Effect of acid hydrolysis combined with heat moisture treatment on structure and physicochemical properties of corn starch

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Revised: 24 March 2013 / Accepted: 3 April 2013 / Published online: 28 April 2013
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Abstract Modification of starch led to new products with new desirable properties. Corn starch samples modified by acid hydrolysis combined with heat moisture treatment (AH-HMT) were made by changing pH, moisture content and treated temperature. After modification, swelling power at temperature higher than 75 °C of corn starches decreased while solubility of the starches increased. After AH-HMT, pasting temperature (PT) of all treated starch samples increased. But lower peak viscosity (PKV), trough viscosity (TV) and break down (BD) of most treated starch samples were observed. AH-HMT increased the gel hardness of all treated starches. And the biggest hardness of modified starch gel was 148.419 g, improving 93.471 g compared with native starch gel. The melting temperatures (T_o , T_p , T_c) of modified starch increased, but the melting range and ΔH decreased. The X-ray pattern remained practically unchanged with or without AH-HMT. Acid hydrolysis combined with heat moisture treatment (AH-HMT) improved the functional properties of corn starch.

Keywords Acid hydrolysis (AH) · Heat moisture treatment (HMT) · Structure · Physicochemical properties · Corn starch

Introduction

Starch is widely used in the food industry, either as a main raw material or as a food additive. As an additive, starch contributes to the thickening and stabilizing effects and

texture modification in food (Eliasson and Gudmundsson 2006). But the starch, in its native form, has limited use in the industry. Chemical and physical modifications are commonly used to produce starches with special properties.

Acid modification changes the physicochemical properties of starch without destroying its granule structure. Acid hydrolysis of amylopectin, whose clusters of short chains (DP 15–17) constitute the starch crystallites, preferentially occurs at the intercrystalline regions to give short segments of linear or lightly branched molecules (Biliaderis et al 1981). Acid modification also increases solubility and gel strength and decreases viscosity of starches (Kim and Ahn 1996; Osunsam et al. 1989). The viscoelastic properties of starches are also affected by acid hydrolysis (Wang et al. 2003). Studies have been conducted on corn, wheat, tapioca, potato, and mung bean starches (Nakazawa and Wang 2003; Shin et al 2004; Chung et al 2003).

Physically modified starch, by use of moisture, heat, shear, or radiation has gained a wider acceptance, because there is no waste of chemical reagents in the modified starch (Adebowale et al. 2005). Heat-moisture treatment of starches is defined as a physical modification that involves treatment of starch granules at low moisture levels (<35 % moisture w/w) during a certain time period (15 min–16 h) and at a temperature (84–120 °C) above the glass transition temperature (T_g) but below the gelatinization temperature (Gunaratne and Hoover 2002). Studies have been conducted on corn, cassava, wheat, oat, barley, triticale and lentil starches (Abraham 1993; Donovan et al. 1983; Hoover and Manuel 1996; Hoover and Vasanthan 1994; Kurakake et al. 1996; Maruta et al. 1994; Stute 1992). The general effects of hydrothermal treatments are manifested in increased gelatinization temperatures, and changes in gelatinization range (narrowing or broadening of the DSC endotherms), X-ray

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diffraction patterns, swelling volume and solubility, with consequent changes in functionality.

Acid hydrolysis and HMT have been extensively studied as a physical method for starch modification, but acid hydrolysis combined with heat moisture treatment (AH-HMT) has rarely been studied. The objectives of this study were to evaluate the effects of acid hydrolysis combined with HMT on properties of corn starch and to provide instructions on application of starch.

Materials and methods

Materials

Corn starch (amylose content 26.33 %, lipid content 1.21 %) was from Shandong Zhucheng Starch Company, China. All other reagents were of analytical grade.

Methods

Preparation of AH-HMT starch

AH-HMT was carried out using the method of Franco et al. (1995) with some modifications. The starch sample was weighed in a glass container, and the moisture content was adjusted to 30 % by adding appropriate amount of pH=4 HCl solution and then mixing completely for 24 h at 4 °C. The exact moisture content was measured using a moisture analyzer (MA-45, Sartorius AG, Goettingen, Germany). The sample was heated in a dry oven for 8 h at 100 °C. After cooling to room temperature, AH-HMT starch was washed sometimes with distilled water until its pH was 7.0, centrifuged at 3,000 rpm for 15 min. The sedimentation was dried at 40 °C until the moisture content of the samples reached about 8 % and was then ground.

There were three different factors (pH, moisture content and treated temperature). One factor was altered to do experiments, the other two factors were regular factor. From sample 1 to sample 5, the pH changed from 1 to 5 while the moisture content remained 30 % and treated temperature 100 °C; from sample 6 to sample 10, moisture content changed from 20 % to 40 % while the pH was 4 and treated temperature was 100 °C; from sample 10 to sample 13, treated temperature changed from 80 °C to 120 °C while the moisture content was 30 % and pH was 4. The details of each parameter used in each treatment was in Table 1.

Swelling power (SP) and solubility (S)

Swelling power (SP) and solubility (S) were determined by a modified method of Schoch (1964). Starch samples (0.8 g dry basis (db) suspended in 80 mL of distilled water) were

Table 1 The treated conditions of samples

Sample	pH	Moisture content (%)	Temperature (°C)
1	1	30	100
2	2	30	100
3	3	30	100
4	4	30	100
5	5	30	100
6	4	20	100
7	4	25	100
8	4	35	100
9	4	40	100
10	4	30	80
11	4	30	90
12	4	30	110
13	4	30	120

placed in 100 mL centrifuge tubes fitted with screw caps and heated in a water bath shaker (150 rpm) at 55–95 °C for 30 min. After heating, the centrifuge tubes were cooled to room temperature and centrifuged at 3,000 rpm (AnkeLXJ-IIB Centrifuge, Shanghai, China) for 15 min. The supernatants were dried to constant weight in a hot air oven at 105 °C. Precipitated paste and dried supernatant were weighed. All measurements were performed three times. Swelling power and percent solubility were calculated as follows:

$$S = \frac{W_r}{W} \times 100\% \quad (1)$$

$$SP = \frac{W_t}{W - W_r} \quad (2)$$

Where W_t is the weight of the wet sediment, W_r is the weight of the dried supernatant, W is the weight of sample (db, mg).

Pasting properties

Pasting properties of the corn starch and modified starch samples were tested as described by Koksel et al. (2008). The pasting properties of starch samples were determined using a Rapid Visco Analyser (RVA, Model 4D, Newport Scientific, Australia). Flour (3.0 g, 14 g/100 g moisture basis) was weighted directly in the RVA canister and distilled water was added to obtain a sample weight of 28.0 g. The sample was held at 50 °C for 1 min, heated to 95 °C in 7.5 min, and then held at 95 °C for 5 min. Afterwards, it was cooled to 50 °C in 7.5 min, and then held at 50 °C for 2 min. The rotating speed was maintained at 160 rpm along the process. Parameters including peak viscosity (PV), viscosity

at the end of hold time at 95 °C or hot-paste viscosity (HPV), final viscosity (FV) at the end of cooling, breakdown (BD=PV-HPV), setback (SB=FV-HPV) and pasting temperature were recorded. All tests were replicated three times.

Gel texture properties

Starch pastes formed in the RVA canisters were prepared for texture profile analysis (TPA) as follows. The gelatinized mixture in the canister was kept overnight at 4 °C, allowing formation of a solid gel. The canister was sealed with parafilm to prevent moisture loss during storage. The gel obtained had a dimension of 37.0 mm diameter and 20.0 mm height. The gel texture was determined using texture analyzer (TA-XT2, Texture technologies Corp, USA) following the method used by Yoenyongbuddhagal and Noohorm (2002). The gels were punctured at 1.0 mm/s to a distance of 10.0 mm using a stainless steel punch probe (P/6, 6.0 mm diameter). The peak force measured was reported as gel hardness. Hardness, springiness and cohesiveness of starch gel were obtained from the TPA curve according to procedures.

Differential scanning calorimetry (DSC)

Thermal properties of the starch samples were determined using a differential scanning calorimeter (DSC-7, Perkin–Elmer, Norwalk, CT), following the method of Song and Jane (2000). For DSC analysis, a Perkin–Elmer DSC 7 analyzer equipped with a thermal-analysis data station (Perkin–Elmer Corp., Norwalk, CT) was used. The starch sample (about 3 mg, dry starch basis) with excess water (1:2) was heated at 10 °C/min from 30 to 110 °C in sealed aluminum pans. An empty pan was used as the reference. Thermal transitions for gelatinization were characterized by To (onset temperature), Tp (peak temperature), Tc (conclusion temperature), and ΔH (enthalpy of gelatinization). All enthalpy calculations were based on dry-starch weight. The sample was analyzed three times, and the data were calculated using Pyris software (Perkin–Elmer, Norwalk, CT).

X-ray diffraction pattern

Crystal structure of starch was studied with an X-ray diffractometer (D8-ADVANCE, Bruker AXS Model, Germany) following the method of Watcharatwinkul et al. (2009). Starch samples were equilibrated in a saturated relative humidity chamber for 24 h at room temperature. Starch X-ray diffraction was performed on an X-ray diffractometer (D8-ADVANCE, Bruker AXS Model, Germany) with copper-cobalt radiation. Signals of the reflection angle of 2θ , from 3° to 60°, were recorded.

Statistical analysis

All experiments were conducted at least three times, for which mean values and standard errors were determined. Also, experimental data were analyzed using Analysis of Variance (ANOVA), and expressed as mean values $\pm$ standard deviations. Differences were considered at significant level of 95 % ($P<0.05$). SPSS software (version 17.0 for Windows) was used to statistically analyze the results obtained.

Results and discussion

Swelling power (SP) and solubility (S)

From Fig. 1 we can see that swelling power and solubility of all starch samples have a continuous rise as heating temperature was elevated from 55 to 95 °C. After modification, swelling power at temperature higher than 75 °C of corn starches decreased while solubility of the starches increased. Some researchers (Kulp and Lorenz 1981) have attributed the enhanced effects of HMT to decrease swelling power of potato starch, which is essentially free of endogenous lipids, to transformation of amorphous amylose into a helical structure. Gunaratne and Hoover (2002) have reported that the content of starch-lipid complexes increased after HMT. Therefore, the decreased swelling power of corn starch after AH-HMT may be also due to the AH-HMT promoted amorphous amylose and endogenous lipid forming more stable starch-lipid complexes.

The effect of pH on the swelling power and solubility of native and modified starches were presented in Fig. 1. When pH was 1 and 2, solubility of sample significantly increased and the highest value was 67 % (Fig. 1). The increased solubility at pH=1 and 2 may be mainly due to AH treatment. AH treatment increased hydrolysis degree of the starch and then produced water-soluble small molecules at these pH values. Similar results for strong acid treated starch were reported by Sandhu et al. (2007) and Wang et al. (2003). Compared to the native starch, solubility at pH=3, 4, 5 respectively had no significant changes.

According to Fig. 1(a, b, c), under 75 °C, 85 °C and 95 °C respectively swelling power of modified corn starch was significantly lower than that of native starch. Likewise, under different moisture content, swelling power of modified corn starch was significantly lower than that of native starch. And with treated temperature increasing, swelling power of modified starches decreased. During acid treatment, hydrogen bonding between adjacent starch polymers were disrupted and the amorphous regions were eroded, leading to lower swelling power. Kainuma and French (1971) also reported that the reduction in swelling power with acid treatment was due to the stiffness of entangled amylopectin network in the crystalline region of the starch. The swelling power of heat-moisture treated rice starch

Fig. 1 Effect of different pH (a), moisture content (b) and temperature (c) on swelling power and solubility of corn starch modified by AH-HMT

decreased from 14.11 g/g to 10.29 g/g (Hormdok, and Noomhorm 2007). Structural changes within the starch granules, after heat moisture conditioning, might be responsible for the reduction in swelling power. The change with respect to crystallinity has been attributed to either crystallite growth or perfection of already existing crystallite (Donovan et al. 1983; Hoover and Vasanthan 1994). Several authors have observed a reduction in the swelling power of the HMT in potato, cassava (Gunaratne and Hoover 2002), rice (Hormdok and Noomhorm 2007), sorghum (Olayinka et al. 2008) and maize starches (Chung et al. 2009). Therefore, the combination of AH and HMT caused the decreased swelling power.

Pasting properties

Heating starch granules in excess water leads to further granule swelling, additional leaching of soluble components and total disruption of granules. This process results in the formation of starch paste (Zobel 1988).

Increases were observed for gelatinization temperature of all treated starch samples (Table 2). The results were in agreement with Adebawale and Lawal (2003). Increase in pasting temperature after modification supports the fact that modification process tends to increase the crystalline perfection, as a result of reorientation of starch granules

Table 2 Pasting indexes of corn starch modified by AH-HMT at different pH, moisture content, treated temperature and time

	Sample	PT (°C)	PKV (RVU)	TV (RVU)	FNV (RVU)	BD (RVU)	SB (RVU)
NS native starch, MC moisture content, TT treated temperature, PT pasting temperature, PKV peak viscosity, TV trough viscosity, FNV final viscosity, BD break down, SB set back, AH-HMT acid hydrolysis combined with heat moisture treatment	NS	74.8±0.00 ^b	268.0±0.23 ^a	172.6±1.48 ^b	269.9±0.71 ^b	95.4±1.24 ^a	97.2±0.77 ^b
	pH						
	2	87.2±0.35 ^a	108.0±0.41 ^d	101.0±0.59 ^d	111.3±0.77 ^d	6.9±0.18 ^b	10.2±0.18 ^d
	3	86.5±0.07 ^b	126.3±0.18 ^c	122.7±0.18 ^c	135.9±0.41 ^c	3.5±0.35 ^c	13.2±0.23 ^c
	4	86.5±0.07 ^b	130.3±0.88 ^b	126.2±0.06 ^b	140.0±0.11 ^b	4.0±0.83 ^c	13.7±0.06 ^{bc}
	5	85.9±0.35 ^b	130.9±1.18 ^b	126.2±1.06 ^b	140.6±0.88 ^b	4.6±0.12 ^c	14.3±0.18 ^b
	MC (%)						
	20	79.0±0.42 ^e	232.8±1.70 ^b	169.0±1.71 ^b	289.0±2.35 ^a	63.8±0.01 ^b	120.0±4.07 ^b
	25	83.4±0.07 ^b	181.0±0.12 ^c	171.4±0.59 ^a	219.2±3.36 ^d	9.6±0.47 ^d	47.7±2.77 ^d
	30	86.5±0.07 ^a	130.3±0.88 ^e	126.2±0.06 ^c	140.0±0.11 ^e	4.0±0.83 ^e	13.7±0.06 ^e
Pasting indexes could not be detected for pH 1 and TT 120 °C All data represent the mean of three determinations	35	79.9±0.28 ^d	181.8±0.18 ^c	117.9±0.41 ^d	252.8±4.18 ^c	63.9±0.23 ^b	134.9±4.59 ^a
	40	81.8±0.00 ^c	157.3±0.59 ^d	102.0±0.06 ^e	217.1±1.53 ^d	55.3±0.53 ^c	115.1±1.59 ^b
	TT (°C)						
	80	81.1±0.21 ^c	189.7±1.06 ^b	165.8±0.71 ^b	240.5±1.77 ^b	23.9±0.35 ^b	74.7±2.47 ^b
	90	83.9±0.35 ^d	158.3±0.42 ^c	150.4±0.88 ^c	179.9±2.77 ^c	7.9±1.30 ^c	29.5±0.66 ^c
	100	86.5±0.07 ^b	130.3±0.88 ^d	126.2±0.06 ^d	140.0±0.11 ^d	4.0±0.83 ^d	13.7±0.06 ^c
	110	85.2±0.35 ^c	99.3±1.00 ^c	94.3±0.71 ^c	112.9±0.94 ^c	5.0±0.29 ^d	18.5±0.23 ^d
	Mean ± standard deviation (n=3)						
	Means with the same letter in each column are not significantly different (<i>p</i> <.05)						

molecules or chains. The strengthening of intragranular bonded forces, allows the starch to require more heat before structural disintegration and paste formation occurs (Eliasson 1980). Peak viscosity (PKV), trough viscosity (TV) and break down (BD) of most treated starch samples were lower than those of native starch. But when moisture content was 20 %, final viscosity (FNV) and set back (SB) were higher than those of native starch. Decrease of PKV, BDV, and FNV can be attributed to the formation of amylose–lipid complex during HMT and osmotic pressure treatment (OPT) processes (Hoover et al. 1993). Lower paste viscosity and higher pasting temperature indicated that the starches were strengthened by HMT (Jiranuntakul et al 2011).

When pH was 1, the curve was a line. This was possibly because starch was hydrolyzed to dextrin, which cannot produce viscosity. It is possible that the hydrolysis causes a significant breaking of the glycoside linkages of the long amylopectin chains, which apparently causes the fall in viscosity (Han et al. 2002). This was corresponded with the increasing solubility in Fig. 1. Setback value indicated short-term retrogradation. Breakdown (BD) is a measure of fragility of starch (Collado et al. 2001). Higher pasting stability of heat-moisture treated starches is consistent with greatly reduced granule break down during the pasting process. The reduction of the breakdown caused by AH-HMT shows that starches are more stable during continuous heating and shearing, which is in agreement with Watcharatwinkul et al (2009). The reorganisation within the granule of the modified starches makes them to be more resistant to the effect of shear and heat as it is observed from the breakdown values. The PKV, TV, FNV, BD and SB of starches modified at higher temperature obviously dropped.

The lower viscosity may be due to the fact that AH-HMT made the starch granule become more perfection which was

Table 3 Gel texture properties of corn starch modified by AH-HMT at different treated traditions pH, moisture content, treated temperature and time

Sample	Hardness (g)	Springiness	Cohesiveness
NS	54.9±0.63 ^c	0.98±0.002 ^a	0.946±0.001 ^b
pH			
2	141.5±0.23 ^a	0.986±0.001 ^a	0.966±0.002 ^a
3	134.7±3.63 ^b	0.985±0.003 ^a	0.967±0.003 ^a
4	143.6±3.36 ^a	0.983±0.001 ^a	0.970±0.001 ^a
5	140.9±1.31 ^a	0.985±0.001 ^a	0.969±0.002 ^a
MC (%)			
20	95.2±0.31 ^{cd}	0.981±0.000 ^a	0.943±0.003 ^c
25	100.8±2.21 ^{bc}	0.982±0.001 ^a	0.957±0.004 ^b
30	143.6±3.36 ^a	0.983±0.001 ^a	0.970±0.001 ^a
35	91.3±0.08 ^d	0.984±0.001 ^a	0.969±0.004 ^a
40	101.6±1.96 ^b	0.985±0.001 ^a	0.964±0.000 ^a
TT (°C)			
80	121.0±0.15 ^b	0.987±0.003 ^a	0.976±0.001 ^a
90	148.4±1.82 ^a	0.981±0.001 ^a	0.973±0.001 ^{ab}
100	143.7±3.36 ^a	0.983±0.001 ^a	0.970±0.001 ^b
110	145.6±1.66 ^a	0.981±0.001 ^a	0.964±0.004 ^c

NS native starch, MC Moisture content, TT Treated temperature, AH-HMT acid hydrolysis combined with heat moisture treatment

Gelling properties could not be detected for pH 1 and TT 120 °C

Mean ± standard deviation (n=3)

Means with the same letter in each column are not significantly different (*p*<.05)

Table 4 DSC data of native starch and AH-HMT corn starch treated at pH=4, 30 % moisture content and 100 °C for 6 h

Sample	To (°C)	Tp (°C)	Tc (°C)	Tc-To (°C)	ΔH (J/g)
Native starch	71.0 $\pm$ 0.14 ^b	74.2 $\pm$ 0.06 ^b	79.0 $\pm$ 0.32 ^b	8.0 $\pm$ 0.08 ^a	11.4 $\pm$ 0.06 ^a
pH=4, 30 % moisture content, 100 °C, 6 h	78.3 $\pm$ 0.42 ^a	83.7 $\pm$ 0.23 ^a	86.4 $\pm$ 0.08 ^a	8.2 $\pm$ 0.05 ^a	5.7 $\pm$ 0.02 ^b

To onset temperature, Tp peak temperature, Tc conclusion temperature, ΔH enthalpy, AH-HMT acid hydrolysis combined with heat moisture treatment
Mean $\pm$ standard deviation ($n=3$)

Means with the same letter in each column are not significantly different ($p<.05$)

hard to swell and/or the degradation of molecular chain of starch at higher temperature.

Gel texture properties

A starch gel is a solid–liquid system, and it has a continuous network in which the liquid phase is entrapped. Higher gel hardness of all treated starches was observed from Table 3. When pH was 1, gel of starch sample was not formed, because the starch was hydrolyzed to small moleculars. The biggest hardness of modified starch gel was 148.419 g, improving 93.471 g compared with native starch gel. Theoretically, decrease in swelling power would increase gel firmness. The reduction in granular swelling power on HMT (Fig. 1) would increase gel hardness. Consistent with previous studies, in potato starch (Hoover and Vasanthan 1994), where a great increase in gel firmness was observed, the large decrease in swelling factor negates the decrease in amylose leaching. Likewise, the hardness of the starch gels from HMT sweet potato starch by Collado and Corke (1999) is also consistent with these findings. While gel springiness and cohesiveness of all treated starch samples showed no significant differences. Several researchers have reported that acid hydrolysis also increased gel strength (Kim and Ahn 1996). The increased gel hardness at pH=2, 3, 4 and 5 respectively may be mainly due to HMT treatment. The starch modified at 120 °C could not form gel. That may be because the high temperature made the starch granule degrade to smaller moleculars.

Fig. 2 X-ray diffraction pattern of native corn starch and AH-HMT corn starch treated at pH=4, 30 % moisture content and 100 °C for 6 h

Differential scanning calorimetry (DSC)

The gelatinization temperature, onset [(To), mid point (Tp), and conclusion (Tc)] and gelatinization enthalpy (ΔH) are presented in Table 3. An increase in gelatinization temperature and melting range were observed for the treated starch compared with native starch (Table 4). To, Tc and Tp of corn starch modified by AH-HMT increased 7.26 °C, 9.43 °C and 7.45 °C, respectively. Tc-To increased from 7.95 °C to 8.15 °C and ΔH decreased from 11.41 J/g to 5.69 J/g. The increase in To, Tp and Tc supported the fact that the melting of crystallites formed as a result of the reorientation of the starch granules and crystalline reorganization after AH-AHM. In starch granules, the surrounding amorphous region affected melting of the crystallite. HMT reduced these destabilizing effects, resulting in higher gelatinization temperatures. A broader gelatinization range at higher temperature was also observed for wheat, potato (Kulp and Lorenz 1981), normal and amylomaize starches (Hoover and Manuel 1996). Vermeylen et al. (2006) also reported that both annealing and HMT of potato starch increased DSC gelatinization temperatures.

On the other hand, gelatinization enthalpy decreased. The ΔH values have been shown to represent the number of double helices that unravel and melt during gelatinization (Cooke and Gidley 1992). HMT tended to increase the crystalline perfection, but AH could damage the crystallinity of starch. The lower ΔH of starch modified at pH=4, 30 % moisture content, 100 °C, 6 h was mainly due to the AH (Table 4). Thus the lower ΔH values for treated starches could be attributed to that some of the double helices present in crystalline and in non-crystalline regions of the granule may have disrupted under the conditions prevailing during AH-HMT. Starch-chain associations within the amorphous regions and the degrees of crystalline order are altered during HMT. The magnitude of these changes was dependent on the moisture content during heat treatment and on the starch source (Hoover and Vasanthan 1994).

X-ray diffraction pattern

Wide-angle X-ray diffraction pattern of the native and AH-HMT corn starch was shown in Fig. 2. Corn starch revealed the typical A-type X-ray pattern with peaks at 15°, 17°, and 23.4°

(2 θ) typical for cereal starches (Fig. 4). The pattern remained practically unchanged with or without AH-HMT. However, the relative crystallinity of modified starch (13.84 %) was much lower than that of native starch (28.66 %). Gunaratne and Hoover (2002) have reported reduction in the relative crystallinity of potato and true yam starches treated by HMT. The relative crystallinity of hydrolyzed maize starches decreased with the acid treatment, indicating some weaker crystallization degraded as a result of AH-HMT.

Conclusions

Corn starch was subject to acid hydrolysis combined with heat moisture treatment (HMT) and some physicochemical properties of the starches were determined. Compared with native starch, swelling power of all modified corn starches decreased at different treated conditions above 75 °C, and solubility of most modified starches increased. Increases were observed for gelatinization temperature of all treated starch samples. But Peak viscosity (PKV), trough viscosity (TV) and break down (BD) of most treated starch samples were lower than those of native starch. However, when pH was 1, gel of starch sample was not formed. After AH-HMT, hardness of most modified starch gels increased significantly. The maximum hardness of modified starch gel was 148.419 g, improving 93.471 g compared with native starch gel. The melting temperatures (T_o , T_p , T_c) of modified starch increased, but the melting range and ΔH decreased. The X-ray pattern remained practically unchanged with or without AH-HMT. AH-HMT can improve the physical and chemical properties of corn starch and this method may provide some practical information on the potential usefulness of corn mixtures in the food industry.

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