Gelatinizing, Pasting, and Gelling Properties of Potato and Amaranth Starch Mixtures

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ABSTRACT

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Physicochemical properties of mixtures of native potato and native amaranth (*Amaranthus cruentus*), heat-moisture treated (HMT) potato and heat-moisture treated amaranth, cross-linked potato and cross-linked amaranth, native potato and heat-moisture treated amaranth, and heat-moisture treated potato, and native amaranth were tested at different ratios. Two peaks were noticed in the pasting curves when large differences of swelling factor and amylose leaching existed between individual components in the mixture. It seems that amylose leaching from one starch in a mixture may affect the swelling and much of the granular break down of the other. The mixtures showed stabilities in hot pastes that were higher than the less stable components in a mixture. Some mixtures such as HMT potato and native amaranth showed very specific nonadditive pasting behavior. Mixing 10% of native amaranth to HMT potato starch caused a large reduction of peak viscosity and cold paste viscosity, resulting in a very soft gel. In the differential scanning calorimeter, each component of a mixture gelatinized independently, showing two peaks corresponding to the individual components. When transition temperatures of both components were similar in DSC, the result was a single endotherm. Dramatic changes of pasting and subsequent gel properties resulted when thermal transition of the two components occurred in the same temperature range. Retrogradation enthalpies as measured by DSC were between the two individual components in all tested mixtures.

Functional properties of starch play a key role in its diverse applications in food and nonfood industries. Native starches generally do not possess desirable functional properties for a wide range of utilization, so they are frequently modified to improve these properties. Chemical modification is widely used to attain this objective, however, with the growing market demand for natural food, there is greater necessity to search for alternatives to chemical modification. One possibility may be the use of blends of different starches, although this is not a common practice. Not much work has been done in this area despite its high potential. Obanni and BeMiller (1997) found that pasting properties of some starch blends behave similarly to cross-linked starches and the tendency to retrogradation decreased after blending. Karam et al (2005) found that blending native starches from maize, cassava, and yam improves some specific sensory properties. In a study of starch gelatinization in a rice and wheat starch blend, Liu and Lelievre (1992) found at low starch concentration (<30%) DSC thermograms are the sum of each individual components in the mixture, but nonadditive behavior was found at higher starch concentration due to the competition for water. The peak temperature for the gelatinization of rice starch increased because the low-temperature gelatinizing starch (wheat) can access more water. Ortega-Ojeda and Eliasson (2001) reported that at low starch concentration (20%), each individual component in the mixture independently gelatinized, whereas at higher starch concentration (50%) they did not.

From the survey of literature, it seems that most studies on starch blending have been limited to the use of native starches; thus, it is worth studying the physical properties of modified and unmodified starch blends, especially using physically modified starch. The size of the starch granule in individual starch components in the mixture could also affect the properties such as starch pasting. Thus, in this study, we chose blends of native, heat-moisture treated, and cross-linked potato and amaranth starches. Amaranth is not a cereal, but its starch properties are similar to those of cereals. Its extremely small starch granules may contribute specific functional properties to the starch blends.

MATERIALS AND METHODS

Materials

Potato starch and phosphoryl chloride were obtained from Sigma Chemical (St. Louis, MO). Amaranth starch was extracted from *Amaranthus cruentus* K 350 (Wu et al 1995).

Isolation of Amaranth Starch

Amaranth starch was isolated by the method of Wu et al (1995). Grain was soaked in 0.25% NaOH solution at 4°C for 24 hr then ground for 6 min in a Waring blender with 6 volumes of 0.25% NaOH. The slurry was filtered through filtering cloth using a small amount of water; the filtrate was then centrifuged at 3,000 × *g* for 10 min. The sediment was washed with distilled water several times, followed by centrifuging at 3,000 × *g* for 15 min each time. The starch cake was then dried at 35°C.

Swelling Factor

Swelling factor, the ratio of the volume of swollen starch granules to the volume of dry starch, was determined by the method of Tester and Morrison (1990a) where starch (50 mg, db) was heated from 60 to 90°C in 5 mL of water.

Amylose Leaching

Distilled water (10 mL) was added to starch (20 mg, db) in a screw-cap tube. Tubes were then heated from 60 to 90°C for 30 min with occasional stirring. After cooling to ambient temperature, samples were centrifuged at 2,000 × *g* for 10 min. The amylose content of the supernatant (0.1 mL) was estimated as described by Chrastil (1987) and the percent of leached amylose calculated based on starch weight.

Differential Scanning Calorimetry (DSC)

Gelatinization parameters of individual starch and the starches and mixtures were measured using differential scanning calorimetry (DSC) (TA 2920 modulated thermal analyzer, Newcastle, DE) equipped with a thermal analysis data station. Starch (3 mg) was directly measured into an aluminum DSC pan and relevant proportions of individual starches were directly measured for the mixtures in the pan separately. Then distilled water (9 μL) was added with a microsyringe and the components were mixed for homogenization. Pans were sealed and allowed to stand for 1 hr at room temperature for even distribution of water. The scanning temperature and heating rates were 30–120°C and 10°C/min, respectively. An empty pan was used as reference for all measurements.

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Pasting Properties

Pasting properties of starches were determined using a Rapid Visco Analyser (RVA) model 3D (Newport Scientific, Warriewood, Australia). Distilled water (25.5 g) was added to the starch (2.5 g, db) in the RVA canister to obtain a total constant sample weight of 28 g (8.9% of starch concentration). Because the cross-linked potato starch showed very high peak viscosity and cold paste viscosity development, the dry starch content for cross-linked starches was decreased to 2.3 g (8.2% of starch concentration). Required proportions of individual components were measured directly to an RVA canister in preparing starch mixtures. The slurry was then manually homogenized using the plastic paddle to avoid lump formation before the RVA run. A programmed heating and cooling cycle was set for 22 min, where it was first held at 50°C for 1.0 min, heated to 95°C in 7.5 min, further held at 95°C for 5 min, cooled to 50°C within 7.5 min, and held at 50°C for 1 min.

Gel Textural Analysis

Gel hardness was determined on the starch gel made in RVA testing using a TA-XT2 texture analyzer (Stable Micro Systems, Godalming, Surrey, England). After RVA testing, the paddle was removed and the starch paste in the canister was covered by Parafilm wrap and stored at 4°C for 24 hr. The gel was compressed at a speed of 0.5 mm/sec to a distance of 10 mm with a 6-mm cylindrical probe. The maximum force peak (g) in the TPA profile represents the gel hardness.

Retrogradation

Starch gel was prepared in the DSC pan using starch-to-water ratio of 1:3 and scanning the sample from 30 to 120°C. Sample was stored at 4°C for 24 hr to initiate nucleation and then kept at 40°C for 10 days before rescanning. Temperature range and heating rate were 30–120°C and 10°C/min, respectively.

Heat-Moisture Treatment

Moisture content of starch samples (20 g) was brought up to 30% in tightly capped bottles. Sample was then kept at room temperature for 24 hr for equilibration of moisture content before heating at 100°C for 8 hr. After cooling, the sample was air-dried to a moisture content of ≈10%.

Cross-Linking

Cross-linking of starch with $POCl_3$ was done as described by Woo and Seib (1997) with some slight modifications. Starch (50 g, db) was mixed with water (70 mL) containing sodium sulfate (1 g) and stirred mechanically at 25°C for 1 hr. The slurry was adjusted to pH 11.0 by slowly adding 1*M* NaOH while maintaining the temperature at 25°C. Phosphoryl chloride (0.01% based on starch dry weight) was injected with a microsyringe into the starch slurry. After 1 hr, the slurry was adjusted to pH 5.5 with 1*M* HCl and starch was recovered by centrifuging (3,000 × *g* for 10 min). The sedimented starch cake was washed three times with distilled water and dried at 35°C.

RESULTS AND DISCUSSION

Gelatinization

Swelling factors and the levels of amylose leached from granules are given in Table I. DSC results of individual components and all tested mixtures are presented in Table II with some representative DSC curves shown in Fig. 1. The gelatinization temperature and the enthalpy of native amaranth starch were higher than for native potato starch. Consistent with previous research (Hoover and Vasnthan 1994; Hoover et al 1994; Eerlingen et al 1996; Gunaratne and Hoover 2002) heat-moisture treatment decreased gelatinization enthalpy while increasing the gelatinization temperature with the changes being greater in potato starch. Cross-linking had little effect on gelatinization parameters of both starches.

Except for the five mixtures of the HMT potato and native amaranth starch shown in Table II, all other tested mixtures (total of 20) showed two peaks during gelatinization. The T_o of a mixture was similar to that of the onset temperature of the low T_p component (potato) and the T_c was similar to that of the high T_p component (amaranth) in the mixture (data not shown). The peak temperatures observed for the two peaks in a mixture were similar to the T_p value of individual components. Because the DSC characteristics of each component appeared unchanged in the gelatinization of their mixtures, it appears that each component gelatinized independently. This is an agreement with Ortega-Ojeda and Eliasson (2001) and Liu and Lelievre (1992). The latter authors found that at low starch concentration (<30%), DSC thermograms are the sum of each individual component in the starch mixture. However, Obanni and BeMiller (1997) noticed that at 33% starch solids, none of the blends of maize and potato, tapioca and wheat, and rice and potato showed two distinct peaks, and the resulting T_p values of the mixtures were different from either component. In our DSC study at 25% starch concentration,

TABLE IA
Swelling Factor of Native, Heat-Moisture Treated (HMT), and Cross-Linked Potato and Amaranth Starches at Different Temperatures[a,b]

Starch	Treatment	60°C	70°C	80°C	90°C
Potato	Native	21.0 ± 0.1	38.4 ± 0.2	56.0 ± 0.3	48.1 ± 0.2
	HMT	3.0 ± 0.2	10.5 ± 0.1	14.2 ± 0.4	18.3 ± 0.2
	Cross-linked	6.3 ± 0.3	17.2 ± 0.1	25.6 ± 0.1	32.1 ± 0.2
Amaranth	Native	6.7 ± 0.4	18.2 ± 0.2	27.6 ± 0.1	30.0 ± 0.1
	HMT	2.6 ± 0.2	5.4 ± 0.1	10.4 ± 0.1	20.0 ± 0.2
	Cross-linked	4.0 ± 0.1	12.2 ± 0.1	16.8 ± 0.2	24.6 ± 0.1

[a] Starch concentration (1%).
[b] Values are means of triplicate determination ± standard deviation.

TABLE IB
Amylose Leaching of Native, Heat-Moisture Treated (HMT), and Cross-Linked Potato and Amaranth Starches at Different Temperatures[a,b]

Starch	Treatment	60°C	70ºC	80ºC	90ºC
Potato	Native	8.2 ± 0.2	13.3 ± 0.1	14.7 ± 0.1	23.4 ± 0.2
	HMT	0.2 ± 0.1	1.8 ± 0.2	3.6 ± 0.1	6.3 ± 0.1
	Cross-linked	2.8 ± 0.1	3.6 ± 0.1	4.1 ± 0.2	6.1 ± 0.3
Amaranth	Native	0.8 ± 0.1	1.9 ± 0.3	3.5 ± 0.1	3.8 ± 0.2
	HMT	0.1 ± 0.3	0.3 ± 0.1	2.4 ± 0.2	3.2 ± 0.1
	Cross-linked	0.4 ± 0.2	1.2 ± 0.2	3.3 ± 0.3	3.5 ± 0.4

[b] Starch concentration (0.2%).
[b] Values are means of triplicate determination ± standard deviation.

except for HMT potato and native amaranth mixture, all tested mixtures showed two peaks during gelatinization. The appearance of a single peak in mixture of HMT potato and native amaranth could be due to overlapping of the two endotherms in the mixture. Heat-moisture treatment of potato starch increased gelatinization temperature from T_p 64.8°C to 77.0°C for HMT potato starch, which was near the T_p 78.5°C of native amaranth starch. Because cross-linking did not much affect gelatinization temperatures of both starches, the two peaks in the cross-linked mixture at a given ratio were very similar to the peaks appearing for the unmixed starches (Fig. 1C). Among all tested mixtures, native potato and HMT amaranth had the biggest difference in gelatinization temperature and thus showed two peaks very clearly in gelatinization (Fig. 1D). It seems that if the thermal transition temperatures of two components were close, the endotherms of the individual components in the mixture will overlap, indicating that starch crystals, which have similar thermal stabilities, will gelatinize at same temperature range, regardless of botanical origin. What is important here is that gelatinization of each component of starch in a mixture, even at the same temperature, may still affect the swelling and interaction between the two components in a mixture. That may be the reason for significant changes of pasting and textural properties resulting from blends of HMT potato and native amaranth starch, and HMT potato and HMT amaranth.

Pasting Properties

Results for pasting properties of individual starches (8–9%) and the blends are presented in Table IIIA-D. As commonly observed, potato starch showed a high peak viscosity development followed by a rapid granular breakdown, leading to a progressive decrease of viscosity at 95°C. Pasting properties of amaranth starch in this study were somewhat similar to the behavior of normal cereal starches with a low peak viscosity and low granular breakdown. Wu and Corke (1999) found a wide variation of pasting properties among amaranth species and among genotypes within species mainly due to differences in amylose content. Generally, amaranth starches are characterized by a low amylose content, or they are waxy. With blends of native potato and native amaranth starches, peak viscosity increased as the proportion of potato starch content increased, whereas a more stable hot paste was produced with increased amaranth starch content. Thus, mixing potato and amaranth starch produced a more shear-resistant product than potato starch alone.

Pasting profiles of mixtures of native potato and native amaranth (Fig 2A) and native potato and HMT amaranth starches (Fig 2D) showed the development of two peaks. In both cases, the first peak corresponded to peak viscosity of native potato starch; the second peak position was slightly before peak viscosity of either native amaranth or HMT amaranth starch. Obanni and BeMiller (1997) also noticed two pasting peaks when normal amylose maize and waxy maize starch were blended at a 1:1 ratio. They speculated that the dual peak characteristic could be attributed to differences in the granular breakdown between two components, i.e., at the time waxy maize granules tended to break down, the normal amylose maize starch granules were producing the viscosity, or the amylose leaching from normal amylose maize starch

TABLE IIA
Gelatinization Parameters for Mixtures of Native, Heat-Moisture Treated (HMT), and Cross-Linked Potato and Amaranth Starches[a–c]

	Native Potato and Native Amaranth		HMT Potato and HMT Amaranth		Cross-linked Potato and Cross-linked Amaranth	
Starch Ratio	T_p (°C)	ΔH	T_p (°C)	ΔH	T_p (°C)	ΔH (J/g)
100:0	64.8 ± 0.1	14.2 ± 0.2	77.0 ± 0.3	9.1 ± 0.2	64.8 ± 0.2	14.3 ± 0.2
0:100	78.5 ± 0.1	15.0 ± 0.1	83.7 ± 0.1	14.1 ± 0.2	78.1 ± 0.1	14.8 ± 0.3
90:10	65.0 ± 0.3 78.8 ± 0.2	14.3 ± 0.2	76.9 ± 0.2 84.1 ± 0.1	9.5 ± 0.4	65.4 ± 0.4 78.0 ± 0.3	14.1 ± 0.4
70:30	65. 4 ± 0.2 79.0 ± 0.1	13.9 ± 0.1	77.2 ± 0.2 84.3 ± 0.1	10.5 ± 0.1	65.1 ± 0.3 78.1 ± 0.2	14.0 ± 0.3
50:50	65.7 ± 0.2 78.9 ± 0.6	14.1 ± 0.2	77.4 ± 0.2 84.1 ± 0.2	10.2 ± 0.1	65.1 ± 0.2 77.8 ± 0.1	14.3 ± 0.1
30:70	65.3 ± 0.4 78.6 ± 0.1	14.3 ± 0.1	77.9 ± 0.3 82.9 ± 0.3	11.5 ± 0.4	65.3 ± 0.1 78.0 ± 0.3	14.0 ± 0.4
10:90	65.3 ± 0.2 78.8 ± 0.1	14.9 ± 0.3	77.6 ± 0.2 84.1 ± 0.1	13.4 ± 0.1	65.4 ± 0.2 77.9 ± 0.3	15.1 ± 0.3

[a] T_p, gelatinization temperature; ΔH, enthalpy.
[b] Starch concentration (25%).
[c] Values are means of triplicate determination ± standard deviation.

TABLE IIB
Gelatinization Parameters for Mixtures of Native and Heat-Moisture Treated (HMT) Potato and Amaranth Starches[a–c]

	Native Potato and HMT Amaranth		HMT Potato and Native Amaranth	
Starch Ratio	T_p (°C)	ΔH	T_p (°C)	ΔH
90:10	65.3 ± 0.2 83.9 ± 0.1	14.1 ± 0.2	77.4 ± 0.1	8.5 ± 0.2
70:30	64.8 ± 0.4 84.0 ± 0.1	14.3 ± 0.2	77.8 ± 0.3	10.5 ± .2
50:50	65.0 ± 0.2 84.1 ± 0.2	14.2 ± 0.1	77.9 ± 0.2	13.8 ± 0.1
30:70	65.2 ± 0.2 84.2 ± 0.3	14.6 ± 0.2	78.0 ± 0.1	11.6 ± 0.2
10:90	65.1 ± 0.2 83.9 ± 0.1	14.2 ± 0.2	78.3 ± 0.2	14.1 ± 0.1

[a] T_p, gelatinization temperature; ΔH, enthalpy.
[b] Starch concentration (25%).
[c] Values are means of triplicate determination ± standard deviation.

granules was preventing the breakdown of waxy maize starch granules. We also observed that the appearance of two peaks was more pronounced with a 1:1 blend of two starches. However, when cross-linked potato and cross-linked amaranth mixture was pasted, the dual peak characteristic disappeared (Fig. 2C).

Starch granular swelling and leaching of soluble carbohydrate (mainly amylose) are the main factors that determine the viscosity development during the pasting process. What we observed after HMT and cross-linking was a reduction of swelling factor and amylose leaching, which reduced the differences in these two factors in blends containing modified starches (Table I). Consequently, the decreased difference in swelling behavior or amylose leaching in the two components in the cross-linked potato and cross-linked amaranth mixture caused the starches in the mixture to swell more equally, producing one peak as usual. We also found that the greater the differences in swelling, amylose leaching, and granular breakdown of the two components in the mixture, the greater the resolution of two peaks in the pasting profile. This explains why native potato and HMT amaranth mixture produced two major pasting peaks. In all cases showing two peaks, there was a large difference of amylose leaching between components. Thus, we speculated that leached amylose from the faster leaching component (potato starch) may inhibit breakdown of amaranth starch granules. Obanni and BeMiller (1997) also claimed that greater amylose leaching from one component (normal amylose maize) may inhibit the granular breakdown in the other component (waxy maize), resulting in two peaks in the pasting process.

HMT decreased the PV of potato starch but increased it in amaranth starch. Additional starch chain interaction within the amorphous region and destabilization and reorientation of amylopectin double helices can take place during heat-moisture treatment (Hoover and Vasanthan 1994; Hoover et al 1994).

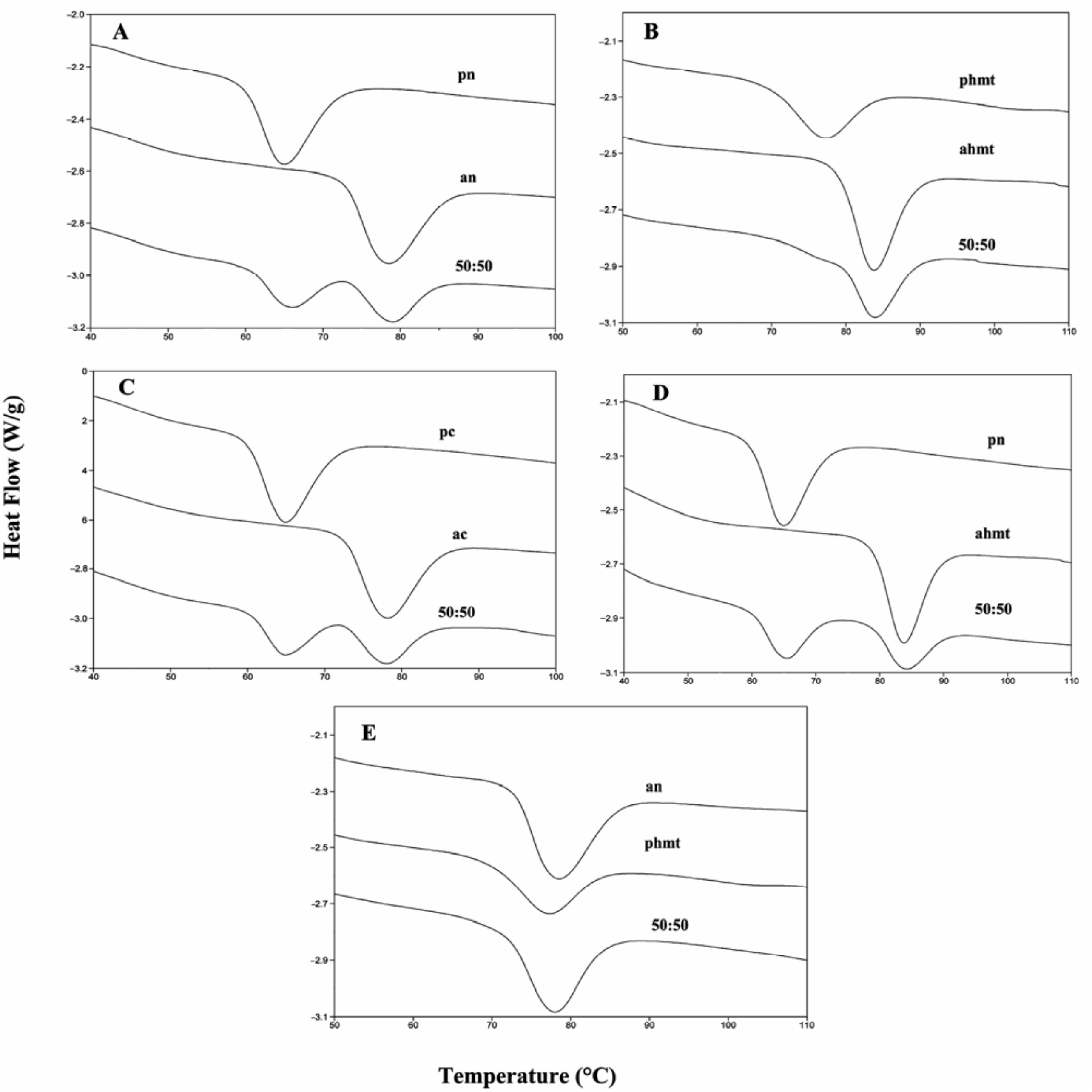

Fig. 1. Differential scanning calorimetry (DSC) curves of 50:50 mixture of native potato and native amaranth (**A**), HMT potato and HMT amaranth (**B**), cross-linked potato and cross-linked amaranth (**C**), native potato and HMT amaranth (**D**), HMT potato and native amaranth (**E**). Abbreviations: pn, potato native; an, amaranth native; phmt, potato heat-moisture treated; ahmt, amaranth heat-moisture treated; pc, potato cross-linked; ac, amaranth cross-linked.

TABLE IIIA
Pasting Properties and Gel Hardness (g) of Mixtures of Native Potato and Amaranth Starches[a–c]

Starch	Ratio	PV	HPV	BD	CPV	SB	GH
Potato	100:0	655 ± 2.2[c]	174 ± 0.9	481 ± 1.7	254 ± 2.9	81 ± 2.2	37 ± 0.5
Amaranth	100:0	165 ± 0.8	127 ± 0.7	38 ± 0.4	183 ± 1.4	57 ± 0.4	9 ± 0.4
Mixed potato and amaranth	90:10	501 ± 1.4	176 ± 0.7	324 ± 0.9	256 ± 1.5	80 ± 2.7	34 ± 0.7
	70:30	376 ± 2.3	164 ± 0.9	212 ± 1.4	241 ± 0.8	78 ± 1.8	27 ± 0.3
	50:50	273 ± 0.8	144 ± 3.6	129 ± 0.9	214 ± 0.7	70 ± 0.2	20 ± 0.3
	30:70	207 ± 1.2	125 ± 0.8	81 ± 0.6	195 ± 1.3	69 ± 1.3	16 ± 0.4
	10:90	162 ± 1.5	117 ± 1.2	45 ± 0.9	177 ± 0.7	60 ± 0.8	12 ± 0.3

[a] PV, peak viscosity; HPV, hot paste viscosity; BD, breakdown; CPV, cold paste viscosity, SB, setback; GH, gel hardness.

[b] Starch concentration (8.9%).

[c] Values are means of triplicate determination ± standard deviation

TABLE IIIB
Pasting Properties and Gel Hardness (g) of Mixtures of Heat-Moisture Treated (HMT) Potato and Amaranth Starches[a–c]

Starch	Ratio	PV	HPV	BD	CPV	SB	GH
HMT potato	100:0	144 ± 1.2	144 ± 1.1	0.0	218 ± 1.2	74 ± 3.5	40 ± 0.6
HMT amaranth	100:0	206 ± 1.3	166 ± 1.4	39 ± 0.7	227 ± 1.9	60 ± 2.8	12 ± 0.6
Mixed HMT potato and HMT amaranth	90:10	48 ± 0.4	48 ± 0.4	0.0	78 ± 0.6	30 ± 0.3	6 ± 0.3
	70:30	46 ± 1.6	46 ± 0.6	0.0	71 ± 0.3	23 ± 2.4	2 ± 0.1
	50:50	94 ± 1.7	94 ± 0.7	0.0	123 ± 1.2	29 ± 1.5	3 ± 0.2
	30:70	130 ± 2.3	121 ± 1.0	8.6 ± 0.3	172 ± 0.7	51 ± 0.8	6 ± 0.2
	10:90	181 ± 1.9	154 ± 1.9	27 ± 0.8	210 ± 0.8	55 ± 1.6	5 ± 0.1

[a] PV, peak viscosity; HPV, hot paste viscosity; BD, breakdown; CPV, cold paste viscosity; SB, setback; GH, gel hardness.

[b] Starch concentration (8.9%).

[c] Values are means of triplicate determination ± standard deviations.

TABLE IIIC
Pasting Properties and Gel Hardness (g) of Mixtures of Cross-Linked Potato and Amaranth Starches[a–c]

Starch	Ratio	PV	HPV	BD	CPV	SB	GH
Native potato	100:0	551 ± 3.2	152 ± 2.1	400 ± 1.4	226 ± 3.3	75 ± 0.9	33 ± 0.7
Native amaranth	100:0	125 ± 1.1	114 ± 2.2	12 ± 1.3	155 ± 0.9	41 ± 0.8	9 ± 0.4
Cross-linked potato	100:0	675 ± 2.1	563 ± 2.4	112 ± 1.2	717 ± 3.5	153 ± 1.4	90 ± 0.5
Cross-linked amaranth	100:0	128 ± 0.9	119 ± 1.3	9 ± 0.2	158 ± 1.2	38 ± 0.8	15 ± 0.2
Mixed cross-linked potato and cross-linked amaranth	90:10	549 ± 3.1	549 ± 3.1	0.00	736 ± 4.5	188 ± 1.6	71 ± 0.6
	70:30	391 ± 2.4	391 ± 3.4	0.00	686 ± 2.3	294 ± 5.2	42 ± 0.1
	50:50	284 ± 3.7	284 ± 3.7	0.00	494 ± 2.2	109 ± 2.3	30 ± 0.3
	30:70	175 ± 1.2	175 ± 1.2	0.00	275 ± 0.7	100 ± 0.3	16 ± 0.5
	10:90	122 ± 2.0	122 ± 2.0	0.00	168 ± 0.4	46 ± 0.4	11 ± 0.4

[a] PV, peak viscosity; HPV, hot paste viscosity; BD, breakdown; CPV, cold paste viscosity; SB, setback; GH, gel hardness.

[b] Starch concentration (8.2%).

[c] Values are means of triplicate determination ± standard deviation.

TABLE IIID
Pasting Properties and Gel Hardness (g) of Mixtures of Native Potato, and Amaranth Starches with Heat-Moisture Treated (HMT) Potato and Amaranth Starches[a–c]

Starch	Ratio	PV	HPV	BD	CPV	SB	GH
Native potato	100:0	655 ± 3.2	174 ± 2.1	481 ± 1.4	254 ± 0.8	81 ± 0.6	37 ± 0.3
HMT amaranth	100:0	206 ± 1.4	166 ± 1.9	39 ± 2.3	227 ± 2.8	60 ± 1.9	12 ± 0.2
Mixed native potato and HMT amaranth	90:10	530 ± 3.1	174 ± 2.1	355 ± 2.5	250 ± 1.2	75 ± 2.1	34 ± 0.7
	70:30	383 ± 0.9	182 ± 3.2	201 ± 1.4	255 ± 0.7	73 ± 0.7	27 ± 0.4
	50:50	326 ± 1.5	181 ± 1.8	144 ± 2.3	250 ± 3.4	68 ± 0.6	23 ± 0.5
	30:70	268 ± 3.1	182 ± 1.2	85 ± 1.5	249 ± 2.2	66 ± 2.1	19 ± 0.7
	10:90	227 ± 3.4	166 ± 2.2	61 ± 3.5	237 ± 2.3	70 ± 2.1	16 ± 0.8
HMT potato	100:0	144 ± 3.7	144 ± 3.7	0.0	218 ± 1.9	74 ± 1.2	40 ± 1.3
Native amaranth	100:0	165 ± 2.1	127 ± 0.9	38 ± 1.2	183 ± 1.8	57 ± 1.4	9 ± 0.8
Mixed HMT potato and native amaranth	90:10	33 ± 2.1	33 ± 2.1	0.0	63 ± 1.3	30 ± 1.9	2 ± 0.2
	70:30	42 ± 0.9	42 ± 0.9	0.0	67 ± 0.8	34 ± 1.3	3 ± 0.6
	50:50	85 ± 1.3	85 ± 1.4	0.0	122 ± 2.1	37 ± 3.3	3 ± 0.2
	30:70	119 ± 2.8	119 ± 2.8	0.0	161 ± 2.4	42 ± 1.9	3 ± 0.8
	10:90	154 ± 3.1	138 ± 1.5	16 ± 0.9	201 ± 2.3	63 ± 3.3	3 ± 0.4

[a] PV, peak viscosity; HPV, hot paste viscosity; BD, breakdown; CPV, cold paste viscosity; SB, setback; GH, gel hardness.

[b] Starch concentration (8.9%).

[c] Values are means of triplicate determination ± standard deviation.

As potato starch is extra responsive to HMT, more starch chain interaction can take place within the amorphous and crystalline regions, leading to a large reduction of swelling and amylose leaching. As a consequence, a decreased peak viscosity is anticipated. But in the case of amaranth starch, more granular rigidity may have been attained after HMT due to starch chain interactions within the amorphous region, which may dominate the negative effect of decreased swelling.

Hoover and Vasanthan (1994) also reported a similar finding for heat-moisture treated wheat starch. They suggested that an increase in the Brabender 95°C viscosity on heat-moisture treatment could be attributed to an increase in granular rigidity resulting from an increase in crystalline order and starch chain interactions within the amorphous region. Rigid granules create more friction between granules during stirring because they deform less than highly swollen granules, resulting in higher PV.

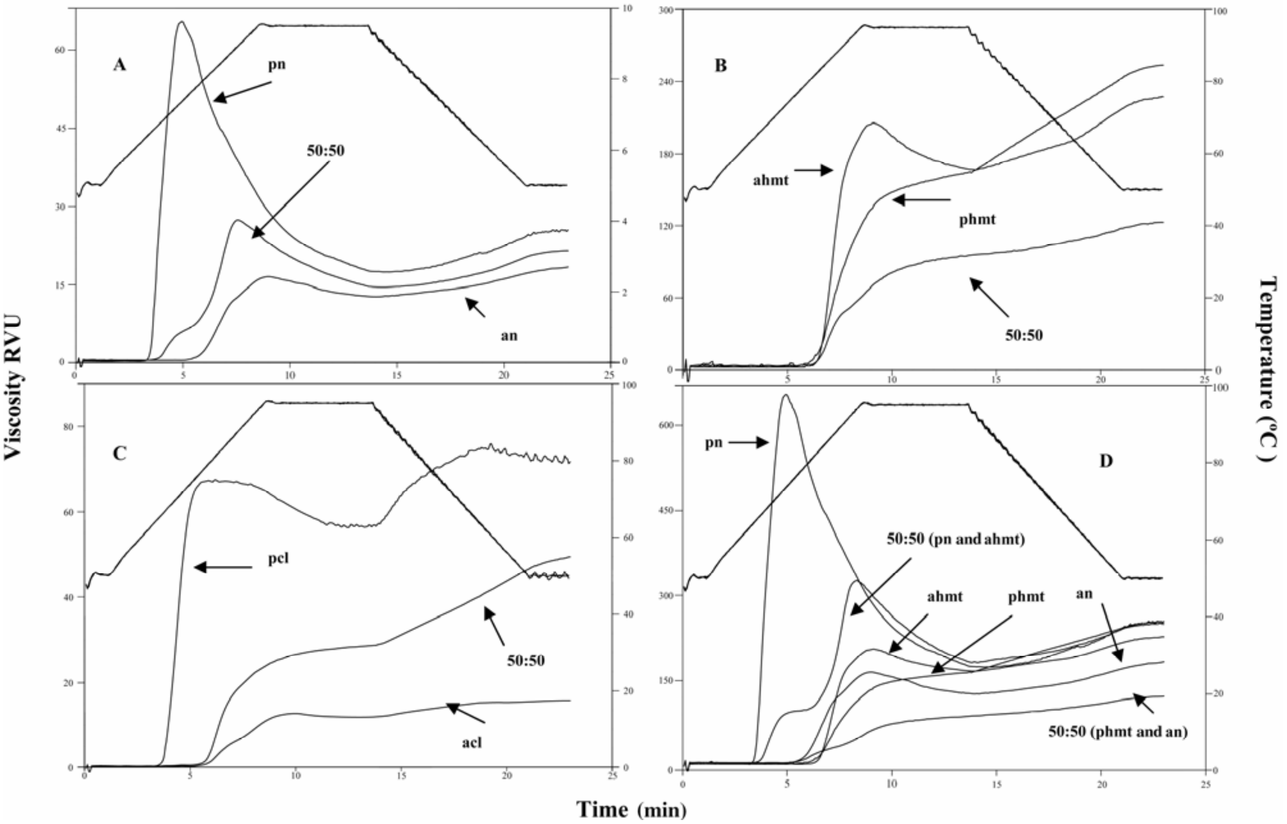

Fig. 2. Pasting curves at 8.9 or 8.2% starch solids for 50:50 mixture of pn and an (**A**), phmt and ahmt (**B**), pcl and acl (**C**), pn and ahmt with phmt and an (**D**). Abbreviations: pn, potato native; an, amaranth native; phmt, heat-moisture treated potato; ahmt, heat-moisture treated amaranth; pcl, cross-linked potato; acl, cross-linked amaranth.

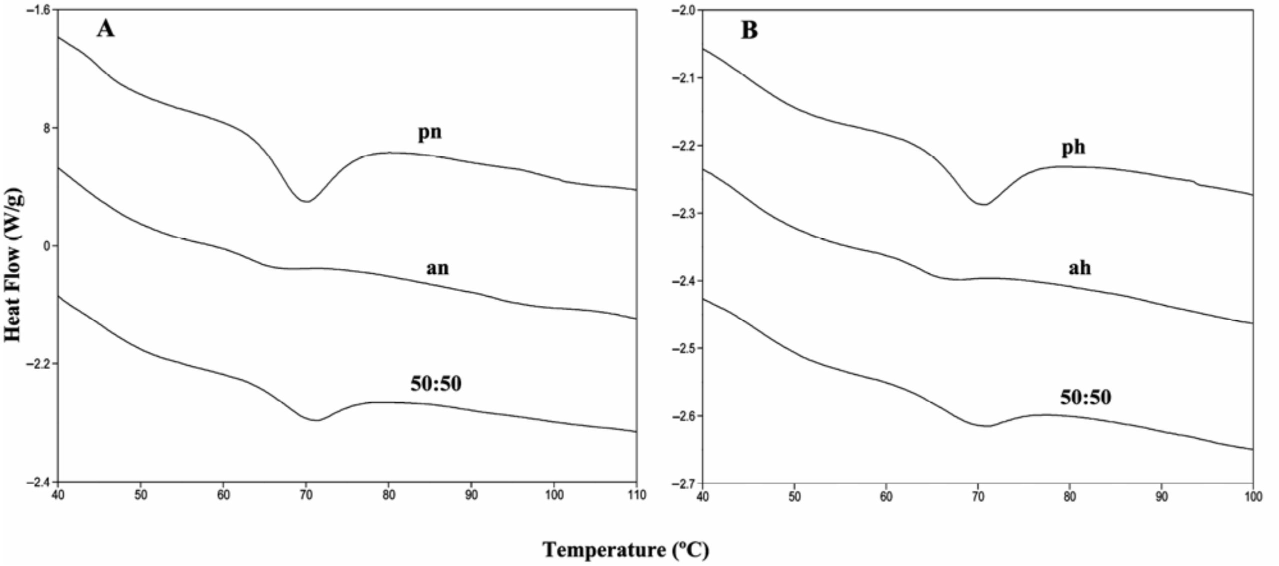

Fig. 3. Differential scanning calorimetry (DSC) curves obtained for retrogradation of 50:50 mixture of pn and an (**A**), ph and ah (**B**). Abbreviations: pn, native potato; an, native amaranth; ph, heat-moisture treated potato; ah, heat-moisture treated amaranth.

A similar explanation can be given for the elevation of PV after cross-linking. Table I shows cross-linking reduces swelling and thus probably increases the stiffness of granules. The relatively low effectiveness of cross-linking on the swelling of amaranth starch could be attributed to its low amylose content. The increased stability of hot paste of HMT and cross-linked starches could be related to lower granular breakdown because both HMT and cross-linking strengthen the starch granules, enabling them to maintain structure at high temperature.

All blends of HMT potato and HMT amaranth, and HMT potato and native amaranth starches showed lower PV and SB than the individual components that had been heat-moisture treated. Interestingly, when a small quantity (10%) of HMT amaranth was mixed with HMT potato, a large decrease in PV resulted without affecting the shape of the pasting profile and the pasting stability ratio (Table IIIB). A similar trend occurred when a small quantity of native amaranth starch was mixed with HMT potato starch (Table IIID). This kind of pasting behavior may be important in some applications and is an area worthy of further research. In these two mixtures, the dramatic reduction in PV indicates decreased swelling characteristics in the mixed system, compared with the individual components alone. When cross-linked potato and cross-linked amaranth starches were mixed, PV increased as the proportion of potato starch increased. Significantly, no breakdown was noticed for all blends, indicating increased hot paste stability of all cross-linked mixtures compared with the individual cross-linked components (Table IIIC).

Gel Hardness

An amaranth starch gel was softer than a potato starch gel. After HMT and cross-linking, the gels produced by the two starches were firmer than their native counterparts (Table IIIA–D). Starch gels are metastable and nonequilibrium systems and therefore undergo structural changes during storage (Ferrero et al 1994). Miles et al (1985) and Ring et al (1987) attributed the initial gel firmness during retrogradation of a normal starch to the formation of an amylose matrix and the subsequent slow increase in gel firmness to reversible crystallization of amylopectin. Morris (1990) explained that starch gel properties relate to the characteristics of the gel matrix of amylose; the deformable fillers or swollen granules that are embedded in the continuous amylose matrix; the volume fraction of the filler; and the filler-matrix interaction. Doublier et al (1987) suggested the main structural parameters of a starch gel are the deformability of swollen starch particles and the amylose concentration in the continuous network. The weak gel of amaranth starch therefore could be attributed to the low concentration of amylose in its continuous network. Eerlingen et al (1997) found that an increase or decrease in gel storage moduli depended upon the heat-moisture treatment conditions and on the concentration of the starch in a gel, as these affect the extent of swelling, solubility, and close-packing concentration. Hoover et al (1994) reported that restriction of swelling by HMT favors the amylose aggregation in the formation of a gel matrix leading to a firmer gel after HMT.

Similar to HMT, a harder gel was formed after cross-linking but the effect was much greater. Cross-linking reinforces the starch granule, improving its rigidity and decreasing the deformability of the starch granules in the gel matrix. The ability of cross-linking to increase gel hardness in both starches is in agreement with the increase in cold paste viscosity. Gel hardness values for the all mixtures of native potato and native amaranth were between those of the individual starch components. A similar trend was seen when cross-linked potato starch was mixed with cross-linked amaranth starch, but a dramatic reduction of gel hardness resulted from the mixtures of HMT potato and HMT amaranth, and HMT potato and native amaranth starches (Table IIIC and D). This is in agreement with the large reduction of peak viscosity and cold paste viscosity seen when these two mixtures were pasted.

Retrogradation

Differential scanning calorimetry (DSC) was used to measure the melting parameters of reorganized or retrograded amylopectin after storage of gels of individual components and mixtures. Nucleation of crystallization in the gels was done at 4°C for 24 hr and growth at 40°C for seven days (Table IV with some representative DSC curves in Fig. 3). DSC curves of retrograded gels of all

TABLE IVA

Melting Parameters Obtained from Differential Scanning Calorimetry (DSC) for Retrograded Starch of Potato and Amaranth Starch Mixtures[a–c]

	Native Potato and Native Amaranth		HMT Potato and HMT Amaranth		Cross-linked Potato and Cross-linked Amaranth	
Starch Ratio	T_p (°C)	ΔH	T_p (°C)	ΔH	T_p (°C)	ΔH
100:0	70.1 ± 0.7	4.5 ± 0.4	69.7 ± 0.5	3.4 ± 0.2	70.2 ± 0.4	4.3 ± 0.8
0:100	66.1 ± 0.3	0.7 ± 0.1	65.9 ± 0.3	0.7 ± 0.1	66.1 ± 0.2	0.8 ± 0.1
90:10	70.1 ± 0.4	4.1 ± 0.1	70.0 ± 0.6	2.8 ± 0.5	70.7 ± 0.3	3.4 ± 0.4
70:30	70.3 ± 0.9	3.5 ± 0.4	70.0 ± 0.7	2.8 ± 0.5	70.5 ± 0.4	2.9 ± 0.5
50:50	70.2 ± 0.5	2.8 ± 0.1	70.1 ± 0.4	2.2 ± 0.3	70.7 ± 0.3	2.7 ± 0.2
30:70	69.7 ± 0.7	1.5 ± 0.3	70.4 ± 0.4	2.0 ± 0.1	71.4 ± 0.8	2.2 ± 0.4
10:90	67.1 ± 0.3	1.3 ± 0.1	67.6 ± 0.6	0.8 ± 0.1	66.9 ± 0.8	1.1 ± 0.1

[a] T_p, gelatinization temperature; ΔH, enthalpy.

[b] Starch concentration (50%).

[c] Values are means of triplicate determination ± standard deviation.

TABLE IVB

Melting Parameters Obtained from Differential Scanning Calorimetry (DSC) for Retrograded Starch of Potato and Amaranth Starch Mixtures[a–c]

	Native Potato and HMT Amaranth		HMT Potato and Native Amaranth	
Starch Ratio	T_p (°C)	ΔH	T_p (°C)	ΔH
90:10	70.1 ± 0.6	3.9 ± 0.3	70.1 ± 0.9	2.8 ± 0.3
70:30	70.2 ± 0.4	3.7 ± 0.2	70.1 ± 0.5	2.1 ± 0.1
50:50	70.1 ± 0.7	2.4 ± 0.1	69.8 ± 0.2	2.0 ± 0.1
30:70	70.0 ± 0.2	1.9 ± 0.4	69.1 ± 0.5	1.6 ± 0.2
10:90	67.5 ± 0.5	1.1 ± 0.2	67.2 ± 0.3	0.9 ± 0.1

[a] T_p, gelatinization temperature; ΔH, enthalpy.

[b] Starch concentration (50%).

[c] Values are means of triplicate determination ± standard deviation.

the individual starches and their blends showed a monomodal endotherm. With the exception of HMT potato ΔH, all the other melting properties of retrograded native, HMT, and cross-linked potato starches were generally similar. In amaranth starches, both HMT and cross-linking had no influence on the melting properties of retrograded amylopectin. Gels of all potato starches showed more retrogradation than the amaranth starches. This may relate to the structural properties of amylopectin, specifically the side chain length and the proportion of long chains. Amylopectin with a long side chain length in a high proportion retrogrades more than that with a short chain length (Kohyama et al 2004). Perhaps the low amylose content of amaranth starch may reduce amylopectin retrogradation. Bulkin et al (1987) showed that amylose has a template effect that accelerates amylopectin retrogradation. According to Gunaratne and Hoover (2002), heat-moisture treatment decreased the retrogradation of B-type starch such as potato, but caused no significant changes to the retrogradation of A-type starch such as wheat. This is in agreement with the observed results in this study.

Cross-linking had no influence on amylopectin retrogradation, indicating that the cross-links largely occurred in the amorphous (amylose) region, and that covaleant bonds formed by a small degree of cross-linking did not interfere with the reassociation of amylopectin chains. The melting temperatures (T_p) of retrograded amaranth starch samples were lower than for potato starch in all cases. In the mixtures, T_p decreased as the proportion of amaranth starch increased. Generally T_p was in between the value of the individual components based on their proportion in the mixture. A similar trend was observed for the melting enthalpies, thus it seems each component in a mixture contributes to the retrogradation according to its proportion.

CONCLUSIONS

This study shows specific nonadditive pasting behavior for some of the potato and amaranth starch mixtures, especially for HMT potato and native amaranth. Such pasting behavior may be useful for some applications in food products and may be an alternative to chemical modification. Interaction between two components in a blend can occur when swelling ability and amylose leaching differed greatly for starch of different granule sizes. In many cases, the paste is stable to breakdown when potato starch is mixed with amaranth starch, depending on the ratio of the mixture. Except for mixtures of HMT potato and HMT amaranth, and HMT potato and native amaranth, pasting properties and gel hardness were intermediate between the two individual components. Individual components in binary starch mixtures appeared to have gelatinized independently during DSC. After retrogradation, all tested mixtures were intermediate between the values of individual components. When the two components in a mixture gelatinized at a similar temperature, increased interaction between two components could take place, causing more changes in pasting properties. It is worth testing more mixtures, including modified and unmodified starches, to determine their optimum ratio for desired physical properties.

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