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Effect of granular characteristics on pasting properties of starch blends

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ABSTRACT

Pasting and morphology properties of starch blends composed of waxy (waxy rice and waxy corn) and non-waxy (normal corn, tapioca and potato) starches at various ratios were investigated for elucidating effect of granular characteristics on pasting of blends. Pasting profiles of blends were between those of the component starches alone, while the changes varied with starch source. Results reveal obvious water competition during pasting for blends composed of waxy starch and highly swelling non-waxy (tapioca or potato) starch. On the contrary, starch blends composed of waxy starch and non-waxy (normal corn) starch with restricted swelling showed less water competition during pasting, and the pasting attributes could be estimated from those of the component starches following the mixing ratio. Results indicate that the pasting properties of starch blends composed of waxy and non-waxy starches depend on not only the mixing ratio, but also the granular characteristics of component starch.

1. Introduction

Native starch does not meet industrial needs for a wide range of application purposes, but can be physically or chemically modified to obtain desired properties. Generally, chemical modification, such as cross-linking and/or acetylation, is more effective and widely used (Jacobs & Delcour, 1998). However, for healthy standpoint, nowadays market's tendency presses the producers toward more natural food components and avoids as much as possible the chemical treatments. It is therefore of interest to find new ways to improve the properties of native starches without chemically modified. One possibility is the mixing of starches with different botanical sources (Ortega-Ojeda & Eliasson, 2001), which had been proposed to use in the mixtures of pudding powder (Stute & Kern, 1994). Sandhu, Kaur, and Mukesh (2010) indicated blending of potato and rice starch in the ratio of 50:50 resulted in good quality noodles as compared to noodles prepared by using of starch with other blending ratios, in terms of their lower cooking time, higher cooked weight, transparency and slipperiness. A 70:30 blend of the pigeon pea and rice starches produced noodles with superior quality as compared to native pigeon pea and rice starch noodles (Yadav, Yadav & Kumar, 2011).

Pasting properties of starch is generally determined by using of Brabender viscoamylography, rapid viscous analysis, or dynamic rheometry, and is useful information for understanding the textural change or retrogradation potency of the applied products. Pasting parameters of starch slurry during heating have been proposed to be related to the granule size (Okechukwu & Rao, 1995), properties of swelling power/solubility (Evans & Lips, 1992), or properties of the swollen granules and soluble materials of starch (Doublier, Llamas & Le Meur, 1987). In summary, swelling of starch is mainly a property of amylopectin, while amylose acts as a diluent.

Properties of blended starches have been proposed to be associated with starch concentration (Liu & Lelievre, 1992), mixing ratio (Chen, Lai & Lii, 2003), amylose/amylopectin ratio (Ortega-Ojeda, Larsson, & Eliasson 2004) and interactions between the granules (Obanni & BeMiller, 1997). Sasaki, Yasui, Matsuki and Satake (2002) studied starches with various amylose content by blending starches isolated from waxy and non-waxy wheat at different ratios and indicated that mixed starches showed higher swelling power than native starches with the same amylose content. Puncha-arnon, Pathipanawat, Puttanlek, Rungsardthong and Uttapap (2008) indicated that swelling capability of canna–rice starch blends decreased with increasing ratio of rice starch content at 70 °C, especially at the ratio of canna to rice starch at 25:75. At the same heating temperature, canna starch granules in the starch blends were obviously less swelled as compared to canna starch alone, this was attributed to the effect of surrounding rice starch granules on gelatinization behavior of canna starch.

Obanni and BeMiller (1997) indicated that the amylogram of starch blend, preparing by mixing common com starch (CCS) and waxy com starch (WCS) at 50:50 ratio, showed two maximum peak viscosities (PV) with the first peak slightly preceding that given by WCS alone and the second peak at the position where CCS

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reached its maximum viscosity when pasted alone. Sandhu et al. (2010) showed PV significantly increased with increasing content of potato starch in potato–rice blends, which was attributed to the higher swelling power of potato starch. Ortega-Ojeda et al. (2004) indicated that when native potato starch was added to high amylopectin potato starch, higher moduli values of starch gels were obtained and could be referred to the presence of amylose in the blends, which led to stronger network formation. This indicates that the existence of amylose is important for the rheological properties in a starch blend of native amylopectin. Obanni and BeMiller (1997) concluded that interactions of starch molecules from different starches occurred very early in the heating process, which could be between leached amylose from one starch and granules of the other starch or between molecules on the outer surfaces of granules of the two starches.

Chen et al. (2003) indicated that the gelatinization thermal properties of rice starch blends were related to the swelling power of component rice starches, and the viscosity of starch blends were determined by the different in swelling ability between the two rice starch species and the resultant shear-induced granular disintegration. Furthermore, influence of granular properties on pasting behaviors of starch blends was higher than that of the soluble materials, implying that the granular characteristics of starch granules plays an important role on pasting properties of starch blends. Although Chen et al. (2003) had proposed the granular characteristic effect on properties of rice starch blends, results were limited due to the restricted variation in properties of component starches, such as granule size or swelling behavior of rice starch used in their study. More supplementary information on other commercially available starch samples, such as corn, tapioca and potato starches, is needed for further understanding granular characteristic effect on properties and application of starch blends. In this study, pasting properties of starch blends composed of waxy (waxy rice and waxy corn) starches and non-waxy (normal corn, tapioca and potato) starches at various ratios, as well as morphology of pastes of starch blends after heated to the desired temperatures, were investigated for systematically illustrating effects of mixing ratio and granular characteristics of component starch on pasting of starch blends. The observed composition-property relationship of mixed starch systems is expected of highly industrial application feasibility.

2. Materials and methods

2.1. Starches and starch blends

Waxy rice starch was isolated from TCW70 waxy rice according to the alkaline steeping method of Lin, Wang and Chang (2008). Waxy corn starch was product of National Starch and Chemical Company (Bridgewater, USA). Tapioca starch was gifted from Vedan Enterprise Corp. (Dong Nai, Vietnam). Corn and potato starches were purchased from Roquette Company (Lestrem, France) and Parachem Company (Brande, Denmark), respectively. Starch blends were prepared by mixing waxy (waxy rice and waxy corn) and non-waxy (normal corn, tapioca and potato) starches at various ratios (90:10 to 10:90) following the procedure of Obanni and BeMiller (1997).

2.2. Granule size

Average granule size of starch was determined by a dynamic laser-light scattering-based particle size analyzer (Mastersizer Micro, Malvern Instruments, Malvern, UK) with 10–15% for obscuration and 1950 rpm for paddle speed.

2.3. Amylose content

Amylose content of starch was calculated from iodine affinity value according to the method proposed by BeMiller (1964). Starch was defatted with 85% methanol in a Soxhlet extractor for 48 h. Defatted starch (0.1 g) was suspended with 1 mL of water. Twenty milliliters of 1 N KOH was added, and the sample was dispersed by stirring at 4 °C for 30 min. This solution was then diluted with 20 mL of water. Ten mL of the solution was added 75 mL of water, 10 mL of 1 N HCl and 5 mL of 0.4 N KI by stirring in water bath at 25 °C. The iodine affinity of starch was determined by amperometric titration method using titrator (702 SM Titrino, Metrohm, Herisau, Switzerland) equipped with a platinum electrode.

2.4. Swelling power and solubility

Starch (0.1 g, db) was heated in 40 mL of distilled water to the desired temperatures for 30 min. The formation of lump was prevented by continuously stirring. The mixture was centrifuged at 4000 × *g* for 15 min. The sediment was weighed immediately and an aliquot of supernatant was evaporated at 130 °C and weighed. Swelling power and solubility of starch were measured at four different temperatures of 60, 70, 80 and 90 °C. Solubility is the ratio of the weight of the dried supernatant to the initial weight of the dry starch, while the swelling power of starch is the ratio of the weight of sediment paste to initial weight of the dry starch (Lin, Pan, Hsu, Singh & Chang, 2012).

2.5. Pasting properties

Pasting properties of starch blends were determined by using of a Rapid Visco-Analyzer (RVA 3D+, Newport Scientific, Warriewood, Australia). Each starch suspension (7%, w/w, 28 g total weight) was equilibrated at 35 °C for 1.5 min, heated to 95 °C at a rate of 6 °C/min, maintained at 95 °C for 5 min, then cooled to 35 °C at a rate of 6 °C/min, and maintained at 35 °C for 5 min. Paddle speed was set at 960 rpm for the first 10 s and then 160 rpm for the rest of the analysis (Chang, Lin & Chen, 2006). The parameters recorded were peak viscosity (PV), hot paste viscosity (HPV) (minimum viscosity at 95 °C), final viscosity (FV), breakdown (BD = PV − HPV), and setback (SB = FV − HPV). Breakdown ratio (BDr) and setback ratio (SBr) were defined as the ratios of BD to PV and SB to HPV, respectively.

2.6. Gelatinization thermal properties

Gelatinization thermal properties of starch blends were determined by using of a differential scanning calorimeter (DSC, Micro DSC VII, Setaram, France). Starch sample (about 150 mg, dry basis) was weighed in the sample pan, mixed with distilled water (starch:water = 1:3), sealed and equilibrated at room temperature for 1 h. The samples were heated from 25 to 115 °C at a heating rate of 1.2 °C/min.

2.7. Microscopic observation

Starch paste (7%, db) was heated to the desired temperatures (60, 70, 80 and 90 °C) in the RVA with the same heating rate and stirring speed used for pasting properties determination. After heating, appropriate amount of sample was loaded on slide and stained by iodine solution (1 mL solution containing 1.67 mg I_2 and 3.33 mg KI). The slide was then observed under the light microscope (BH2, Olympus, Japan).

Table 1
Average[a] granule size, amylose content, swelling power and solubility of starches.

Starch	Average granule size (μm)	Amylose content (%)	Swelling power (g/g)				Solubility (%)			
			60 °C	70 °C	80 °C	90 °C	60 °C	70 °C	80 °C	90 °C
Waxy rice	6.7 ± 0.0[a]	0.3 ± 0.0	3.5 ± 0.0	42.4 ± 0.3	43.6 ± 0.6	53.7 ± 0.6	10.6 ± 0.3	11.2 ± 0.6	15.8 ± 1.4	17.8 ± 3.1
Waxy corn	16.4 ± 0.0[a]	0.6 ± 0.1	3.3 ± 0.1	16.3 ± 0.1	41.1 ± 2.4	60.7 ± 1.3	0.9 ± 0.1	4.1 ± 1.3	7.3 ± 0.3	22.6 ± 1.1
Normal corn	15.4 ± 0.0	25.9 ± 0.2	4.4 ± 0.1	9.2 ± 0.1	8.8 ± 0.1	10.6 ± 0.1	4.4 ± 0.3	7.7 ± 0.6	8.0 ± 0.8	9.2 ± 0.1
Tapioca	16.7 ± 0.1	19.6 ± 0.1	3.0 ± 0.0	20.0 ± 0.4	29.6 ± 0.6	40.8 ± 1.5	7.5 ± 0.6	11.3 ± 0.6	12.7 ± 0.3	13.0 ± 0.4
Potato	47.2 ± 0.2	21.4 ± 0.3	12.5 ± 0.4	35.0 ± 0.4	66.0 ± 0.4	82.2 ± 2.9	8.6 ± 0.1	8.6 ± 0.5	11.9 ± 0.6	15.0 ± 0.4

[a] Mean ± standard deviation, $n = 3$.

3. Results and discussion

3.1. Granule size and amylose content

Table 1 shows that the average granule size of waxy rice starch (6.7 μm) was much smaller than that of waxy corn starch (16.4 μm). For non-waxy starches, potato starch exhibited the largest average size (47.2 μm), while similar granule size for normal corn (15.4 μm) and tapioca (16.7 μm) starches were observed. The amylose contents of waxy rice and waxy corn starch were below 1%, while normal corn starch had the highest amylose content (25.9%) among the non-waxy starches examined. The amylose contents of potato and tapioca starches were comparable, which were 19.6 and 21.4%, respectively.

3.2. Swelling power and solubility

Swelling power of waxy rice starch was low at 60 °C and increased sharply from 3.5 to more than 40 g/g at temperature higher than 60 °C (Table 1). For waxy corn starch, swelling power was also low at 60 °C (3.3 g/g), but the swelling power of waxy corn starch linearly increased with increasing temperature. Waxy rice starch had higher swelling power at 60 to 80 °C than waxy corn starch, while waxy corn starch had higher swelling power (60.7 g/g) than waxy rice starch (53.7 g/g) at 90 °C. Solubility of waxy rice starch was higher than 10% at 60 °C, while waxy corn starch showed very low solubility (0.9%) at the same temperature. In contrast to its low swelling power at 60 °C, the high solubility of waxy rice starch could be attributed to its small granule size. Small granule size of starch results in granule suspension and loss in supernatant during centrifugation in determination. Solubility of waxy rice starch only slightly increased with increasing temperature, while solubility of waxy corn starch increased with increasing temperature, especially at temperature from 80 to 90 °C. Results of swelling power and solubility of starches are in line with our previous study (Lu, Duh, Lin & Chang, 2008), revealing that waxy rice starch had lower swelling temperature than waxy corn starch. Since the changes on swelling power and solubility of waxy rice starch (from 42.4 to 53.7 g/g and 11.2 to 17.8%, respectively) accompanying with temperature increase were less obvious than those of waxy corn starch (from 16.3 to 60.7 g/g and 4.1 to 22.6%, respectively), swollen granules of waxy rice starch was more stable than waxy corn starch, especially at temperature higher than 70 °C. Consequently, the swelling of waxy corn starch at 90 °C was more profound than that of waxy rice starch even though the swelling temperature of waxy rice starch was lower.

Normal corn starch had the lowest swelling power among the non-waxy starches, which was increased from 4.4 to 10.6 g/g as temperature increased from 60 to 90 °C. Swelling power of tapioca and potato starches increased with increasing temperature, while potato starch had the highest swelling power among the non-waxy starches studied, which was about two-times higher swelling power than normal corn and tapioca starches. Solubility of the three non-waxy starches slowly increased with increasing temperature, and potato starch also showed the highest solubility among the non-waxy starches. Tsai, Li, and Lii (1997) concluded that weaker granular rigidity resulted in higher swelling power and solubility of starch. Higher solubility of starch can be attributed to more solubilizing and leaching of polymers from starch granules with weaker rigidity as heated and broken at high temperature. Therefore, waxy corn starch had weaker granular rigidity than waxy rice starch as heated in temperature higher than 80 °C. The same is true for potato starch as compared to tapioca and normal corn starches.

3.3. Pasting properties

3.3.1. Waxy and non-waxy starches

Fig. 1 shows the pasting profiles of waxy and non-waxy starches alone. Pasting temperatures (PT) of waxy rice and waxy corn starches were 69.1 and 72.2 °C, respectively. Waxy rice and waxy corn starches showed comparable values of peak viscosity (PV), which was 2162 and 2268 cP, respectively. However, waxy rice starch had higher hot paste viscosity (HPV) and final viscosity (FV) than those of waxy corn starch. On the other hand, waxy rice starch showed lower breakdown viscosity (BD) and breakdown ratio (BDr) than waxy corn starch. Comparing to waxy corn starch, the higher HPV, lower BD and BDr of waxy rice starch corresponds

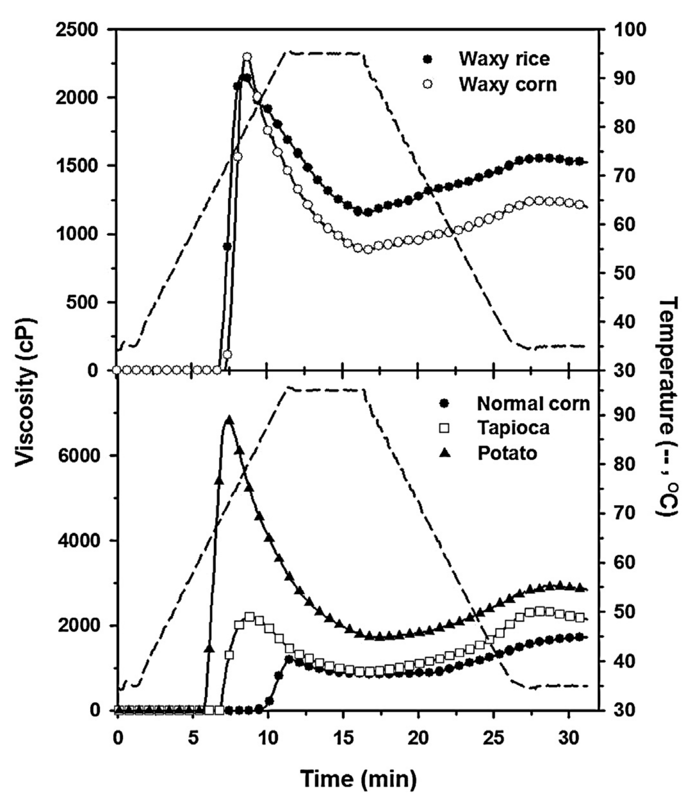

Fig. 1. Pasting profiles of starches.

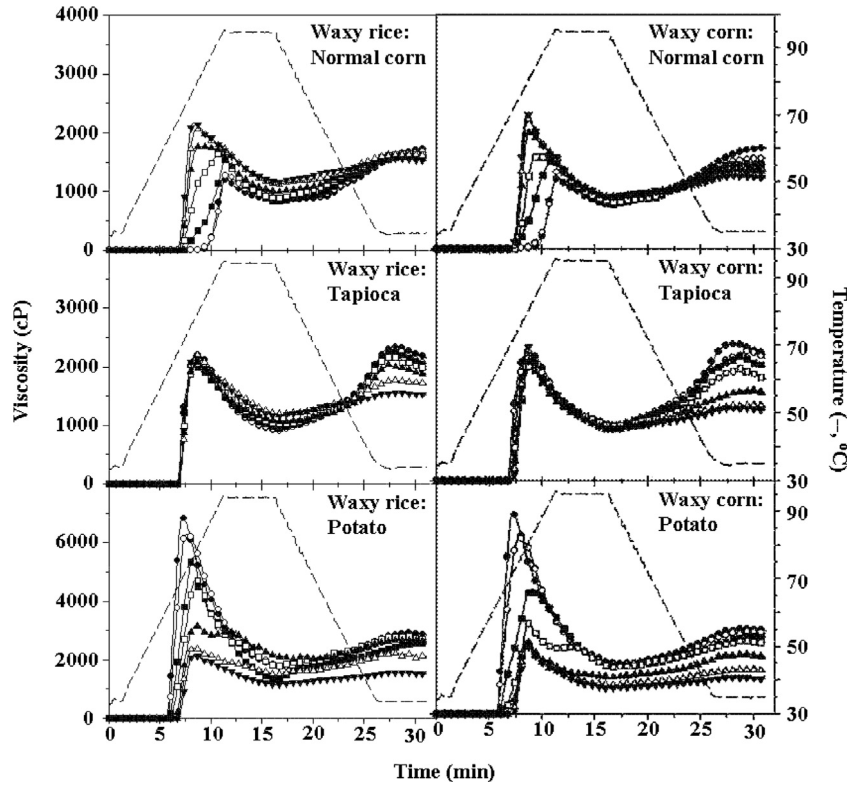

Fig. 2. Pasting profiles of starch blends composed of waxy starches and non-waxy starches at different ratios: 100:0 (▾), 90:10 (△), 70:30 (▴), 50:50 (□), 30:70 (■), 10:90 (◯) and 0:100 (●).

to its lower swelling power and solubility at 90 °C (Table 1). This reveals that waxy rice starch is more resistant to shearing and cooking than waxy corn starch; in other words, waxy rice starch has higher granular rigidity than waxy corn starch. Similar conclusion was reported by Lu et al. (2008) from data of pasting properties and dynamic rheological properties of waxy rice and waxy corn starches.

Non-waxy starches exhibited diverse values of PT, which were 84.9, 69.1 and 62.4 °C for normal corn, tapioca and potato starches, respectively. Potato starch had the highest PV (6785 cP), which was over two-times higher than that of tapioca (2189 cP) and normal corn starch (1197 cP). Although the highest HPV of potato starch was observed, the highest BD and BDr for potato starch were also obtained. Tapioca and normal corn starches showed comparable HPV, however the BD and BDr of tapioca starch were higher than those of normal corn starch. Normal corn starch possessed the lowest swelling power and BD among the three non-waxy starches, revealing that the granular rigidity of normal corn starch is stronger than other non-waxy starches studied.

Potato starch also had the highest FV and normal corn starch had the lowest one, while tapioca starch had the highest SBr among the three non-waxy starches. Even though normal corn starch had the highest amylose content, it showed lower SBr than tapioca starch. Lower SB in RVA determination of starch was attributed to lower amylose leaching during heating (Naguleswaran, Vasanthan, Hoover & Liu, 2010), therefore the lower SBr of normal corn starch could be due to the less amount of amylose leached in restrict swelling of normal corn starch granules. This can be confirmed by the lowest solubility of normal corn starch among the non-waxy starch studied. Furthermore, PT and PV of tapioca starch were comparable to those of waxy rice and waxy corn starch (Fig. 1), indicating that tapioca starch exhibited similar change in viscosity to waxy starches during the initial heating period of RVA determination.

3.3.2. Starch blends

Fig. 2 shows the pasting profiles of starch blends composed of waxy and non-waxy starches with various ratios. Compared to waxy rice starch alone, pasting peaks of starch blends, consisting of waxy rice and normal corn starches at various ratios, shifted toward higher temperature with increasing ratio of normal corn starch. PT of the waxy rice-normal corn starch blends also increased, while PV and HPV decreased, with increasing ratio of normal corn starch. Furthermore, the starch blends showed comparable FV to that of waxy rice or normal corn starches alone. Consequently, SB of the starch blends increased with increasing ratio of normal corn starch. The amylose leached from normal corn starch granules led to stronger network formation, therefore SB of the waxy rice-normal corn starch blends increased with increasing ratio of normal corn starch.

Pasting profiles of starch blends, consisting of waxy rice and tapioca starches with various ratios, were similar. Similar PT and PV of the waxy rice–tapioca starch blends were observed despite of mixing ratio of starches (Fig. 2). HPV of the starch blends slightly decreased with increasing ratio of tapioca starch, while FV and SB of the blends showed reverse trends. Swelling power and PT of tapioca starch were similar to those of waxy rice starch, resulting in the comparable PV of the waxy rice–tapioca starch blends in spite of mixing ratio. Moreover, the introducing of amylose from tapioca starch to the waxy rice–tapioca starch blend significantly enhanced the SB during cooling, and further improved the network strength of gel/paste of starch blend.

Pasting peaks of starch blends, consisting of waxy rice and potato starches, slightly shifted toward lower temperature with increasing ratio of potato starch. PT of waxy rice–potato starch blends decreased, while PV noticeably increased, with increasing ratio of potato starch. Nevertheless, starch blend with ratio of 50:50 had the highest HPV. FV of the waxy rice–potato starch blends were obviously higher than that of waxy rice starch alone, and were similar to that of potato starch alone, except for the starch blend with

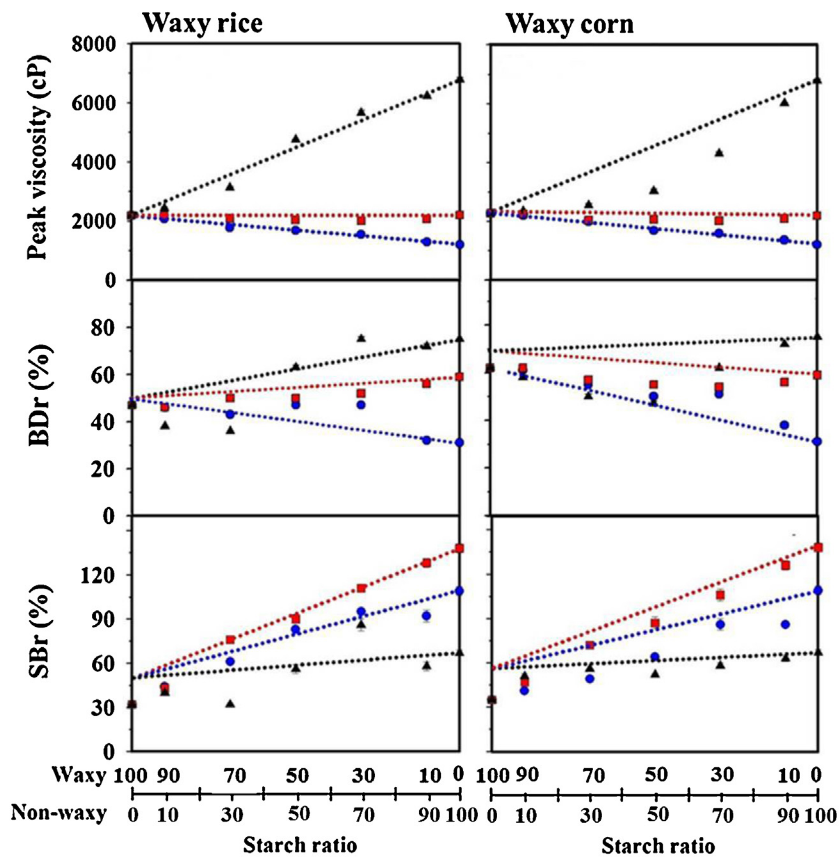

Fig. 3. Effect of mixing ratio on peak viscosity (PV), breakdown ratio (BDr) and setback ratio (SBr) of waxy starches blended with normal corn starch (●), tapioca starch (■) and potato starch (▲). The dotted lines stand for the calculated expected values.

mixing ratio of 90:10. Both waxy rice and potato starches possessed high values of swelling power, indicating high water absorption during pasting, therefore water competition between waxy rice and potato starch granules during pasting was more profound as expected.

Pasting properties of starch blends composed of waxy corn starch and non-waxy starches were found similar to those of the counterpart starch blends composed of waxy rice starch and non-waxy starches, while the differences among starch blends with various ratios of same component starches were more noticeable for starch blends composed of waxy corn starch than the counterpart starch blends composed of waxy rice starch, especially for the differences in FV of starch blends.

3.3.3. *Effect of mixing ratio*

Physicochemical properties of starch blends were affected by mixing ratio and tended to those of the starch with higher ratio (Sasaki et al., 2002; Hagenimana & Ding, 2005; Puncha-arnon et al., 2008), however the changes in pasting attributes of starch blends did not show a linear correlation with mixing ratio (Fig. 2). For elucidating the influence extent of mixing ratio on pasting of starch blends, PV, BDr and SBr were selected for further investigation. Dotted lines in Fig. 3 represent the expected values of the pasting attributes for starch blends at each mixing ratio, which were calculated based on the pasting attributes of the waxy and non-waxy starches alone and followed the mixing ratio of starch in a first order linear model. Results of Fig. 3 show that the PV of starch blends, consisting of waxy rice and non-waxy starches with various mixing ratios, were in line with the expected values. The same is true for starch blends composed of waxy corn and non-waxy starches, except for waxy corn–potato starch blends. PV of waxy corn–potato starch blends with different mixing ratios was obviously lower than the counterpart expected value.

Compared to waxy starches, normal corn starch exhibited higher PT and restricted granular swelling (Fig. 1), therefore granules from waxy starch would fully swell during heating of starch blends composed of waxy starch and normal corn starch. Although the swelling of waxy rice starch granules could result in less amount of water for normal corn starch granules to swell, the water competition between granules of waxy starch and normal corn starch was not obvious for starch blends composed of waxy starch and normal corn starch (Fig. 3). This was owing to the restricted granular swelling property of normal corn starch, which leaded to less requirement of water for normal corn starch as heated in starch blends with other starches. Consequently, the pasting attributes of starch blends composed of waxy starch and normal corn starch showed linear correlations with the mixing ratio of component starch.

For starch blends composed of waxy starch and tapioca starch, tapioca starch exhibited similar pasting properties to that of waxy starch during heating (Fig. 1), hence both waxy starch and tapioca starch swelled and adsorbed water at the same time. Consequently, pasting profile of starch blends composed either waxy rice or waxy corn starches with tapioca starch were very similar (Fig. 2), and PV of the starch blends was comparable to the expected values.

Correlation between PV and mixing ratio of starch blends composed of waxy starch and potato starch varied with type of waxy starch. The obviously lower PV of waxy corn–potato starch blends as compared to the expected values could be attributed to the larger granule size and higher swelling power at high temperature of waxy corn starch (Table 1), which resulted in more water competition between waxy corn starch and potato starch as compared to that between waxy rice starch and potato starch. Hence starch granules in waxy corn–potato starch blends exhibited limited swelling during heating, and lower PV than expected was observed accordingly.

BDr of waxy rice–tapioca starch blends was comparable to its expected values, while BDr of waxy rice-normal corn starch blends with mixing ratio of 50:50 and 30:70 were higher than the counterpart expected values. Moreover, BDr of waxy rice–potato starch blends with mixing ratio of 90:10 and 70:30 were significantly lower than their expected values, and higher value than expected was observed for starch blend with mixing ratio of 30:70. BDr of waxy corn–normal corn starch blends with mixing ratio of 50:50 and 30:70 were higher than their expected values, similar to that of waxy rice-normal corn starch blends. BDr of waxy corn–tapioca starch blends were slightly lower than the counterpart expected values. BDr of waxy corn–potato starch blends were significantly lower than their expected values, especially at mixing ratio of 30:70 to 70:30.

Correlation between BDr and mixing ratio of starch also varied with type of starch. Due to the similar pasting properties and granular characteristics of waxy starches and tapioca starch, BDr of starch blends composed of waxy starches and tapioca starch could be predicted from BDr of the component starches alone following the mixing ratio. BDr of starch blend composed of waxy starch and normal corn starch with mixing ratio of 30:70 was obviously higher than its expected value. It is acknowledged that amylose restrains swelling of starch granules, both waxy rice and waxy corn starches had high swelling power and less granular rigidity, while normal corn starch showed limited swelling and high granular rigidity. Starch blends composed of waxy starch and normal corn starch were mixed two types of starch with obviously different granular strength, friction of granules during heating and shearing could cause rupture and breakdown of granules with less rigidity in starch blends.

Starch blends composed of waxy rice and potato starch showed lower BDr than their expected values at mixing ratios of 90:10 and 70:30. The same is true for waxy corn–potato starch blends at each mixing ratio. This reveals that the breakdown of starch granules were reduced owing to the water competition between both component starches during pasting. Water competition between waxy starch and potato starch was also observed on PV for waxy corn–potato starch blends. Moreover, BDr of waxy rice–potato starch blend with mixing ratio of 30:70 was higher than its expected value. On the other hand, similar result was not found for waxy corn–potato starch blends.

SBr of waxy rice-normal corn starch blends showed slightly higher or similar values to their expected values. Waxy rice–tapioca starch blends also show similar SBr to their expected values. Comparable values of SBr for waxy rice–potato starch blends and the counterpart expected values were also observed, except for starches blended with mixing ratio of 30:70. SBr of waxy rice–potato starch blend with mixing ratio of 30:70 was higher than its expected value. Alternatively, SBr of starch blends composed of waxy corn and non-waxy starches were in line with the counterpart expected values. While gelation of solubilized amylose appears to dominate the initial stage of starch gelation (Miles, Morris, Orford & Ring, 1985), results of this study indicate that the introducing of amylose in to waxy starch enhances retrogradation of starch during cooling period of RVA determination, and retrogradation extent of starch blends composed of waxy and non-waxy starches were directly related to mixing ratio of the component non-waxy starch.

3.4. Gelatinization thermal properties

The gelatinization onset temperature (T_0) of waxy rice–normal corn, waxy rice–tapioca, waxy corn–normal corn and waxy corn–tapioca starch blends were ranged from 61.9 to 63.1 °C, and no significantly differences were found in T_0 among starch blends with various mixing ratio of waxy starches and normal corn/tapioca starch. This can be attributed to the similar T_0 of these starches (62.1, 62.7, 62.9 and 62.9 °C for waxy rice, waxy corn, normal corn and tapioca starch, respectively). On the other hand, the T_0 of potato starch (55.0 °C) was significantly lower than waxy starches, the T_0 of waxy rice–potato and waxy corn–potato starch blends varied with mixing ratio. At mixing ratio (waxy starch:potato starch) 10:90 to 70:30, the T_0 of both waxy rice–potato and waxy corn–potato starch blends were comparable to that of potato starch alone, while the T_0 of starch blends at mixing ratio 90:10 were comparable to that of the component waxy starch alone.

The gelatinization enthalpy change (ΔH) of waxy rice, waxy corn, normal corn, tapioca and potato starches were 16.0, 16.2, 13.0, 15.0 and 16.9 (J/g), respectively. Fig. 4 illustrates the changes in ΔH, corresponding to the mixing ratio, of starch blends. Starch blends showed higher values of ΔH than the expected values, especially for starches blended at mixing ratio of 50:50. This was more profound for waxy starches blended with potato starch. The higher value of ΔH for starch blends confirms the occurrence of water competition of starch granules in blends during pasting.

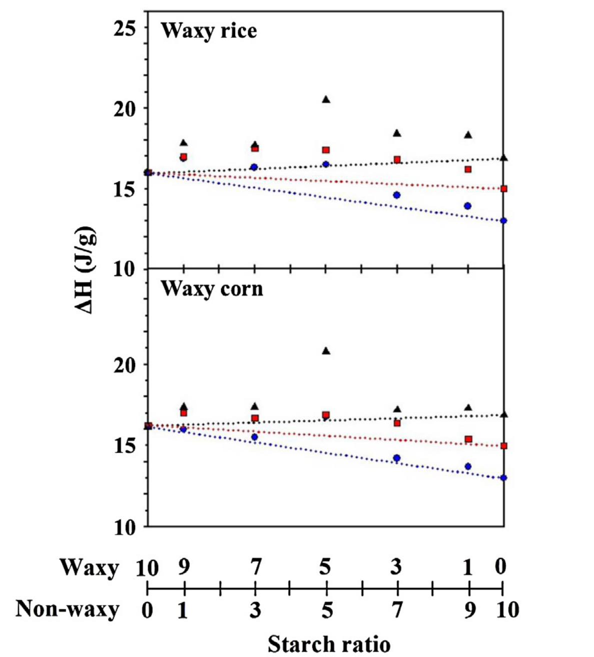

Fig. 4. Effect of mixing ratio on gelatinization enthalpy change (ΔH) of waxy starches blended with normal corn starch (●), tapioca starch (■) and potato starch (▲). The dotted lines stand for the calculated expected values.

3.5. Microscopic observation

Light microscopic observations on iodine-stained starch blends pre-heated to the assigned temperatures are illustrated in Figs. 5 and 6. Stained waxy starches showed purple brown color, which is the typical color of amylopectin stained by iodine (Obanni & BeMiller, 1996). Granules of waxy rice starch remained intact at 60 °C but disappeared at temperature above 70 °C (Fig. 5). After staining by iodine, non-waxy starch granule exhibited blue color, resulting from the complex of amylose and iodine. Granules of normal corn starch swelled after heating and the granule size increased with increasing temperature, even after heated to 90 °C normal corn starch still remained its granular appearance. For starch blends composed of waxy rice and normal corn starches,

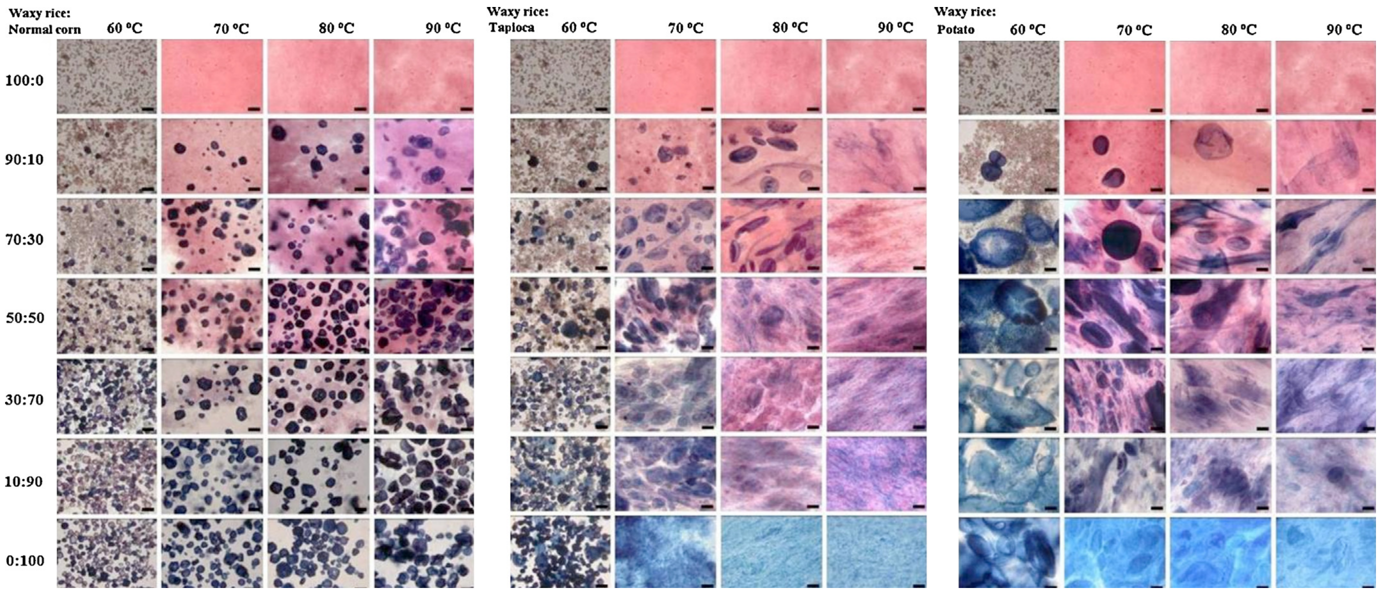

Fig. 5. Micrographs of iodine-stained starch blends, consisting of waxy rice and non-waxy starches with different ratios, after heated in RVA to the desired temperature (Bar = 30 μm).

only granules/ghosts of normal corn starch could be observed at temperature above 70 °C.

Granules of tapioca starch after heated to 60 °C showed slightly swelling and expansion, however most granules remained intact. After heated to 70 °C most granules of tapioca starch swelled and collapsed, and were fully broken at temperature above 80 °C. Tapioca starch granules dispersed in water after heated to 80 °C or higher temperature, and no starch ghosts or fragments could be found. After heated to 70 °C or higher temperature, swelled tapioca starch granules, while no waxy rice starch granules, could be observed for the waxy rice–tapioca starch blends. Presence of tapioca starch ghosts or fragments after heating was more profound for waxy rice–tapioca starch blends with mixing ratio of 50:50 to 90:10.

Potato starch granules swelled after heated to 60 °C, most granules disappeared at 70 °C or higher temperature and only a few starch ghosts or fragments could be observed at 90 °C. Presence of potato starch ghosts or fragments after heating was more profound for waxy rice–potato starch blends with mixing ratio of 50:50 and 70:30, similar to that for waxy rice–tapioca starch blends. The color of iodine-stained potato starch granules in waxy rice–potato starch blends was darker than that of potato starch alone, this could be owing to the swelling of potato starch granules was limited in starch blends during heating as compared to that of potato starch alone.

Slightly granule swelling were found for waxy corn starch after heated to 60 °C, while most granules disappeared after heated to 70 °C and fully dispersed at temperature above 80 °C (Fig. 6). After heated to the desired temperatures, starch blends composed of waxy corn and non-waxy starches showed similar changes in morphologic observation to those of starch blends composed of waxy rice and non-waxy starches. No obvious change was found for

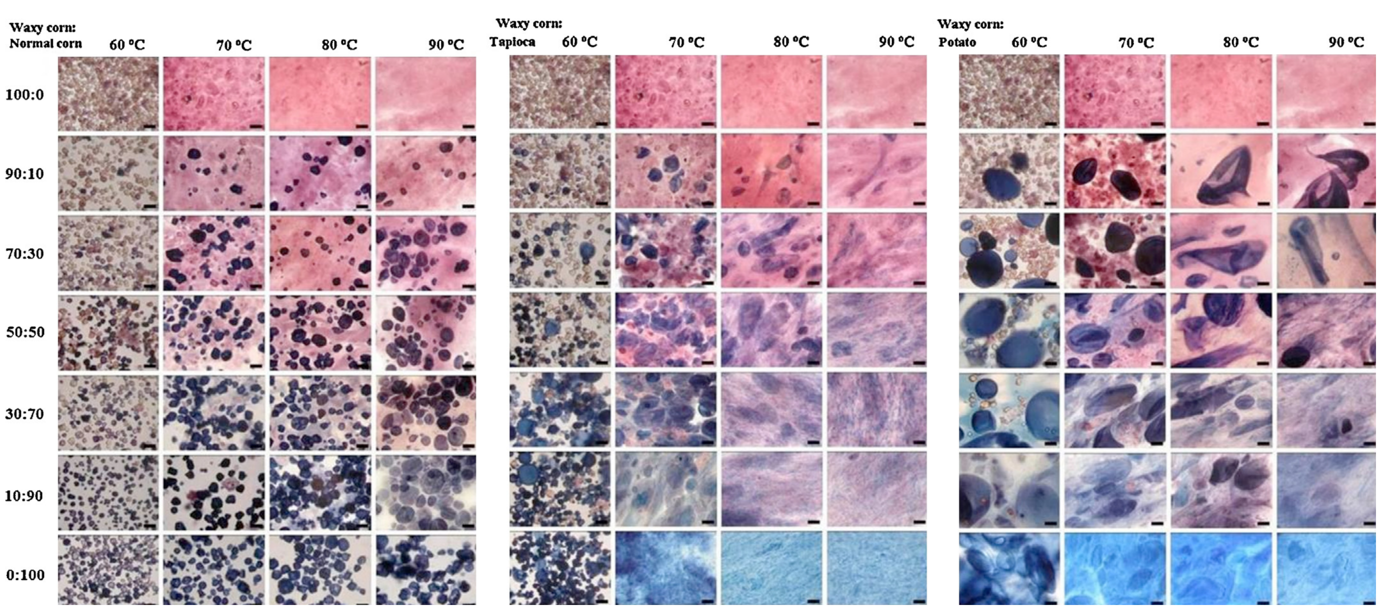

Fig. 6. Micrographs of iodine-stained starch blends, consisting of waxy corn and non-waxy starches with different ratios, after heated in RVA to the desired temperature (Bar = 30 μm).

normal corn starch granules after heated in blends, mixing with either waxy rice or waxy corn starch, as compared to that of normal corn starch alone. It reveals that water competition between waxy starch and normal corn starch was not obvious. However, the swelling of both tapioca and potato starch granules after heating were limited in starch blends, especially for potato starch. This indicates that water competition between waxy starch and potato starch in blends was more profound than that between waxy starch and other non-waxy starches. Moreover, the restricted swelling of normal corn starch granules resulted in less influence on water competition in starch blends composed with waxy starch and normal corn starch during pasting. While tapioca and potato starch exhibited high swelling during heating and were similar to that of waxy starches, therefore obvious water competition between high swelling starches occurred in starch blends composed of these starches. This phenomenon was more intense for potato starch and could be attributed to the obviously lower PT and larger granule size of potato starch as compared with waxy rice and waxy corn starches.

4. Conclusion

Although the pasting profiles of starch blends were found between those of the component waxy and non-waxy starches, the pasting attributes did not showed linearly correlation to the mixing ratio. Restricted swelling of normal corn starch during pasting caused its less influence on water competition in starch blends as composed with waxy starch, therefore the pasting attributes of starch blends could be estimated from those of the component starches following the mixing ratio. Tapioca and potato starches, as well as waxy starches, exhibited high granular swelling during pasting, consequently more obvious water competition between different types of starch granules in blends was expectable, especially for waxy starch blended with potato starch. The larger granule size and lower pasting temperature of potato starch resulted in more obvious water competition between potato starch and waxy starch in blends during pasting as compared to blends composed of waxy starch and tapioca or normal corn starches.

Results of this study reveal that pasting properties of starch blends depend on not only mixing ratio of starch but also granular characteristics of the component starches. Mixing of waxy and non-waxy starch varies the pasting properties of starch, and enhances variation on application and improving physicochemical property diversity of starch. Further investigation on gel properties and application of starch blends in processed foods is underway.

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