ORIGINAL ARTICLE

Characterisation of hydroxypropylated crosslinked sago starch as compared to commercial modified starches

Saowakon Wattanachant[1] , Sharifah Kharidah Syed Muhammad[2], Dzulkify Mat Hashim[3] and Russly Abd Rahman[4]

Abstract

Wattanachant, S., Muhammad, S. K. S., Mat Hashim, D. and Rahman, R. A.
Characterisation of hydroxypropylated crosslinked sago starch as compared to commercial modified starches
Songklanakarin J. Sci. Technol., 2002, 24(3) : 439-450

The characteristics of hydroxypropylated crosslinked sago starch (HPST) were determined and compared with five types of commercial modified starches (CMST) in order to evaluate its quality for further applications. The HPST was prepared on a large scale having molar substitution (MS) and degree substitution (DS) values in the range of 0.038 to 0.045 and 0.004 to 0.005, respectively. The properties of HPST in terms of sediment volume, swelling power, solubility and paste clarity were 15.75%, 16.7, 8.62% and 5.18%T_{650}, respectively. The MS value, phosphorus content, paste clarity, swelling power and syneresis after six freeze-thaw cycles of HPST when compared to that of commercially available modified starches which are normally used or incorporated in acidic, frozen and canned foods did not differ significantly. The pasting characteristic of HPST exhibited thin to thick viscosity which was similar ($P>0.05$) to that of commercial hydroxypropylated crosslinked tapioca starch (NAT 8). The acid stability, solubility

---

[1] **M.Sc. (Food Science and Technology), Department of Food Technology, Faculty of Agro-Industry, Prince of Songkla University, Hat Yai, Songkhla 90112 Thailand , [2] Ph.D. (Food Chemistry), Assoc. Prof., Department of Food Science, [3] M.Sc. (Food Engineering), Department of Food Technology, [4] Ph.D. (Food Technology), Assoc. Prof., Department of Food Technology, Faculty of Food Science and Biotechnology, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor D.E. Malaysia.**
Corresponding e-mail : ssaowako@ratree.psu.ac.th

Received, 18 October 2001 Accepted, 3 January 2002

and freeze-thaw stability of both starches were also similar (P>0.05) but the swelling power of HPST was slightly lower (P<0.05) than that of NAT 8 .

Key words : sago starch, modified starch, hydroxypropylation, crosslinking, starch properties, starch characterisation, commercial starch

บทคัดย่อ

เสาวคนธ์ วัฒนจันทร์ [1] ชาริฟาห์ ฆารีดา ซายด์ มูฮาหมัด [2] ซูกริฟฟี่ หมัด ฮาซิม [3] และ รูสรี ราห์มาน [3]

การศึกษาลักษณะของแป้งสาคูดัดแปรโดยกระบวนการไฮดรอกซีโพรพิลเลชันและครอสริงค์ในเชิงเปรียบเทียบกับแป้งดัดแปรทางการค้า

ว. สงขลานครินทร์ วทท. 2545 24(3) : 439-450

ลักษณะของแป้งสาคูดัดแปรโดยกระบวนการไฮดรอกซีโพรพิลเลชันและครอสริงค์ได้ถูกศึกษาและเปรียบเทียบกับแป้งดัดแปรทางการค้าจำนวน 5 ชนิด เพื่อประเมินลักษณะคุณภาพและเป็นข้อมูลสำหรับการใช้ประโยชน์ในอุตสาหกรรมอาหารต่อไป แป้งสาคูดัดแปร (HPST) มีค่าโมเลกุลทดแทนและดีกรีของครอสริงค์อยู่ในช่วง 0.038-0.045 และ 0.004-0.005 ตามลำดับ สำหรับคุณสมบัติของน้ำแป้งสุกพบว่า มีเปอร์เซ็นต์การตกตะกอนของเม็ดแป้งที่พองตัวเท่ากับ 15.75% มีกำลังการพองตัวของเม็ดแป้ง การละลาย และความใสเท่ากับ 16.7 8.68% และ $5.18\%T_{650}$ ตามลำดับ ซึ่งค่าโมเลกุลทดแทน ปริมาณฟอสฟอรัส ความใส กำลังการพองตัว และปริมาณของเหลวหลังจากผ่านการแช่แข็ง-ทำละลายจำนวน 6 รอบของแป้งสาคูดัดแปรไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ เมื่อเปรียบเทียบกับคุณสมบัติของแป้งดัดแปรทางการค้าที่นิยมใช้ในอาหารที่มีความเป็นกรด อาหารแช่แข็ง และอาหารกระป๋องที่ผ่านความร้อนสูง ลักษณะการเปลี่ยนแปลงความหนืดของแป้งสาคูดัดแปร (HPST) เป็นแบบความหนืดต่ำขณะให้ความร้อนและความหนืดเพิ่มสูงขึ้นขณะทิ้งให้เย็นตัว โดยมีลักษณะการเพิ่มความหนืดแบบเดียวกับแป้งมันสำปะหลังดัดแปรทางการค้า (NAT 8) แป้งสาคูดัดแปรยังมีความคงตัวต่อสภาวะกรด ความคงตัวต่อการแช่แข็ง-ทำละลาย และการละลาย เช่นเดียวกับแป้งทางการค้า NAT 8 (P>0.05) แต่มีกำลังการพองตัวของเม็ดแป้งต่ำกว่าแป้ง NAT 8 เล็กน้อย (P<0.05)

---

[1] ภาควิชาเทคโนโลยีอาหาร คณะอุตสาหกรรมเกษตร มหาวิทยาลัยสงขลานครินทร์ อำเภอหาดใหญ่ จังหวัดสงขลา 90112 [2] ภาควิชา Food Science [3] ภาควิชา Food Technology คณะ Food Science and Biotechnology, มหาวิทยาลัย Universiti Putra Malaysia 43400 มาเลเซีย

Native sago starch needs to be modified to improve its quality. The suitability of native sago starch as a base for hydroxypropylation and crosslinking has been studied (Wattanachant *et al.*, 2002). The effect of hydroxypropylation and crosslinking on dual-modified sago starch properties has been reported and discussed (Wattanachant and Muhammad, 2001; Saowakon *et al.*, 2001). However, physicochemical properties of modified starch are important for food manufacturers in terms of quality control and criteria for selecting starches capable of imparting specific requirements. Furthermore, the measurement of chemical residual is necessary for food safety. Inclusively, the physical properties of the dual-modified sago starch should be considered, and are compared to that of commercially available modified starches in order to ascertain whether the former can be an alternative modified starch source.

The applications of modified starches in food can be divided into three groups based on the types of food involving: acidic, frozen and canned foods. Many types of modified starches are commercially available to be incorporated in these food products; however, all of them are produced from waxy corn and tapioca starches. In this study, therefore, the characteristics of the hydroxypropylated crosslinked sago starch were determined and compared with those of commercially modified starches in order to evaluate its quality for further applications.

Materials and Methods

The native sago starch used was obtained from Ajinomoto Co. Ltd. Five types of commercially modified starches derived from waxy corns (Clearjel, Colflo97, NAT 1390S, and NAT 1333) and tapioca (NAT 8) obtained from National Starch and Chemical (M) Sdn. Bhd were used in this study. Types of modification, properties and uses of these commercially modified starches are shown in Table 1. Their pasting characteristics

Table 1. Types of commercially modified starches.

Sample	Starch base	Modification	Properties and Use
Clearjel	Waxy corn	Medium cross-link	More sour Jelly product in can/container
Colflo 67	Waxy corn	Medium stabilise Medium cross-link	More sour Bottle sauces
Nat 1390S	Waxy corn	Medium stabilise Less cross-link	Less harsh cooking condition
Nat 1333	Waxy corn	Medium stabilise High cross-link	Harsh cooking condition e.g. High shearing
Nat 8	Tapioca	High stabilise Medium cross-link	Not sour, bland taste, hot viscosity is lower than waxy corn but cold viscosity is the same

Source: Information from National Starch and Chemical (Malaysia) Co., Ltd.

Table 2. Pasting characteristic of commercially modified starches at the condition of 6.0% starch solid, pH 3.5 and 6.5.

Sample	Pasting temp. (°C)		Viscosity (BU)						Consistency (BU) (C-H)	
			95 °C		After 30 min (H)		50 °C (C)			
pH	3.5	6.5	3.5	6.5	3.5	6.5	3.5	6.5	3.5	6.5
Clearjel	63.0	66.0	780	695	1025	1035	1370	1395	345	360
Colflo 67	60.0	61.5	750	755	1045	1230	1305	1535	260	305
Nat 1333	58.5	60.0	545	560	995	1225	1530	1720	535	495
Nat 1390S	60.0	61.5	700	715	890	1140	1080	1515	190	375
Nat 8	51.0	52.5	725	440	750	1150	1410	2035	660	885

at neutral and acidic pH were determined in a Brabender Amylograph and their paste properties are presented in Table 2 and 3, respectively.

Table 3. Paste properties of commercially modified starches.

Sample	MS	P content (%)	Clarity %T_{650}	Sediment volume (ml)	Swelling power At 85 °C	Solubility At 85 °C (%)	Freeze-thaw stability (% syneresis)	Gel strength (g)
Clearjel	0.01	0.006	5.20	19.0	14.67	3.20	28.75	43.7
Colflo 67	0.08	0.006	6.00	25.4	16.90	4.15	1.30	32.8
Nat 1333	0.08	0.007	4.50	26.0	14.20	3.52	1.07	34.0
Nat 1390S	0.08	0.005	3.40	30.5	19.54	4.58	25.43	27.3
Nat 8	0.05	0.006	3.00	17.5	16.85	7.23	0.71	20.8
Mean±sd	0.06±0.03	0.006±0.001	4.42±1.24	23.7±5.36	16.43±2.13	4.53±1.60	11.45 ± 14.33	31.7±8.5

Preparation of hydroxypropylated crosslinked sago starch

Sago starch was doubly modified in duplicates of six batches by hydroxypropylation and cross-linking with 12% propylene oxide and a mixture of 2% STMP and 5% STPP at 40 °C for 24 and 2 hours, respectively; as described in previous researches (Wattanachant and Muhammad, 2001; Saowakon *et al*., 2001). Results from preliminary studies indicated that treatment of sago starch with 10-12% propylene oxide and this mixture of phosphate salts yielded the best distarch phosphate (crosslinking) with optimum substitution (Saowakon *et al*., 2001). However, the preparation of hydroxypropylated cross-linked sago starch in several batches resulted in less stable pasting characteristic at 10% propylene oxide level. Hereupon, the dual-modified sago starch at 12% propylene oxide was selected for this study.

Determination of phosphorus content

The content of phosphorus in starch was determined in four replicates for each sample by the method of Egan *et al*. (1981).

Degree of substitution (DS) and molar substitution (MS)

The extent of hydroxypropylation of modified starch was determined according to Johnson (1969). The degree of substitution (DS) and the molar substitution (MS) were calculated in the normal fashion (Rutenberg and Solarek, 1984).

Pasting characteristics

The pasting of starch samples was examined in a Brabender Amylograph at 6% starch solid and pH 6.5, which is similar to the procedure described by Wattanachant and Muhammad (2001). The following measurements were taken from the Amylograph curve: the pasting temperature, the peak consistency during the heating stage, the consistency after being held for 30 min at 95 °C and the consistency after cooling to 50 °C.

Acid stability

To determine the acid resistance on starch paste, a few drops of 30% acetic acid solution was used to adjust the pH of starch slurry to 3.5 to simulate pasting of starch having nearly the same pH of high-acid food. The pasting of starch samples was examined in a Brabender Amylograph and the procedure was similar to the examination of pasting behaviour at pH 6.5.

Paste clarity

The clarity (% T_{650}) of a 1% starch paste which had been heated in a boiling water bath for 30 min and cooled to 25 °C for one hour was evaluated using percent transmittance at 650 nm against a water blank in a spectrometer (Kerr and Cleveland, 1959).

Sediment volume

Sediment volume was determined as described by Tessler (1978). One gram of starch based on dry basis was weighed into a beaker and 95 ml of distilled water was then added. The pH of the starch slurry was adjusted to pH 7.0 using 5% NaOH or 5% HCl, followed which the slurry was cooked in a boiling water bath for 15 min. Distilled water was then added to bring the total weight to 100 g. The mixture was then stirred thoroughly and transferred to a 100 ml graduated cylinder. The cylinder was sealed with aluminium foil and the starch slurry was kept at room temperature for 24 hr. The volume of the sediment, consisting of swollen starch granules, was then measured.

Swelling power and solubility

Swelling power and solubility were determined as described by Schoch (1964).

Freeze-thaw stability

Freeze-thaw stability was expressed as the percentage of water separated from 20 g each of the gels (8% starch solid) after each freeze-thaw cycle. The procedure was modified from Takahashi *et al*. (1989) and Wu and Seib (1990). A starch solution (8% starch solid) was adjusted to pH 6.5 and heated to 95 °C, holding at 95 °C for 30 min and cooled to 50 °C in a shaking water bath. After cooling at 50 °C, starch paste was weighed (accurately 20 g each) into known weight 50 ml conical centrifugal tubes which were sealed tightly with screw caps. The tubes were shelved for 24 hr at 4 °C followed by freezing at -20 °C for 48 hr and thawing for 4 hr at 25 °C. Then the freeze-thaw stability was measured as the percentage of water separated on alternate freezing and thawing of the pastes followed by centrifugation at 3000 rpm for 15 min. The percentage of syneresis was the ratio of the weight of the separated water to the weight of the paste. In this study, six freeze-thaw cycles were conducted.

Gel strength

The texture of a gel (8% starch solid) was determined in four replicates using a Stable Micro Systems (TAXT-2 Texture Analyser). To prepare gels, the procedure described by Takahashi *et al.* (1989) was followed. All starches were adjusted to pH 6.5 using 5% NaOH or 5% HCl solution before cooking from 30 to 95 °C, held at 95 °C for 30 min , and then cooled to 50 °C. The hot paste was poured to a height of 2.7 cm into a cylindrical plastic container (diam. = 4.0 cm, height 5.5 cm) and stored for 24 hr at 25 °C and 4 °C before measurement. For gel strength measurements, the gels were compressed at a speed 2.0 mm/sec to a distance of 15 mm (Takahashi *et al*., 1989) using a cylindrical plunger (diam.= 10 mm). For gels, the maximum force during compression was considered as the gel strength and for pastes, the maximum force of deformation at 15 mm compression was regarded as ‘gel strength’. The paste and gel characteristics were recorded by visual evidence.

Statistical analysis

The data were analysed using the two-sample t-test assuming equal variances and the paired two sample t-test for means to evaluate the difference of means (Steel and Torie, 1980).

Results and Discussion

Chemical control measurement

In the fact that each starch needs to be modified to increase its usefulness but it is unlikely that any new derivatives or degree of substitution will be allowed (BeMiller, 1997). In this study, therefore, the degree of substitution and phosphorus content of modified sago starch were controlled being in the range of commercially available modified starches and followed the U.S. regulation of CFR (1991) cited by Lim and Seib (1993). The hydroxypropylated crosslinked sago starch that was prepared in six batches exhibited MS and degree of crosslinking (DS) in the range of 0.038 to 0.045 and 0.004 to 0.005, respectively. The accumulated dual-modified sago starch (HPST) was re-sampled to determine the MS, DS and P content so as to compare with the means of the results of five commercially modified starches (CMST). Table 4 shows the properties of HPST and CMST which had MS values that were close to each other (P>0.05). P content of HPST was 0.097% which was lower than the maximum level (0.4%) allowed by the U.S. regulation. However, the value was significantly lower (P<0.01) for CMST. The reason could be due to the different types of crosslinking reagents employed in the commercial modification of starches. The mixture of STMP and STPP was reported to impart high P content ranging from approximately 0.3 to 0.5% in the phosphorylation of wheat and corn starches (Lim and Seib, 1993).

Physical characteristics

Crosslinking could have a profound effect on the paste properties of cooked starch by strengthening the granules to resist rupturing and impart to a short salve-like texture at the cooked sols while hydroxypropylation is known to produce soft paste (Wurzburg, 1986; Tuschhoff, 1986). Figure 1 illustrates the effect of hydroxypropylation and crosslinking on the texture of cooked paste of dual-modified sago starch. The sample on the right was hydroxypropylated and crosslinked at which MS 0.033 and DS 0.004 achieved in counteracting the cohesive elastic gel of the native sago starch (Saowakon *et al.*, 2001).

Table 4. Physicochemical properties of hydroxypropylated crosslinked sago starch (HPST) and commercially available modified starches (CMST) for application in canned, high acid and frozen foods.

Starch Properties	HPST[/a]	CMST[/b]	P ($T \leq t$) two-tail
MS	0.041 ± 0.003	0.060 ± 0.031	0.259
P content (%)	0.097 ± 0.003	0.006 ± 0.001	9.579×10^{-11}
Paste clarity (%T_{650})	5.18 ± 0.05	4.42 ± 1.24	0.269
Sediment volume (ml)	15.75 ± 0.96	23.48 ± 5.27	0.024
Swelling power[/c]	16.70 ± 0.29	16.43 ± 2.13	0.814
Solubility[/c] (%)	8.62 ± 0.22	4.55 ± 1.62	0.002
Gel strength[/d] (g)	10.60 ± 0.88	31.72 ± 8.50	0.002
Syneresis[/e] (%)	1.14 ± 0.15	11.45 ± 14.33	0.197

Note: [/a] **The average mean of four determinations**
[/b] **The average mean for five types of commercially modified starches , Clearjel, Cloflo97, Nat 1333, Nat 1390S, Nat 8 (as shown in Table 3)**
[/c] **Swelling power and solubility at 85°C**
[/d] **Starch-water slurry at pH 6.5 with 8% starch solid cooked in a closed water bath from 30 to 95°C, held at 95°C for 30 min, cooled to 50°C, then poured into moulds and aged for 24 hr at 25°C.**
[/e] **Percent syneresis of starch pastes or gels after 6 freeze-thaw cycles**

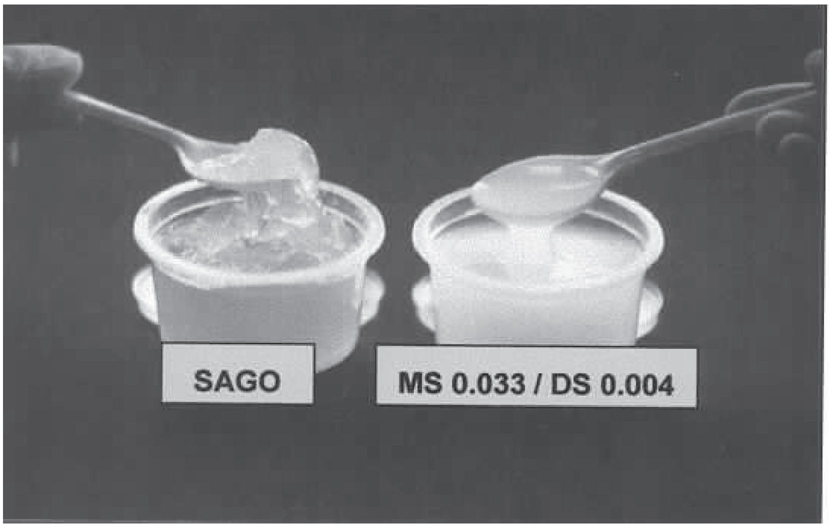

Figure 1. Textural of gel and paste property of the native sago and hydroxypropylated crosslinked sago starch with MS 0.033/DS 0.004

In addition, the undesirable reddish colour of sago starch gel was removed as evidenced visually from Figure 1. However, the reason why the colour of sago starch gel could be improved after undergoing hydroxypropylation and crosslinking is still not known. In order to evaluate the quality of the hydroxypropylated crosslinked sago starch (HPST), the important physical properties were examined comparatively with the average mean of the data obtained using five commercially modified starches (CMST) which were Clearjel, Colflo97, Nat 1390S, Nat 1333 and Nat 8 as illustrated in Tables 4 and 5. The t-test was used to compare the means of the two samples.

Paste and gel properties

HPST and CMST did not differ significantly in their paste clarity, swelling power, and freeze-thaw stability (P>0.05) but their sediment volume (P<0.05), solubility and gel strength (P<0.01) differed as shown in Table 4. The paste clarity, swelling power and solubility of HPST were higher than that of CMST whereas the percent syneresis of the former starch after 6 freeze-thaw cycles was much lower than that of the latter. This indicated that HPST was more freeze-thaw stable than the commercially modified starches.

CMST exhibited high syneresis with a mean value of 11.45% and a high standard deviation that was caused by the difference in the starch base and modification method used in the preparation of commercially modified starches (Yeh and Yeh, 1993; Wu and Seib, 1990). According to Wu and Seib (1990), most modified waxy maize starch had poorer freeze-thaw stability than similarly modified tapioca starch. In addition, modification methods were also reported to affect the freeze-thaw stability of starch. For instance, hydroxypropylation was more effective in improving freeze-thaw stability than acetylation while crosslinking decreased this property (Wu and Seib, 1990).

The lower sediment the volume of HPST may indicate that sago starch experienced a greater degree of crosslinking than CMST. However, the type of starches used may have an influence on this. The obvious difference between HPST and the commercially modified starches was in the gel strength. HPST (8% starch solid) did not form gel after ageing at 25 ºC for 24 hours and

Table 5. Pasting characteristics of hydroxypropylated crosslinked sago starch (HPST) and commercially available modified starches (CMST) for application in canned, high acid, and frozen foods.

Characteristics	HPST[/a]	CMST[/b]	P (T ≤ t) two-tail
At pH 6.5			
-Pasting Temp.	60.0 ± 0.0	60.3 ± 4.9	0.938
-Viscosity at 95 °C	50.0 ± 7.1	633.0 ± 130.4	0.002
-Viscosity after 30 min	780.0 ± 42.4	1156.0 ± 79.3	0.002
-Viscosity at 50 °C	1670.0 ± 28.3	1640.0 ± 249.6	0.879
-Consistency	890.0 ± 484.0	484.0 ± 234.6	0.071
At pH 3.5			
-Pasting Temp.	58.5 ± 0.0	58.5 ± 4.5	1.000
-Viscosity at 95 °C	470.0 ± 14.1	700.0 ± 91.6	0.020
-Viscosity after 30 min	590.0 ± 28.3	941.0 ± 122.3	0.012
-Viscosity at 50 °C	1042.0 ± 45.9	1339.0 ± 166.4	0.065
-Consistency	452.5 ± 17.7	398.0 ± 195.3	0.725

Note: [/a] **Data are mean of duplicate determinations**
[/b] **Data are mean of duplicate determination for five types of commercially available modified starches; Clearjel, Colflo97, Nat 1333, Nat 1390S and Nat 8 (as shown in Table 2)**

had a lower gel strength ($P<0.01$) when compared to that of the commercially modified starches.

Pasting characteristics

Table 5 illustrates that the pasting temperature of HPST was similar to that of CMST ($P>0.05$) and the HPST exhibited thin to thick viscosity. Its hot paste viscosity at 95 °C and after holding at 95 °C for 30 min was significantly lower ($P<0.01$) than that of CMST. After the cooling period at 50 °C, its cold paste viscosity increased to the same range as that of CMST ($P> 0.05$). For food production, the viscosity of starch paste is a property that needs to be considered, particularly if special equipment has to be used during the production of the item. For example, in the retorting of canned foods, thin-thick viscosity is the most desirable property of the starch thickener (Tessler, 1975; Valle *et al.*, 1976). Furthermore, HPST showed a higher paste consistency although the value was not significantly different ($P>0.05$) from that of CMST at the neutral condition of pH 6.5.

The determination of acid resistance of both modified starches was conducted at pH 3.5, achieved by adjusting with acetic acid solution. Both HPST and CMST had reduced pasting temperatures from 60.0 °C and 60.3 °C at pH 6.5, respectively, to 58.5 °C at pH 3.5. The hot paste viscosity at 95 °C was remarkably higher for both modified starches, at pH 3.5 than at pH 6.5 since hydrogen bonding in starch granules was weakened by acid hydrolysis, resulting in the starch swelling at a faster rate. However, acid treatment resulted in a reduction in the cold paste viscosity and paste consistency of these modified starches. The consistency of HPST was higher but its viscosity was lower than that of CMST. The acid resistance of HPST was acceptable when compared to that of the commercially modified starches and its pasting characteristic did not differ significantly ($P>0.01$) from that of CMST as illustrated in Table 5.

Quality of hydroxypropylated crosslinked sago starch

It is known that the viscosity of native sago is similar to that of native tapioca starch (Wattanachant *et al.*, 2002). Through the same method of modification, therefore, a similar pasting characteristic should be obtained with HPST and the commercially hydroxypropylated crosslinked tapioca starch (NAT 8). The amylograms of both starches are shown in Figure 2. In order to evaluate the quality of HPST as compared to that of NAT 8, various critical points in their pasting behaviors were noted and analysed using Student's t-test.

Heat and acid resistance

Both starches showed high heat and shear resistance as affirmed by no viscosity breakdown as illustrated in Figure 2. In addition, Table 6 presents the pasting characteristics of both starches in different pH conditions to evaluate the acid resistance of HPST and NAT 8. Results of a two-tailed t-test indicate that both starches were acid resistant because the mean of pasting characteristic of both starches was not significantly affected by acidic condition (P>0.05). However, HPST had significantly lower viscosity (P<0.05) than NAT

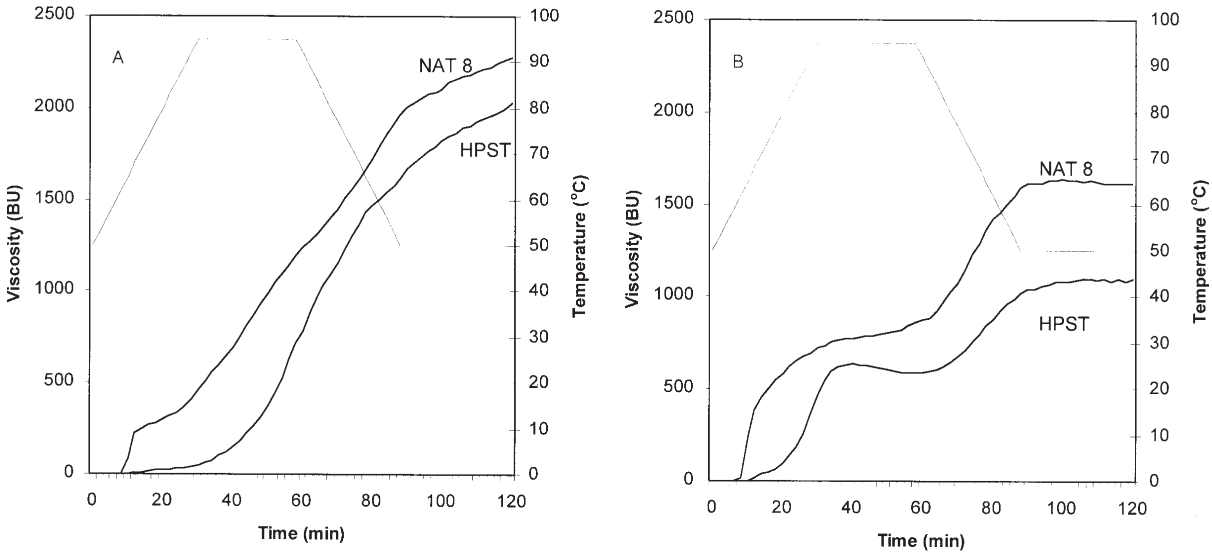

Figure 2. Amylograms of hydroxypropylated crosslinked sago starch (HPST) and hydroxypropylated crosslinked tapioca starch (NAT 8) at 6% starch solid, pH 6.5 (A) and pH 3.5 (B).

Table 6. Pasting characteristics of hydroxypropylated crosslinked sago starch (HPST) and commercial hydroxypropylated crosslinked tapioca starch (NAT 8) at different pH conditions.

Pasting Characteristic	HPST	NAT 8	P (T ≤ t) two-tail[/a]
At pH 6.5	690.0 ± 673.6	905.8 ± 753.1	0.140
At pH 3.5	522.7 ± 352.8	801.8 ± 556.0	0.038
P (T ≤ t) two-tail[/b]	**0.408**	**0.446**	**ns (P > 0.05)**

Note: - [/a] t-Test: Paired two samples for means of two starch types
- [/b] t-Test: Paired two samples for means of two pH conditions
- Data presented are the grand average means of viscosity (BU) at 95 °C, viscosity after holding at 95 °C for 30 min, viscosity at 50 °C and paste consistency in duplicate determinations.

8 at pH 3.5.

Swelling power and solubility

The viscosity of HPST was lower than that of NAT 8 since the former starch had lower swelling power ($P<0.05$) than the latter as shown in Table 7. The swelling power of HPST and NAT 8 were 15.09 and 18.06, respectively, while their solubility was not significantly different ($P> 0.05$). Generally, the native sago starch was reported to have higher swelling power and solubility than the native tapioca starch (Pomeranz, 1991). The lower swelling power of HPST observed in this study may be due to the higher degree of crosslinking obtained when compared to that of NAT 8.

Hydroxypropylation and crosslinking altered the swelling power and solubility of native sago starch as illustrated in Figures 3 and 4. As the temperature was increased, the native sago starch experienced a rapid increase in swelling power and solubility. However, these properties of the HPST were almost unaffected by the increase in temperature and a similar observation was made with NAT 8. It was noticed that HPST had higher

Table 7. Some properties of hydroxypropylated crosslinked sago starch (HPST) and commercial hydroxypropylated crosslinked tapioca starch (NAT 8).

Starch Properties	HPST	NAT 8	P ($T \leq t$) two-tail[/a]
Swelling power[/b]	15.09 ± 1.74	18.06 ± 1.30	0.042
Solubility[/b] (%)	7.39 ± 1.18	6.94 ± 0.45	0.390
Syneresis[/c] (%)	1.04 ± 0.14	0.93 ± 0.17	0.056

Note: - [/a] **t-Test: Paired two sample for means of two starch types**
- [/b] **Swelling power and solubility at the temperature of 65, 75, 85 and 95 °C.**
- [/C] **Syneresis after 1 to 6 freeze-thaw cycles**
- **Data presented are the grand average means of four determinations.**

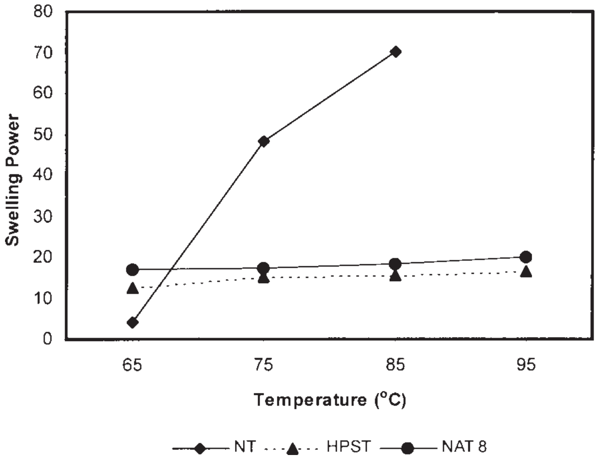

Figure 3. Swelling power of native (NT), hydroxypropylated crosslinked sago starch (HPST) and hydroxypropylated crosslinked tapioca starch (NAT 8).

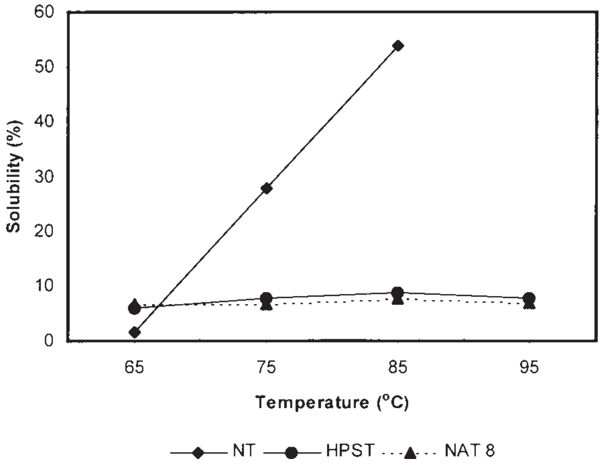

Figure 4. Solubility of native (NT), hydroxypropylated crosslinked sago starch (HPST) and hydroxypropylated crosslinked tapioca starch (NAT 8).

swelling power and solubility than the native sago starch at 65 °C. This is because hydroxypropylation reduces hydrogen bonding inside the starch granules, resulting in a reduction in the temperature required for hydration.

Freeze-thaw stability

The syneresis exhibited by HPST did not differ significantly ($P>0.05$) from that of NAT 8 after 1 to 6 freeze-thaw cycles (see Table 7) but it was lower than that experienced by native sago starch as illustrated in Figure 5. These results indicate that HPST with its high freeze-thaw stability could be used as an alternative of NAT 8 in frozen food products.

Conclusions

Hydroxypropylated crosslinked sago starch had pasting characteristics and paste properties almost in the range obtained with commercially available modified starches used in high acid, frozen and canned foods except for its gel strength. It exhibited excellent thin-thick viscosity behaviour which is a desirable property for heat-processed products such as canned foods. It was also heat, shear and acid resistant, and had high freeze-thaw stability suitable for cold storage. Its behaviour was similar to that of a commercial dual-modified tapioca starch (NAT 8) except in its ability to be a thickening agent. Thus, it can be used as an alternative to NAT 8 in food production except that a slightly higher amount of the former than the latter should be used to achieve the same viscosity.

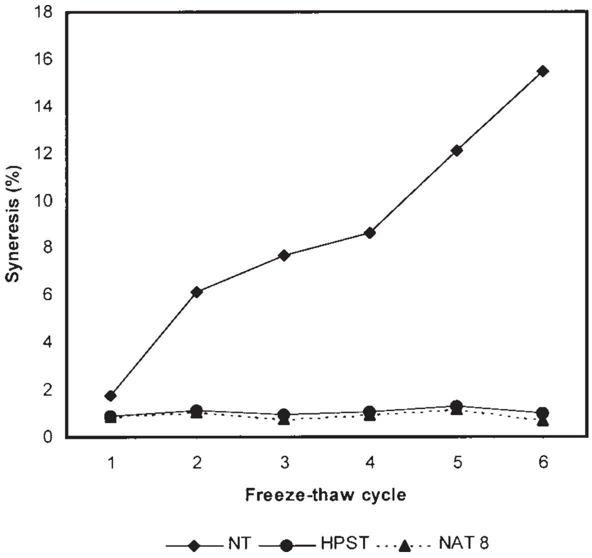

Figure 5. Freeze-thaw stability of native (NT), hydroxypropylated crosslinked sago starch (HPST) and hydroxypropylated crosslinked tapioca starch (NAT 8).

References

BeMiller, J. N. 1997. Starch modification: challenges and prospects. Starch/Starke. 49(4) : 127-131.

Egan, H., Kirk, R. S., and Sawyer, R. 1981. Pearson's chemical analysis of food. 8th ed. Churchill Livingstone London. p.29-30.

Johnson, D. P. 1969. Spectrophotometric determination of the hydroxypropyl group in starch ethers. Anal. Chem. 41: 859-860.

Kerr, R. W. and Cleveland, F. C. 1959. Orthophosphate esters of starch. US Patent. 2884413.

Lim, S. and Seib, P. A. 1993. Preparation and pasting properties of wheat and waxy corn starch phosphates. Cereal Chem. 70: 137-144.

Pomeranz, Y. 1991. Functional properties of food components. (2nd ed.). Academic Press, Inc. p.24-78.

Rutenberg, M. W., and Solarek, D. 1984. Starch derivatives: production and uses. Pages 311-388 in R. L. Whistler, J. N. BeMiller, and E. F. Paschall, eds., Starch chemistry and technology, 2nd ed. Academic Press: Orlando, FL.

Saowakon W., Kharidah M., Dzulkify M.H. and Russly Abd R. 2001. Effect of crosslinking reagents and hydroxypropylation levels on dual-modified sago starch properties. Food chem. (in press)

Schoch, T. J. 1964. Swelling power and solubility of granular starches. Pages 106-108 in R. L. Whistler, ed., Methods of carbohydrate chemistry, Vol.4. Academic Press: New York.

Steel, R. G. D. and J. H. Torie. 1980. Principles and procedures of statistics (A Biometric approach). 2nd ed. McGraw-Hill: New York.

Takahashi, S., Maningat, C.C. and Seib, P. A. 1989. Acetylated and hydroxypropylated wheat starch: paste and gel properties compared with modified maize and tapioca starches. Cereal Chem. 66: 499-506.

Tessler, M. M. 1975. Hydroxypropylated, inhibited high amylose retort starches. US Patent. 3904601.

Tessler, M. M. 1978. Process for preparing cross-linked starches. US Patent. 4098997.

Tuschhoff, J. V. 1986. Hydroxypropylated starches. Pages 89-96 in O.B. Wurzburg, ed., Modified starches: properties and uses. CRC Press, Inc. Florida.

Valle, F., Tuschoff, J. V. and Streaty, C. E. 1976. Thin-thick retort starch derivatives. US Patent. 4000128.

Wattanachant, S. and Muhammad, S.K.S. 2001. Effects of hydroxypropylation and crosslinking on dual-modified sago starch properties. Songklanakarin J. Sci. Technol. 23(4): 555-562.

Wattanachant, S., Muhammad, S.K.S., Mat Hashim, D. and Rahman, R.A. 2002. Suitability of sago starch as a base for dual-modification. Songklanakarin J. Sci. Technol. 24(3) : 431-438.

Wu, Y. and Seib, P. A. 1990. Acetylated and hydroxypropylated distarch phosphates from waxy barley: paste properties and freeze-thaw stability. Cereal Chem. 67: 202-208.

Wurzburg, O. B. 1986. Cross-linked starches. Pages 41-53 in O. B. Wurzburg, ed., Modified Starches: Properties and Uses. CRC Press, Inc., Florida.

Yeh AN-I and Yeh Su-Lan. 1993. Some characteristics of hydroxypropylated and cross-linked rice starch. Cereal Chem. 70: 596-601.