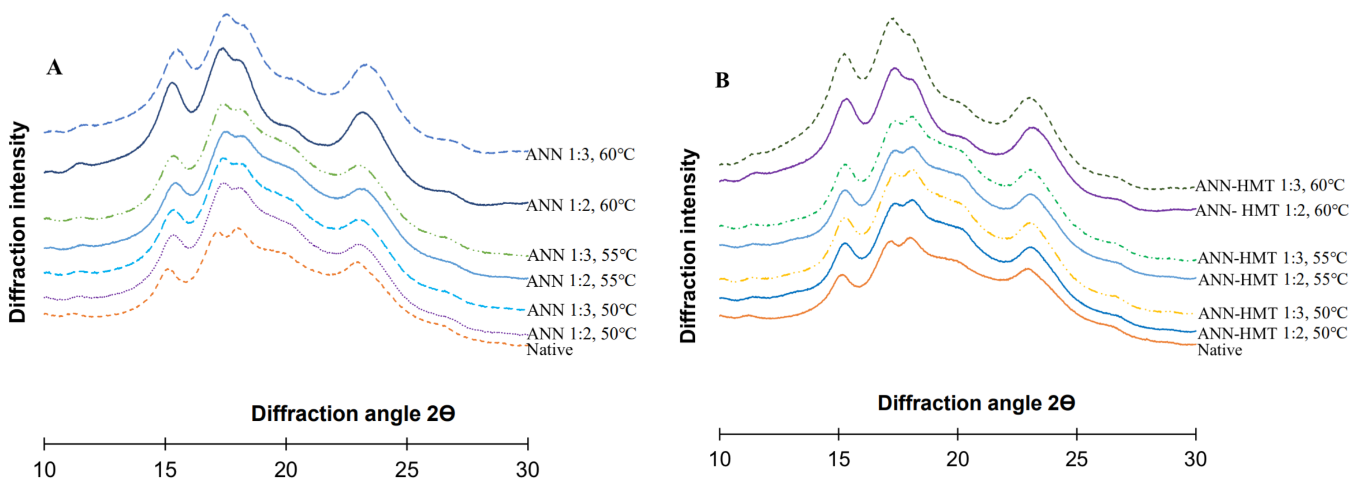

Figure 2. XRD Pattern of native and modified jack bean starch treated by a single (A) and dual (B) modification methods with different ratios of jack bean starch and water at a temperature of 50°C, 55°C, and 60°C.

Table 3. Pasting properties of native and modified jack bean starch

Sample	The ratio of native jack bean and water	Temperature (°C)	Peak Viscosity (cP)	Trough Viscosity (cP)	Breakdown Viscosity (cP)	Final Viscosity (cP)	Setback Viscosity (cP)	Time (minute)	Pasting Temperature (°C)	Stability Ratio
Native	-	-	1702	953	749	4360	2658	7.93	82.45	0.56
Single-modified jack bean starch (ANN)	1:02	50	3328	2112	1216	6117	2789	8.33	83.00	0.63
		55	1915	1164	751	3968	2053	8.19	84.00	0.61
		60	3059	1893	1166	7194	4135	8.00	83.60	0.62
	1:03	50	1777	1268	509	3931	2154	8.73	84.65	0.71
		55	3070	1014	2056	3310	240	8.53	86.80	0.33
		60	2446	1218	1228	2971	525	8.56	86.70	0.50
Dual-modified jack bean starch (ANN-HMT)	1:02	50	1899	1279	620	3990	2091	8.53	84.60	0.67
		55	2665	1105	1560	3304	639	8.53	86.20	0.41
		60	2371	1011	1360	3253	882	8.59	86.85	0.43
	1:03	50	1120	630	490	2467	1347	7.99	83.59	0.56
		55	3401	2910	490	1048	708	8.53	87.15	0.86
		60	3117	1271	1846	3537	420	8.59	87.25	0.41

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reduction of swelling power values as also shown in the study of Marta and Tensiska (2017).

Trough Viscosity (TV) and Final Viscosity (FV) parameters tended to increase after the starch modification. However, a decrease in the TV and FV value was still shown, particularly in the starch modified by dual technique with native starch and water ratio of 1:3 at 50°C. The TV value was recorded at 630 cP which was lower than the TV value of the native starch (749 cP). A previous study by Cahyana *et al.* (2019) also reposted a decrease in the TV value of modified banana flour. Lower in TV value indicated that the starch is more stable on shear force because it strengthens the interaction between amylose-amylopectin causing a decrease in swelling power value (Wang *et al.*, 2014; Wang *et al.*, 2015).

The stability ratio (SR) of native jack bean starch was 0.56. The highest SR value was 0.86, which was obtained by the annealing technique with native starch and water ratio of 1:3 at 50°C combined with HMT. The SR value, calculated by TV/PV, indicates the stability of starch to heat and shear stress. Starch with an SR value lower than 0.65 is unstable under high temperature and shear stress (Shafie *et al.,* 2016). Hence, the modified starch obtained in this study has high stability on high temperature and shear stress. The SR values were indeed affected by the TV and PV values of the starch. The modification decreased both the TV value from 1702 cP to 1120 cP and the PV value from 630 cP to 953 cP.

Furthermore, it was shown that single and dual modification also decreased the Final Viscosity (FV) and Setback Viscosity (SB) values of jack bean starch. For instance, the SB value of native jack bean starch was 2658 cP). The dual modification resulted in a more pronounced reduction of SB value than the single annealing modification, which was at the level of 420 cP -2091 cP and 525 cP-2789 cP, respectively. Similar results were also obtained on the modification of corn starch (Chung *et al.,* 2009). According to Wang *et al.* (2015), starch with lower SB values has a lower retrogradation ability. Also, a decrease in SB value indicated the existence of intact granules that is resistant to fragmentation, thus improving the stability of the granules (Chung *et al.*, 2009). The combination of annealing and HMT decreased the SB values more effectively than the single annealing modification. SB value is dependent on various factors like swelling power capability, size granules, and amylose content (Klein *et al.*, 2013).

4. Conclusion

In conclusion, the effect of dual modification of annealing and Heat Moisture Treatment was more pronounced than the single annealing method regardless of the ratio of native jack bean and water as well as the modification temperature. The dual modification can be employed to increase the gelatinization temperature, through Viscosity and peak viscosity of jack bean starch. The dual modification caused a decrease in Breakdown, Setback Viscosity, and Final Viscosity without changing its crystalline type pattern. The modified jack bean starch prepared by dual modification with starch and water ratio of 1:3 treated at 55°C had a better pasting property. The starch was identified to have high stability on high temperature and shear stress as indicated by SR values of 0.86. The dual modification can be considered an effective method to improve the stability of jack bean starch, and thus the modified starch can be potentially used in the food industry.

Conflict of interest

The authors declare no conflict of interest.

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References

Adebowale, K.O., Olu-Owolabi, B.I., Olayinka, O.O. and Lawal, O.S. (2005). Effect of heat moisture treatment and annealing on physicochemical properties of red sorghum starch. *African Journal of Biotechnology*, 4(9), 928-933. https://doi.org/10.5897/AJB2005.000-3197

Akande, K.E. (2016). Effects of anti-nutritive constituents of unprocessed jack bean (*Canavalia ensiformis*) (L)(DC) seed meal on poultry performance. *Journal of Experimental Agriculture International*, 10(6), 1-10. https://doi.org/10.9734/AJEA/2016/21980

AOAC International. (2012). Official Methods of Analysis of AOAC International. AOAC Official Method. 19th ed. Gaithersburg, USA: AOAC International.

Ariyantoro, A.R., Katsuno, N. and Nishizu, T. (2018). Effects of dual modification with succinylation and annealing on physicochemical, thermal and morphological properties of corn starch. *Foods*, 7(9), 133. https://doi.org/10.3390/foods7090133

Cabrera-Canales, Z.E., Velazquez, G., Rodríguez-Marín, M.L., Méndez-Montealvo, G., Hernández-Ávila, J., Morales-Sánchez, E. and Gómez-Aldapa, C.A.

(2020). Dual modification of achira (*Canna indica L*) starch and the effect on its physicochemical properties for possible food applications. *Journal of Food Science and Technology,* 58(3), 952-961. https://doi.org/10.1007/s13197-020-04609-w

Cahyana, Y., Wijaya, E., Halimah, T.S., Marta, H., Suryadi, E. and Kurniati, D. (2019). The effect of different thermal modifications on slowly digestible starch and physicochemical properties of green banana flour (*Musa acuminata colla*). *Food Chemistry*, 274, 274-280. https://doi.org/10.1016/j.foodchem.2018.09.004.

Chatpapamon, C., Wandee, Y., Uttapap, D., Puttanlek, C. and Rungsardthong, V. (2019). Pasting properties of cassava starch modified by heat-moisture treatment under acidic and alkaline pH environments. *Carbohydrate Polymers*, 215, 338-347. https://doi.org/10.1016/j.carbpol.2019.03.089

Chung, H.J., Hoover, R. and Liu, Q. (2009). The impact of single and dual hydrothermal modifications on the molecular structure and physicochemical properties of normal corn starch. *International Journal of Biological Macromolecules*, 44(2), 203-210. https://doi.org/10.1016/j.ijbiomac.2008.12.007

Da Rosa Zavareze, E. and Dias, A.R.G. (2011). Impact of heat-moisture treatment and annealing in starches: A review. *Carbohydrate Polymers*, 83(2), 317-328. https://doi.org/10.1016/j.carbpol.2010.08.064

Gani, A., Haq, S.S., Masoodi, F.A., Broadway, A.A. and Gani, A. (2010). Physico-chemical, morphological, and pasting properties of starches extracted from water chestnuts (*Trapa natans*) from three lakes of Kashmir, India. *Brazilian Archives of Biology and Technology*, 53(3), 731-740. https://doi.org/10.1590/S1516-89132010000300030

Hrynets, Y., Bhattacherjee, A. and Betti, M. (2018). Nonenzymatic Browning Reactions: Overview, p. 233–244. Encyclopedia of Food Chemistry. E-Book. https://doi.org/10.1016/B978-0-08-100596-5.21629-6.

Kittipongpatana, O.S. and Kittipongpatana, N. (2011). Preparation and physicochemical properties of modified jackfruit starches. *LWT-Food Science and Technology*, 44(8), 1766-1773. https://doi.org/10.1016/j.lwt.2011.03.023

Klein, B., Pinto, V.Z., Vanier, N.L., da Rosa Zavareze, E., Colussi, R., do Evangelho, J.A. and Dias, A.R.G. (2013). Effect of single and dual heat–moisture treatments on properties of rice, cassava, and pinhao starches. *Carbohydrate polymers*, 98(2), 1578-1584. https://doi.org/10.1016/j.carbpol.2013.07.036

Lawal, O.S. and Adebowale, K.O. (2005). Physicochemical characteristics and thermal properties of chemically modified jack bean (*Canavalia ensiformis*) starch. *Carbohydrate Polymers*, 60(3), 331-341. https://doi.org/10.1016/j.carbpol.2005.01.011

Marta, H. and Tensiska, T. (2017). Functional and amylographic properties of physically-modified sweet potato starch. *KnE Life Sciences*, 2(6), 689-700. https://doi.org/10.18502/kls.v2i6.1091

Mendes, M.P., Demiate, I.M. and Monteiro, A.R.G. (2018). Effect of individual and combined physical treatments on the properties of corn starch. *Acta Scientiarum. Technology*, 40(1), 35118. https://doi.org/10.4025/actascitechnol.v40i1.35118

Muhammad, D.R.A., Lemarcq, V., Alderweireldt, E., Vanoverberghe, P., Praseptiangga, D., Juvinal, J.G. and Dewettinck, K. (2019). Antioxidant activity and quality attributes of white chocolate incorporated with *Cinnamomum burmannii Blume* essential oil. *Journal of Food Science and Technology*, 57(5), 1731-1739. https://doi.org/10.1007/s13197-019-04206-6

Obi, O.F., Ezeoha, S.L. and Egwu, C.O. (2016). Evaluation of air oven moisture content determination procedures for pearl millet (*Pennisetum glaucum* L.). *International Journal of Food Properties*, 19(2), 454-466. https://doi.org/10.1080/10942912.2015.1038566

Rafiq, S.I., Singh, S. and Saxena, D.C. (2016). Effect of heat-moisture and acid treatment on physicochemical, pasting, thermal and morphological properties of Horse Chestnut (*Aesculus indica*) starch. *Journal Food Hydrocolloid*, 57, 103-113. https://doi.org/10.1016/j.foodhyd.2016.01.009

Reddy, I. and Seib, P.A. (1999). Paste properties of modified starches from partial waxy wheat. *Journal Cereal Chemistry*, 76(3), 341-349. https://doi.org/10.1094/CCHEM.1999.76.3.341

Ríos-Ríos, K., González-Mondragón, E., Segura-Campos, M., Ramírez-Jiménez, M., López-Luna, J., López-Martínez, I. and Betancur-Ancona, D. (2016). Physicochemical and Nutritional Characterization of Starch Isolated from *Colocasia antiquorum* Cultivated in Oaxaca, Mexico. *Journal of Chemistry*, 2016, 6721418. https://doi.org/10.1155/2016/6721418

Shafie, B., Cheng, S.C., Lee, H.H. and Yiu, P.H. (2016). Characterization and classification of whole-grain rice based on rapid visco analyzer (RVA) pasting profile. *International Food Research Journal*, 23(5), 2138-2143.

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Singh, G.D., Bawa, A.S., Riar, C.S. and Saxena, D.C. (2009). Influence of heat-moisture treatment and acid modifications on physicochemical, rheological, thermal, and morphological characteristics of Indian water chestnut (*Trapa natans*) starch and its application in biodegradable films. *Starch-Stärke*, 61 (9), 503-513. https://doi.org/10.1002/star.200900129

Sudheesh, C., Sunooj, K.V., Navaf, M., Bhasha, S.A., George, J., Mounir and S Sajeevkumar, V.A. (2020). Hydrothermal modifications of nonconventional kithul (*Caryota urens*) starch: physicochemical, rheological properties, and in vitro digestibility. *Journal of Food Science and Technology*, 57(8), 2916-2925. https://doi.org/10.1007/s13197-020-04323-7

Suriya, M., Reddy, C.K. and Haripriya, S. (2019). Functional and thermal behaviors of heat-moisture treated elephant foot yam starch. *Journal of Biological Macromolecules*, 137, 783-789. https://doi.org/10.1016/j.ijbiomac.2019.06.228

Takagi, H., Suzuki, S., Akdogan, G. and Kitamura, S. (2017). Surface structure and water adsorption behavior of waxy/amylose extender (wx/ae) double-mutant rice starch. *Starch-Stärke*, 69(11-12), 1600374. https://doi.org/10.1002/star.201600374

Wang, S. and Copeland, L. (2015). Effect of acid hydrolysis on starch structure and functionality: A review. *Critical Reviews in Food Science and Nutrition*, 55(8), 1081-1097. https://doi.org/10.1080/10408398.2012.684551

Wang, S., Wang, J., Yu, J. and Wang, S. (2014). A comparative study of annealing of waxy, normal, and high-amylose maize starches: The role of amylose molecules. *Journal of Food Chemistry*, 164, 332-338. https://doi.org/10.1016/j.foodchem.2014.05.055

Wang, S., Wang, J., Zhang, W., Li, C., Yu, J. and Wang, S. (2015). Molecular order and functional properties of starches from three waxy wheat varieties grown in China. *Journal of Food Chemistry*, 181, 43-50. https://doi.org/10.1016/j.foodchem.2015.02.065

Yao, M., Tian, Y., Yang, W., Huang, M., Zhou, S. and Liu, X. (2019). The multi-scale structure, thermal and digestion properties of mung bean starch. *Journal Biology Macromolecules*, 131, 871-878. https://doi.org/10.1016/j.ijbiomac.2019.03.102

