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Influence of acetic anhydride on physicochemical, morphological and thermal properties of corn and potato starch

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Abstract

The physicochemical, morphological, thermal and rheological properties of acetylated corn and potato starches, prepared using acetic anhydride at different levels (4–12 g), were compared. Corn starch showed lower acetyl (%) and degree of substitution (DS) than potato starches under similar experimental conditions. The acetylated corn and potato starches showed slightly higher amylose contents than their counterpart native starches. Acetylated starches showed higher swelling power, solubility and light transmittance than native starches, which subsequently increased with the increase in acetic anhydride concentration in the reaction medium. The extent of change in these properties, as a function of acetic anhydride concentration, was significantly higher in potato than corn starches. Both potato and corn starches were fused after conversion to acetylated starches; however, this effect was more pronounced in the former under similar reaction conditions. The syneresis (%) of both acetylated and native starches increased during storage at 4 °C; however, the increase was less pronounced in acetylated starches.

Keywords: Acetylation; Corn starch; Potato starch; Physicochemical; Morphological; Thermal; Syneresis

1. Introduction

Starch is found as a reserve material in most plants in the form of granules comprised of amylose and amylopectin chains in a relatively constant ratio of 20:80 (Garci'a-Alonso, Jime'nez-Escrig, Mart'in-Carron, Bravo, & Saura-Calixto, 1999). Starch is utilized for its various functionalities in thickening, stabilizing, texturizing, gelling, film forming, encapsulation, moisture retention and shelf life extension. Potato starch has a bland flavour and forms high viscosity paste that is susceptible to shear. The potato starch granules are large and are extremely susceptible to breakage. The high molecular weight amylose and phosphate groups esterified to amylopectin contribute to high transparency, swelling power, water-binding capacity and freeze–thaw stability of potato starches (Craig, Maningat, Seib, & Hoseney, 1989). The hydrophilic nature of starch is a major constraint that seriously limits the development of starch-based products; so chemical derivatisation is a way to solve the problem and produce water-resistant materials (Peltonen & Harju, 1996). Acetylation of starches is an important substitution method that has been applied to starches that impart the thickening needed in food application. Acetylated starch is a granular starch ester with the CH_3CO group introduced at low temperature. Acetylated starch has improved properties over its native form and has been used for its stability and resistance to retrogradation (Wurzburg, 1986). Acetylated starches are used in fruit pies, gravies, salad dressings and filled cakes (Moore, Tuschhoff, Hastings, & Schanefelt, 1984). Non-food applications of acetylated starches include wrap-sizing for textiles and surface-sizing for papers and gummed tape adhesives (Sanford & Baird, 1985). Acetylated starches are produced with acetic anhydride in the presence of an alkaline agent, such as sodium hydroxide (Wurzburg, 1978). The acetylation of starches depends upon certain factors, such as starch source, reactant concentration, reaction time and pH. DeBoer (1991) reported that waxy and dull waxy

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corn starches reacted differently to several modifications, including acetylation combined with cross-linking. No studies have been reported that compare how starches from corn and potato respond to acetylation treatment. The objective of this study was to compare the properties of acetylated corn and potato starches prepared using different concentration of acetic anhydride.

2. Materials and methods

2.1. Materials

The commercial variety of potatoes was procured from the market, for starch isolation, while the corn starch was supplied by Sukhjit Starch Ltd., Phagwara (India). Analytical grade acetic anhydride, sodium hydroxide and hydrochloric acid were procured from Glaxo India Limited, Mumbai (India) and ethanol was obtained from Hayman Ltd., Essex (UK).

2.2. Isolation of potato starch

Starch was isolated from the potatoes as described earlier (Singh & Singh, 2001).

2.3. Preparation of acetylated corn and potato starches

Acetylated starches were prepared as described by Phillips, Liu, Pan, and Corke (1999). Starch (100 g) was dispersed in 225 ml of distilled water and stirred for 60 min at 25 °C. The suspension was adjusted to pH 8.0 with 3.0% NaOH. Acetic anhydride (2, 4, 6, 8, 10, 12 g) was added drop-wise to the stirred slurry, while maintaining the pH within the range 8.0–8.4 using 3.0% NaOH solution. The reaction was allowed to proceed for 10 minutes after the completion of acetic anhydride addition. The slurry was then adjusted to pH 4.5 with 0.5 N HCl. After sedimentation, it was washed free of acid, twice with distilled water and once with 95% ethanol, and then oven-dried at 40 °C. Yield (%) of modified a starch was calculated on a starch dry weight basis.

2.4. Determination of acetyl (%) and degree of substitution (DS)

Acetyl (%) was determined titrimetrically, following method of Wurzburg (1978). Acetylated starch (1.0 g) was placed in a 250 ml flask and 50 ml of 75% ethanol in distilled water was added. The loosely stoppered flask was agitated, warmed to 50 °C for 30 min, cooled and 40 ml of 0.5 M KOH was added. The excess alkali was back-titrated with 0.5 MHCl using phenolphthalein as an indicator. The solution was stood for 2 h, and then any additional alkali, which may have leached from the sample, was titrated. A blank, using the original unmodified starch, was also used.

$$\text{Acetyl\%} = \frac{([\text{Blank} - \text{Sample}] \times \text{Molarity of HCl} + 0.043 \times 100)}{\text{Sample weight}}.$$

Blank and sample were titration volumes in ml, sample weight was in g. DS is defined as the average number of sites per glucose unit that possess a substituent group (Whistler & Daniel, 1995).

$$\text{DS} = \frac{(162 \times \text{Acetyl\%})}{(4300 - [42 \times \text{Acetyl\%}])}.$$

2.5. Fourier transform infrared (FT-IR)spectra

FT-IR spectra of native and acetylated corn and potato starches were acquired on a Shimadzu FT-IR instrument (Shimadzu Corporation, Kyoto, Japan) using potassium bromide (KBr) discs prepared from powdered samples mixed with dry KBr.

2.6. Physicochemical properties

2.6.1. Swelling power and solubility index

The swelling power and solubility were determined by the method of Leach, McCowen, and Schoch (1959).

2.6.2. Amylose content and water-binding capacity (WBC)

Amylose content was determined by the rapid colorimetric method of Williams, Kuzina, and Hlynka (1970). A method described by Yamazaki (1953), as modified by Medcalf and Gilles (1965), was adopted for measuring WBC of starch.

2.6.3. Light transmittance (%)

The value of light transmittance (%) was measured by the method described by Craig et al. (1989). An aqueous suspension of starch (2%) was heated in a water bath at 90 °C for 30 min with constant stirring. The suspension was cooled to 30 °C and stored for five days at 4 °C and transmittance was measured at 640 nm against a water blank with a colorimeter.

2.7. Morphological properties

Scanning electron micrographs of native and acetylated starches were obtained with a scanning electron microscope (Jeol JSM-6100, Jeol Ltd., Tokyo, Japan). Starch samples were sprinkled on double stick tape fixed on an aluminium stub, and the starch was coated with gold-palladium (60:40).

2.8. Thermal properties

Thermal properties of the starches were studied using a differential scanning calorimeter (DSC – 821° Mettler Toledo, Switzerland), following the procedure of Singh and Singh (2001).

2.9. Retrogradation properties

Syneresis was determined as % of water released after centrifugation. Starch suspension (2%) was heated at 85 °C for 30 min in a water bath and then cooled to room temperature. The starch samples (20 g) were stored in preweighed centrifuge tubes at 4 °C and centrifuged at 3200 rpm for 10 min after every 7 days.

3. Results and discussion

3.1. Acetyl (%) and degree of substitution

The effect of addition of acetic anhydride, at different levels, on acetyl (%) and degree of substitution (DS) of corn and potato starch is shown in Table 1. The potato starch showed greater acetyl (%) and DS than corn starch under similar acetylation treatments. The acetyl (%) of potato starch ranged from 4.68 to 5.97 while corn starch showed a lower acetyl (%), from 3.43 to 4.68, at different levels of addition of acetic anhydride. The difference in the acetyl percentages of potato and corn starches, under similar acetylation conditions, may be attributed to differences of size and fragility of granules. The potato starch granules have been reported to be large and more fragile than corn starch (Singh, Singh, & Saxena, 2002). Phillips et al. (1999) also reported higher acetyl (%) for potato starch than cornstarch under similar experimental conditions. The acetyl (%) progressively increased with increase in level of acetic anhydride (up to 8%) in the case of potato starch. However, any further increase in level of acetic anhydride (up to 12%) did not result in an increase of acetyl content. The acetyl content (%) increased progressively, up to 10% level of addition of acetic anhydride, in cornstarch but further increase caused a decrease of substitution. This might have occurred due to the difference in the granular structure of starch, which in turn affected the introduction of acetyl groups into the starch molecules (Singh et al., 2002). Nieto (1993) observed similar effect in *Xanthosoma violaceum* starch granules in which higher values of acetyl substitution were observed at moderate acetic anhydride concentration (7.2%) at pH 8.0–8.4. Similar trends were observed for DS in both corn and potato starches. The conclusion regarding increased acetyl (%) with increasing amount of acetic anhydride, in the case of potato starch, was also corroborated by the infrared spectral analysis. A comparison of the spectrum of native potato starch with acetylated potato starch clearly indicated the introduction of acetyl moiety, through a band at 1733.25 cm^{-1}. The relative intensity of this band vis-à-vis the band at 1652.59 cm^{-1} increased when 12 g of acetic anhydride was employed. A similar comparison of the IR spectra of native and acetylated corn starches clearly indicated that the degree of acetylation, under comparable conditions of reaction, was very low, as shown by the intensity of the band at 1733–1734 cm^{-1} and carbonyl group of the acetyl moiety. IR spectroscopy thus provides a rapid and reliable method for evaluating the extent of acetylation in starches.

Table 1
Effect of acetic anhydride levels on acetyl (%) and degree of substitution (DS) of potato and corn starches

Acetic anhydride (g/100 g starch)	Potato starch		Corn starch	
	Acetyl (%)	DS	Acetyl (%)	DS
Native starch	0.00	0.00	0.00	0.00
2	4.68^{a}	0.180^{a}	3.43^{a}	0.133^{a}
4	5.57^{b}	0.220^{bc}	3.53^{a}	0.137^{a}
6	5.81^{c}	0.232^{c}	3.73^{b}	0.145^{b}
8	5.97^{c}	0.238^{c}	3.82^{b}	0.149^{b}
10	5.20^{d}	0.206^{ab}	4.68^{c}	0.184^{c}
12	5.20^{d}	0.206^{ab}	3.74^{b}	0.150^{b}

Values with similar superscripts in column do not differ significantly ($p < 0.05$).

3.2. Physicochemical properties

3.2.1. Swelling power and solubility (g/g)

Native potato starch showed higher swelling power (20.3%) than native cornstarch (10.3%). This might be due to the large granule size and weak internal organization resulted from negatively charged phosphate ester groups within the potato granules (Kim, Wiesenborn, Lorenzen, & Berglund, 1996). The low swelling power of cornstarch may be attributed to the presence of lipids in cornstarch (Galliard & Bowler, 1987). The acetylation treatment increased the swelling power of both potato and cornstarch (Table 2). This might be due to the presence of hydrophilic substituting groups that retained water (Betancur, Chel, & Canizares, 1997). Amylose content and swelling power showed significant correlations, R^2 of 0.947 and 0.842, respectively, in acetylated potato and corn starches. Similar results have been reported by Jae-Hong-Jeong and Man-Jin-Oh (1993). Acetylation also increased the solubility of both starches. However, maximum solubility was observed with addition of acetic anhydride, at 8% and 6% levels, in potato and corn starch, respectively. The acetyl content showed a significant correlation with solubility in acetylated potato starches.

Table 2
Effect of acetic anhydride levels on swelling, solubility, amylose and water-binding capacities of potato and corn starches

Acetic anhydride (g/100 g starch)	Potato starch				Corn starch			
	Swelling power (g/g)	Solubility (g/g)	Amylose (%)	WBC (%)	Swelling power (g/g)	Solubility (g/g)	Amylose (%)	WBC (%)
Native starch	20.3[a]	0.050[a]	19.1[a]	91.6[e]	10.3[a]	0.125[a]	22.2[a]	95.6[e]
2	22.8[b]	0.200[b]	19.5[a]	88.5[d]	11.3[b]	0.175[c]	22.5[a]	88.6[d]
4	24.9[c]	0.250[c]	20.2[b]	86.8[c]	11.5[b]	0.200[d]	22.9[a]	86.2[c]
6	27.1[d]	0.340[d]	20.9[b]	82.8[b]	12.6[c]	0.250[e]	23.4[b]	84.8[b]
8	29.3[e]	0.350[d]	21.4[c]	81.4[b]	12.9[c]	0.150[b]	23.9[b]	80.6[a]
10	33.2[f]	0.275[c]	22.9[d]	79.8[a]	12.9[c]	0.150[b]	24.5[c]	80.5[a]
12	34.4[g]	0.275[c]	22.8[d]	79.0[a]	13.1[d]	0.150[b]	24.9[c]	80.5[a]

Values with similar superscripts in column do not differ significantly ($p < 0.05$).

3.2.2. Amylose content

Acetylated corn and potato starches had slightly higher amylose contents than their counterpart native starches. The amylose content increased from 19.1% to 22.9% in potato starch and 22.2% to 24.9% in corn starch during acetylation with the highest concentration of acetic anhydride. Similar effects of acetylation on the amylose content of the starches have been observed earlier (Betancur et al., 1997). The presence of acetyl groups has been reported to interfere with the functioning of amylose and amylopectin fractions of starch and it affects the absorption of iodine during amylose testing (Betancur et al., 1997; Whistler & Daniel, 1995).

3.2.3. Water-binding capacity

WBC of corn starch (95.6%) was higher than potato starch (91.6%). The loose association of amylose and amylopectin molecules in the corn starch granules has been observed to be responsible for high WBC (Soni, Sharma, Bisen, Srivastava, & Gharia, 1987). Acetylated corn and potato starches showed slightly lower WBC values than their native starches (Table 2). The engagement of hydroxyl groups, to form hydrogen and covalent bonds between starch chains, lowers WBC (Hoover & Sosulski, 1986). WBC and amylose contents of acetylated potato and corn starches showed significant negative correlations ($R^2 = 0.92$, $R^2 = 0.88$, respectively). The differences in degrees of availability of

Table 3
Effect of acetic anhydride levels on light transmittance (%) of potato starch pastes

Acetic anhydride (g/100 g starch)	Storage (days)					
	1	2	3	4	5	6
Native starch	34.8[a]	30.6[a]	30.2[a]	29.0[a]	25.8[a]	24.6[a]
2	47.8[b]	47.6[b]	46.2[b]	45.4[b]	40.7[b]	38.8[b]
4	51.0[c]	49.6[b]	48.2[b]	46.7[b]	44.4[c]	42.5[c]
6	66.0[d]	65.4[c]	64.8[c]	63.2[c]	61.0[d]	59.5[d]
8	72.8[e]	71.2[d]	70.0[d]	68.9[d]	67.6[e]	66.4[e]
10	74.0[e]	73.8[d]	72.9[e]	72.1[e]	71.6[f]	70.1[f]
12	78.0[f]	77.6[e]	77.3[f]	77.1[f]	76.4[g]	76.0[g]

Values with similar superscripts in column do not differ significantly ($p < 0.05$).

Table 4
Effect of acetic anhydride levels on light transmittance (%) of corn starch pastes

Acetic anhydride (g/100 g starch)	Storage (days)					
	1	2	3	4	5	6
Native starch	2.6[a]	2.2[a]	2.0[a]	1.6[a]	1.4[a]	1.4[a]
2	3.2[b]	3.0[b]	2.8[b]	2.6[b]	2.4[b]	2.2[b]
4	4.4[c]	4.2[c]	4.0[c]	3.8[c]	3.6[c]	3.6[c]
6	4.6[c]	4.4[c]	4.2[c]	4.2[d]	4.0[d]	4.0[d]
8	4.8[c]	4.9[cd]	4.4[c]	4.2[d]	4.2[d]	4.2[d]
10	5.4[d]	5.2[d]	5.0[d]	4.8[de]	4.6[d]	4.6[e]
12	5.8[d]	5.4[d]	5.2[d]	5.0[e]	5.0[e]	5.0[e]

Values with similar superscripts in column do not differ significantly ($p < 0.05$).

water-binding sites among the starches may have also contributed to the variation in WBC (Wotton & Bamunuarachchi, 1978).

3.2.4. Light transmittance (%)

Native potato starch showed higher transmittance (%) than native cornstarch (Tables 3 and 4). This may be due to the presence of fewer granule remnants in the potato starch paste, which in turn depends on the morphological structure of the starch granules. Potato starch granules are fragile during pasting and remnants of granules are largely absent from the paste. Potato starch paste showed high clarity and almost no whiteness, which might be due to little or no refraction of light because of swollen granular remnants (Craig et al., 1989). The low light transmittance exhibited by corn starch may be due to high refraction of light by swollen granular remnants (Craig et al., 1989). The covalently bound phosphate groups in potato starch granules may also be responsible for the high transmittance (Banks & Greenwood, 1975). The differences in the light transmittance of the starches may also be attributed to the

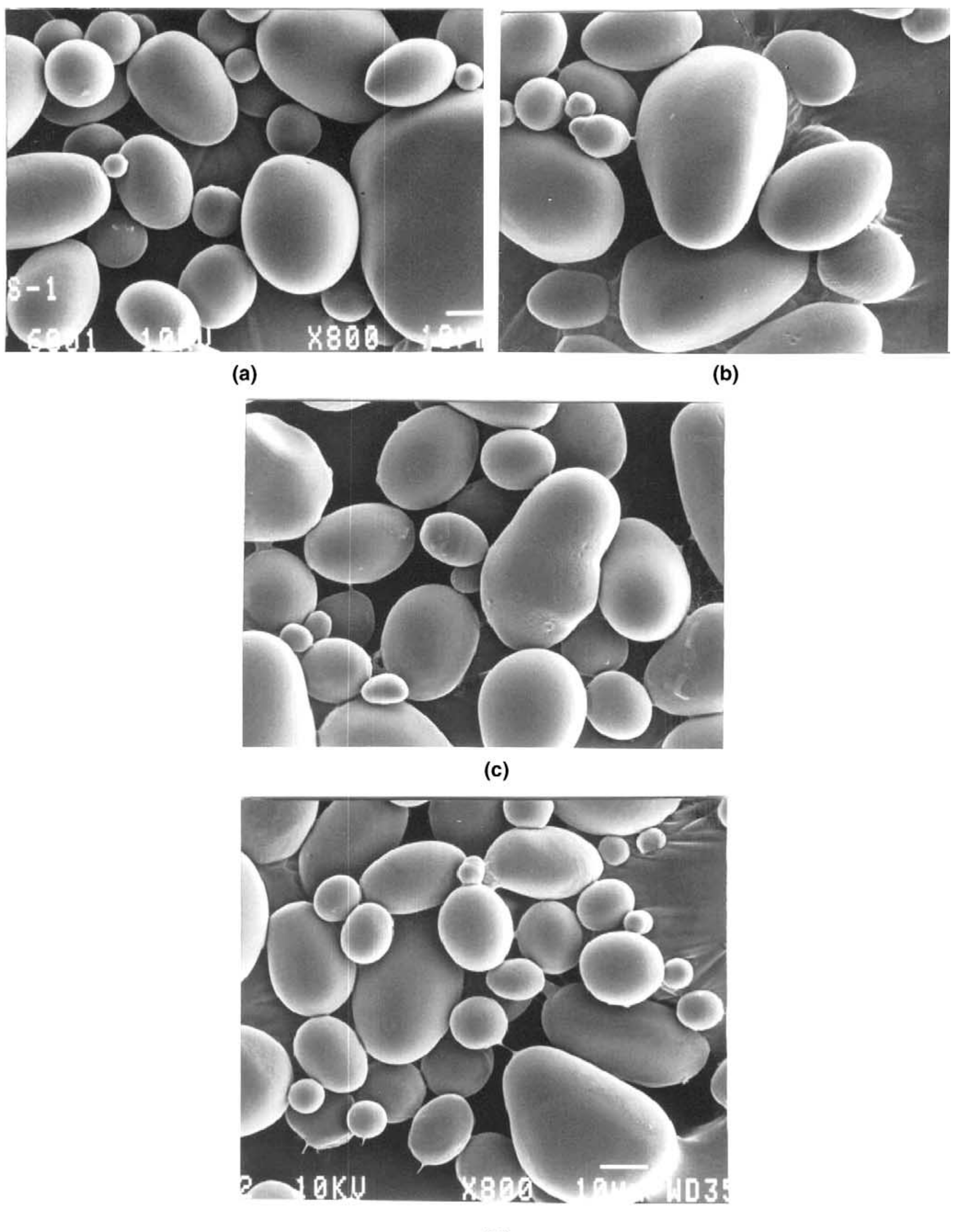

Fig. 1. Scanning electron micrographs (SEM) of native and acetylated potato starches: (a) Native, (b) 4 g acetic anhydride, (c) 8 g acetic anhydride, (d)12 g acetic anhydride (800×, Bar = 10 μm).

difference in granule morphology (Singh, Singh, Kaur, Sodhi, & Gill, 2003). The acetylation treatment increased the light transmittance in both starches due to increased swelling. This increase may be attributed to the introduction of hydrophilic substituting groups, which retained the water molecules to form hydrogen bonds in starch granules, resulting in higher light transmittance (Betancur et al., 1997).

The transmittances of all the suspensions of native and acetylated starches decreased during storage. The transmittance decreased from 34.8% to 24.6% in native potato starch and 2.6% to 1.4% in native corn starch during six days of storage. The light transmittance of acetylated starches remained higher than their counterpart native starches during storage. This may have occurred due to lower levels of retrogradation that prevented the aggregation of amylose and amylopectin in the starch pastes (Singh et al., 2002). Acetylated starches, from both sources, with higher acetyl (%) showed slower decrease in the light transmittance and vice versa.

3.3. Morphological properties

The granular structures of corn and potato starches showed significant variations in size and shape SEM (Figs. 1 and 2). The granule size ranged from 15 to 20 μm for small and 20 to 45 μm for large granules in potato starch. The size of corn starch granules ranged from 5 to 7 μm for small and 15 to 18 μm for large granules. The potato starch granules were observed to be smooth, oval and irregular or cuboidal-shaped. The sizes and shapes of the acetylated corn and potato starches showed slight variations from their native counterparts (Figs. 1 and 2). The acetylation treatment brought granule fusion in both starches. The fusion of starch granules after acetylation could be attributed to the introduction of hydrophilic groups to the starch molecules, which resulted in increase of hydrogen bonding. Therefore, starch molecules coalescing together resulted in fusion of starch granules. The fusion of granules was higher in potato than acetylated corn starches prepared using similar concentrations of acetic anhydride. These differences may be attributed to the differences in the granular structure of the starches. Corn starch granules have been reported to be more rigid and show more resistance towards modification than potato starch granules (Singh et al., 2003). The higher acetyl (%) in potato starches may have increased the hydrogen bonding, resulting in the fusion of starch granules. The addition of 4% acetic anhydride resulted in the fusion of granules in potato starches, which subsequently increased with the increase in levels of acetic anhydride. The acetylated corn starches tended to fuse slightly at 8%, or higher concentrations of acetic anhydride. SEM pictures of acetylated starches clearly revealed that the acetylated corn and potato starches with higher acetyl (%) and higher DS had more fused granules (Figs. 1 and 2).

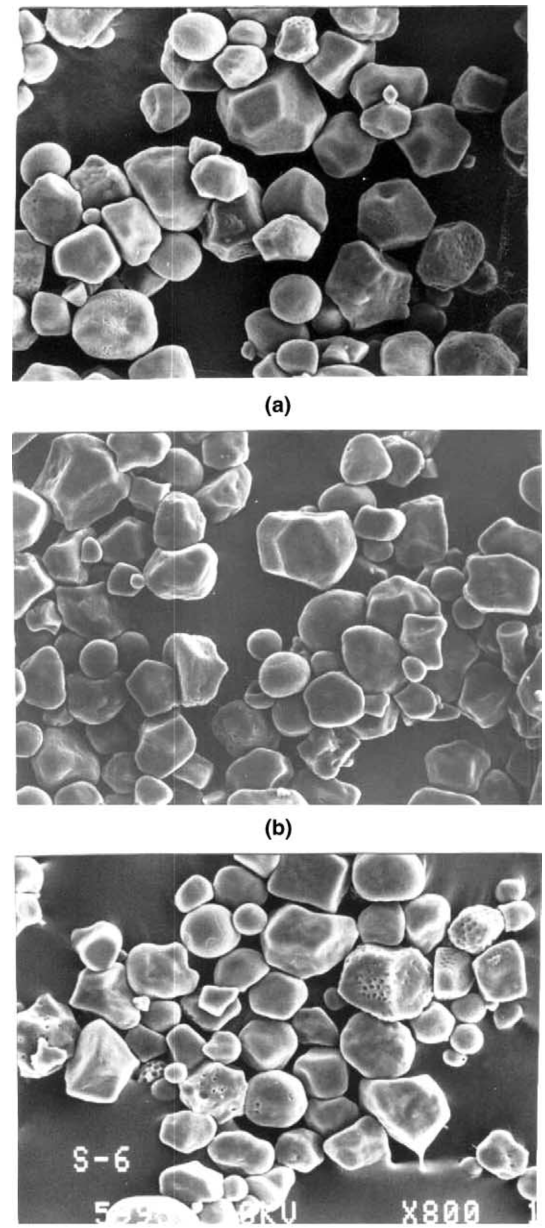

Fig. 2. Scanning electron micrographs (SEM) of native and acetylated corn starches: (a) Native, (b) 10 g acetic anhydride, (c) 12 g acetic anhydride (800×, Bar = 10 μm).

3.4. Thermal properties

The effect of addition of acetic anhydride, at different levels, on thermal properties of corn and potato starch is shown in Table 5. Native corn and potato starches showed endothermic peaks between 62 and 74 °C while the peaks for acetylated starches appeared between 54 and 75 °C. Corn starch showed higher transition tem-

Table 5
Effect of acetic anhydride levels on thermal properties of potato and corn starches

Acetic anhydride (g/100 g starch)	Potato starch				Corn starch			
	T_0 (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J/g)	T_0 (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J/g)
Native starch	57.4^e	62.6^e	69.1^f	12.1^d	69.2^c	73.3^c	77.4^c	10.6^d
2	55.9^d	61.1^d	67.9^e	11.4^c	69.3^c	73.2^c	77.4^c	9.7^c
4	54.2^c	59.5^c	66.4^d	10.4^b	66.3^b	71.3^b	76.2^b	9.4^b
6	52.8^b	58.1^b	65.1^c	10.2^a	66.3^b	71.2^b	76.2^b	9.2^b
8	54.2^c	59.1^c	64.9^b	10.2^a	65.8^a	70.4^a	75.3^a	9.1^b
10	53.4^{bc}	58.7^b	65.4^c	10.2^a	65.2^a	70.2^a	75.1^a	9.0^b
12	48.8^a	54.4^a	61.7^a	10.1^a	65.2^a	70.2^a	75.1^a	8.9^a

Values with similar superscripts in column do not differ significantly ($p < 0.05$).

Table 6
Effect of acetic anhydride levels on syneresis (%) of potato and corn starches

Acetic anhydride (g/100 g starch)	Storage (days)									
	Potato starch					Corn starch				
	4	8	12	16	20	4	8	12	16	20
Native starch	15.3^f	15.5^f	16.1^e	18.9^f	21.6^g	3.75^e	5.86^c	5.96^e	6.20^e	7.40^e
2	9.26^e	9.64^e	10.9^d	11.9^e	12.8^f	2.95^d	3.80^b	3.90^c	5.79^d	6.40^d
4	7.80^d	9.45^e	9.55^d	10.2^d	11.1^e	2.60^c	3.69^b	3.79^c	4.76^c	5.80^c
6	6.90^c	7.06^d	7.34^c	8.19^c	9.29^d	2.50^c	3.26^b	4.50^d	4.60^c	5.60^c
8	6.00^c	6.40^c	7.07^c	7.80^c	7.90^c	1.90^b	2.90^a	3.04^b	4.17^b	4.68^b
10	3.19^b	3.29^b	4.10^b	4.25^b	5.20^b	1.74^a	3.72^b	3.77^c	4.37^b	6.53^d
12	0.36^a	0.84^a	0.91^a	1.24^a	1.26^a	1.65^a	2.76^a	2.89^a	3.93^a	3.94^a

Values with similar superscripts in column do not differ significantly ($p < 0.05$).

perature and lower ΔH_{gel} than potato starches. This may be attributed to the differences in their granular structure and amylose content and the presence of lipids (Singh & Singh, 2001; Singh et al., 2002). The acetylation decreased the transition temperatures and ΔH_{gel} in both corn and potato starches. Among the acetylated potato starches, the starch treated with 10–12% acetic anhydride showed lowest ΔH_{gel} values (10.1 J/g). The starches with similar levels of acetic anhydride also had lower T_0 values of 48.81 and 53.42 °C, respectively. This may be attributed to the presence of hydrophilic substitution groups and increase in hydrogen bonding in starch molecules, which favoured gelatinization at low temperature. Eliasson, Finstand, and Ljunger (1988) also reported that acetylation of high amylose corn starch caused the gelatinization temperature of starch to decrease from 74.6 to 72.1 °C. These results are in agreement with those reported by Wotton and Bamunuarachchi (1979). They suggested that introduction of acetyl groups into polymer chains resulted in destabilization of granular structure, thus causing increase in swelling and decrease in gelatinization temperature. The extent of decrease in the transition temperatures and ΔH_{gel} in corn starch was less than potato starches. This may be due to the rigid nature of corn starch granules and presence of lipids (Singh et al., 2002).

3.5. Retrogradation properties

Native corn starch showed move syneresis (%) than native potato starches, which may be attributed to the rigid granular structure and presence of lipids in the former (Singh et al., 2002). The syneresis increased progressively during storage (Table 6). However, acetylated corn and potato starch showed less increase in syneresis (%) than their native counterparts. Liu, Ramsden, and Corke (1997) reported that amylose–amylose chain association may also be responsible for the decrease in starch retrogradation in acetylated starch. The retrogradation properties of starches are indirectly influenced by the structural arrangement of starch chains within the amorphous and crystalline regions of the ungelatanized granule. This might have influenced the extent of granule breakdown during gelatinization and the interactions that occur between starch chains during gel storage (Perera & Hoover, 1999).

4. Conclusion

Corn and potato starches showed variations in the introduction of acetyl groups during the modification process under similar reaction conditions. The starches from different sources may require different reaction times and reactant levels to achieve a constant acetyl level in the acetylated starch.

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