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RVA study of mixtures of wheat flour and potato starches with different phosphorus contents

I.S.M. Zaidul *, Hiroaki Yamauchi, Sun-Ju Kim, Naoto Hashimoto, Takahiro Noda

Department of Upland Agriculture, National Agricultural Research Center for Hokkaido Region, Shinsei, Memuro, Kasai, Hokkaido 082-0071, Japan

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Abstract

A rapid visco analysis (RVA) system was used to study the pasting properties of mixtures of wheat flour and potato starches with high phosphorus (HPS), medium phosphorus (MPS) and low phosphorus (LPS) contents, different granule sizes and different amylose contents. The peak viscosities, trough and breakdown, final viscosities, setback viscosities and peak times of control potato starches were found to be higher than those of wheat flour. The peak viscosities were increased significantly with increase of potato starches in the mixtures. Thus, the peak times decreased with increase of potato starch in the mixtures. The breakdown viscosities increased significantly with increase of potato starches in the mixtures and the values were found to be higher in HPS-wheat, followed by MPS-wheat and LPS-wheat mixtures. The final viscosities of HPS-wheat mixtures were highest, followed by MPS-wheat and LPS-wheat mixtures. The setback viscosities of LPS-wheat were significantly higher than those of MPS-wheat and HPS-wheat mixtures at 30 to 50% potato.

Keywords: Potato starch; Phosphorus content; Wheat flour; Mixtures; Pasting properties

1. Introduction

The potato (*Solanum tuberosum* L.) is an important upland crop in Japan. The total annual production of potatoes in Japan was approximately 2.96 million tons in 1999, and about 75% of the total production comes from Hokkaido, the northernmost and second largest island of Japan (Mori, 2001). Potatoes for starch production, which account for 35–40% of the domestic output, are grown exclusively in Hokkaido. On the other hand, Japan, produced 0.7 million tons of wheat in 2002, and it satisfied only 13% of the domestic demand. Consequently, Japan imported 5.5 million tons of wheat and, thus, became the fourth-largest wheat importer in the world wheat market in 2002. The imports came mainly from the USA (52%), Canada (27%), and Australia (21%) (Wickramasinghe, Miura, Yamauchi, & Noda, 2005). Thus, a proportion of wheat flour could be replaced by potato starches in wheat-based food products such as instant noodles.

Phosphorus is one of the non-carbohydrate constituents present at relatively higher concentration in potato starch, which may affect the functional properties of starch. Phosphorus is present as phosphate monoesters and phospholipids in various starches. The phosphate monoesters are covalently bound to the amylopectin fraction of the starch and increase starch paste clarity and viscosity, while the presence of phospholipids results in opaque and lower-viscosity pastes (Craig, Maningat, Seib, & Hoseney, 1989). A relatively high degree of phosphate substitution in potato starch leads to starch gels with high viscosity (Noda et al., 2006a; Suzuki, Shibanuma, Takeda, Abe, & Hizukuri, 1994; Wiesenborn, Orr, Casper, & Tacke, 1994). Therefore, potato starch is used in fish paste products, as a favourite ingredient in several types of noodles and in the production of glucose and isomerized-glucose syrup. Phospholipid content of the starch is

* Corresponding author. Tel.: +81 155 62 9278; fax: +81 155 62 2926.
E-mail addresses: zaidul@naro.affrc.go.jp, zaidulsarker@yahoo.com (I.S.M. Zaidul).

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proportional to the amylose content of the starch (Morrison, Milligan, & Azudin, 1984; Morrison, Tester, Snape, Law, & Gidely, 1993). Phospholipids present in starch have a tendency to form a complex with amylose and long-branched chains of amylopectin, which results in limited swelling. Wheat starch has more phospholipids and produces starch paste with lower transmittance than does potato starch with a lower phospholipid (Singh, Singh, Kaur, Sodhi, & Gill, 2003).

Protein content of wheat flour ranges from 6% to 14% and lipid constitutes about 1% of the granular weight, with surface lipids up to 0.05% (Eliasson et al., 1981; Morrison, 1988; Zaidul, Karim, Manan, Ariffin, Norulaini & Omar, 2003a; Zaidul, Karim, Manan, Norulaini & Omar, 2003b; Zaidul, Karim, Manan, Ariffin, Norulaini & Omar, 2002). Protein content has significant effects on rheological profiles, e.g. viscosity, peak viscosity temperature, viscoelasticity, breakdown, setback and pasting temperature (Zaidul et al., 2004; Zaidul et al., 2003a; Zaidul et al., 2003b; Zaidul et al., 2002). The lipids are present at lower levels and significantly affect the swelling of wheat flour (Morrison et al., 1993; Zaidul et al., 2004; Zaidul et al., 2003a; Zaidul et al., 2003b; Zaidul et al., 2002). Wheat starches, especially, have a bimodal distribution of A-type (large) and B-type (small) granules. A-type granules have been reported to contain more amylose than do B-type granules (Peng, Gao, Aal, Hucl, & Chibbar, 1999). On the other hand, potato starch granules are relatively larger than are wheat starch granules, in addition to having more phosphorus in the amylopectin (Noda et al., 2004a; Noda et al., 2004b). Potato starch displays a normal distribution in granule size, but the range of the size distribution is wide (Chen, Schols, & Voragen, 2003; Noda et al., 2005). Koo, Park, Jo, Kim, and Baik (2005) also reported that the pasting properties of starch were highly dependent on the granule size and swelling degree of starch granules. They were also related to the heat and shear stability of the swelled granule, as well as to the structural differences of amylose and amylopectin (Koo et al., 2005). Thus, phosphorus and granular size and shape of potato–wheat mixtures will have positive or negative effect on RVA pasting properties.

The objective of this work was to investigate the pasting properties of potato starches and wheat flour (individually and of their mixtures) to observe the effects of substituting potato starches in wheat-based food products based on pasting properties, which were analyzed using a rapid visco analyzer (RVA). The effects of phosphorus, protein, fat, amylose content and granule size on pasting properties of potato–wheat mixtures were observed. Also, this study should help to better understand the functionalities of starch phosphorus and protein during processing of starch-based foods.

2. Materials and methods

2.1. Materials

Commercial hard-wheat flour milled from the Japanese cultivar, Kitanokaori, was purchased from the Ebetsu Flour Milling Co. Ltd., Ebetsu, Japan. Three potato starches, with different granule sizes, phosphorus and amylose contents, were purchased from Jinno Starch Co., Sarabetsu, Hokkaido. These three potato starches were derived from three potato cultivars of Eniwa, Benimaru and Norin no. 1, grown in 2005, and labelled as high phosphorus (HPS), medium phosphorus (MPS) and low phosphorus (LPS), respectively, in this work, as shown in Table 1.

2.2. Moisture content

Moisture content of the samples was determined by a moisture analyzer, model no. MX-50 (A & D Co. Ltd., Tokyo).

2.3. Granule size

The granule size of samples was measured using a sympatec HELOS particle size analyser. The mean diameter, based on volume distribution was measured according to Noda et al. (2004a, 2004b).

2.4. Amylose content of potato starch

The blue value (BV) at 680 nm was estimated according to Noda, Takahata, Sato, Kumagai, and Yamakawa (1998a) and Noda et al. (1998b), using intact starch rather than defatted starch. The amylose content was calculated from the BV according to the equation of Takeda, Takeda, and Hizukuri (1983). The average BVs of amylose and amylopectin isolated from two potato cultivars were 1.40 and 0.243, respectively, determined by Suzuki et al. (1994). These BVs were used in the calculation of the amylose content of the potato starches.

Table 1
Median granule size, phosphorus, amylose, protein, fat (neg. = negligible) and moisture content of three varieties of potato starch and wheat flour used in the experiment

Sample	Granule size (μm)	Phosphorus (ppm)	Amylose (%)	Protein (%)	Fat (%)	Moisture (%)
Wheat	59.3[a]	1138[a]	27.2 ± 0.9[a]	13.2	1.4	15.0
Eniwa (HPS)	37.7[c]	878[b]	19.4 ± 2.4[c]	<0.1	neg.	15.5
Benimaru (MPS)	44.4[b]	599[c]	23.6 ± 0.8[b*]	<0.1	neg.	16.4
Norin no. 1 (LPS)	34.1[d]	541[d]	24.3 ± 1.7[b*]	<0.1	neg.	15.7

* Values followed by the same letters in the same column are not significant at $P < 0.05$ level.

2.5. Amylose content of wheat starch

The amylose content of wheat starch was calculated from the BV according to the equation of Shibanuma, Takeda, and Hizukuri (1994). They determined the BVs, at 680 nm, of amylose and amylopectin of some wheat starches. The average BVs of amylose and amylopectin were 1.24 and 0.10, respectively, and were used in the calculation of the amylose content of wheat starch.

2.6. Protein and fat

Protein content was determined by the micro-Kjeldhahl distillation method. The Soxhlet extraction method was used to determine fat content and petroleum ether (b.p. 40–60 °C) was applied to extract the fat (AOAC, 1990).

2.7. Phosphorus content

The phosphorus content of the starch samples was determined using the energy dispersive X-ray fluorescence method according to Noda et al. (2006b).

2.8. Preparation of blended samples

Wheat flour and three types of potato starches, with different granule sizes and phosphorus contents, were used in the experiment. Each potato starch was mixed with wheat flour at 10–50% of potato starch (on weight basis) in the mixture, as shown in Table 2.

Table 2
Mixing ratios (%) of wheat flour and potato starches of different granule size, and high phosphorus (HPS), medium phosphorus (MPS) and low phosphorus (LPS) contents

Sample	Mixing ratio
Potato:wheat	0:100 (control wheat)
Potato:wheat	100:0 (control potato)
HPS:wheat MPS:wheat LPS:wheat	10:90 (10% potato)
HPS:wheat MPS:wheat LPS:wheat	20:80 (20% potato)
HPS:wheat MPS:wheat LPS:wheat	30:70 (30% potato)
HPS:wheat MPS:wheat LPS:wheat	40:60 (40% potato)
HPS:wheat MPS:wheat LPS:wheat	50:50 (50% potato)

2.9. Determination of pasting properties by rapid visco analyzer (RVA)

The RVA parameters were determined using the RVA-4 (Newport Scientific Pvt., Ltd., Australia) according to Noda et al. (2004a, 2004b). Each sample of control wheat, control potato and their mixtures (Table 2) was added to 25 ml of distilled water to prepare 8%, 4% and 8% of suspension, respectively, on a dry weight basis (w/w). The suspension was kept at 50 °C for 1 min then heated to 95 °C at 12.2 °C/min and held for 2.5 min at 95 °C. It was then cooled to 50 °C (cooling rate of 11.8 °C/min) and kept for 2 min.

2.10. Statistical analysis

The determinations of amylose content were done in triplicate. Other experiments were carried out in duplicate. The averages and Duncan's *t*-test were used to measure variations in three different potato starches and wheat flour and their mixtures. The least significant difference at the 5% probability level ($P < 0.05$) was calculated for each parameter.

3. Results and discussion

The median granule sizes, and phosphorus, amylose, protein, fat and moisture contents of potato starches of different cultivars and wheat flour used in the experiment are shown in Table 1. The RVA parameters of peak viscosity, trough and breakdown, final viscosity, setback viscosity, peak time and pasting temperature of control wheat flour and potato starches are shown in Table 3. Blennow, Bay-Smidt, and Bauer (2001) found that the starches extracted from potato tubers showed high viscosities while sorghum, cassava and *Curcuma zedoaria* starches had relatively low viscosities. For the starches with high amylose contents, namely cassava, sorghum and *C. zedoaria* starches, low viscosities and very small differences between the peak and final viscosities were obtained (Blennow et al., 2001). Lui, Weber, Currie, and Yada (2003) indicated that potato starches of smaller granule size exhibited higher pasting temperature and lower peak viscosity. Huang, Lin, and Wang (2006) found a similar trend in studying pasting properties of yam starches. Our observations (Table 3) were supported by the report of Huang et al. (2006). When the temperature was cooled to 50 °C, the final viscosity in LPS increased. The larger granule size of MPS presumably caused higher peak viscosities than those of HPS and LPS. The protein and fat contents in potato starches were found to be negligible whereas a high amount of protein and some fat were present in wheat flour. Thus, the peak time of wheat flour was longer than those of the potato starches. Ragaee and Aal (2006) found that the RVA parameters of hard wheat flour exhibited much lower values than did soft wheat. Apparently, this character might be due to the lower rate of absorption and swelling of wheat starch

Table 3
RVA parameters of control potato starches, of different phosphorus contents, of Eniwa (HPS), Benimaru (MPS), Norin no. 1 (NPS), and control wheat flour used in the experiment

Control sample	Peak viscosity (RVU)	Trough (RVU)	Break down (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (min)	Pasting temperature (°C)
Wheat	89.1	53.9	35.8	103.7	49.8	5.7	–
Eniwa (HPS)	317.6	113.7	203.9	128.7	15.1	3.27	70.3
Benimaru (MPS)	241.2	101.3	139.9	123.2	21.9	3.73	68.5
Norin no. 1 (LPS)	193.0	108.9	84.1	128.2	19.3	4.3	69.8

Values of RVA parameters are means of three determinations, where the maximum standard deviation was ±0.89%.

granules. However, potato starches were mixed with hard wheat flour at 10–50% of potato starches to obtain acceptable RVA parameters, which are discussed in this work.

Fig. 1 shows the typical RVA pasting curves for the mixtures of LPS-wheat flour, MPS-wheat flour and HPS-wheat flour at 20 and 40 potato starches. Fig. 2 shows the peak viscosity of HPS-wheat, MPS-wheat and LPS-wheat mixtures at 10–50% of potato starch. The peak viscosity was highest in HPS-wheat mixture, followed by MPS-wheat and LPS-wheat mixtures. Significant differences ($P < 0.05$) were found in peak viscosities among HPS-wheat, MPS-wheat and LPS-wheat. This was due to the higher phosphorus content in HPS and MPS than in the LPS (Table 1). As phosphorus is covalently bound to the amylopectin molecules, the higher amount of phosphorus in potato starch usually indicates a lower amylose content. Due to the lower amount of amylose content in HPS than in the control wheat, the viscosity of the mixture increased as the amylose content of wheat, was diluted with potato starches in the mixtures. The other reason for higher peak viscosity, characteristic of potato starches, was the higher swelling power of starch granules in HPS, MPS and LPS than in wheat flour (Table 3). In the mixtures, the peak viscosities were increased significantly ($P < 0.05$) with increase of potato starches in the mixtures. Thus, the peak time was shorter in HPS-wheat than in the MPS-wheat and LPS-wheat mixtures (Fig. 3) where in the peak time decreased with increase of potato starches (HPS, MPS and LPS) in the mixture and a more rapid decrease of the peak time was found in HPS-wheat than in MPS-wheat and LPS-wheat at 50%. However, the differences of peak times among HPS-wheat, MPS-wheat and LPS-wheat were found to be significant ($P < 0.05$) at 40% and 50%. The peak viscosity/pasting temperature was high in the control wheat and was lower in the control potato starches (Table 3). Therefore, it is recommendable to blend the potato starches with wheat flour for minimizing and maximizing the viscosity temperature. Zaidul et al. (2003a) observed similar trends of peak viscosity characteristics when substituting sago starch for wheat flour at 10–50% sago starch. The trough (Fig. 4) and the breakdown (Fig. 5) viscosities of the mixtures, of HPS-wheat were found to be always higher than those of the MPS-wheat, followed by the LPS-wheat mixtures. However, the values were increased significantly ($P < 0.05$) with increase of potato starches in the mixtures. Similarly, the final viscosities of HPS-wheat were higher than that of MPS-wheat, followed by LPS-wheat mixtures (Fig. 6). The values were always significantly increased with increase of each potato starch in the mixture ($P < 0.05$) and were found to be highest in 50% potato starches. Values increased linearly for HPS-

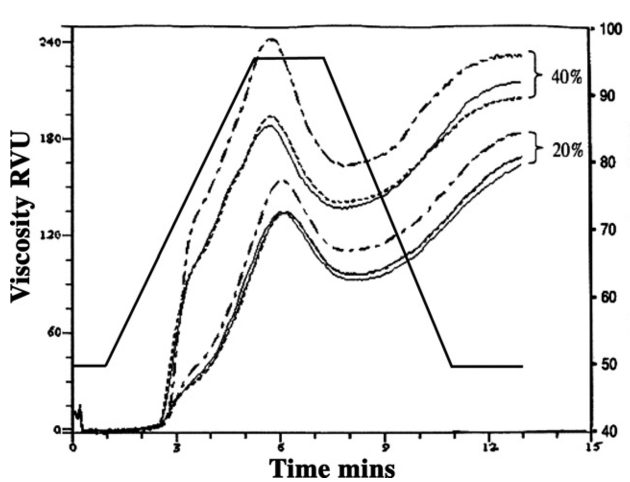

Fig. 1. Typical RVA pasting curves for the mixtures of low phosphorus potato starch-wheat flour (—— LPS-wheat), medium phosphorus potato starch-wheat flour (······ MPS-wheat) and high phosphorus potato starch-wheat flour (— — — HPS-wheat) at 20% and 40% potato.

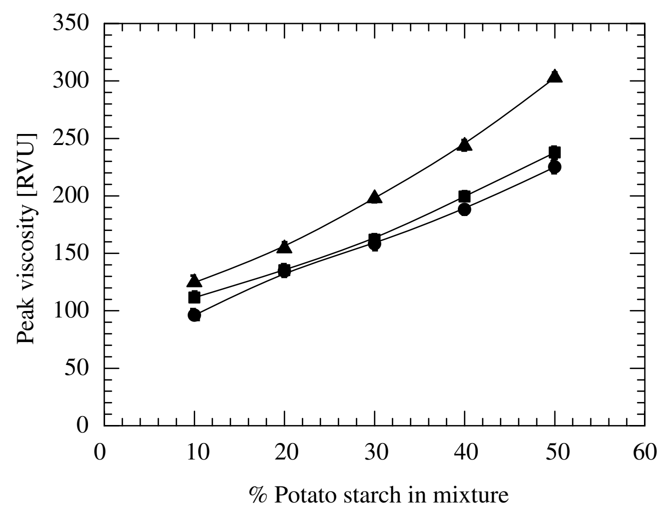

Fig. 2. Peak viscosity for the mixtures of high phosphorus potato starch-wheat flour (▲ HPS-wheat), medium phosphorus potato starch-wheat flour (■ MPS-wheat) and low phosphorus potato starch-wheat flour (● LPS-wheat) at different percentage of potato.

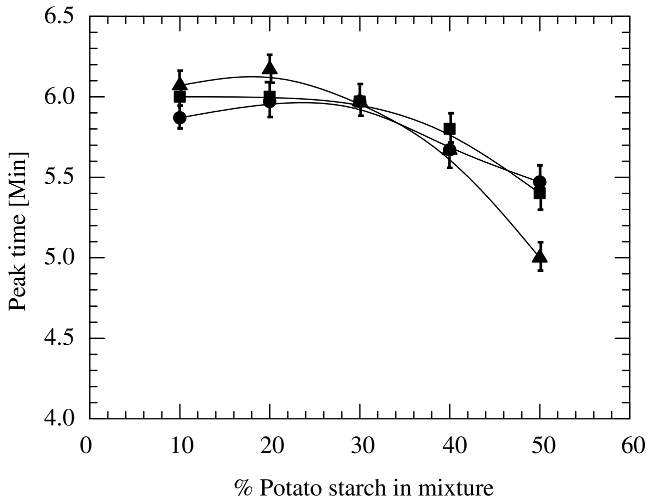

Fig. 3. Peak time for the mixtures of high phosphorus potato starch-wheat flour (▲ HPS-wheat), medium phosphorus potato starch-wheat flour (■ MPS-wheat) and low phosphorus potato starch-wheat flour (● LPS-wheat) at different percentage of potato.

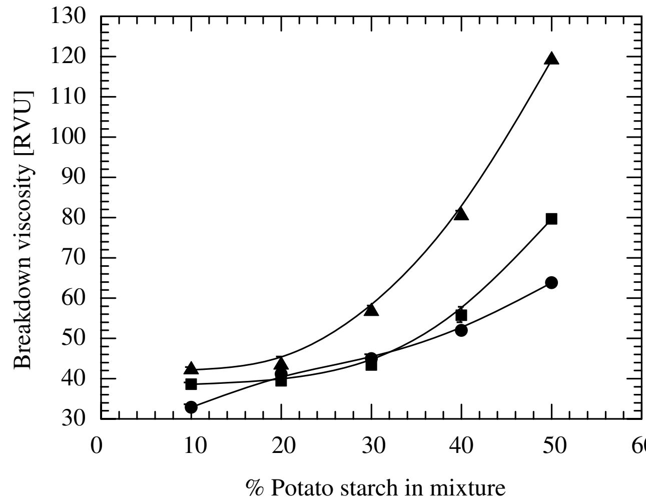

Fig. 5. Breakdown viscosity for the mixtures of high phosphorus potato starch-wheat flour (▲ HPS-wheat), medium phosphorus potato starch-wheat flour (■ MPS-wheat) and low phosphorus potato starch-wheat flour (● LPS-wheat) at different percentage of potato.

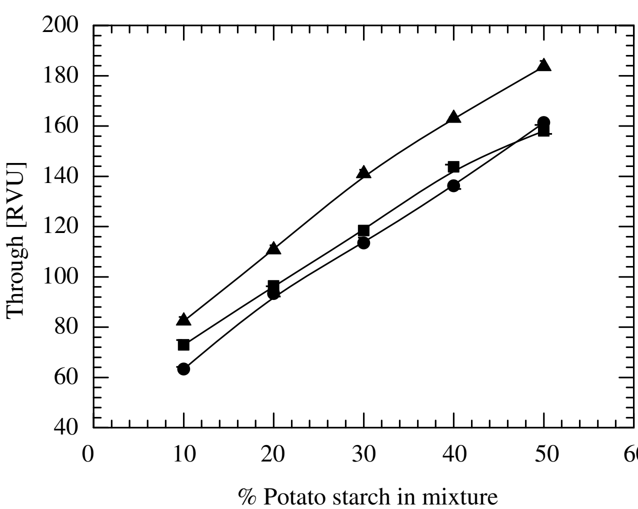

Fig. 4. Trough for the mixtures of high phosphorus potato starch-wheat flour (▲ HPS-wheat), medium phosphorus potato starch-wheat flour (■ MPS-wheat) and low phosphorus potato starch-wheat flour (● LPS-wheat) at different percentage of potato.

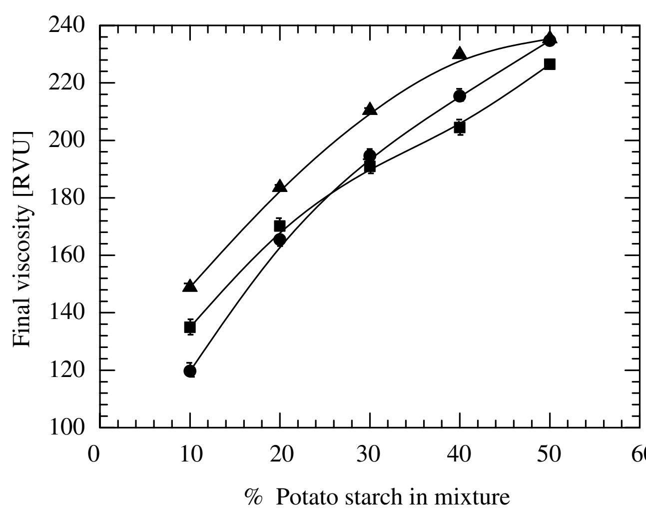

Fig. 6. Final viscosity for the mixtures of high phosphorus potato starch-wheat flour (▲ HPS-wheat), medium phosphorus potato starch-wheat flour (■ MPS-wheat) and low phosphorus potato starch-wheat flour (● LPS-wheat) at different percentage of potato.

wheat and MPS-wheat, and were similar at 50% (Fig. 6). These trends were close to those of sago-wheat mixtures studied by Zaidul et al. (2003a). Finally, the setback viscosities (Fig. 7) for the HPS-wheat and MPS-wheat in the mixtures were increased up to 20% and then decreased rapidly up to 50%. In the LPS-wheat mixture the value was found to be increased up to 30% and then trended to decrease at 40% and 50%. The final viscosity of the HPS-wheat mixture again tended to decrease at 50% and the setback value was decreased drastically at 50% in the HPS mixture. Thus, it was not advisable to increase the potato starches in the mixture above 50%. However, the setback viscosities of HPS-wheat and MPS-wheat were not significantly ($P > 0.05$) different at 10–30%. On the other hand, significant ($P < 0.05$) differences were found between LPS-wheat and HPS-wheat, and between LPS-wheat and MPS-wheat at 10–50%. The values in the LPS-wheat mixture were always higher than those in the HPS-wheat and MPS-wheat mixtures. The high setback value represents a lower peak viscosity, as the amylose content of LPS was higher than those of HPS and MPS. Olkku and Rha (1978) pointed out that proteins form complexes with the starch granule surface, preventing the release of exudates and so lowering the peak viscosity. Eliasson et al. (1981) reported that protein was bound to granule surfaces at 1.5–4.7 mg/g. The cooled paste is often stirred up to 60 min to measure the stability (Olkku & Rha, 1978). These effects may also be due to the presence of lipids in wheat starch (Russell,

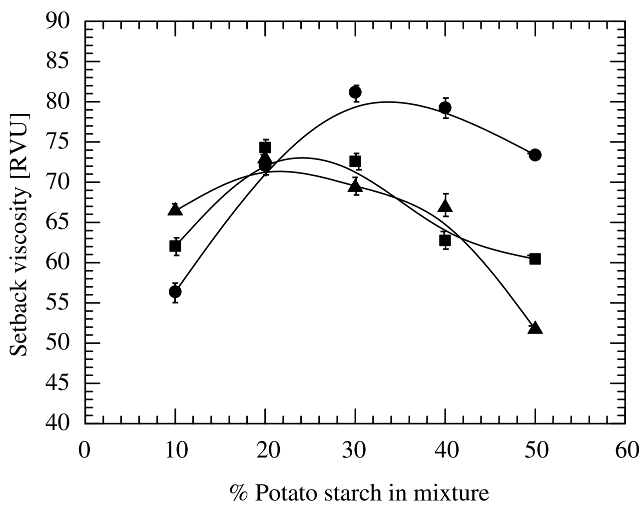

Fig. 7. Setback viscosity for the mixtures of high phosphorus potato starch-wheat flour (▲ HPS-wheat), medium phosphorus potato starch-wheat flour (■ MPS-wheat) and low phosphorus potato starch-wheat flour (● LPS-wheat) at different percentage of potato.

1987). The differences between concentrated potato starch and wheat flour systems cannot be ascribed solely to the lipids present in wheat starch. Another explanation for these different properties suggested by Keetels, van Vliet, and Walstra (1996), was the larger number of chain entanglements in the swollen wheat starch granules than in the swollen sago starch granules.

Peak viscosities were observed at about 6 min for all samples and the HPS-wheat showed the highest peak viscosity, followed by the MPS-wheat and LPS-wheat mixtures (Fig. 1). These results indicated that the LPS-wheat mixture had the lowest swelling power. However, the peak viscosity, prior to disruption of the swollen granules, was determined from the volume occupied by these swollen granules. This observation was supported by swelling characteristics of Korean ginseng starch granules reported by Koo et al. (2005).

The strong swelling power makes it easy to reach maximum viscosity, but pastes are likely to break down easily because of their weak intermolecular forces and because they are more sensitive to the shear force as the temperature goes up. Thus, starch granules were easily broken down by the shear force, which increased the swelling power (Kim, Lee, & Seok, 1999). This result suggests that the LPS-wheat mixture, which showed the lowest viscosity at the same initial pasting temperature, had a more dense structure or higher crystallinity than had the MPS-wheat and HPS-wheat mixtures. The breakdown is regarded as a measure of the degree of disintegration of granules or paste stability (Dengate, 1984; Newport Scientific, 1995). At breakdown, the swollen granules disrupt further, and amylose molecules will generally leach out into the solution (Newport Scientific, 1995; Whistler & BeMiller, 1997). The HPS-wheat mixture showed the highest breakdown value, followed by MPS-wheat and LPS-wheat mixtures as the higher values of breakdown are associated with higher peak viscosities (Fig. 2) which, in turn, are related to the degree of swelling of the starch granules during heating (Ragaee & Aal, 2006). This means that the LPS-wheat mixture was more resistant to heat and shear force than were the MPS-wheat and HPS-wheat mixtures. The setback (i.e. final viscosity-holding strength) indicated the value that resulted from rearrangement of excreted amylose molecules from the starch granules after swelling. The setback revealed the gelling ability or retrogradation tendency of the amylose (Newport Scientific, 1995). The highest setback was observed in the HPS-wheat mixture, suggesting that the highest amylose retrogradation occurred therein.

4. Conclusions

Potato starches with different granule sizes, phosphorus and amylose contents, and wheat flour mixtures represented the better RVA parameters. Peak viscosity, breakdown viscosity, final viscosity and setback viscosity of control potato starches were found to be higher than that of control wheat flour. Therefore, in the mixtures of potato starch and wheat flour, the peak viscosity, breakdown and final viscosity increased significantly ($P < 0.05$) with increase of potato starches in the mixtures. However, the values were always significantly ($P < 0.05$) higher in HPS-wheat mixture, followed by MPS-wheat and LPS-wheat mixtures. The reverse trends were observed in the setback viscosities and the differences were not significant ($P > 0.05$) between HPS-wheat and MPS-wheat at 10–30% potato starch in the mixture. Significant ($P < 0.05$) differences were observed in the peak viscosities between LPS-wheat and HPS-wheat, and between LPS-wheat and MPS-wheat at 10–50% potato starch. However, the results of setback viscosities suggested that retrogradation had occurred. The results of this work might encourage substituting of potato starches in wheat-based food products. Further studies are needed to determine the interaction between wheat flour and potato starches, and to interpret their rheological properties using the differential scanning calorimeter (DSC) and rheometer.

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