Starches from different botanical sources II: Contribution of starch structure to swelling and pasting properties

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Abstract

Swelling and pasting properties of 15 starches from different plant origins were studied to elucidate their relationship with structural features using simple and multiple regression analyses. Avoidance of additional effects of starch minor components showed that swelling power and pasting parameters were associated with the ratio of the relative molar distribution of amylopectin branch-chains with a degree of polymerization (DP) of 6–12 to that of chains with DP 6–24 (amylopectin unit-chain (APC) ratio). Swelling power of starch granules increased with APC ratio. Multiple regression analysis revealed that the peak viscosity (PkV) of starch paste increased with low APC ratio, low amylose content (AC) and large average granule size (AGS). At a high starch concentration, pasting temperature (PT) was reduced by a high APC ratio and large AGS. Peak time (PkT) decreased with increasing APC ratio and AC. Percentage of breakdown viscosity (BD%) and setback viscosity (SB) were primarily affected by APC ratio. At a low concentration, AC and AGS had more profound effects on BD%. SB was also reduced by higher AC. Models of pasting profile, which is influenced by individual factors, were also proposed.

Keywords: Starch; Swelling; Pasting; Amylopectin; Amylose; Granule size

Article Outline

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1. Introduction

In food systems, cooking starch together with water results in gelatinization. Crystalline structures of starch molecules are disrupted by increased hydrogen bonding between water molecules and hydroxyl groups, and this induces granular swelling. At the same time, amylose molecules diffuse out of the swollen starch granules (Whisler & BeMiller, 1997). Swelling ability contributes to important characteristics of most starchy food products, such as pasting and rheological behaviors. The loss of free water and restricted flow of water due to enormously swollen granules occupying more space contribute to the increased viscosity of the starch heating system. Gelatinized starch is, in essence, an amylose gel network with the swollen granules as a filler (Miles, Morris, Orford, & Ring, 1985). As the mixture cools, there is a decrease in kinetic energy, which allows the starch molecules to reassociate and form a network. This short-term re-association results in texture changes of cooked paste. Longer storage induces reversible re-crystallization of amylopectin, which increases the rigidity of the swollen granules embedded in the continuous amylose network (Miles et al., 1985 and Ring et al., 1987).

Amylopectin is expected to play a dominating role in properties of starch, because the semi-crystalline nature of starch is mainly constituted by its short branched-chains. Tester and Morrison (1990) proposed that the swelling property of starch granules is the result of the property of amylopectin, with amylose acting as a dilutant. Swelling and gelatinization properties are controlled, in part, by the molecular structure of amylopectin, starch compositions and granule architecture (crystalline to amorphous ratio) (Tester, 1997). For this reason, the difference in swelling and pasting properties among starches should be attributed to variation in amylopectin unit-chain length distribution. However, it has been well documented that minor components of starch, such as phospholipids and phosphate monoesters also have enormous effects on these properties (Galliard and Bowler, 1987, Lorberth et al., 1998, Noda et al., 2004, Singh et al., 2003, Suzuki et al., 1994 and Tester and Morrison, 1990). Such additional effects would hinder investigation of the influence of fine structures on swelling and pasting properties.

In this study, starch samples were selected from a wide range of botanical origins to determine swelling and pasting properties. Simple and multiple regression analyses were used to study the contribution of fine structures to functional properties. This information will provide additional information for better understanding how fine structures affect the properties of starch.

2. Materials and methods

2.1. Materials

The same 15 starch specimens used previously (Srichuwong, Sunarti, Mishima, Isono, & Hisamatsu, 2005) were also used in this study. Defatted starch was prepared according to Sunarti, Yoshio, and Hisamatsu (2001). The amylopectin unit-chain length distribution, apparent amylose content, average granule size and gelatinization temperatures of these starches were previously reported (Srichuwong et al., 2005).

2.2. Phosphorus and nitrogen contents

Total phosphorus content of native and defatted starches was analyzed by molybdenum blue spectrophotometric analysis (Smith & Caruso, 1964). Nitrogen content was determined using a colorimetric assay based on the Berthelot reaction after micro-Kjeldahl digestion (Nkonge & Balance, 1982).

2.3. Swelling behaviors

Swelling behaviors were determined by modifying the method of Li and Yeh (2001). Starch (1% w/v) in volume-calibrated sealed tubes was heated at 50, 60, 70, 80 and 90 °C in a shaking water bath for 30 min with renewed suspension every 5 min. After heating, the tubes were cooled to room temperature and centrifuged at 6200×*g* for 15 min. The supernatant was separated and swollen starch as the precipitate was weighted. Total carbohydrate content of the dissolved material in the supernatant was estimated by phenol-sulfuric assay (Dubois, Giles, Hamilton, Rebers, & Smith, 1956). Solubilized starch (SS) was reported as the ratio of total carbohydrate in the supernatant to the weight of dry matter starch. Swelling power (SP, g/g) was calculated as follows:

$$\begin{aligned}\mathrm{SP} = {} & [\text{precipitate weight} \\ & \times 100]/[(\text{dry matter starch weight}) \times (100 - \%\mathrm{SS})]\end{aligned}$$

Leached amylose (LAM) in the dissolved material was determined following the colorimetric method (Chrasil, 1987) and reported as mg of amylose leached per 100 mg of dry matter starch. Amylose from potato (Wako pure chemical industries Ltd, Osaka, Japan) was used for the calibration curve.

2.4. Pasting properties

Pasting properties were analyzed using a Rapid Visco-Analyzer (RVA) (model 3D; Newport Scientific Ltd, Sydney, Australia). Viscograms of starch was monitored using starch–water suspensions (6 and 8%, w/w, dry starch basis, 28.0 g total weight). Each suspension was tested under the same temperature–time conditions: heating from 50 to 95 °C at 6 °C/min (after an equilibration time of 1 min at 50 °C), a holding period at 95 °C for 5 min, cooling from 95 to 50 °C at 6 °C/min and a holding phase at 50 °C for 2 min. The constant rotating speed of the paddle was 160 rpm. Pasting parameters were automatically computed and reported.

2.5. Statistical analysis

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Determinations of total phosphorous were done in triplicate. Other tests were carried out in duplicate. Simple and multiple regression analyses were evaluated using SPSS 11.0 software (SPSS, Inc., Chicago, IL, USA).

3. Results and discussion

3.1. Phosphorus and nitrogen content

As shown in Table 1, potato starch was found to contain the highest total phosphorus content (715 ppm), followed by edible canna (339 ppm); those of the other starches ranged from 82 to 302 ppm. A large decrease in the phosphorus content of corn and rice starches by defatting supported that the phosphorus of normal cereal starch is mainly in the form of phospholipids (Suh, Verhoeven, Denyer, & Jane, 2004). Starches from root and tubers are known to contain a trace quantity of lipids (Hoover, 2001). Nitrogen was undetectable in sweet potato, kudzu, arrowroot, sago and lesser yam starches; other starches contained low contents (0.003–0.055%) (data not shown), implying that samples contained only a small amount of proteins.

Table 1.

Phosphorus content and APC ratio[a] of starches

Starch source	Phosphorus content (ppm)		APC ratio
	Native starch	Defatted starch	
Elephant yam	173	172	0.349
New cocoyam	166	151	0.371
Sweet potato	226	221	0.419
Kudzu	203	195	0.393
Sago	110	107	0.397
Taro	196	177	0.388
Yam bean	82	75	0.439
Cassava	113	87	0.489
Corn	171	61	0.392
Rice	270	10	0.449
Lesser yam	290	282	0.394

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Starch source	Phosphorus content (ppm)		APC ratio
	Native starch	Defatted starch	
Arrowroot	211	203	0.352
Edible canna	339	313	0.312
Water yam	302	285	0.253
Potato	715	691	0.364

[a] APC (Amylopectin unit-chain) ratio, ratio of relative molar distribution of amylopectin unit-chains with DP 6–12 to that of DP 6–24 (Srichuwong et al., 2005).

3.2. Swelling properties

Fig. 1 shows the changes in swelling power (SP), solubilized starch (SS) and leached amylose (LAM) of starch granules as a function of temperature. Each starch showed individual swelling patterns. At 60 °C, granular swelling was clearly observed in cassava, corn, rice and potato starches. The other starches except for water yam starch showed significant SP at 70 °C. With increasing temperature, SP of sago, cassava and potato starches reached their highest level and then decreased. A maximum SP was observed at 70 °C for cassava and potato starches, and that of sago starch was observed at 80 °C. The decrement of SP in these starches suggested the loss of granule integrity after successively swelling. On the other hand, SP of new cocoyam, corn and water yam starches increased slowly with temperature. The diversity of SP might be attributed to variation in the minor components and fine structures of starches.

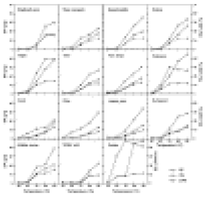

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Fig. 1. Swelling properties of 1% (w/v) starch suspension.

The aspects of leached material during the swelling process could be followed by SS and LAM (Fig. 1). It was found that both SS and LAM were positively correlated with SP ($P<0.01$)

(data not shown), suggesting solubilization along with granular swelling. The ratio of LAM at 90 °C (LAM$_{90}$) to apparent amylose content (AC) of each starch was estimated (data not shown). The average ratio for all starches was 93.0±9.0%. The ratio was lower in new cocoyam (86.0%), corn (85.7%), rice (87.5%), edible canna (83.8%) and water yam (69.0%) starches. This might suggest that swollen granules are enriched in amylopectin, whereas most amylose molecules leached out of the swollen granules at 90 °C. At high temperatures, the continuous increment of SS indicated an increase of solubilized amylopectin; this increase was enormous after granule disruption in sago, cassava and potato starches.

3.3. Pasting properties

The changes in viscosity during prolonged heating and subsequent cooling were characteristic for starches of different origin (Fig. 2). Different concentrations (6 and 8% w/w) were determined to cover the whole range of pasting characteristics. Because of insufficient amounts of yam bean starch, only 6% w/w suspension was measured. At higher starch concentration, lower pasting temperature, higher overall viscosity, sharper peak and faster peak time was observed. This might be due to the lower degree of free water and higher proportion of swollen granules occupying the space at higher starch concentration, contributing to higher viscosity (Rasper, 1980). In addition, viscosity breakdown also increased at higher concentration, particularly in elephant yam, new cocoyam and edible canna starches. This might be due to increased friction between swollen granules, elevating higher fragmentation during shear mixing. However, this effect was less pronounced in water yam starch, agreeing with its degree of granular swelling, which was lowest among all the starches observed.

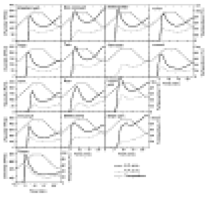

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Fig. 2. Rapid Visco-Analyzer viscograms of 6 and 8% w/w starch suspensions, except for yam bean starch which only 6% w/w suspension was determined.

The pasting parameters of 8% w/w suspension are summarized in Table 2. Potato starch exhibited the highest peak viscosity (PkV) and lowest pasting temperature (PT). Starches of elephant yam, corn and water yam had higher PT (81.6–83.2 °C) than the other starches (67.3–78.0 °C). Peak time (PkT), which reflects the temperature at peak viscosity, was very slow for corn, rice, lesser yam and water yam starches (8.2–11.1 min), whereas those of sago, cassava and potato starches were much faster (5.1–6.3 min). Percentage of breakdown (BD%) was calculated to represent the extent of viscosity breakdown from the maximal swelling capacity (PkV). Sago, cassava and potato starches displayed substantially higher BD% (62.6–71.2%) than the other starches (4.5–59.2%). A higher degree of BD% reflects the successive degree of granular swelling and friction between swollen granules. As shown in Table 2, starches with lower BD% (e.g. new cocoyam, edible canna and water yam) had a greater setback viscosity (SB) than those with higher BD% (e.g. sago, cassava and potato).

Table 2.

Pasting properties of 8% w/w starch suspension measured by Rapid Visco-Analyzer (RVA)

Source	**PT (°C)**	**PkT (min)**	**Viscosity (RVU)**					
			PkV	**HV**	**BD**	**BD%**	**FV**	**SB**
Elephant yam	81.6	7.5	204.3	111.8	92.5	45.3	197.5	85.7
New cocoyam	73.6	7.3	248.0	149.4	98.6	39.8	269.8	120.3
Sweet potato	75.2	7.0	265.1	114.0	151.1	57.0	187.3	73.3
Kudzu	76.0	7.3	231.0	121.8	109.2	47.3	187.9	66.1
Sago	72.8	6.3	203.9	76.2	127.7	62.6	137.4	61.2
Taro	78.0	7.7	251.2	139.6	111.6	44.4	249.4	109.8
Cassava	67.4	6.1	188.1	66.3	121.8	64.8	113.3	47.0
Corn	82.0	8.5	175.7	90.5	85.2	48.5	167.5	77.0
Rice	71.3	8.5	211.3	86.2	125.1	59.2	170.7	84.5
Lesser yam	75.7	8.2	291.7	172.8	118.9	40.8	246.3	73.5
Arrowroot	77.8	6.7	361.8	158.8	203.0	56.1	255.0	96.2
Edible canna	72.4	7.5	397.2	257.4	139.8	35.2	381.2	123.8
Water yam	83.2	11.1	394.6	376.9	17.7	4.5	556.3	179.4
Potato	67.3	5.1	791.4	228.3	563.1	71.2	286.8	58.5

PT, pasting temperature; PkT, peak time; PkV, peak viscosity; HV, hot paste viscosity; BD, breakdown viscosity (PkV-HV); BD%, percentage of breakdown [(BD/PkV)×100]; FV, final viscosity; SB, setback viscosity (FV-HV).

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The presence of non-starch components is widely reported to influence the swelling and pasting properties of starch. The difference in pasting behavior between normal cereal (e.g. corn and rice) and other starches can be attributed to phospholipids. Phospholipids are known to form water-insoluble complexes with amylose during heating. These complexes severely restrict granular swelling, and maintain the integrity of swollen granules (Galliard and Bowler, 1987, Jane et al., 1996, Singh et al., 2003, Suh et al., 2004 and Tester and Morrison, 1990). Presumably, the granules of normal cereal starch do not reach actual swelling capacity, resulting in short body and opaque paste, which differs from that of waxy cereal, tuber and root starches. The large phosphorus content of potato amylopectin as phosphate monoesters results in excessive granular swelling, which leads to low PT and PkT, and high PkV and BD (Fig. 2, Table 2) (Lorberth et al., 1998, Noda et al., 2004 and Suzuki et al., 1994). It is possible that such effects might also affect the pasting properties of edible canna starch, according to its phosphorus content, relatively low PT and DSC gelatinization temperature (Srichuwong et al., 2005). For this reason, in this study, significant additional effects of minor components on swelling and pasting properties were expected in corn, rice, potato and edible canna starches.

3.4. Correlation analysis

The relationship between structural features and swelling–pasting properties was analyzed using simple and multiple regression analyses. To minimize the additional effects of minor components, the parameters of corn, rice, potato and edible canna starches were excluded from analysis. In this respect, the swelling and pasting properties of other starches were assumed to be mainly impacted by their structural features. In the present study, the ratio of the relative molar distribution of short chains with a degree of polymerization (DP) of 6–12 to that of chains with DP 6–24 was named the amylopectin unit-chain (APC) ratio (Table 1). This ratio was used to characterize the proportion of short chains composed in the crystalline regions of starch.

The correlation coefficients (*r*) of simple regression analysis between the functional parameters are summarized in Table 3 (*n*=10). Swelling power at 70 °C (SP$_{70}$) was used since degree of granule disintegration was very low at this temperature. Pasting parameters were of 8% w/w starch suspension. The results showed that significant correlations were obtained among SP$_{70}$, RVA parameters and DSC temperatures. In addition, APC ratio positively correlated with SP$_{70}$ and BD%, but negatively with PT, PkT, PkV, hot paste viscosity (HV), final viscosity (FV) and SB. These results suggest that dissociation of double helices of amylopectin leads to granular swelling and affects pasting properties, to some extent. Using simple linear regression analysis, insignificant correlations were found between apparent amylose content (AC), average granule size (AGS) and functional properties (Table 3).

Table 3.

Correlation coefficients (*r*) between functional parameters[a]

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Functional parameters	**RVA parameters**[b]							**SP_{70}**[c]
	PT	**PkV**	**PkT**	**BD%**	**HV**	**FV**	**SB**	
PkV	0.59							
PkT	0.73*	0.69*						
BD%	−0.71*	−0.65*	−0.97**					
HV	0.68*	0.84**	0.95**	−0.94**				
FV	0.70*	0.83**	0.94**	−0.95**	0.99**			
SB	0.70*	0.73*	0.85**	−0.89**	0.90**	0.95**		
SP_{70}[c]	−0.93**	−0.63	−0.75*	0.77**	−0.70*	−0.72*	−0.70*	
APC ratio[d]	−0.88**	−0.74*	−0.82**	0.85**	−0.86**	−0.88**	−0.87**	0.83**
AC[e]	0.29	−0.14	−0.01	−0.08	−0.03	0.06	0.20	−0.14
AGS[e]	0.20	0.31	0.04	0.02	0.20	0.20	0.19	0.18
T_{oG}[e]	0.89**	0.55	0.66*	−0.73*	0.64*	0.69*	0.77**	−0.92**
T_{pG}[e]	0.93**	0.53	0.69*	−0.75*	0.65*	0.70*	0.77**	−0.95**
T_{cG}[e]	0.86**	0.48	0.62	−0.68*	0.60	0.65*	0.71*	−0.84**

*$P<0.05$; **$P<0.01$.

[a] The parameters from corn, rice, edible canna and potato starches were excluded from analysis ($n=10$).
[b] RVA parameters of 8% w/w suspension, see Table 2 for definitions of parameters.
[c] SP_{70}, swelling power at 70 °C.
[d] APC ratio, amylopectin unit-chain ratio.
[e] AC, apparent amylose content; AGS, average granule size; T_{oG}, T_{oG} and T_{oG}, DSC onset, peak and conclusion temperature of native starch, respectively (Srichuwong et al., 2005).

Since it is likely that pasting properties of starch are affected by several factors, multiple regression analysis was conducted to reveal the extent of each factor. The results showed that the pasting parameters (PT, PkT, PkV, BD%) of 6 and 8% w/w suspensions could be expressed as multiple equations with APC ratio, AC and AGS (Table 4). According to the equations of 8%

w/w suspension, low APC ratio markedly increased PT, PkV, and PkT and reduced BD%. Higher AC reduced PkV and PkT, but affected PT and BD% to a lesser extent. Larger AGS increased PkV and slightly reduced PT, but did not significantly alter BD%. Similar findings of the effects of amylopectin unit-chain length (Edwards et al., 1999, Jobling et al., 2002 and Wong et al., 2003), granule size (Fortuna et al., 2000, Kainuma et al., 1978 and Yamamoto et al., 1982) and amylose content (Collado, Mabesa, & Corke, 1999) on pasting properties of starches from the same botanical origin were reported elsewhere. Although similar effects of APC ratio, AC and AGS on PT and PkV were also observed at a lower starch concentration (6% w/w suspension), BD% was greatly reduced by higher AC and smaller AGS.

Table 4.

Multiple regression equations between pasting parameters and structural features[a]

n	**Equation**	**Coefficient (*r*)**
	8% w/w starch suspension	
10	$\frac{\text{ated with epoxide } (w_d)}{(w_d)} \times 100$	0.92**
10	$\mathrm{PkT} = 19.061 - 22.355(\text{APC ratio}) - 0.137(\mathrm{AC}) - 0.015(\mathrm{AGS})$	0.89*
10	$\mathrm{PkV} = 871.898 - 967.835(\text{APC ratio}) - 15.011(\mathrm{AC}) + 2.675(\mathrm{AGS})$	0.93**
10	$\%\mathrm{BD} = -82.383 + 272.654(\text{APC ratio}) + 0.925(\mathrm{AC}) + 0.306(\mathrm{AGS})$	0.90*
10	$\mathrm{HV} = 894.891 - 1390.862(\text{APC ratio}) - 12.347(\mathrm{AC}) + 1.278(\mathrm{AGS})$	0.93**
10	$\mathrm{HV} = 822.196 - 1093.171(\text{APC ratio}) - 14.974(\mathrm{LAM}_{90}) + 1.057(\mathrm{AGS})$ [b]	0.98**
10	$\mathrm{FV} = 1237.876 - 1968.886(\text{APC ratio}) - 13.913(\mathrm{AC}) + 1.234(\mathrm{AGS})$	0.93**
10	$\mathrm{FV} = 1173.843 - 1618.52(\text{APC ratio}) - 18.285(\mathrm{LAM}_{90}) + 1.121(\mathrm{AGS})$	0.97**
10	$\mathrm{SB} = 343.056 - 578.038(\text{APC ratio}) - 1.570(\mathrm{AC}) - 0.043(\mathrm{AGS})$	0.88*
10	$\mathrm{SB} = 351.633 - 525.302(\text{APC ratio}) - 3.312(\mathrm{LAM}_{90}) + 0.0638(\mathrm{AGS})$	0.90*
	6% w/w starch suspension	
11	$\mathrm{PT} = 105.041 - 70.089(\text{APC ratio}) + 0.16(\mathrm{AC}) - 0.187(\mathrm{AGS})$	0.95**
11	$\mathrm{PkT} = 23.939 - 29.131(\text{APC ratio}) - 0.157(\mathrm{AC}) - 0.068(\mathrm{AGS})$	0.80
11	$\mathrm{PkV} = 322.967 - 235.247(\text{APC ratio}) - 7.28(\mathrm{AC}) + 0.879(\mathrm{AGS})$	0.76
11	$\%\mathrm{BD} = -69.449 + 261.055(\text{APC ratio}) - 1.589(\mathrm{AC}) + 1.352(\mathrm{AGS})$	0.94**

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n	**Equation**	**Coefficient (*r*)**
11	$HV = 342 - 435.848(\text{APC ratio}) - 4.217(AC) - 0.672(AGS)$	0.93**
11	$HV = 298.558 - 352.958(\text{APC ratio}) - 3.596(LAM_{90}) - 0.868(AGS)$	0.92**
11	$FV = 617.257 - 844.265(\text{APC ratio}) - 7.650(AC) - 0.621(AGS)$	0.93**
11	$FV = 546.237 - 686.559(\text{APC ratio}) - 7.191(LAM_{90}) - 0.914(AGS)$	0.93**
11	$SB = 274.888 - 408.097(\text{APC ratio}) - 3.443(AC) + 0.054(AGS)$	0.82*
11	$SB = 247.652 - 333.017(\text{APC ratio}) - 3.610(LAM_{90}) - 0.044(AGS)$	0.84*

*$P<0.05$; **$P<0.01$.

[a] The parameters from corn, rice, edible canna and potato starches were excluded from analysis, see Table 2 and Table 3 for definitions of parameters.
[b] LAM_{90}, leached amylose at 90 °C.

Table 3 shows that HV, FV and SB had a highly negative correlation with BD% ($P<0.01$). It is likely that the re-association between starch molecules during cooling was related to the extent of granule dissociation. Multiple regression analysis showed that HV, FV and SB had significant correlations with APC ratio, AC or LAM_{90} and AGS (Table 4). At an 8% w/w concentration, SB primarily decreased with increasing APC ratio. At a lower concentration (6% w/w), SB was also reduced with increasing AC or LAM_{90}. In contrast, SB was not altered by AGS at any starch concentration. Based on the multiple regression equations in Table 4, models of the pasting profile of starch as a function of each individual factor were proposed (Fig. 3).

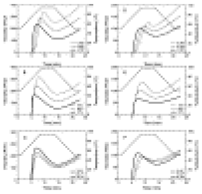
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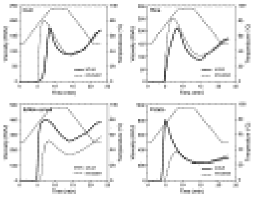
Fig. 3. Models of the pasting profile of starch as a function of each individual factor of 8% w/w suspension: (A) APC ratio (AC=20%, AGS=20 μm); (B) AC (APC ratio=0.400, AGS=20 μm); (C) AGS (APC ratio=0.400, AC=20%) and 6% w/w suspension: (D) APC ratio (AC=20%, AGS=20 μm); (E) AC (APC ratio=0.400, AGS=20 μm); (F) AGS (APC ratio=0.400, AC=20%).

Our results suggest that deficiencies in chains with DP 6–12 (enrichment in chains with DP 13–24) in crystalline regions of starch; that is, a low APC ratio, would increase the stability of crystalline packing, retard the swelling process and maintain the integrity of swollen granules. This would allow the granules to swell to a greater degree and achieve a higher viscosity (increased PT, PkT, and PkV, but decreased SP and BD%). In contrast, granules containing plenty of short chains; that is, those with a high APC ratio, are easily swollen and broken resulting in a substantially lower PT, PkT and PkV and higher BD%. This is consistent with the hypothesis, whereby swollen granules are important for the rheological properties of starch gel (Eliasson & Gudmundsson, 1996). Since amylopectin is primarily responsible for granule swelling (Tester & Morrison, 1990), higher amylose content would reduce the concentration of swelling fraction of starch and thus decrease the viscosity. Larger starch granules might increase the rate of swelling, which might occupy more volume and enhance viscosity. At low starch concentrations, friction between swollen granules, which leads granule fragmentation is likely to be deficient; this might be enhanced by a higher swelling fraction (lower amylose content) and larger granules.

As the mixture is cooled, re-association among gel components occurs. Since starch with high APC ratio was extensively swollen, disintegrated and dispersed, bonding of numerous water molecules with starch chains is likely to block or delay re-association among starch chains, resulting in lower SB. Possibly, leached amylose chains mainly form a continuous phase and influence total viscosity to a lesser extent. The solution separated by centrifugation of gelatinized starch suspension was also reported to have very low viscosity (Evans & Haisman, 1979). This might indicate the important role of amylopectin fine structure on the viscosity of cold paste. At a low starch concentration, the distinct decrease in SB with increasing AC or LAM_{90} might be due to a lower proportion of amylopectin in the swollen granules. However, an increase in SB with increasing amylose content has also been reported in some cereal starches (Sasaki et al., 2000 and Vandeputte et al., 2003). The authors postulated that the arrangement of leached amylose molecules was the reason for this. In our opinion, this could also be attributed to a higher numbers of amylose–lipid complexes in higher amylose-containing starch. Less granular swelling and more granule integrity might increase re-association among gel components.

3.5. Additional effects of minor components on pasting properties

To elucidate the influence of minor components on pasting properties of corn, rice, potato and edible canna starches, pasting profiles (8% w/w) were simulated using multiple regression equations and compared with the actual profiles (Fig. 4). In cereal starches, amylose–lipid complexes in actual starch were shown to contribute to higher PT and PkT and lower PkV and BD%. In the case of edible canna and potato starches, lower PT and PkT and higher PkV and BD% was observed in actual starch. These drastic differences indicated the additional effects of amylose–lipid complexes and phosphate monoesters on pasting properties of starch.



Full-size image (24K)

Fig. 4. Comparison between actual and simulated RVA viscograms of 8% w/w starch suspension of corn, rice, edible canna and potato starches.

4. Conclusion

The results of this study revealed the influence of fine structures on swelling and pasting properties. Multiple regression analysis is a useful tool for evaluating the extent of these effects among individual factors. Amylopectin plays a critical role on starch physico-chemical properties. Pasting properties were directly related to granular swelling and the integrity of swollen granules, which are attributed to the distribution of amylopectin unit-chains with DP 6–24. Variation in amylose content affected the total swelling fraction and starch granule size might be related to the size of swollen granules occupying restricted space. The effect of amylopectin fine structure, amylose content and granule size on pasting properties was also dependent on starch concentration.

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