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Comparison of the starch properties of Japanese wheat varieties with those of popular commercial wheat classes from the USA, Canada and Australia

Hetti Arachichige Mangalika Wickramasinghe [a,1], Hideho Miura [a], Hiroaki Yamauchi [b], Takahiro Noda [b,*]

[a] *Department of Crop Science, Obihiro University of Agriculture and Veterinary Medicine, Inada-cho, Obihiro, Hokkaido 080-8555, Japan*
[b] *Department of Upland Agriculture, National Agricultural Research Center for Hokkaido Region, Shinsei, Memuro, Hokkaido 082-0071, Japan*

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Abstract

The starch properties of four Japanese wheat varieties/breeding lines suitable for both bread and noodles were compared with those of popular commercial wheat classes from the USA, Canada and Australia. All starches were analyzed for amylose content, pasting properties measured by a rapid visco analyzer (RVA), swelling power, thermal properties measured by differential scanning calorimetry (DSC), enzyme digestibility, and chain length distribution of amylopectin (DP 6–17). All starch characteristics studied, except the chain length distribution of amylopectin, were significantly different among the tested wheat classes and varieties/breeding lines. Including Japanese wheat varieties/breeding lines, higher amylose contents and lower peak viscosities were found in hard wheats than in soft wheats. Interestingly, enthalpy, in the amylose–lipid complex measured by DSC, showed significant correlations with the pasting temperature from the RVA and swelling power.

Keywords: Wheat starch; Pasting properties; Swelling power; Differential scanning calorimetry

1. Introduction

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%). Thirty-three percent of the total consumption was in different forms of noodles, mainly Japanese white salted (WSN) and Chinese yellow alkaline noodles (YAN) (Nagao, 1996), which are second to the consumption of bread and other bakery products (40%).

Softness, smoothness, and some degree of stickiness are desirable for WSN, whereas a relative hardness, elasticity and chewiness are best for YAN. WSN are made from flours with low protein content (8–10%), and, by contrast, relatively high-protein (10.5–12%) hard wheats are used to prepare YAN (Huang & Morrison, 1988). The quality factors of wheat that govern the eating quality of noodles are very different from those for leavened baked products, in which the protein content and quality are the most important factors. The pasting properties of starch have been identified as the major quality parameters for WSN

* Corresponding author. Tel.: +81 155 62 9278; fax: +81 155 62 2926.
E-mail address: noda@affrc.go.jp (T. Noda).
[1] Present address: Department of Agriculture Biology, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.

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(Moss, 1980; Oda, Yasuda, Okazaki, Yamauchi, & Yokoyama, 1980), whereas the quality of alkaline noodles depends on both the starch and protein properties, in which the color and chewiness are mainly influenced by the protein content of the flour.

The traditional wheat varieties grown in Japan are soft; consequently, they are used almost entirely for the production of WSN and other domestic products. Therefore, bread and other bakery products and YAN are totally dependent on wheat importation. Some wheat varieties suitable for both bread and YAN were developed recently. This study is a comparison of the starch properties of four Japanese wheat varieties, including one breeding line, and those of popular commercial wheat classes imported from the USA, Canada and Australia.

2. Materials and methods

2.1. Plant materials

Four Japanese wheat varieties, including one breeding line, and five classes of foreign wheat, were used in this study. Kachikei No. 33, an extra strong breeding line, is promising for bread and YAN when blended. Kitanokaori is a newly released hard wheat that is a variety suitable for bread and YAN. Haruyutaka is a spring wheat variety that is suitable for bread. Hokushin is a soft wheat variety frequently used as the standard for WSN. Dark northern spring (DNS) and hard red winter-high protein (HRW-HP) are two American commercial wheat classes grown in the north central and central parts of the USA, respectively. DNS is used for bread making, while HRW-HP is considered as a blend suited to both bread and other products except WSN and cakes. Prime hard (PH) and Australian standard white (ASW) are two common classes of Australian wheat that Japan imports. PH is a hard class of wheat that is imported for making Chinese YAN, and ASW has relatively low amylose and is best suited for WSN. 1CW is a Canadian Western red spring type that is suitable for bread making. Haruyutaka, Kachikei No. 33, Hokushin, and Kitanokaori were grown at the National Agricultural Research Center for the Hokkaido Region, Hokkaido, Japan, in 2002 under standard field management. Flour from DNS, HRW-HP, PH, ASW and 1CW were kindly provided by the Ebetsu Flour Milling Co., Ltd., Ebetsu, Japan.

2.2. Starch preparation

Grain samples of each Japanese wheat variety were milled on a Bühler experimental mill (Bühler Inc., Uzwil, Switzerland) to produce 60% extraction. Starch was extracted from 50 g of flour from each of nine wheat samples according to a previously reported method (Mangalika, Miura, Yamauchi, & Noda, 2003). The moisture content was estimated by oven drying 1 g of a sample at 115 °C for 3 h.

2.3. Amylose content

The amylose content of all wheat starch samples was determined by the Concanavalin A method (Gibson, Solah, & McCleary, 1997) using an amylose/amylopectin assay kit (Megazyme Inc., Wicklow, Ireland). The analysis was repeated four times.

2.4. Pasting properties by a rapid visco analyzer

The pasting properties were determined by using the rapid visco analyzer (RVA-4) (Newport Scientific Pty., Ltd., Australia) according to Noda et al. (2004), except that the measurement was carried out with 10% starch suspension (dry weight basis, w/w), not with 4%. All values for viscosity parameters are expressed in RVA units. The analysis was repeated twice.

2.5. Swelling power

The swelling power was measured at 70 °C according to the method of Yasui, Sasaki, and Matsuki (1999). Two hundred milligram of starch in a dry weight basis was weighed into a screw-cap test tube, and 5 ml of distilled water was added. The capped tubes were then placed on a vortex mixer for 10 s and incubated in a 70 °C water bath for 20 min with frequent mixing by inverting at 2-min intervals. The tubes were then cooled in a water bath at 20 °C for 5 min and centrifuged at 1700*g* for 4 min, and the supernatant was removed with suction. The swelling power was calculated as the weight of swelled starch residue per 1 g of dry starch.

2.6. Glucoamylase digestibility

The enzyme digestibility of the starch granules of experimental materials was determined by using crystalline glucoamylase of *Rhizopus niveus* (Seikagaku Kogyo Co., Japan), which has a high affinity to raw starch, according to the modified method of Noda, Takahata, and Nagata (1992). Starch suspension (4%, 500 μl) along with 250 μl of a 0.1 M acetate buffer was digested with 250 μl of a glucoamylase solution (5 U) by incubating at 40 °C for 4 h with continuous stirring. Excess raw starch was then removed by filtration, and the glucose content of the filtrate was determined by the phenol sulfuric method (Dubois, Gilles, Hamilton, Rebers, & Smith, 1956). The percentage of hydrolysis, which is the ratio of glucose released during incubation to the total amount of sugar content at starch on a weight basis, was calculated. This analysis was repeated three times.

2.7. Thermal properties by differential scanning calorimetry

Differential scanning calorimetry (DSC) measurements were conducted at a heating rate of 2 °C/min over the temperature range of 25–130 °C using DSC 6100 (Seiko Instruments Inc., Tokyo, Japan) as described by Noda et al. (2004). The onset temperature (T_o), peak temperature (T_p), and enthalpy (ΔH) of the first peak and the peak temperature (T_p) and enthalpy (ΔH) of the second peak were recorded. Each starch sample was analyzed twice.

2.8. Amylopectin chain length

The shorter chain length of amylopectin (DP 6–17) was determined by high-performance anion-exchange chromatography (HPAEC) using the DX-300 system (Dionex Co., CA) equipped with a pulsed amperometric detector (PAD). The column used was a CarboPac PA-1 (4 × 250 mm) with a CarboPac PA-1 guard column. The analysis was done as described previously (Noda et al., 2004) with two replicates per sample.

2.9. Statistical analysis

Statistical data analyses were performed using Microsoft Excel 2000 software. The least significant difference (LSD) at the 5% probability level was calculated for each property, and a significant difference among experimental materials was observed. Furthermore, regression analysis was done for all possible parameters.

3. Results and discussion

3.1. Amylose content and pasting properties

The amylose contents of the hard wheats tested in this experiment were significantly higher than those of the soft wheats, ASW and Hokushin (Table 1). The range of the amylose contents of the hard wheats was from 22.4% to 24.9%, with an average of 23.7%, which was 3% higher than the average of soft wheats (20.6%). Oda et al. (1980) indicated that DNS and 1CW exhibited a higher amylose content than ASW, similar to the data obtained in the current study. All pasting properties, peak viscosity, breakdown, setback, and pasting temperature, showed significant differences among the tested wheat classes or varieties. The soft wheat variety Hokushin and the class ASW showed higher peak viscosity, and Kachikei No. 33, which had the highest amylose, showed the least peak viscosity. Generally, lower pasting temperatures were observed in soft wheats than in hard wheats, while some similarity was recognized between the two hard wheats, PH and Haruyutaka, and soft wheats. It is well accepted that amylose content and starch pasting properties are the major factors contributing to noodle quality. Lower amylose is considered as a quality factor associated with superior WSN (Baik & Lee, 2003; Noda, Tohnooka, Taya, & Suda, 2001; Oda et al., 1980; Toyokawa, Rubenthaler, Powers, & Schanus, 1989). Generally, high peak viscosity (Crosbie, 1991; Konik & Miskelly, 1992; Panozzo & McCormick, 1993) and high breakdown (Konik & Miskelly, 1992; Oda et al., 1980) were proven to be associated with good WSN quality. In contrast, high peak viscosity is considered to be negatively associated with YAN quality, as it reduces the firmness of noodles (Miskelly & Moss, 1985). Moreover, the breakdown and final viscosity from the

Table 1
Amylose content and pasting properties by RVA of starch samples from popular commercial wheat classes and Japanese wheat varieties*

Starch sample	Amylose content (%)	Pasting properties by RVA (RVU)			
		Peak viscosity	Breakdown	Setback	Pasting temperature (°C)
Hard wheats					
1CW[A]	$24.1 \pm 0.9^{ab*}$	360 ± 13^{d}	86 ± 0^{bc}	179 ± 2^{a}	84.7 ± 1.2^{a}
PH[A]	23.3 ± 1.0^{bc}	337 ± 4^{f}	88 ± 1^{b}	169 ± 1^{b}	73.0 ± 0.7^{f}
HRW-HP[A]	24.9 ± 0.6^{a}	310 ± 2^{g}	62 ± 2^{de}	121 ± 3^{i}	83.1 ± 1.3^{b}
DNS[A]	22.9 ± 1.8^{bc}	350 ± 2^{e}	63 ± 3^{de}	150 ± 1^{ef}	81.0 ± 0.6^{c}
Kachikei No. 33[B]	24.9 ± 0.5^{a}	291 ± 4^{h}	66 ± 0^{d}	126 ± 1^{g}	83.6 ± 0.5^{ab}
Haruyutaka[B]	23.1 ± 0.4^{bc}	372 ± 6^{c}	54 ± 7^{f}	146 ± 2^{f}	75.9 ± 0.1^{e}
Kitanokaori[B]	22.4 ± 0.5^{c}	362 ± 4^{d}	64 ± 5^{de}	157 ± 3^{b}	83.6 ± 0.6^{ab}
Soft wheats					
ASW[A]	21.0 ± 1.2^{d}	382 ± 0^{b}	104 ± 1^{a}	155 ± 1^{cd}	71.4 ± 0.6^{g}
Hokushin[B]	20.2 ± 0.5^{d}	395 ± 2^{a}	58 ± 0^{ef}	150 ± 6^{de}	76.9 ± 0.0^{d}

[A] Foreign wheat market classes.
[B] Japanese wheat varieties/breeding lines.
[*] Mean ± SD; different letters within each column show significant difference at $P < 0.05$.

RVA were significantly related to the firmness, elasticity, and surface smoothness of YAN (Ross, Quail, & Crosbie, 1997). High breakdown has a negative effect on YAN quality, as it reduces the firmness and elasticity, while final viscosity has a positive effect on both of the above parameters of YAN. This study revealed that, including Japanese wheat varieties, starches from hard wheats generally exhibited lower peak viscosity than those from soft wheats, suggesting their promise for YAN. Even though no data were available for the YAN quality of Japanese wheat varieties, the YAN quality of Hokushin flour, which is usually used for WSN making, was improved by blending with Kachikei No. 33 flour (Yamauchi et al., 2003). In addition to its high protein content compared to other Japanese wheat varieties, Kachikei No. 33 possesses higher protein quality with very strong gluten.

3.2. Swelling power

We examined the starch swelling power at 70 °C in this study, because 70 °C was found to be suitable for grouping of different types of wheat starches (Mangalika et al., 2003). As shown in Fig. 1, a significant difference was found in the starch swelling power at 70 °C among the tested wheat classes or varieties. Even though two hard wheats, PH and Haruyutaka, showed higher starch swelling power than one soft wheat variety, Hokushin, the starch swelling power tended to be higher in soft wheats than in hard wheats. The results nearly agreed with the data of Akashi, Takahashi, and Endo (1999), who revealed that the relative order of starch swelling power is 1CW = DNS < PH < ASW. The swelling power is very simple and is a recognized test as an indicator of noodle quality. High swelling is good for WSN, as it improves the softness of WSN (Crosbie, 1991; Crosbie, Lambe, Tsutui, & Gilmour, 1992; Oda et al., 1980; Seib, Liang, Guan, Liang, & Yung, 2000; Yun, Quail, & Moss, 1996), while it is considered to indicate poor quality for YAN. Highly swelled starches increase the smoothness and thereby reduce the firmness and elasticity of YAN (Konik, Mikkelsen, Moss, & Gore, 1994; Ross et al., 1997), consequently, lowering the total textural quality.

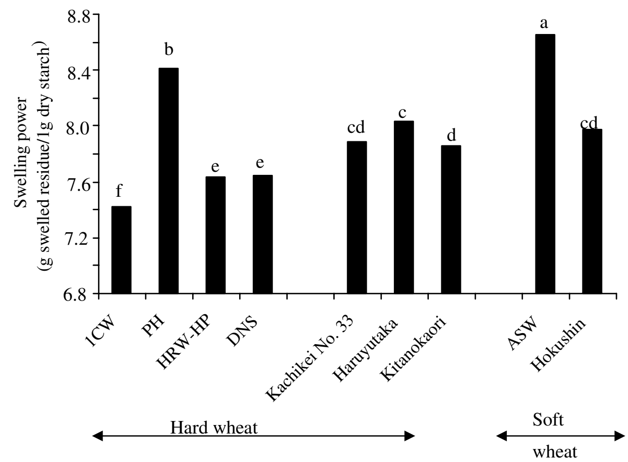

Fig. 1. Swelling power of starches from popular commercial wheat classes and Japanese wheat varieties. Bars labeled with same letters are not significantly different at $P < 0.05$.

3.3. Glucoamylase digestibility

The enzyme digestibility of starch granules by *Rhizopus* glucoamylase, expressed as the hydrolysis rate, is presented in Fig. 2. The hydrolysis rate ranged from 17.0% to 27.1%, showing a significant difference among the starch samples examined. Similar hydrolysis rates (16.1–28.8%) were found in seven wheat starches containing 17.1–24.4% amylose under the same condition for enzyme reaction (Mangalika et al., 2003). It tended to be higher in soft wheats than in hard wheats. However, two Japanese hard wheat varieties, Kachikei No. 33 and Haruyutaka, and two hard wheat classes, HRW-HP and 1CW, did not show significantly different

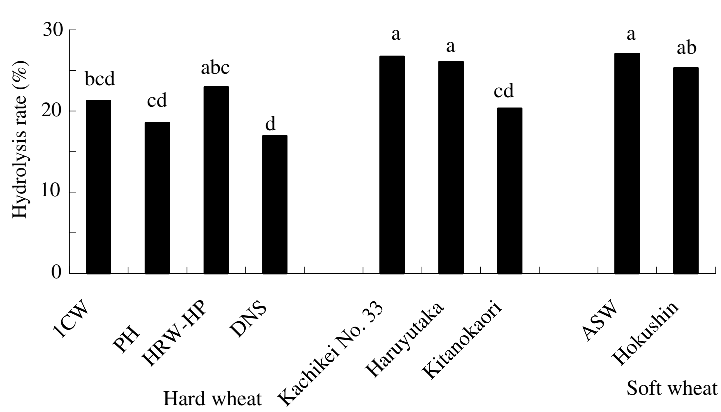

Fig. 2. Enzyme digestibility of starch granules from popular commercial wheat classes and Japanese wheat varieties. Enzyme digestibility was expressed as the hydrolysis rate (%), which is the ratio between the amount of glucose released during enzyme digestion to the total amount of starch in the original suspension. Bars labeled with same letters are not significantly different at $P < 0.05$.

Table 2
DSC results of starch samples from popular commercial wheat classes and Japanese wheat varieties*

Starch sample	Gelatinization			Amylose–lipid complex	
	T_o (°C)	T_p (°C)	ΔH	T_p (°C)	ΔH
Hard wheats					
1CW[A]	52.1 ± 0.0^{e}	60.9 ± 0.1^{bc}	9.6 ± 0.4^{d}	102.3 ± 0.1^{a}	2.1 ± 0.1^{d}
PH[A]	54.9 ± 0.9^{ab}	61.7 ± 0.0^{a}	10.0 ± 0.1^{cd}	100.5 ± 0.3^{c}	1.7 ± 0.1^{e}
HRW-HP[A]	52.9 ± 0.1^{e}	61.0 ± 0.0^{b}	9.8 ± 0.5^{cd}	102.6 ± 0.3^{a}	2.2 ± 0.1^{cd}
DNS[A]	52.7 ± 0.0^{e}	61.1 ± 0.2^{b}	$9.9 \pm 0.4c^{d}$	102.2 ± 0.1^{ab}	2.6 ± 0.1^{a}
Kachikei No. 33[B]	52.0 ± 0.3^{e}	58.8 ± 0.1^{f}	11.4 ± 0.8^{ab}	102.4 ± 1.2^{a}	2.2 ± 0.0^{cd}
Haruyutaka[B]	54.4 ± 0.2^{b}	60.5 ± 0.3^{d}	10.3 ± 0.4^{bcd}	102.9 ± 0.2^{a}	2.3 ± 0.2^{bc}
Kitanokaori[B]	52.2 ± 1.5^{e}	59.4 ± 0.0^{e}	$9.9 \pm 0.2c^{d}$	102.1 ± 0.1^{ab}	2.4 ± 0.0^{ab}
Soft wheats					
ASW[A]	52.8 ± 0.4^{e}	60.7 ± 0.1^{cd}	10.9 ± 1.2^{abc}	101.4 ± 0.0^{b}	1.7 ± 0.0^{e}
Hokushin[B]	55.6 ± 0.1^{a}	61.2 ± 0.1^{b}	11.7 ± 0.1^{a}	102.2 ± 0.3^{ab}	2.0 ± 0.0^{d}

[A] Foreign wheat market classes.
[B] Japanese wheat varieties/breeding lines.
* Mean ± SD; different letters within each column show significant difference at $P < 0.05$.

hydrolysis percentages from those of soft wheats, ASW and/or Hokushin.

3.4. Thermal properties by DSC

As shown in Table 2, the thermal properties by DSC showed significant differences among the tested materials. DSC thermograms of non-waxy starches show two gelatinization peaks, a larger peak at lower temperatures (around 60 °C) for starch gelatinization and a smaller peak at higher temperatures (around 102 °C) for dissolving the amylose–lipid complex. Significant but small variations in the onset and peak temperatures for gelatinization were found among the starch samples examined. Starches from soft wheats tended to show higher gelatinization enthalpies than those from hard wheats. PH and ASW starches exhibited significantly lower values of enthalpy in the second peak (amylose–lipid complex) than other starches, which is in agreement with the report of Akashi et al. (1999). Noda et al. (2001) observed a positive correlation between the starch gelatinization temperature and the softness of WSN. Moreover, they reported that the enthalpy in the second peak, which is a property of the amylose–lipid complex, was negatively correlated with the softness, elasticity, and smoothness of WSN (Noda et al., 2001). In our study, soft wheats suitable for WSN generally showed lower melting temperatures and enthalpies for the amylose–lipid complex. It is assumed that the melting properties of this complex depend on the types of ligands, the crystallization condition (Liu, Arntfield, Holley, & Aime, 1997).

3.5. Amylopectin chain length distribution

The distribution of amylopectin short chains between DP 6 and DP 17 was almost identical for all wheats tested in this experiment. The representative profile of the molar distribution of amylopectin unit-chains is shown in Fig. 3. In all amylopectins examined, there was a peak at DP 10 and a relatively lower content of DP 6–8. Since no significant differences were observed among the tested wheats for the molar distribution of amylopectin, correlation analysis was avoided.

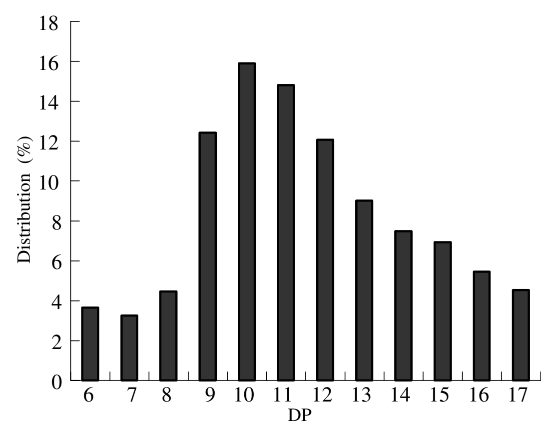

Fig. 3. Molar distribution of amylopectin unit-chains (DP 6–17) of wheat variety, Hokushin.

3.6. Correlation analysis

All possible correlations among 12 parameters of nine wheat starches examined in this study are listed in Table 3. The present study indicates that the amylose content was negatively correlated with the peak viscosity. This relationship had been observed previously (Black, Panozzo, Wright, & Lim, 2000). However, the relationships between amylose content and pasting properties measured by RVA were not observed, except for the amylose content and peak viscosity, and that

Table 3
Correlation analysis among starch properties

	1	2	3	4	5	6	7	8	9	10	11
1. Amylose content											
2. Peak viscosity	−0.87**										
3. Breakdown	−0.14	0.12									
4. Setback	−0.32	0.55	0.53								
5. Pasting temperature	0.59	−0.48	−0.44	−0.23							
6. Swelling power	−0.53	0.29	0.53	0.11	−0.87**						
7. Enzyme digestibility	−0.17	0.09	0.01	−0.42	−0.24	0.36					
8. T_o (gelatinization)	−0.51	0.44	−0.18	0.12	−0.64*	0.37	0.08				
9. T_p (gelatinization)	−0.27	0.37	0.23	0.40	−0.47	0.08	−0.37	0.59			
10. ΔH (gelatinization)	−0.46	0.14	−0.08	−0.33	−0.31	0.42	0.71*	−0.27	0.33		
11. T_p (amylose–lipid complex)	0.26	−0.07	−0.71*	−0.50	0.59	−0.66*	0.32	−0.39	−0.26	0.02	
12. ΔH (amylose–lipid complex)	0.29	−0.17	0.73*	−0.31	0.67*	−0.72*	−0.32	−0.36	−0.39	−0.30	0.70*

* and ** are significant at 0.05 and 0.01 probability levels, respectively.

would probably be due to the narrow range of variation of amylose content of the tested materials. It has been shown that the amylose content has an inverse correlation to the swelling power (Sasaki & Matsuki, 1998; Yamamori & Quynh, 2000). Tester and Morrison (1990, 1992) suggested that starch swelling is peculiar to the characteristics of amylopectin and that amylose acts as a diluent. However, no significant relationship was found between the amylose content and the swelling power in this experiment, probably due to the fact that relatively narrow ranges were found in these two parameters of the tested materials.

Starch gelatinization properties mainly reflect the granule structure, crystalline perfection, and molecular order (Cooke & Gidley, 1992; Tester & Morrison, 1990). Amylopectin plays a key role in starch granule crystallinity; therefore, the presence of more amylose lowers the melting temperatures in the crystalline region and the energy for gelatinization (Flipse, Keetels, Jacobson, & Visser, 1996; Sasaki, Yasui, & Matsuki, 2000). Since our materials have a narrow range of amylose content, no correlation between the amylose content and starch gelatinization properties was observed.

In barley and wheat, the amylose–lipid complex inhibits the swelling power of starch (Morrison, Tester, Snape, Law, & Gidley, 1993; Tester & Morrison, 1992; Yasui et al., 1999). This relationship was again shown in this study: the peak temperature and enthalpy in the second peak (amylose–lipid complex) in DSC showed significant negative correlations to the swelling power. Furthermore, a positive correlation was observed between the enthalpy for the amylose–lipid complex and the pasting temperature. It seems that the higher stability of the structure of the amylose–lipid complex prevents the swelling of starch granules.

This study revealed a positive correlation ($r = 0.71$) between the enzyme digestibility and enthalpy for starch gelatinization and no correlation between the enzyme digestibility and amylose content. The previous study showed a negative correlation between enzyme digestibility and enthalpy for starch gelatinization using 30 sweet potato starches (Noda, Takahata, & Nagata, 1993). The gelatinization enthalpy reflects the crystalline order and the level of amylopectin double-helical order (Cooke & Gidley, 1992). Generally, the higher the content of the crystalline structure, the lower the digestibility by amylase. Contrary to this, other studies have shown that a marked reduction in amylose content enhances the enzyme digestibility of starch granules (Noda et al., 2002; Noda, Nishiba, Sato, & Suda, 2003). The conflicting results between this and previous (Noda et al., 2002, 2003, 1993) experiments are probably due to the relatively narrow ranges of enthalpy for the starch gelatinization, amylose content, and enzyme digestibility of starch granules of the materials tested in this experiment.

4. Conclusion

In this study, the physicochemical properties of starches from representative Japanese wheat varieties and wheat classes from the USA, Canada and Australia were analyzed. Starches from hard wheats exhibited higher amylose content and lower peak viscosity than those from soft wheats. The enthalpy in the amylose–lipid complex measured by DSC seemed to be a critical factor in controlling the starch pasting properties, as it showed significant correlations with the pasting temperature from the RVA and swelling power. Consequently, this information will be very useful in further studies on the utilization of these representative Japanese wheat varieties and breeding lines for the bread and YAN industries in Japan.

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