FOOD
RESEARCH

Effect of heat-moisture treatment on functional and pasting properties of potato (*Solanum tuberosum L.* var. Granola) starch

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Abstract

The objective of this research was to determine the effect of heat-moisture treatment (HMT) on functional and pasting properties of potato starch. Descriptive experimental methods that consist of 5 treatment conditions (80, 90, 100, 110, and 120°C) were applied for HMT of potato starch (var. Granola). The result showed that the higher temperature of HMT decreased the whiteness degree, syneresis, swelling volume, water absorption capacity, peak viscosity, and hold viscosity, but increased pasting point and setback viscosity. HMT at 110°C resulted in a minimum point for swelling volume (6.47 mL/g), solubility (36.15%), water absorption capacity (1.14 g/g), peak viscosity (1113 cP), hold viscosity (1063 cP), breakdown viscosity (50 cP), final viscosity (1655 cP), setback viscosity (592 cP) and maximum point for gelatinization temperature (82.09°C). Based on pasting properties, HMT potato starch was resistant to heating and suitable to be applied to sterilization products.

1. Introduction

Potato of var. Granola is a large-diameter potato with tuber yield per hectare reaching about 28 tons/ha (Eaton *et al*., 2017), which dominates potato production in Indonesia reaches about 85% of the total planting area (Putter and Gunadi, 2014). Potatoes can be used directly or processed in the form of starch, but the utilization of starch is very diverse. Industries use potato starch for various food products such as bakery, baby foods, ice cream, sauce, and snacks (Yassaroh *et al*., 2019). However, the use of natural starch has several problems related to retrogradation, syneresis, and low stability of pH and temperature (Hoover, 2010; Cahyana *et al*., 2019).

Many studies were carried out to modify potato starch in an enzymatic, chemical, or physical modification. The physical modification has an advantage of does not produce hazardous waste and damage the structure of starch granules (Zavareze and Dias, 2011). The previous research about physical modifying potato starch includes multiple deep freezing and thawing (Szymońska and Wodnicka, 2005), annealing (Xu *et al.,* 2018), and superheated steam (Hu *et al*., 2018). Modification of starch using the Heat Moisture Treatment (HMT) method is a physical modification that can increase starch resistance to heat, mechanical treatment and acidic pH (Hoover, 2010).

HMT can change physicochemical properties of starch such as swelling power, viscosity, gelatinization, pasting time, and thermal stability (Zavareze and Dias, 2011; Yassaroh *et al*., 2019). HMT can also increase slowly digestible starch which is good for health (Chung *et al*., 2009; Abioye *et al*., 2018).

HMT can be affected by several factors including material moisture content and heating temperature. Temperature is a factor that greatly influences the characteristics of modified starch by HMT. The higher temperature of the HMT can reduce swelling power and peak viscosity (Yassaroh *et al*., 2019). Therefore, the objective of this research was to evaluate the effect of HMT on functional and pasting properties of potato starch. The evaluation was carried out on changes in the functional properties (swelling volume, water absorption capacity, whiteness degree, freeze-thaw stability) and pasting properties of modified potato starch by HMT.

2. Materials and methods

2.1 Materials

Potato (var. Granola) with a harvest age of 90-100 days obtained from Jawa Barat, Indonesia. All chemicals used in this work were analytical grade.

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2.2 Potato starch preparation

Potato starch was prepared according to the method of Lawal (2004). Potato tubers were washed to remove the contamination, then ground using Fomac miller machine FCT Z-300. The slurry was filtrated using filter cloth. Starch produced were washed in water with a ratio of water to starch was 2:1 (w/v) for two times to remove the contaminants. The starch sediment was then recovered and dried in a cabinet drier at $40^{o}C$ for 12 hrs to 9–10% moisture content.

2.3 Heat moisture treatment of potato starch

HMT was according to Collado *et al*. (2001) with some modification. Potato starch was adjusted to the water content by spraying aquadest while stirring until the moisture content was 27%. The starch was then incubated in the refrigerator at $10^{o}C$ for 12 hrs. The starch was then packed with tightly closed aluminum foil, then heating using an oven at $80^{o}C$, $90^{o}C$, $100^{o}C$, $110^{o}C$, and $120^{o}C$ for 16 hrs. The starch was then dried at a temperature of $50^{o}C$ to moisture content about 10-12%. The starch was then ground using a grinder and sifted using a Tyler 100 mesh sieve.

2.4 Functional properties

2.4.1 Determination of swelling volume and solubility

Swelling volume and solubility were determined according to Collado and Corke (1999) and Cahyana *et al*. (2019). A total of 0.35 g (db) starch was suspended in 12.5 mL of water, then mixed using vortex for 30 s. The samples were stored in a water bath at 80°C for 30 mins, then cooled in cold water, and centrifuged using "Beckman Model TJ-6 Centrifuge" at 3500 x g ($25^{o}C$, 30 mins). The volume of the supernatant was measured and then dried in an oven at $110^{o}C$ for 24 hrs to measure the solubility.

$$Swelling\ volume = \frac{total\ volume - supernatant\ volume}{weight\ sample\ (db)}$$

$$Solubility = \frac{weight\ dried\ supernatant}{weight\ sample\ (db)} x100\%$$

2.4.2 Determination of water absorption capacity (WAC)

WAC of starch was determined following to Beuchat (1977). One gram of starch was suspended in 10 mL of water and vortexed for 30 s. The sample was left at room temperature (26±2°C) for 30 mins, then centrifuged at 3500 x g for 30 mins. WAC was then calculated as mL of water absorbed per gram of starch.

2.4.3 Determination of freeze-thaw stability (FTS)

Freeze-thaw stability was determined following to Wattanachant *et al*. (2003) and (Cahyana *et al*., 2019). The starch suspension (5%) was heated to gelatinization temperature for 30 mins. The sample was then cooled in an ice water bath. The 20 g an aliquot paste was taken and transferred in a centrifuge tube and underwent a frozen thaw cycle carried out by storing the sample at 4°C for 24 hrs, then frozen at -15°C for 48 hrs, followed by melting at 25°C for 3 hrs. The sample was centrifuged at 3500 x g for 15 mins. Supernatant separated from the gel was then weighed and the syneresis level was then calculated.

2.4.4 Determination of whiteness

Whiteness degree was measured using Kett Photoelectric Tube Whiteness-meter for Powder Model-1 with the light source of LED, the measurement principle of reflectance, and the resolution of 0.1, by using $Ba(SO)_4$ which has a 100% whiteness degree as standard. About 50 g of starch was placed in the available sample container and then closed. The sample was then inserted into the Whiteness-meter and the value of whiteness degree can be read on the screen. The whiteness was then determined according to the equation:

$$Whiteness\ (\%) = \frac{Value\ of\ sample}{value\ of\ BaSO_4} \times 100$$

2.5 Pasting properties (RVA analysis)

Pasting properties of potato starch were determined according to Koksel *et al*. (2008) using Rapid Visco Analyzer (RVA-SM2, Warriewood Australia). 2.8 g of starch samples were added with 25 mL of aquadest in an RVA tube. RVA was set with a temperature profile, initially held at 50°C for 1 min, then heating from 50 to 95°C at 6°C/min, the temperature was held at 95°C for 5 mins, then cooling to 50°C at 6°C/min. The gel was then maintained at 50°C for 5 mins.

2.6 Statistical analysis

Data were analyzed using one way ANOVA, then followed by Duncan Test to detect differences. Significance was confirmed at P values <0.05.

3. Results and discussion

3.1 Swelling volume and solubility

The higher the temperature of HMT, the swelling volume decreased significantly until 110°C (Figure 1). The same results were obtained by Wulandari *et al*. (2018) that HMT on taro starch showed that HMT decreased the swelling volume. Marta and Tensiska

(2018) carried out HMT on sweet potato starch obtained that the swelling volume was lower than native starch. Decreasing the swelling volume of starch granules can be caused by molecular rearrangement of granules, the formation of amylose-lipid complex, degradation of amylopectin molecules, increased interaction between amylose chains, and changes in interactions between amorphous and crystalline matrix (Adebowale *et al*., 2005). The increased in swelling volume at a temperature of 120°C can be caused by the formation of A-type starch crystals and reduced B-type starch crystals. Swelling volume of HMT modified potato starch lower than native starch (11.41 mL/g). This was due to the higher temperature of HMT, the formation of hydrogen bonds between water molecules outside the granule with starch molecules (amylose and amylopectin) was more difficult, so the ability of the granules to swell was limited (Huang *et al*., 2016).
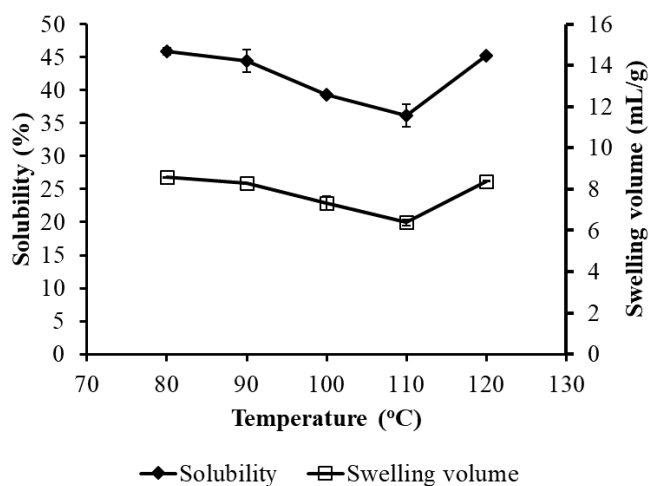

Figure 1. The effect of HMT on swelling volume and solubility of potato starch

Figure 1 also shows that the higher the temperature of HMT, the solubility decreased significantly until 110°C. The same results were obtained by Marta and Tensiska (2018) that HMT on sweet potato starch showed that HMT decreased the solubility. Decreasing solubility can be caused by a large amount of amylose that formed complexes with amylose, amylopectin, and fat during the HMT process. The formation of complex bonds caused the starch to had a more tight and compact bond, so the amount of amylose released during heating was lower. The increase in solubility at a temperature of 120°C was caused by changes in the structure of crystalline starch, B-type crystals change to A-type which had a higher amorphous region so that water more easily entered the granule and increased the solubility of starch (Chung *et al*., 2010).

HMT potato starch in all treatments had a higher solubility than natural potato starch (14.49%). This indicated that the HMT increased amylose release during

modification. The increase in solubility of HMT modified potato starch rather than native starch can be caused by the increasing amorphous portion of amylose and amylopectin molecules. This is consistent with the research Sankhon *et al*. (2014) and Li and Gao (2010) that HMT modified starch had a higher solubility compared to native starch.

3.2 Water absorption capacity (WAC)

The higher the temperature of HMT, the WAC decreased significantly until 110°C (Figure 2). Cahyana *et al*. (2019) also carried out HMT on banana flour obtained that the swelling volume was lower than native flour. The same results were obtained by Marta and Tensiska (2018) that HMT on sweet potato starch decreased the WAC. The decreased in WAC was due to an increase in the crystalline area during HMT treatment, where the part had a stronger and denser structure so that the starch was more difficult to absorb water (Hoover, 2010). The increase in WAC at a temperature of 120°C was thought to be part of the starch crystals turned into A-type so that the WAC value increased again. This showed the tendency of hydrophilic properties of starch to increased where the amorphous portion was wider and some hydrogen bonds between amorphous and crystalline parts were damaged (Adebowale *et al*., 2005).
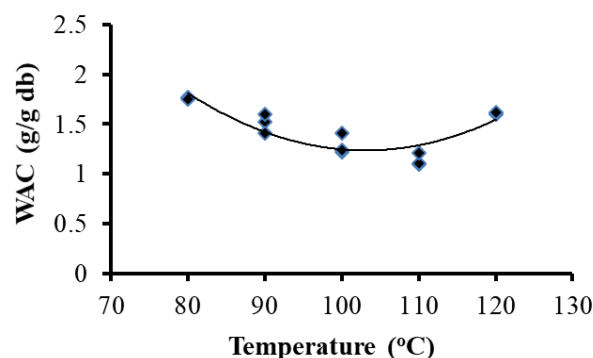

Figure 2. The effect of HMT on the water absorption capacity of potato starch

Native potato starch had a WAC of 2.15 g/g. The HMT treatment produced lower WAC compared to its native starch. Hydrothermal treatments such as HMT caused starch granules to be more resistant to deformation due to the strengthening of starch intra-granule bonding forces. Rearranging the double helix chain due to modification of HMT changed the crystallinity of the modified starch (Cahyana *et al*., 2019).

3.3 Freeze-thaw stability/syneresis

The higher the temperature of HMT decreased the syneresis significantly (Figure 3). Each temperature

increase of 10°C caused a decrease in the synthesis of HMT modified potato starch of 1.35%. Wulandari *et al.* (2018) carried out HMT on taro starch obtained that the syneresis was lower than native starch. HMT caused water molecules to be bound and trapped in the amylose-amylopectin crystalline structure so that water molecules trapped inside the starch gel matrix were difficult to get out.
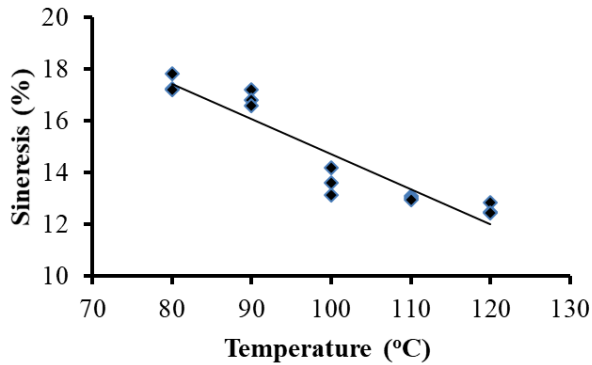

Figure 3. The effect of HMT on freeze-thaw stability of potato starch

Freeze-thaw stability of modified HMT potato starch was 12.59% to 17.43%, while the freeze-thaw stability of native starch was 25.18%. This shows that HMT reduced the value of freeze-thaw stability to be more resistant to frozen storage. HMT caused amylose released from the gelatinized granule to have a small amount and distance between the amylose molecules. This was due to the HMT decreased amylose release when the granules were gelatinized by increasing the bond between molecules in the amorphous region. Therefore, in HMT starch the amount of water that comes out when thawing was lower than its native starch (Hoover and Manuel, 1996).

3.4 Whiteness degree

The higher temperature of HMT resulted in a declining whiteness degree significantly (Figure 4). Each temperature increase of 10°C resulted in a decrease in the whiteness degree of HMT potato starch about 0.73%. The same results were obtained by Syafutri *et al.* (2017) that HMT on sago starch decreased the whiteness degree significantly. High temperatures generate browning reactions which were triggered by the presence of amino-carbonyl reaction or other non-carbohydrate components (Nakamura *et al.*, 2017). The whiteness degree of HMT potato starch was 54.4% to 57.31%, while native potato starch had a whiteness degree of 62.45%. HMT caused the starch to undergo browning reactions. Non-enzymatic browning reactions in starch, especially the Maillard reaction between hydroxyl groups in reducing sugars with amino groups of proteins or amino acids produced brown polymers (Hrynets *et al.*, 2017).
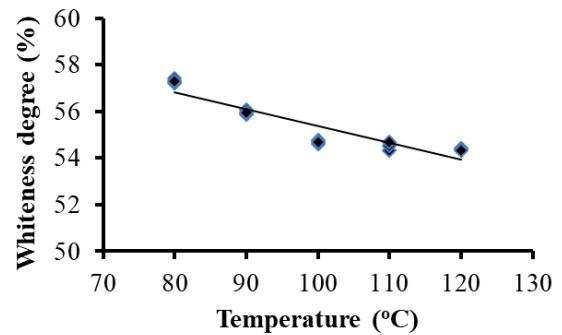

Figure 4. The effect of HMT on the whiteness degree of potato starch

3.5 Effect of HMT on pasting properties

Effect of HMT on pasting properties can be seen in Figure 5 and Table 1. Pasting properties can be used to identify amylograph response changes due to differences in material or process variables, estimation of starch properties during processing, and identification of initial data for the need to set up starch processing equipment. HMT caused changes in physicochemical characteristics of starch significantly. HMT changed the thermal characteristics of starch, increase gelatinization temperature, and change the gelatinization range temperature (Arns *et al.*, 2015).
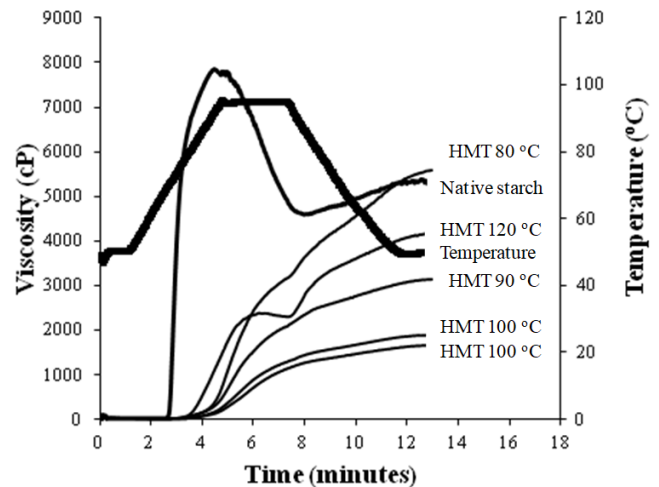

Figure 5. The RVA viscoamylograph of potato starch before and after HMT

3.5.1 Pasting point

The higher the temperature of HMT, the pasting point increased significantly until 110°C (Figure 5 and Table 1). Cahyana *et al.* (2019) also carried out HMT on banana flour obtained that the pasting point was higher than native flour. The same results were obtained by Marta and Tensiska (2018) that HMT on sweet potato starch increased the pasting point. The pasting point increased in HMT starch shows the increased interaction of amylose molecules in the amorphous region.

Table 1. Pasting properties of potato starch before and after HMT at various temperature

Properties	Treatments					
	Native starch	HMT 80°C	HMT 90°C	HMT 100°C	HMT 110°C	HMT 120°C
Pasting point (°C)	62.26 ± 0.64[a]	76.31 ± 0.05[c]	77.73 ± 1.49[c]	81.90 ± 0.43[d]	81.17 ± 0.55[d]	74.57 ± 1.44[b]
Peak viscosity (cP)	7841 ± 180.45[e]	3144 ± 87.58[d]	1871 ± 40.67[b]	1271 ± 173.50[a]	1113 ± 185.83[a]	2407 ± 117.30[c]
Hold viscosity (cP)	4580 ± 179.34[e]	3041 ± 107.09[d]	1810 ± 51.54[b]	1220 ± 174.23[a]	1063 ± 185.24[a]	2300 ± 142.68[c]
Final viscosity (cP)	5336 ± 185.87[d]	5592 ± 197.32[d]	2844 ± 155.00[b]	1885 ± 226.21[a]	1655 ± 217.03[a]	4160 ± 189.38[c]
Breakdown viscosity (cP)	3261 ± 146.41[d]	91 ± 11.36[c]	62 ± 12.42[b]	51 ± 1.00[a]	50 ± 1.00[a]	106 ± 32.25[c]
Setback viscosity (cP)	756 ± 59.50[b]	2539 ± 108.91[e]	1035 ± 103.55[c]	665 ± 58.39[ab]	592 ± 34.36[a]	1860 ± 159.45[d]

Each value is presented as mean ± standard deviation. Different letters in the same row indicated significantly different values ($p < 0.05$).

Increased interaction of amylose-amylose (amorphous region) and amylose-amylopectin (intercrystalline region) caused a decrease in the swelling of granules which were resistant to destabilization of the amorphous region when melting crystals. Decreasing pasting point at 120°C was caused by starch re-forming A-type crystals. In general, HMT can increase the pasting point of starch. The increase in pasting point was caused by the re-formation of the structure in starch granules (Lawal and Adebowale, 2005).

3.5.2 Peak viscosity

The higher the temperature of HMT, the peak viscosity decreased significantly until 110°C (Figure 5 and Table 1). The same results were obtained by Sankhon *et al*. (2014) that HMT on African locust bean starch decreased the peak viscosity. The decreased in peak viscosity was due to the interaction between the molecules of water, amylose-amylopectin which occurred in starch granules through hydrogen bonds. These interactions caused a rearrangement the structure of starch granule. This rearrangement caused the bond formed between amylose-amylose, amylose-amylopectin, and amylopectin-amylopectin to be stronger so that peak viscosity decreased (Gunaratne and Hoover, 2002). While the increase in peak viscosity at 120°C can be caused by the re-formation of A-type starch crystals which resulted in the structure of the starch granules changed. Peak viscosity can be affected by amylose/amylopectin levels and ratios, molecular weight, intermolecular conformation and the degree of polymerization of amylose and amylopectin, the amount of amylopectin branching and the presence of minor components (Mélo *et al*., 2003).

Based on Figure 5 and Table 1, the peak viscosity of HMT potato starch was lower than native starch. The decreased in peak viscosity during HMT was caused by increased hydrogen bonds and the formation of inter amylose and amylose complexes with fat (Miyoshi, 2002). Fat can affect the functional properties of starch because it limits the interaction of starch with other molecules outside the granule (Svihus *et al*., 2005).

3.5.3 Hold viscosity and breakdown viscosity

The higher the modification temperature, the hold viscosity decreased significantly until 110°C (Figure 5 and Table 1). The same results were obtained by Cahyana *et al*. (2019) that HMT on banana flour showed that HMT decreased the hold viscosity. The decreased in hold viscosity was due to an increase in the stability of starch paste against heating due to a shift in the type of crystallization from A-type to C-type which increased stability of starch granules. An increased in hold viscosity at 120°C can be caused by the re-formation of type A starch crystals which further decreased granule stability. The number of B-type crystals decreased gradually which can be seen from the total crystalline, then followed by the formation of A-type crystals (Vermeylen *et al*., 2006).

Hold viscosity of HMT modified potato starch was lower than native starch. This was due to the re-formation of starch granules which resulted in more double helix amylopectin bonds, especially in the amorphous region. The formation of these bonds played a role in changing the nature of crystallinity of starch into a more stable form (Lawal and Adebowale, 2005).

Breakdown viscosity of HMT potato starch decreased significantly during modification compared to a breakdown viscosity of native starch (Figure 5 and Table 1). The same results were obtained by Sankhon *et al*. (2014) that HMT on African locust bean starch decreased the breakdown viscosity. This was due to increased crystalline matrix regularity and the formation of amylose-fat complexes which reduced the swelling capacity of granules and improved paste stability during

heating. The increased breakdown viscosity at 120°C can be caused by the re-formation of A-type crystals which further affected the overall pasting properties. The increased temperature of HMT triggered an increase in the formation of A-type crystals and a decrease in B-type crystals (Vermeylen *et al*., 2006).

3.5.4 Final viscosity and setback viscosity

The higher the temperature of HMT, the final viscosity decreased significantly until 110°C. The same results were obtained by Cahyana *et al*. (2019) that HMT on banana flour showed that HMT decreased the final viscosity. The decreasing in the final viscosity was caused by the interaction of the amylose-amylose chain with the amylose-amylopectin chain that occurred during the modification process, so that the bonds between molecules were denser and stronger (Gunaratne and Hoover, 2002). In general, modification of HMT increase the final viscosity of starch (Collado and Corke, 1999). The decreased in final viscosity was due to rearrangement between amylose and amylopectin molecules which resulted in more bonding between amylose and amylopectin molecules in starch granules to reduce the tendency of retrogradation (Zavareze *et al*., 2010). The increase in viscosity during cooling determined the tendency of re-joining of starch which reflects the trend of the product for retrogradation. The joining of amylose molecules resulted in a strong gel structure so that the final viscosity increased (Hagenimana *et al*., 2006).

The higher the temperature of HMT decreased setback viscosity significantly until 110°C (Figure 5 and Table 1). The same results were obtained by Cahyana *et al*. (2019) that HMT on banana flour showed that HMT decreased the setback viscosity. The decrease in setback viscosity was due to an increased in the interaction of amylose and amylopectin molecules during cooling. An increased in setback viscosity at 120°C was also caused by the re-formation of microcrystalline from amylose and amylopectin molecules which bind back to one another outside the starch granule. An increased or decreased in setback viscosity depends on the intensity of the process. Low intensity produced high setback viscosity and vice versa (Stute, 1992).

Based on Figure 5 and Table 1 it can be seen that setback viscosity in HMT modified potato starch was higher than native starch. Setback viscosity can be used to measure the ability to re-crystallize starch that has undergone gelatinization during cooling (Beta and Corke, 2001). The increased in setback viscosity was caused by retrogradation of starch, which was the joining of adjacent amylose molecules through molecular hydrogen bonds.

4. Conclusion

HMT affected the functional and pasting properties of potato starch. The higher temperature of HMT decreased swelling volume, WAC, syneresis, whiteness degree, peak viscosity, and hold viscosity, but increased pasting point and setback viscosity. HMT 110°C was the minimum point for swelling volume (6.47mL/g), solubility (36.15%), WAC (1.14 g/g), peak viscosity (1113 cP), hold viscosity (1063 cP), breakdown viscosity (50 cP), final viscosity (1655 cP), setback viscosity (592 cP) and the maximum point for pasting point (82.09°C). Based on pasting properties, HMT potato starch was resistant to heating and was suitable to be applied to sterilization products.

Conflict of Interest

The authors declare no conflict of interest.

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