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Molecular and pasting properties of some wheat starches

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Molecular structures and pasting properties of starches from four wheat varieties, (Egret and Rosella, soft grain; Vasco and Halberd, hard grain) were characterized and the relationships between pasting and molecular properties were analyzed. The starches (10%, w/w) showed pasting temperatures in the range of 63.4–67.6°C, maximum viscosities (V_{max}) 201–323 RVU, breakdown 54–176 RVU, and consistency 118–198 RVU measured by a Rapid Visco Analyzer. The strong positive correlations have been found between the V_{max} by RVA (10%) and number- ($\overline{DP}_n$) and weight-average DP ($\overline{DP}_w$) of amyloses and $\overline{DP}_n$ of amylopectins. $V_{max}=0.425\cdot\overline{DP}_n$ (amylose)-315($r=0.989$). $0.303=\overline{DP}_w$ (amylose)-953($r=0.998$) and $V_{max}=0.0234\cdot\overline{DP}_n$ (amylopectin)-116 ($r=0.912$). The breakdown showed a good positive correlation to V_{max}. The amylopectins of the high viscosity (HV) starches (Rosella and Halberd) gave lower values of iodine affinities and comprised a lower amount (2% of total) of extra long chains (ELC, weight-average CL > 500) than those (3 or 4%) of the low viscosity (LV) starches (Vasco and Egret). It has been suggested that the high molecular weights of amylose and amylopectin and probably low amounts of ELC of amylopectin increase the viscosity of wheat starches on pasting. Copyright © 1996 Elsevier Science Limited.

INTRODUCTION

The main component of wheat grains is starch and its pasting and retrogradation properties appear to be one of the key factors determining the qualities of wheat products, many investigations of this have been carried out (Seib, 1994). Wheat starch was reported to have superior properties for baking compared to those from other plant sources, but its small granules were inferior to large granules (Kulp, 1973; Hoseney *et al.*, 1971). Properties of wheat starch have been suggested to be important factors for Japanese type noodle making (Konik *et al.*, 1993; Kim & Seib, 1993). Several workers (Medcalf & Gilles, 1965; D'Appolonia & Gilles, 1971; Hoseney *et al.*, 1971; Kulp, 1973; Oda *et al.*, 1980; Endo *et al.*, 1988; Ito *et al.*, 1991) have reported that the pasting properties of starches are closely connected to the qualities of starchy food. Lipids have been suggested to be related to starch swelling, positively (Takahashi & Seib, 1988) or negatively (Medcalf *et al.*, 1968; Melvin, 1979). Substances complexing with amylose have been shown to increase pasting temperature, maximum viscosity, and consistency on a Brabender amylography (Krog, 1973). Wheat starches with low amylose contents were reported to give high breakdown viscosities by an amylograph (Oda *et al.*, 1980). Two types of amylose, free and complexing with lipid have been shown to exist in barley starch, which affect starch swelling positively and negatively, respectively (Morrison *et al.*, 1993). However, the relationship between pasting properties and molecular structure of starch has not been studied in detail.

Recently, we investigated the molecular structures of some wheat starches (Shibanuma *et al.*, 1994), but not pasting properties. Here we investigated the pasting properties together with molecular structures of starches from four Australian wheats and found some relationships among them.

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MATERIALS AND METHODS

Materials

Wheat flours of Rosella, Halberd, Vasco and Egret were gifts from the Bread Research Institute of Australia Inc. Rosella and Egret are soft wheats, and Halberd and Vasco are hard wheats. Starches were prepared from wheat flours as described previously (Hizukuri & Maehara, 1990) and purified by shaking with toluene (Suzuki *et al.*, 1992). Sweet potato β-amylase was

prepared by the method of Takeda & Hizukuri (1969) and was further recrystallized from aqueous ammonium sulfate. Crystalline *Pseudomonas* isoamylase was obtained from Hayashibara Biochemical Laboratories Inc. (Okayama).

Fractionation of starch

Amylose and amylopectin were separated by the method of Lansky *et al.* (1949) with minor modifications (Takeda *et al.*, 1986). ß-Limit dextrin (ß-LD) of amylose (Takeda *et al.*, 1987a) and debranched amylopectin were prepared as described previously (Hizukuri & Maehara, 1990). The purity of the amylose specimen was examined by gel-permeation chromatography (Takeda *et al.*, 1984).

Analytical methods for examining pasting property

Pasting properties of starches were examined with a Rapid Visco-Analyzer, RVA (Walker *et al.*, 1988; RVA-3D, Newport Scientific Instruments and Engineering) under the conditions described by Suzuki *et al.* (1994), but the concentration was 7–12% (w/w). The unit of viscosity was expressed as RVU.

Analytical methods for molecular structures

The iodine affinity (*IA*) was determined at 25°C by a modified amperometric titration (Takeda *et al.*, 1987b) of Larson *et al.* (1953). The limit of ß-amylolysis (ßal), blue value (*BV*), limiting viscosity number ([η], 1M KOH, 22.5°C) (Suzuki *et al.*, 1981) and phosphates esterified to C-6 (Hizukuri *et al.*, 1970) were determined as described elsewhere. Carbohydrate and reducing sugars were determined by the phenol–sulfuric acid method (Dubois *et al.*, 1956) and the Somogyi (1952)–Nelson (1944) method with a minor modification (Hizukuri *et al.*, 1970), respectively. Phosphorus was determined as inorganic phosphorus (Itaya & Ui, 1966) after ashing with perchloric acid (Allen, 1940). The number-average degree of polymerization ($\overline{DP}_n$) was determined by the modified Park–Johnson method (Hizukuri *et al.*, 1981). The addition of ferricyanide solution erroneously came out in the original literature, but it was corrected elsewhere (Hizukuri *et al.*, 1983). The number-average chain length ($\overline{CL}_n$) of amylopectin was determined by rapid Smith degradation (Hizukuri & Osaki, 1978) and isoamylolysis (Suzuki *et al.*, 1981), and that of amylose was determined fluorometrically (Hizukuri *et al.*, 1981; Takeda *et al.*, 1984). The average number of chains ($\overline{NC}$) was calculated as $\overline{DP}_n/\overline{CL}_n$. The molar fraction of branched molecules (*Bf*) was determined from the number of branch linkages of amylose and its ß-limit dextrins according to the following equation (Hizukuri *et al.*, 1972; Takeda *et al.*, 1987a). *Bf* = (number of branch linkages in amylose)/(number of branch linkages of ß-LD).

The weight-average degree of polymerization ($\overline{DP}_w$) and DP distribution of amylose were determined by gel-permeation HPLC (Takagi & Hizukuri, 1984; Hizukuri & Takagi, 1984). The weight-average CL ($\overline{CL}_w$) and CL distribution of amylopectin were determined by gel-permeation HPLC as described (Hizukuri & Maehara, 1990), but using connected columns of Asahipak GS-320 (7.6mm×500mm), GFA-30 (7.6mm×500mm) (Asahi Chemical Industry Co., Ltd, Tokyo), and TSKgel G3000PW (7.5mm×600mm) (Tosoh, Tokyo) with a refractometer (RI, Tosoh RI-8000) and a low-angle laser-light-scattering (LALLS) photometer (Tosoh LS-8000) (Suzuki *et al.*, 1994) using 0.1M sodium phosphate buffer (pH6.1) containing 1.5% acetonitrile and 0.02% sodium azide as an eluent. Sample solution was filtered through a 0.22μm filter and 0.2ml was injected into the chromatograph.

High performance anion exchange chromatography (HPAEC) was carried out as previously described (Koizumi *et al.*, 1991) with minor modifications. The following pulse potential and duration were used in the range 10×10^3nA (sampling period, 200ms), E_1, 0.10V (t_1 480ms), E_2, 0.60V (t_2 120ms), and E_3, −0.60V (t_3 120ms). The eluent A was 150mM sodium hydroxide and the eluent B was 150mM sodium hydroxide containing 500mM 2-sodium acetate. The gradient program was as follows: 30% eluent B at 0min, 40% at 5min, 50% at 15min, 60% at 30min, 65% at 45min, 70% at 65min, 75% at 85min, 80% at 95min, and 100% at 105min. Sample solution was filtered through a 0.22μm filter and 125μg (25μl) was applied.

RESULTS

Pasting properties

In Fig. 1, RVA viscograms of wheat starches (10%, w/w) are shown, and their characteristics are summarized in Table 1. Rosella and Halberd starches (HV starches) showed lower pasting temperatures (63.4 and 63.6°C,

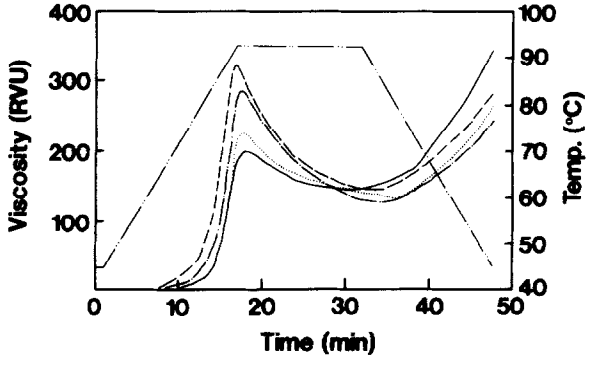

Fig. 1. Viscograms (10%, w/w) of Rosella (– – – –), Halberd (—•—), Vasco (·····), and Egret (———), and starches with RVA. —••—, temperature.

Table 1. Pasting properties of starches (10%, w/w)[a]

Property\Variety	Rosella	Halberd	Vasco	Egret
Pasting temp., °C	63.4	63.6	66.2	67.6
Maximum				
Viscosity (V_{max}), RVU	323	285	226	201
Temp., °C	92.2	92.5	92.5	92.5
Time[b], min	−0.1	+0.6	+0.7	+0.9
Minimum viscosity (V_{min}), RVU	147	127	134	147
Viscosity at 45°C ($V_{45°C}$), RVU	283	245	266	345
Breakdown				
RVU	176	158	92	54
%[c]	55	55	41	27
Consistency[d], RVU	136	118	132	198

[a]Data are mean values of duplicate analyses.
[b]Period after attaining 92.5°C. [c]$(V_{max}-V_{min})/V_{min}\times 100$. [d]$V_{45°C}-V_{min}$.

respectively) and considerably higher maximum viscosities at shorter times at 92.5°C (−0.1min and 0.6min, respectively) than those of Egret and Vasco starches (LV starches). These observations suggested that the granules of HV starches were less resistant to swelling, than those of LV starches. The breakdown values of HV starches were much greater than those of LV starches, indicating that the HV starch granules became softer and more fragile than those of LV starches on gelatinization. Egret starch showed the highest consistency, the difference between the final viscosity at 45°C and the minimum viscosity, among the starches, suggesting the greater retrogradation tendency of Egret starch. The $\log[V_{max}]$ of these starches showed a good linear regression with log*C* (concentrations) between 7–12% (Fig. 2) by the following equation, which has been found by Brabender amylography (Anker & Geddes, 1944). The values of *a* and *b*, and coefficient (*r*) of the correlation for each variety are listed in Table 2. Both *a* and *b* values showed varietal differences of pasting properties. Egret showed particularly high dependency on *C*, but the reason for this is uncertain.

$$\log[V_{max}] = b + a\log[C] \quad (1)$$

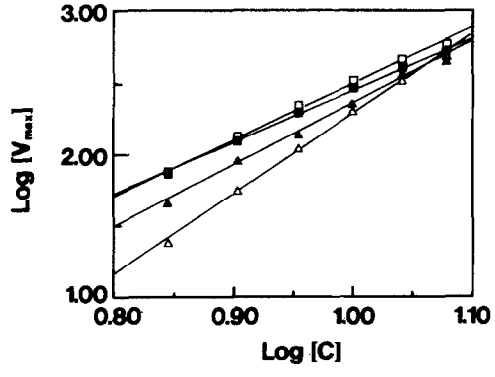

Fig. 2. Relationships between concentration (w/w) and maximum viscosities of the RVA viscograms. Rosella (□), Halberd (■), Vasco (▲), Egret (△).

Structure of amylose

The amyloses showed some structural differences by varieties (Table 3), although they had similar *IA* (20.4–21.2), *BV* (1.45–1.56), λ_{max} (625–656nm) and essentially no phosphorus (less than 1ppm). The values of $[\eta]$, $\overline{DP}_n$ and $\overline{DP}_w$ showed that HV amylose molecules were a little larger than LV amyloses. The following Mark–Houwink–Sakurada equation, which has been proposed for amyloses in general (Hizukuri, 1988), has been confirmed to fit for these wheat amyloses.

$$[\eta] = 0.41\overline{DP}_w^{0.78} \quad (2)$$

The amylose showed a similar molecular size distribution by HPLC (Fig. 3), however, the peak shapes were a little different by varieties. The HV amyloses had a relatively abundant ~5500 DP fraction compared with LV amyloses (Fig. 3). Vasco amylose had the highest amount of branch linkages (0.32%) and $\overline{NC}$ (5.2), shortest $\overline{CL}_n$ (250) and lowest ßal (81%), among the amyloses. However, its molar fraction of branched molecules was similar to those of Halberd and Egret, and that of Rosella gave considerably higher values (0.63) than the others (0.38–0.42).

The fine structure of the branched amylose was analyzed on its ß-LD (Table 4 and Fig. 3). The *IA* and *BV* of the ß-LDs had similar values or only slightly less than those of the parent amyloses, indicating that

Table 2. Relationship[a] between concentrations (*C*) and maximum viscosities (V_{max}) by RVA

Variety	*a*	*b*	*r*
Rosella	3.86	−1.37	0.997
Halberd	3.56	−1.12	0.999
Vasco	4.27	−1.92	0.998
Egret	5.59	−3.31	0.999

[a]$\log[V_{max}] = b + a\log[C]$.

Table 3. Properties of amyloses

Property\Variety	Rosella	Halberd	Vasco	Egret
Iodine affinity (*IA*), g/100 g, ($n=3$)	20.7±0.3[a]	20.7±0.2	21.2±0.0	20.4±0.1
Blue value (*BV*)	1.59	1.45	1.49	1.55
λ_{max}, nm	655	656	652	656
Limiting viscosity number ([η]), ml/g	269	271	262	255
Number-average DP ($\overline{DP}_n$), ($n=4$)	1500±110[a]	1400±50	1300±30	1200±20
Weight average DP ($\overline{DP}_w$)	4200	4100	3900	3800
$\overline{DP}_w/\overline{DP}_n$	2.80	2.93	3.00	3.17
Apparent DP distribution[b]	410–15000	290–14000	350–13000	320–13000
Number-average chain length ($\overline{CL}_n$)	300	320	250	270
Number of branch linkage, %[c]	0.27	0.24	0.32	0.28
Average number of chain ($\overline{NC}$)	5.0	4.4	5.2	4.4
ß-Amylolysis limit (ßal), %, ($n=4$)	85±0.6[a]	86±0.9	81±0.5	86±0.8
Organic phosphorus, ppm	<1	<1	<1	1
Branched fraction (*Bf*), %	0.63	0.38	0.43	0.38
Linear fraction (*Lf*), %	0.37	0.62	0.57	0.62

[a]Mean value±standard deviation.
[b]$\overline{DP}_w$ of 10% of the lowest and highest molecular weight fractions (Hizukuri & Takagi, 1984).
[c]$[(\overline{NC}-1)/\overline{DP}_n]\times 100$.

the interior structures of branched amyloses had long linear portions even though they had several branch linkages. The $\overline{CL}_n$ values were 130–160 but the main CL was considerably longer than these values because some side-chains (A chains) were only maltose or maltotriose by degradation with ß-amylase. The $\overline{DP}_n$ and $\overline{DP}_w$ values also decreased only slightly and the DP distribution was narrowed by ß-amylolysis. These results suggest that the linear fractions of amyloses were much smaller molecules than the branched fractions. Assuming the ßal of branched molecules to be 41%, which has been deduced for amylose from 26 sources (Hizukuri, unpublished), the $\overline{DP}_n$ of branched and linear molecules are calculated from $\overline{DP}_n$ of ß-LD, and the linear (*Lf*) and branched (*Bf*) fractions of each amylose by equations (3) and (4) (Hizukuri *et al.*, 1989), and these values are shown in Table 5.

$$\overline{DP}_n(\text{Branched}) = \overline{DP}_n(\beta - \text{LD})/0.59 \quad (3)$$

$$\overline{DP}_n(\text{Linear}) = [\overline{DP}_n(\text{Amylose}) - Bf \cdot \overline{DP}_n(\text{Branched})]/Lf \quad (4)$$

These calculations suggested that Rosella amylose comprised smaller branched molecules and larger linear molecules than other amyloses. The branched molecules of Rosella amylose had DP 1860 that was 2.1-fold larger than the linear molecules, while those of others had DP 2200–2710, 3.8 to 4.8-fold larger than the linear molecules. The $\overline{NC}$ of Rosella (7.3) was

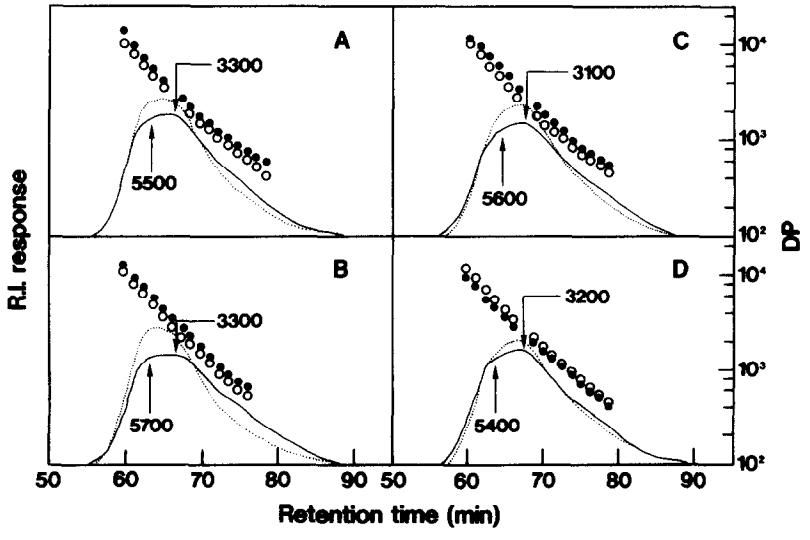

Fig. 3. Gel permeation HPLC chromatograms of amyloses and their ß-LD from Rosella (A), Halberd (B), Vasco (C), and Egret (D). — and •, response of RI and DP of amyloses, respectively; number with arrow, DP of the peaks or shoulders; --- and ○, response of RI and DP of ß-LDs, respectively.

Table 4. Properties of ß-limit dextrins from amyloses[a]

Property\Variety	Rosella	Halberd	Vasco	Egret
IA, g/100 g	19.8	20.3	19.2	19.8
BV	1.49	1.49	1.46	1.48
λ_{max}, nm	657	662	655	658
$\overline{DP}_n$	1100	1600	1400	1300
$\overline{DP}_w$	3800	3900	3200	3200
$\overline{DP}_w/\overline{DP}_n$	3.45	2.44	2.29	2.46
Apparent DP distribution	120–4000	50–4100	120–3600	80–3200
$\overline{CL}_n$	150	160	130	130
Number of branch linkage, %	0.57	0.56	0.70	0.69
$\overline{NC}$	7.3	10.0	10.8	10.0

[a]Mean values of duplicate determinations.

Table 5. $\overline{DP}_n$ of linear and branched fractions of amyloses

Amylose	Rosella	Halberd	Vasco	Egret
Branched (*B*)	1860	2710	2370	2200
Linear (*L*)	880	600	490	590
B/*L*	2.1	4.5	4.8	3.8

lower than those of others (~10). From these points, the structures of Rosella amylose were characteristic among the four.

Structure of amylopectin

Table 6 summarizes the properties of the amylopectins. The *IA*, *BV*, and λ_{max} of LV amylopectins were higher than those of HV amylopectins. Each amylopectin had a similar $\overline{CL}_n$ (~20), but differed slightly in the distribution of chain length (Fig. 4). Table 7 summarizes the distribution by each chain fraction as previously reported (Hizukuri, 1986). Each amylopectin contained small amounts of extra long chain component (ELC) which had been first observed in rice amylopectin (Takeda *et al.*, 1987b). LV amylopectins comprised higher amounts (3–4%) of the fraction ELC than those (2%) of HV amylopectins. The high BV indicated large amounts of ELC as observed on rice amylopectin (Takeda *et al.*, 1986; Hizukuri, 1988). Each fraction of B3, B2, B1 and A of Halberd had the highest $\overline{CL}_w$ of the four varieties and the rest showed similar distributions. The more detailed CL distribution of shorter chains (< 60 of DP) was examined by HPAEC (Figs 5 and 6). All of the amylopectins had the same peak and shoulder at DP 11 and 19, respectively (Fig. 5). These distributions were compared with those of normal maize by the differences present for each chain as shown in Fig. 6. The histograms indicate that these wheat amylopectins had the common features of higher amounts of chains of lengths 6–12 and 22–~40 and lower amounts of chains of lengths 12–22 than normal maize amylopectin and these differences were most prominent in Halberd amylopectins. ßal (56–58%), content of phosphorus (4–10ppm), and essentially no phosphorus attached to C-6 of the glucosyl residue of these amylopectins were characteristics common to all amylopectins.

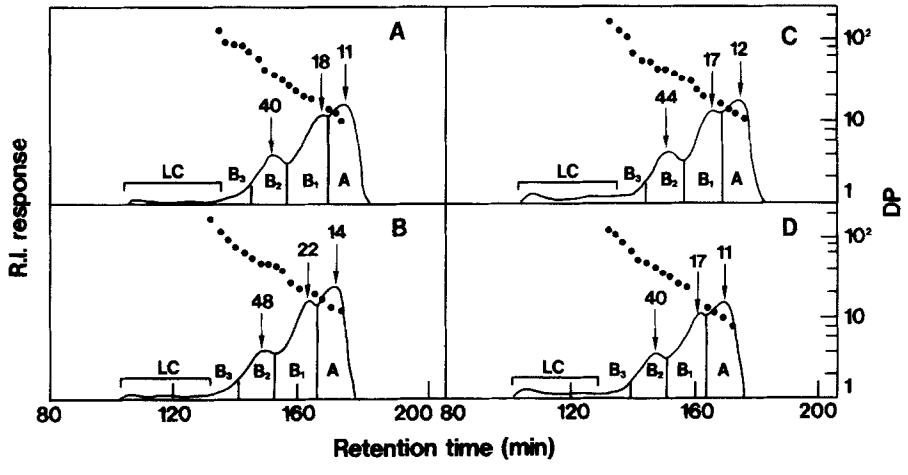

Fig. 4. Gel permeation HPLC chromatograms of isoamylase debranched amylopectins of Rosella (A), Halberd (B), Vasco (C), and Egret (D). — and •, response of RI and DP, respectively; number with arrow, DP of peaks.

Table 6. Properties of amylopectins

Property\Variety	Rosella	Halberd	Vasco	Egret
IA, g/100 g ($n=3$)	0.40±0.005[a]	0.44±0.001	0.78±0.012	0.68±0.012
BV ($n=5$)	0.093±0.01	0.090±0.01	0.133±0.02	0.117±0.01
λ_{max}, nm ($n=5$)	535±1.7	537±1.7	548±1.1	545±1.2
$[\eta]$, ml/g	147	151	154	148
$\overline{DP}_n$ ($n=6$)	18000±2200	17000±2000	16000±1800	13000±900
$\overline{CL}_n$				
Smith degradation ($n=3$)	19.9±1.3	20.1±1.3	19.5±1.2	20.0±0.4
Isoamylolysis ($n=3$)	19.2±1.7	19.3±1.7	19.2±1.1	19.3±1.2
ßal, % ($n=5$)	57±4.3	56±4.2	57±3.5	58±3.1
Phosphorus, ppm				
Organic	4	6	10	7
C-6[b]	<1	1	<1	<1

[a]Mean value±standard deviation.
[b]Phosphorus linked to C-6 glucosyl residue.

IA OF STARCH AND AMYLOSE CONTENT

The differences in *IA* values of the starches before and after defatting of the hard-wheat (Vasco and Halberd) starches were about 1.5 times higher than those of the soft-wheat (Egret and Rosella) starches (Table 8), the content of phosphorus was higher in the hard-wheat starches than in the soft-wheat starches, suggesting that the hard-wheat starches contained higher amounts of lipid (mainly lisophospholipid) (Morrison, 1988) than the soft-wheat starches. These starches had similar amylose contents (23.6–24.6%), calculated from the *IA* of starches, amyloses, and amylopectins, and these values were 2.4–4.5% lower than the apparent contents calculated assuming *IA* values of amylose and amylopectin of 20 and 0, respectively.

DISCUSSION

The pasting properties characterized by a Brabender amylograph or a similar viscograph appear to be related to complicated factors. However, the polymeric nature of molecules appears to be of primary importance and therefore the molecular structures of amylose and amylopectin were investigated in detail.

Although the specimens were limited in number, it would be worthwhile to discuss the relationships between the pasting properties and the molecular properties. The HV starches had larger molecules of both amylose and amylopectin than those of the LV starches. This is consistent with the previous observation on sago starches (Takeda *et al.*, 1989). The following good positive linear regressions have been found between the

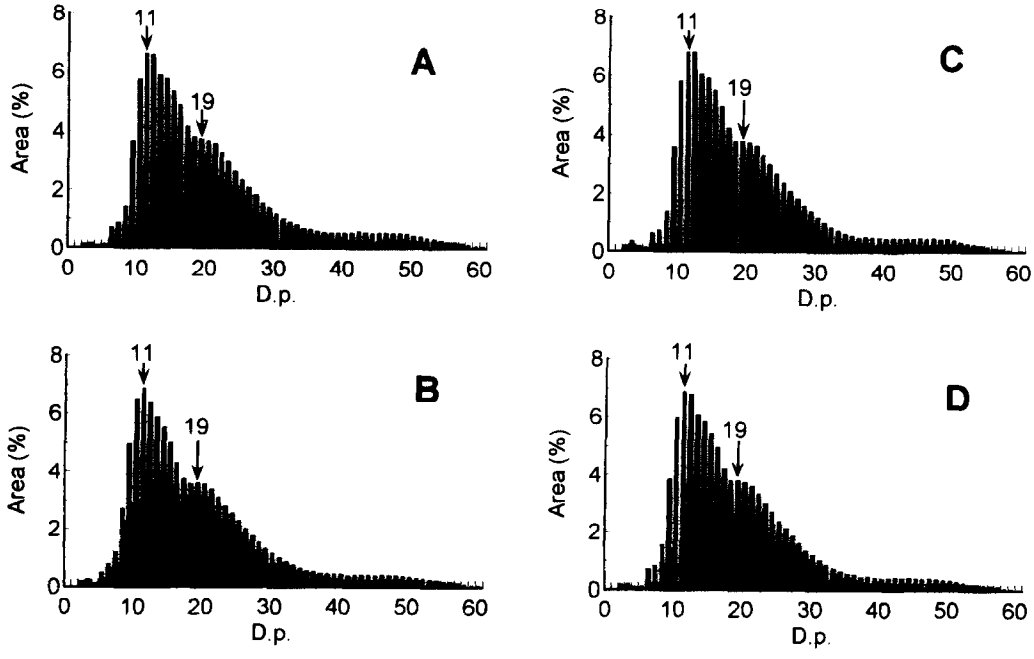

Fig. 5. Comparisons of area (%) of each peak on the HPAEC chromatograms of isoamylase debranched amylopectins of Rosella (A), Halberd (B), Vasco (C), and Egret (D). Total peak area of each specimen was taken as 100%.

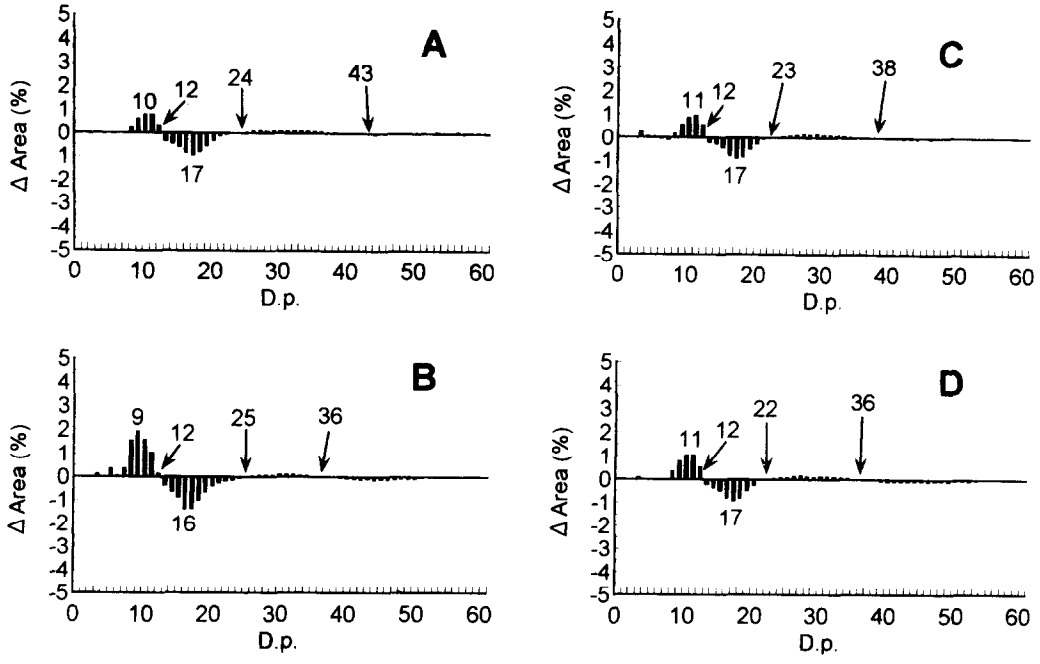

Fig. 6. Comparisons of differences of peak areas (%) of isoamylase debranched amylopectins of Rosella (A), Halberd (B), Vasco (C), and Egret (D) subtracted from that of maize amylopectin prepared with alkali (Takeda *et al.*, 1988) as a standard. Number with arrow, DP of peaks or inflection points positive from negative or vice versa.

V_{max} at 10% and molecular masses ($\overline{DP}_n$ and $\overline{DP}_w$) of amylose, and that of amylopectin ($\overline{DP}_n$) as follows and the best correlation was found with $\overline{DP}_w$. It is of interest that the pasting viscosity is closely dependent on the molecular size of amylose, which is a minor component of starch.

$$V_{max} = 0.425 \cdot \overline{DP_n}(\text{Amylose}) - 315\,(r = 0.989) \quad (5)$$

$$= 0.303 \cdot \overline{DP_w}(\text{Amylose}) - 953\,(r = 0.998) \quad (6)$$

$$= 0.0234 \cdot \overline{DP_n}(\text{Amylopectin}) - 116\,(r = 0.912) \quad (7)$$

The breakdown [V_{bd}] of the viscosity also correlated well with the molecular sizes of amylose and amylopectin, as given by the following equations.

$$V_{bd} = 0.432 \cdot \overline{DP_n}(\text{Amylose}) - 463\,(r = 0.980) \quad (8)$$

$$= 0.31 \cdot \overline{DP_w}(\text{Amylose}) - 1120\,(r = 0.994) \quad (9)$$

$$= 0.0249 \cdot \overline{DP_n}(\text{Amylopectin}) - 277\,(r = 0.943) \quad (10)$$

The greater V_{max} gave increased V_{bd} as shown in equation (11). These relationships suggest that the molecular masses of starch components are important factors affecting the pasting behaviors. The ratio of amylose to amylopectin is probably an important factor but the values of these specimens were similar to each other and consequently the effect of the molecular mass was emphasized.

$$V_{bd} = 1.01 \cdot V_{max} - 141\,(r = 0.985) \quad (11)$$

Table 7. Carbohydrate amounts and $\overline{CL}_w$ of each fraction for isoamylase-debranched amylopectins

	ELC	B3	B2	B1	A	∑A–B3	Whole
$\overline{CL}_w$							
Rosella	600	75	43	22	13	24	34
Halberd	700	99	51	25	15	28	39
Vasco	800	69	43	23	13	24	55
Egret	800	88	46	22	12	25	48
Amount (% of total)							
Rosella	2	3	19	36	40	98	100
Halberd	2	3	17	37	41	98	100
Vasco	4	4	18	35	39	96	100
Egret	3	3	19	35	40	97	100

Table 8. Iodine affinities of starches and amylose contents[a]

Property\Variety	Rosella	Halberd	Vasco	Egret
IA, g/100 g				
Non-defatted	4.20	3.66	4.06	4.51
Defatted	5.26	5.09	5.65	5.53
Difference (L-amylose)	1.06	1.43	1.59	1.02
Difference/defatted (%)	20.15	28.09	28.14	18.44
Phosphorus, ppm	442	522	554	432
Amylose content, %				
Real (*A*)	23.9	23.0	23.8	24.6
Apparent (*B*)	26.3	25.5	28.3	27.7
B–A	2.4	2.5	4.5	3.1

[a]Mean values of duplicate analyses.

The HV amylopectin appeared to contain a smaller amount (2%) of the ELC fraction than those (3 or 4%) of the LV amylopectin, agreeing with the case of sago starches (Takeda *et al.*, 1989). The ELC fraction seems to be another factor which controls pasting behavior similar to amylose through hydrogen bonding or making thermostable complexes with lipids. The low amount of lipid-complexed amylose in Rosella, as suggested by the difference in *IA* between defatted and non-defatted starches (Morrison, 1988), could be an additional reason for the high viscosity.

Rosella amylose showed some unique structural properties, because of its high $\overline{DP}_n$ and $\overline{DP}_w$ (Table 3) but low $\overline{DP}_n$ of its ß-LD (Table 5), and had a considerably higher branched fraction (*Bf*) and a lower $\overline{NC}$ of branched molecules (Tables 3 and 4). There has been no information on the effect of *Bf* on the physical properties of starch. Morrison *et al.* (1993) suggested that amylopectin and lipid free amylose promoted swelling of barley starch granules. If branched amylose was more lipid-free than linear amylose, *Bf* and/or $\overline{NC}$ of branched amylose would influence gelatinization and retrogradation of starch. To clarify this, further investigations are needed.

Each specimen had slightly larger molecules of both amylose and amylopectin than the starches of Japanese varieties examined previously (Shibanuma *et al.*, 1994). This may be one of the reasons for the inferior quality of our domestic wheat for Japanese noodles.

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