Available online at www.sciencedirect.com
ScienceDirect
Food Chemistry 105 (2007) 164–172
Food Chemistry
www.elsevier.com/locate/foodchem

Correlation between the compositional and pasting properties of various potato starches

I.S.M. Zaidul *, H. Yamauchi, S. Takigawa, C. Matsuura-Endo, T. Suzuki, T. Noda

Memuro Upland Farming Research Station, National Agricultural Research Center for Hokkaido Region, Shinsei, Memuro, Kasai, Hokkaido 082-0071, Japan

Received 11 December 2006; received in revised form 15 February 2007; accepted 25 March 2007

Abstract

Multiple linear regression equations were used to develop the correlation between the compositional and rapid visco-analysis (RVA) pasting properties of various potato starches. The amylose of potato starches had a negative correlation with the peak viscosity (PV) and breakdown (BD) and a positive correlation with the setback viscosity (SV) and peak viscosity temperature (PVT). By contrast, phosphorus had a positive correlation with PV, BD, and SV and a negative correlation with PVT. In addition, the median granule size had a positive correlation with PV and BD. By contrast, a negative correlation of the median granule size was observed with SV and PVT. The correlation coefficients of amylose–phosphorus, amylose–granule size, and phosphorus–granule size interactions indicated that amylose had more influence than had phosphorus or had the median granule size on PV and BD. Furthermore, amylose had a greater influence than had the granule size on SV and PVT. Similarly, amylose had more influence than had phosphorus or had the median granule size on PVT. However, the correlation developed in this study was useful for predicting the influence of a specific component and the compositional interaction on the RVA pasting properties.

Keywords: Potato starches; Compositional properties; Pasting properties; Correlations

1. Introduction

Potato starch is an important raw material in the food industry because of its desirable properties of low gelatinization temperature, low tendency to retrograde, no residual proteinaceous material or soil residues, non-cereal flavor, high viscosity, high water-binding capacity, bland taste, translucent paste, and relatively good stability.

The potato (*Solanum tuberosum* L.) is an important upland crop in Japan. Potatoes for starch production, accounting for about 40% of the domestic output, are grown exclusively in Hokkaido, the northernmost and second largest island of Japan (Mori, 2001). Phosphorus, a non-carbohydrate constituent, is present in relatively high quantities in potato starch, which may affect its functional properties. Analysis of the phosphorus content is assumed to be useful for predicting the pasting properties of potato starches (Noda et al., 2004a). Potato starch displays a normal distribution for granule size, but the range for size distribution is wide (Chen, Schols, & Voragen, 2003; Noda et al., 2005). Koo, Park, Jo, Kim, and Baik (2005) reported that the pasting properties of starch are highly dependent on the granule size as well as the degree of swelling of starch granules. Thermal and pasting properties are the most important functional properties of starches. Among all commercial starches, potato starch has the highest swelling power and gives the highest viscosity of pasting properties (Mitch, 1984). Matveev et al. (2001) concluded that the melting thermodynamic properties of starches were directly correlated to their amylose content. Pasting behavior is usually studied by observing changes in the

* 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).

0308-8146/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2007.03.061

viscosity of a starch system based on rheological principles.

Starch properties are generally influenced by the cultivars and by environmental factors. The starch properties of potato cultivars significantly affect the rheological properties (Cottrell, Duffus, Paterson, & Mackay, 1995; Ganga & Corke, 1999; Kim, Wiesenborn, Orr, & Grant, 1995; Morrison et al., 2000; Suzuki, Shibanuma, Takeda, Abe, & Hizukuri, 1994; Wiesenborn, Orr, Casper, & Tacke, 1994), and the developmental stage of a potato also affects the starch properties (Madsen & Christensen, 1996; Sugimoto, Yamashita, Hori, Abe, & Fuwa, 1995). Noda et al. (2004a, 2004b) reported that there were some variations in the properties of potato starches grown in Hokkaido even within the same cultivar due to the influence of the harvest date. The objective of this work was to investigate the influence of amylose, phosphorus, and the median granule size on the pasting properties of potato starches, using a rapid visco-analyzer (RVA), from representative potato cultivars grown in Hokkaido. In addition, the aim was to predict the influence of a specific component, in the combined compositional effect, such as amylose–phosphorus, amylose–granule and phosphorus–granule, on the pasting properties. Thus, we aimed to find a simple and multiple regression equation to correlate the compositional and pasting properties of the potato starches. The present study will provide additional information for a better understanding of the functional properties of potato starch for the processing of starch-based food products which is affected by the specific components of amylose, phosphorus, and median granule size.

2. Materials and methods

2.1. Materials

The 105 potato samples used in this study are listed in Table 1. Eighty-seven potato samples were grown in 2001 and 2002 on the experimental farm at the National Agricultural Research Center for the Hokkaido Region at Memuro, Hokkaido. Starches were isolated from those potato samples as described by Noda et al. (2004b). Nine potato starches, isolated by Jinno Starch Co., Sarabetsu, Hokkaido, were purchased for this experiment. Five of the nine were derived from Konafubuki, Benimaru, Eniwa, Hokkaikogane and Norin No. 1, which had been produced in 2002 on a farm near Jinno Starch Co., and four were derived from Benimaru, Eniwa, Hokkaikogane and Waseshiro, which had been produced in 2003 on the farm near Jinno Starch Co. Nine potato samples were produced at the Nakashari Starch Factory, Hokkaido.

2.2. Analysis of the starch properties

The analyses of the compositional properties of amylose, phosphorus, and median granule size (Table 2) have

Table 1
List of potato samples used in the correlations (Harv.: harvested; D/M: day/month)

Potato No.	Cultivars	Plant D/M	Harv. D/M	Year
1[a]	Konafubuki	09/05	27/09	2001
2[a]	Benimaru	09/05	27/09	2001
3[a]	Sakurafubuki	09/05	27/09	2001
4[a]	Astarte	09/05	27/09	2001
5[a]	Early Starch	09/05	27/09	2001
6[a]	Hokkai No.87	09/05	27/09	2001
7[a]	Irish Cobbler	09/05	27/09	2001
8[a]	Sayaka	09/05	27/09	2001
9[a]	Toyoshiro	09/05	27/09	2001
10[a]	May Queen	09/05	27/09	2001
11[a]	Norin No. 1	09/05	27/09	2001
12[a]	Eniwa	09/05	27/09	2001
13[a]	Hokkaikogane	09/05	27/09	2001
14[a]	Green Moun.	09/05	27/09	2001
15[a]	Early Rose	09/05	27/09	2001
16[a]	VermontGold Coin	09/05	27/09	2001
17[a]	Kintoki-imo	09/05	27/09	2001
18[a]	Pepo	09/05	27/09	2001
19[a]	Kennebec	09/05	27/09	2001
20[a]	Cherokee	09/05	27/09	2001
21[a]	Rishiri	09/05	27/09	2001
22[a]	Hokkai-aka	09/05	27/09	2001
23[a]	Yukijiro	09/05	27/09	2001
24[a]	Dejima	09/05	27/09	2001
25[a]	Waseshiro	09/05	27/09	2001
26[a]	Tarumae	09/05	27/09	2001
27[a]	Tunika	09/05	27/09	2001
28[a]	Nishiyutaka	09/05	27/09	2001
29[a]	Toyoakari	09/05	27/09	2001
30[a]	Kita-akari	09/05	27/09	2001
31[a]	Musamaru	09/05	27/09	2001
32[a]	Touya	09/05	27/09	2001
33[a]	Atlantic	09/05	27/09	2001
34[a]	Beni-akari	09/05	27/09	2001
35[a]	Konafubuki	09/05	29/08	2001
36[a]	Benimaru	09/05	29/08	2001
37[a]	Sakurafubuki	09/05	29/08	2001
38[a]	Astarte	09/05	29/08	2001
39[a]	Early Starch	09/05	29/08	2001
40[a]	Hokkai No.87	09/05	29/08	2001
41[a]	Irish Cobbler	09/05	24/08	2001
42[a]	Sayaka	09/05	27/08	2001
43[a]	Toyoshiro	09/05	24/08	2001
44[a]	Waseshiro	08/05	18/09	2001
45[a]	Hokkaikogane	08/05	01/10	2001
46[a]	Benimaru	08/05	01/10	2001
47[a]	Irish Cobbler	24/04	14/09	2001
48[a]	May Queen	24/04	14/09	2001
49[a]	Toyoshiro	24/04	14/09	2001
50[a]	Konafubuki	09/05	01/10	2001
51[a]	Hokkai No.87	08/05	01/10	2001
52[a]	Astarte	08/05	20/09	2001
53[a]	Kita-akari	08/05	18/09	2001
54[a]	Inca Purple	25/04	14/09	2001
55[a]	Inca Red	25/04	14/09	2001
56[a]	Kitamurasaki	25/04	14/09	2001
57[a]	Hokkai No.92	25/04	14/09	2001
58[a]	Hokkai No.91	25/04	14/09	2001
59[a]	Inca-no-mezame	25/04	14/09	2001
60[b]	Benimaru	Unknown	Unknown	2002
61[b]	Konafubuki	Unknown	Unknown	2002
62[b]	Eniwa	Unknown	Unknown	2002

(*continued on next page*)

Table 1 *(continued)*

Potato No.	Cultivars	Plant D/M	Harv. D/M	Year
63[b]	Hokkaikogane	Unknown	Unknown	2002
64[b]	Norin No. 1	Unknown	Unknown	2002
65[a]	Konafubuki	07/05	03/10	2002
66[a]	Early Starch	07/05	03/10	2002
67[a]	Irish Cobbler	07/05	03/10	2002
68[a]	Sayaka	07/05	03/10	2002
69[a]	Toyoshiro	07/05	03/10	2002
70[a]	Eniwa	07/05	03/10	2002
71[a]	Touya	07/05	03/10	2002
72[a]	May Queen	07/05	03/10	2002
73[a]	Norin No. 1	07/05	03/10	2002
74[a]	Beni-akari	07/05	03/10	2002
75[a]	Waseshiro	07/05	03/10	2002
76[a]	Hokkaikogane	07/05	03/10	2002
77[a]	Kita-akari	07/05	24/09	2002
78[a]	Inca-no-mezame	07/05	13/09	2002
79[a]	Toyoshiro	24/04	30/09	2002
80[a]	Rishiri	02/05	25/09	2002
81[a]	Irish Cobbler	24/04	30/09	2002
82[a]	Early Starch	24/04	30/09	2002
83[a]	Cherokee	02/05	25/09	2002
84[a]	Green Moun.	02/05	25/09	2002
85[a]	Kennebec	02/05	25/09	2002
86[a]	Hokkai No.87	24/04	30/09	2002
87[a]	Eniwa	24/04	30/09	2002
88[a]	Touya	24/04	30/09	2002
89[a]	Sakurafubuki	24/04	30/09	2002
90[a]	Hokkaikogane	24/04	30/09	2002
91[a]	Konafubuki	24/04	30/09	2002
92[a]	Benimaru	24/04	30/09	2002
93[b]	Benimaru	Unknown	Unknown	2003
94[b]	Waseshiro	Unknown	Unknown	2003
95[b]	Eniwa	Unknown	Unknown	2003
96[b]	Hokkaikogane	Unknown	Unknown	2003
97[c]	Unknown	Unknown	Unknown	2001
98[c]	Unknown	Unknown	Unknown	2002
99[c]	Unknown	Unknown	Unknown	2003
100[c]	Unknown	Unknown	Unknown	2001
101[c]	Unknown	Unknown	Unknown	2002
102[c]	Unknown	Unknown	Unknown	2003
103[c]	Unknown	Unknown	Unknown	2001
104[c]	Unknown	Unknown	Unknown	2002
105[c]	Unknown	Unknown	Unknown	2003

[a] Experimental farm at the National Agricultural Research Center for the Hokkaido Region at Memuro.
[b] Farm near Jinno Starch Co.
[c] Farm near Nakashari Starch Factory. Nos. 97–99, Nos. 100–102, and Nos. 103–105 are regarded as large, small, and extremely small starch granules, all of which were produced by air-classification.

been discussed by Noda et al. (2004b). The pasting properties (Table 3), using RVA-4 (Newport Scientific Pvt., Ltd., Australia), of the potato starches were determined according to Noda et al. (2004b). Each sample of potato starch was added to 25 ml of distilled water to prepare a 4% suspension (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 at 95 °C for 2.5 min. It was then cooled to 50 °C (cooling rate of 11.8 °C/min) and kept at that temperature for 2 min.

Table 2
Compositional properties of different potato starches used in the correlations (refer to Table 1)

Potato No.	Amylose (%)	Phosphorus (ppm)	Granule (μm)
1	20.0	814	42.7
2	21.1	602	46.5
3	22.0	709	48.5
4	22.5	637	49.1
5	23.1	837	45.6
6	18.4	979	45.6
7	18.8	760	33.1
8	18.4	976	44.8
9	20.9	811	34.8
10	19.4	725	38.4
11	21.9	684	36.2
12	15.6	1008	42.8
13	16.4	1193	38.5
14	19.9	657	42.4
15	17.3	810	41.6
16	17.7	924	40.4
17	21.8	750	34.2
18	15.8	1095	43.7
19	12.4	1257	41.5
20	18.4	1334	40.7
21	17.1	649	28.9
22	15.7	783	33.4
23	19.0	757	29.5
24	18.4	798	46.1
25	13.9	1070	35.3
26	15.9	851	37.5
27	20.1	1001	43.1
28	19.1	772	46.6
29	13.3	1069	46.0
30	19.2	1008	34.4
31	20.8	933	43.6
32	18.0	1201	36.6
33	18.4	1164	46.2
34	18.6	809	39.6
35	19.5	732	36.2
36	21.0	590	44.9
37	20.9	653	45.2
38	21.1	581	45.3
39	20.9	787	39.9
40	17.7	860	38.0
41	19.3	866	35.1
42	19.8	837	37.2
43	19.8	852	32.9
44	16.9	935	34.3
45	19.3	997	40.2
46	24.0	621	46.6
47	17.9	921	33.0
48	20.2	768	39.8
49	19.9	834	35.2
50	20.1	752	38.6
51	18.3	885	46.0
52	22.4	679	42.9
53	20.9	870	40.1
54	16.7	900	38.0
55	11.4	1102	26.8
56	18.8	1029	41.5
57	17.8	1033	37.4
58	19.5	1110	34.0
59	19.2	1030	31.2
60	22.2	659	46.9
61	20.0	777	42.3
62	19.2	880	42.4

(*continued on next page*)

Table 2 (*continued*)

Potato No.	Amylose (%)	Phosphorus (ppm)	Granule (μm)
63	18.6	797	43.7
64	22.9	654	36.4
65	20.8	822	41.2
66	21.8	919	37.9
67	21.4	776	33.5
68	20.4	849	37.4
69	24.2	754	35.8
70	17.2	1090	37.9
71	19.6	920	33.0
72	20.5	683	42.6
73	22.4	564	36.0
74	21.7	798	42.0
75	18.1	926	30.9
76	18.8	969	42.0
77	19.6	847	35.2
78	20.7	960	36.0
79	19.9	622	33.1
80	19.3	648	27.6
81	19.8	652	32.8
82	21.1	714	39.7
83	18.3	1079	36.8
84	20.8	693	38.6
85	16.1	961	37.3
86	18.1	744	40.1
87	15.4	790	37.8
88	19.6	914	31.4
89	19.5	732	44.1
90	17.2	987	41.1
91	19.1	764	41.8
92	21.5	510	43.6
93	22.3	644	46.3
94	19.6	762	33.0
95	19.4	825	38.0
96	20.9	874	41.6
97	20.5	764	43.7
98	21.5	790	43.2
99	20.2	715	39.9
100	20.6	990	23.4
101	19.9	1011	21.2
102	19.4	935	20.3
103	19.6	1128	14.0
104	22.5	1090	13.5
105	18.5	1125	13.2

Standard deviation (SD); maximum SD of amylose: ±1.4%, phosphorus: ±47%, median granule size: ±1.2%.

2.3. Statistical analysis

The determination of the amylose content was performed in triplicate. The analyses of the median granule size and RVA pasting properties and the estimations of the phosphorus content were carried out in duplicate. The averages and Duncan *t*-test were computed to measure variations in different potato starches. The least significant difference at the 5% probability level ($P < 0.05$) was calculated for each parameter. A correlation was made among the starch compositional and RVA pasting properties using a multiple linear regression equation, and the coefficients of the starch compositional properties were determined. The residuals were determined to show the differences between the calculated and experi-

Table 3
RVA properties of peak viscosity (PV), breakdown (BD), setback viscosity (SV), pasting temperature (PT), and peak viscosity temperature (PVT) of different potato starches (refer to Table 1)

Potato No.	PV (RVU)	BD (RVU)	SV (RVU)	PVT (°C)
1	302	178	14.1	80.4
2	254	140	14.8	83.5
3	279	170	15.2	81.3
4	265	155	15.4	82.7
5	309	195	16.4	80.3
6	365	252	13.7	74.8
7	264	145	13.8	83.2
8	365	241	13.4	75.8
9	261	163	15.2	82.3
10	272	147	14.6	83.1
11	240	130	15.3	84.3
12	364	249	12.1	74.5
13	396	270	13.1	72.6
14	265	150	13.9	82.6
15	310	200	12.6	78.8
16	338	220	13.3	76.6
17	237	135	15.5	83.6
18	401	280	12.6	72.4
19	444	314	10.5	68.5
20	440	324	15.3	68.3
21	237	112	12.7	85.4
22	286	156	12.1	81.1
23	250	131	13.8	83.5
24	318	210	13.0	78.1
25	359	243	11.7	74.3
26	305	190	12.6	79.1
27	355	230	15.8	75.4
28	308	190	14.8	79.3
29	415	290	11.7	70.0
30	320	200	14.7	77.9
31	335	230	15.3	76.6
32	385	271	14.6	71.9
33	420	298	14.8	69.1
34	298	180	13.1	79.4
35	261	150	13.9	82.4
36	245	130	14.8	82.8
37	267	146	14.9	82.1
38	250	132	14.2	83.3
39	285	172	14.5	80.7
40	311	185	13.1	78.1
41	295	167	14.7	79.2
42	287	168	14.4	79.6
43	275	172	14.2	80.3
44	318	200	13.8	77.0
45	346	225	14.7	75.9
46	246	143	15.8	83.2
47	302	182	14.4	78.4
48	290	171	14.3	80.6
49	285	176	14.7	80.1
50	264	155	14.8	81.3
51	353	240	13.6	75.6
52	260	147	15.1	81.7
53	306	200	15.2	77.9
54	323	220	13.3	76.9
55	337	222	11.6	75.1
56	360	242	14.5	75.4
57	342	243	14.6	73.9
58	341	230	15.7	76.9
59	311	200	14.9	78.2
60	262	151	15.3	81.3
61	290	170	14.6	78.6

(*continued on next page*)

Table 3 (*continued*)

Potato No.	PV (RVU)	BD (RVU)	SV (RVU)	PVT (°C)
62	324	205	14.4	77.5
63	312	195	13.4	77.2
64	230	113	16.3	86.0
65	285	174	14.3	80.2
66	304	200	15.7	78.5
67	255	135	15.3	82.0
68	286	167	14.3	79.4
69	245	140	17.6	84.3
70	368	260	13.4	73.6
71	295	170	15.5	79.7
72	269	164	13.8	80.3
73	210	97	14.6	85.0
74	281	176	15.3	79.1
75	289	169	14.3	80.3
76	333	228	14.2	75.4
77	283	163	14.7	79.0
78	309	182	16.1	77.8
79	230	115	13.9	83.0
80	220	110	13.8	84.3
81	235	130	14.2	83.1
82	266	140	15.1	81.1
83	356	244	15.0	74.2
84	258	140	15.3	82.2
85	340	225	13.1	75.4
86	290	185	12.8	79.7
87	306	200	12.0	78.3
88	286	180	15.4	79.6
89	293	165	14.6	79.7
90	353	252	13.7	74.8
91	284	166	14.2	79.0
92	225	125	14.4	83.8
93	255	150	16.1	80.7
94	260	135	15.5	82.2
95	283	178	15.4	78.6
96	299	186	15.6	78.2
97	310	200	15.6	77.6
98	302	210	14.6	78.1
99	284	185	15.4	80.5
100	283	165	17.7	78.8
101	277	158	17.2	79.7
102	265	150	16.8	80.2
103	225	114	18.3	84.6
104	217	92	18.5	86.2
105	220	105	17.6	85.3

Standard deviation (SD): the maximum SD of PV: ±42%, BD: ±39%, SV: ±5.2%, PVT: ±1.5%.

mental values. Calculations were performed using Microsoft Excel 5.0 for Windows.

3. Results and discussion

3.1. Compositional properties

Among the cultivars studied, the amylose content ranged from 11.4% in Inca Red (potato No. 55) to 24.2% in Toyoshiro (potato No. 69). Cottrell et al. (1995), Kaur, Singh, Ezekiel, and Guraya (2007) and Kim et al. (1995) stated that the difference in amylose content among various starches from different potato cultivars may be due to different factors, such as the genotype, environmental conditions, and cultural practice. However, the cultivars differed widely in the phosphorus content of their starch depending on the cultivation time. The phosphorus content varied from 510 ppm in Benimaru (potato No. 66) to 1334 ppm in Cherokee (potato No. 20). The range of phosphorus (510–1334 ppm) content was similar to that reported by Kim et al. (1995) (596–1022 ppm) and Wiesenborn et al. (1994) (609–1031 ppm). Marked differences in the median starch granule size were observed among the cultivars studied. An extremely small median granule size (13–14 μm) was found in air-classified potato starches (potatoes Nos. 103–105) produced in 2003 and the highest granule size (49.1 μm) was found in Astrate (potato No. 4). Noda et al. (2004a) also reported that the cultivars used for starch production had a larger median value for granule size (40.7 μm) than those that were not mainly used for starch production (34.8 μm). Lower values of mean granule size were reported by Murakami, Asama, Itoh, and Itoh (1978) (16.5–27.5 μm), while higher values were reported by Wiesenborn et al. (1994) (38.7–53.8 μm). These results are presumably attributed to differences in the cultivars, cultivation times, soil, and growing temperature. However, many researches have reported that the compositional properties of amylose, phosphorus, and median granule size directly affect the pasting properties of peak viscosity (PV), breakdown (BD), setback (SV) and peak viscosity temperature (PVT) of starches (Noda et al., 2004a, 2004b, 2005; Zaidul, Yamauchi, Kim, Hashimoto, & Noda, 2007).

3.2. Correlation between the pasting properties and compositional characteristics of various potato starches using multiple linear regression equation

The pasting properties (Table 3) from RVA indicated that PV, BD, SV, and PVT ranged from 210 to 444 RVU, 97 to 324 RVU, 10.5 to 18.5 RVU, and 68 to 86 °C, respectively. The large differences in all RVA parameters were considered sufficient to allow a valid analysis of the correlation coefficient using a multiple linear regression equation. The correlation coefficients were useful to determine the RVA parameters of the pasting properties, which could be calculated using the compositional properties of amylose, phosphorus, and median granule size with a multiple linear regression equation. Secondly, from the coefficients, it was clearly evident whether the compositional properties correlated positively or negatively to the pasting properties or had no correlation. Thirdly, it could be determined how compositional interactions influence the pasting properties of starches, that were derived from the same botanical origin.

A multiple linear regression equation was applied to make a correlation between the pasting properties and amylose, phosphorus, and median granule size of different potato starches. The purposes of developing such a relation was to determine the pasting properties using compositional characteristics and to observe the effect of the compositional properties, in a wide range of potato starches, on the RVA pasting properties:

$$Y_1 = AX_1 + BX_2 + CX_3 + D, \quad (1)$$

$$Y_2 = EX_1X_2 + FX_1X_3 + GX_2X_3 + H, \quad (2)$$

where Y_1 represents the RVA pasting properties of PV, BD, SV, and PVT, which were affected by the compositional properties of potato starches of different cultivars. In addition, Y_2 represents the RVA pasting properties (PV, BD, SV, and PVT) affected by the interaction of the compositional properties. However, the starch compositional properties of amylose, phosphorus, and median granule size were used to determine their relationship with the pasting properties. A, B, and C are the coefficients of amylose (X_1), phosphorus (X_2) and median granule size (X_3), respectively, and D is a constant (Eq. (1)). E, F, and G are the coefficients of interaction of amylose–phosphorus (X_1X_2), amylose–median granule size (X_1X_3), and median granule size–phosphorus (X_2X_3), respectively, and H is a constant of the combined interaction of the composition (Eq. (2)). Table 4 shows the result of the regression of the composition and their interactions. The regression coefficients of amylose, phosphorus, and median granule size indicated a strong correlation with the compositional and pasting properties. From the values of the regression coefficient, it was observed that the amylose, phosphorus, and median granule size had a significantly positive or negative effect on the pasting properties. Amylose had a negative correlation and phosphorus and the granule size had a positive correlation with PV. Thus, the negative values of the correlation coefficients (Table 4) of the combined amylose–phosphorus interaction indicated that amylose had more influence than the phosphorus content on PV. Similarly, the amylose–median granule size interaction had a negative correlation, indicating that amylose had more influence than the median granule size. In addition, amylose had a negative correlation, and the granule size and phosphorus had a positive correlation with BD. The negative correlation of amylose–phosphorus and amylose–median granule size interaction indicated that amylose had more influence than had the phosphorus and median granule size on BD. Similarly, the median granule size had more influence than had the phosphorus on SV. It was obvious that amylose had more influence than had phosphorus and the granule size on PVT (Table 4). The lower-amylose (Table 2) potato starches usually exhibited a higher PV (Table 3) than did the PV of higher-amylose potato starches. Similar tendencies were observed in BD: the lower-amylose (Table 2) potato starches exhibited a higher BD (Table 3) than did the higher-amylose potato starches. Furthermore, the PVT was relatively lower (Table 3) in the higher phosphorus-containing potato starches than in the lower phosphorus-containing potato starches (Table 2). Similarly, the SV and the PVT were found to be higher in the smaller granule size potato starches than in the larger granule size potato starches.

Fig. 1a shows the variability of residuals (the differences between the calculated and experimental values) of PV with the effect of the compositional properties. Similarly, Fig. 1b

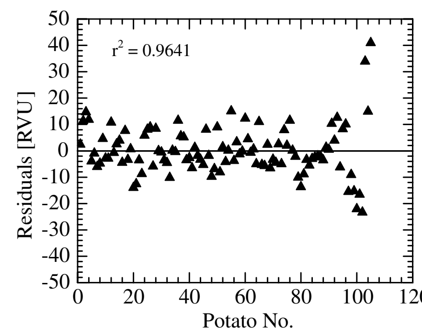

Fig. 1a. Residuals (▲) of calculated and experimental peak viscosity (PV) with the correlation of compositional properties.

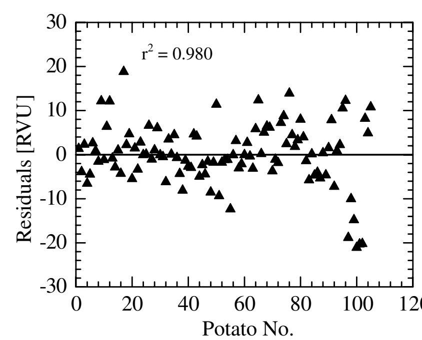

Fig. 1b. Residuals (▲) of calculated and experimental peak viscosity (PV) with the correlation of combined compositional properties.

Table 4
Result of the regression of the composition and their interactions

RVA properties	Coefficient of components				Coefficients of component's interaction			
	A	B	C	D	E	F	G	H
PV (RVU)	−5.5247	0.2328	4.2190	45.5336	−0.0006	−0.0958	0.0065	171.4005
BD (RVU)	−4.6642	0.2299	4.2973	−85.8919	−0.0003	−0.0805	0.0062	48.2847
SV (RVU)	0.6286	0.0034	−0.0682	2.0218	0.0005	0.0052	−0.0002	8.5138
PVT (°C)	0.4061	−0.0175	−0.3091	97.9447	0.0001	0.0072	−0.0005	88.5121

A, B, and C are the correlation coefficients of amylose content (X_1), phosphorus (X_2) content, and median granule size (X_3), respectively, and D is a constant (Eq. (1)). E, F, and G are the correlation coefficients of amylose–phosphorus (X_1X_2), amylose–median granule size (X_1X_3), and median granule size–phosphorus (X_2X_3) interaction, respectively, and H is the interaction constant (Eq. (2)).
PV, peak viscosity; BD, breakdown; SV, setback viscosity; PVT, peak viscosity temperature.

shows the variability of the residuals of PV with the combined interaction of the compositional properties. A relatively higher deviation in the residuals was found in potatoes Nos. 100–105 (Fig. 1a), among which the highest deviation was 40 RVU for potato No. 105. It was assumed that the deviation occurred due to the extremely small granule size with relatively higher phosphorus levels (potatoes Nos. 100–105) that existed in the samples. Relatively higher residuals were found in potatoes Nos. 100–102 (Fig. 1b), but the overall residuals were lower due to the combined compositional interaction. However, the residuals were randomly distributed in Figs. 1a and 1b. In addition, in BD, the highest deviation in the residuals (38 RVU) was found in potato No. 105 (Fig. 2a), which was reduced in the combined compositional interaction (Fig. 2b). However, the overall residuals were distributed randomly in Figs. 2a and 2b. Similarly, the residuals were random in the correlation of the compositional properties (Fig. 3a) and combined compositional interaction (Fig. 3b) with SV. Thus, in PVT, a trend of higher deviation in the residuals (±3 °C) was observed in potatoes Nos. 100–105 (Fig. 4a), and a reduction was observed in the combined compositional interaction (Fig. 4b). However, a smaller variability in the residuals of PV, BD, SV, and PVT was observed in our correlations. The smaller variability meant that the prediction was better, where the residuals were smaller and acceptable, and distributed randomly within the coefficient determinations (r^2) of 0.96–0.98 for PV (Figs. 1a and 1b), 0.95–0.96 for BD (Figs. 2a and 2b), 0.90–0.92 for SV (Figs. 3a and 3b) and 0.93 for PVT (Figs. 4a and 4b).

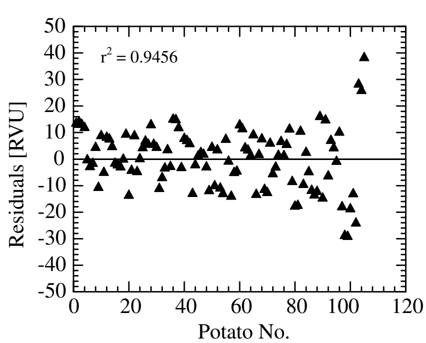

Fig. 2a. Residuals (▲) of calculated and experimental breakdown viscosity (BD) with the correlation of compositional properties.

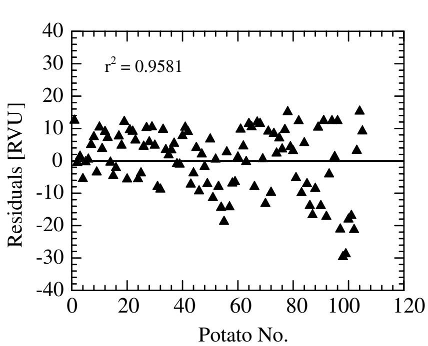

Fig. 2b. Residuals (▲) of calculated and experimental breakdown viscosity (BD) with the correlation of combined compositional properties.

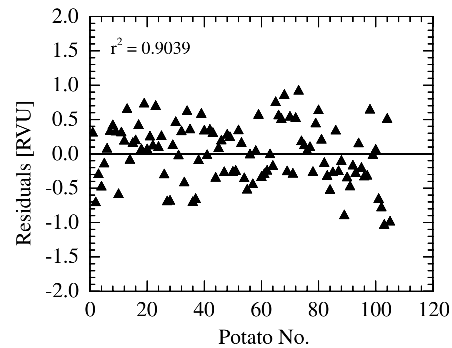

Fig. 3a. Residuals (▲) of calculated and experimental setback viscosity (SV) with the correlation of compositional properties.

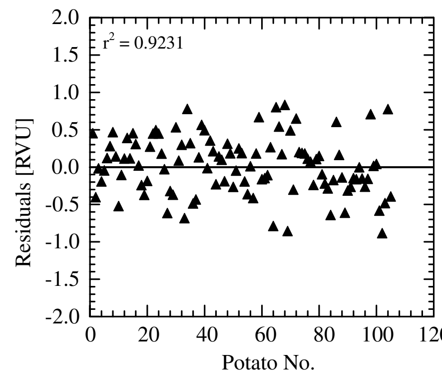

Fig. 3b. Residuals (▲) of calculated and experimental setback viscosity (SV) with the correlation of combined compositional properties.

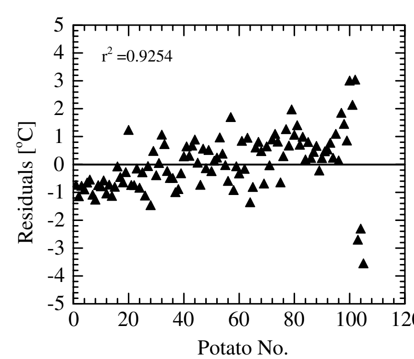

Fig. 4a. Residuals (▲) of calculated and experimental peak viscosity temperature (PVT) with the correlation of compositional properties.

However, Noda et al. (2004a) observed that higher-amylose content was a factor that contributed to lowering the PV, since the extent of starch swelling is presumed to be interrupted by an increase in the amylose content (Beta & Corke, 2001; Black, Panozzo, Wright, & Lim, 2000; Collado, Mabesa, & Corke, 1999). On the other hand, Ganga and Corke (1999) and Wiesenborn et al. (1994) reported,

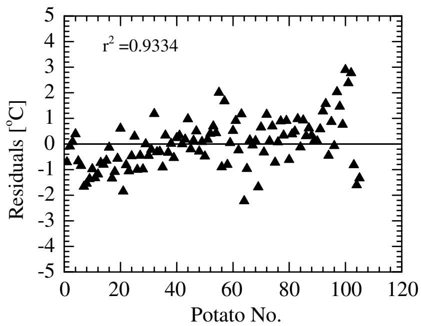

Fig. 4b. Residuals (▲) of calculated and experimental peak viscosity temperature (PVT) with the correlation of combined compositional properties.

with the use of many potato starches, that the amylose content did not have a significant effect on PV. In other studies, it has been well established that starch-bound phosphate enhances the PV in potato (Kim et al., 1995; Wiesenborn et al., 1994). Noda et al. (2004a) reported that the phosphorus content had a positive effect, while the amylose content had a negative effect on the PV and BD. Amylose had a positive effect on the PVT. Authors also reported that the mean granule size had no significant effect to the PV and BD. Our study showed a positive correlation of the median granule size with PV and BD.

Noda et al. (2005) also studied the effects of the granule size on the physicochemical properties, using potato starches with large, small, and extremely small granules. They found that the PV and BD were greatly influenced by the median granule size. The PV and BD markedly decreased as the median granule size was reduced. A smaller median granule size was also closely associated with higher values of PVT and, their observations are in agreement with our correlations. Zaidul et al. (2007) studied three potato starches of three cultivars and found that PV and BD were lower in the higher amylase-containing potato starches and the reverse trends were observed in the higher phosphorus content potato starches. However, the correlation developed at this study was very useful for determining the RVA properties using a multiple linear regression equation and for accurately predicting the effects of amylose, phosphorus, and granule size on the RVA properties.

4. Conclusions

A correlation was developed between the compositional properties of amylose, phosphorus, and median granule size and their combined interaction with the RVA pasting properties of 105 various potato starches using multiple linear regression equations. We found that PV and BD decreased in the higher amylase-containing potato starches, which meant that amylose had a negative correlation with PV and BD. On the other hand, amylose had a positive correlation with SV and PVT. Similarly, the phosphorus content of potato starch had a positive correlation with PV, BD, and SV and a negative correlation with PVT. In addition, the median granule size had a positive correlation with the PV and BD. However, in the correlation coefficients of combined compositional interaction, we found that amylose had more influence than had the phosphorus and median granule size on PV and BD. Furthermore, amylose had more influence than had the granule size on SV and PVT. Similarly, amylose had a greater effect on PVT than had phosphorus and the median granule size. The correlation developed in this study could be useful for determining and accurately predicting the influence of compositional properties on the RVA pasting characteristics of starches with the same botanical origin. In addition, the study of this correlation will help to increase the use of potato starches in the food industry.

Acknowledgements

This work was financially supported by the Japan Society for the Promotion of Science (JSPS) and in part by a Grant-in-Aid for the Research and Development Program for New Bio-industry Initiatives from the Bio-oriented Technology Research Institution (BRAIN), Japan. We are indebted to the Nakashari Starch Factory of the Shari Agricultural Cooperative Association for providing potato starches with a variety of granule sizes. We are also indebted to Mr. Motoyuki Mori and Mr. Shogo Tsuda for supplying us the potatoes that were cultivated at Memuro Upland Farming Research Station, Hokkaido.

References

Beta, T., & Corke, H. (2001). Noodle quality as related to sorghum starch properties. *Cereal Chemistry, 78*, 417–420.

Black, C. K., Panozzo, J. F., Wright, C. L., & Lim, P. C. (2000). Survey of white salted noodle quality characteristics in wheat land races. *Cereal Chemistry, 77*, 468–472.

Chen, Z., Schols, H. A., & Voragen, A. G. J. (2003). Starch granule size strongly determines starch noodle processing and noodle quality. *Journal of Food Science, 68*, 1584–1589.

Collado, L. S., Mabesa, R. C., & Corke, H. (1999). Genetic variation in the physical properties of sweet potato starch. *Journal of Agricultural and Food Chemistry, 47*, 4195–4201.

Cottrell, J. E., Duffus, C. M., Paterson, L., & Mackay, G. R. (1995). Properties of potato starch: Effects of genotype and growing conditions. *Phytochemistry, 40*, 1057–1064.

Ganga, Z. N., & Corke, H. (1999). Physical properties of starch of Asian-adapted potato varieties. *Journal of the Science of Food and Agriculture, 79*, 1642–1646.

Kaur, A., Singh, N., Ezekiel, R., & Guraya, H. S. (2007). Physicochemical, thermal and pasting properties of starches separated from different potato cultivars grown at different locations. *Food Chemistry, 101*, 643–651.

Kim, Y. S., Wiesenborn, D. P., Orr, P. H., & Grant, L. A. (1995). Screening potato starch for novel properties using differential scanning calorimetry. *Journal of Food Science, 60*, 1060–1065.

Koo, H. J., Park, S. H., Jo, J. S., Kim, B. Y., & Baik, M. Y. (2005). Gelatinization and retrogradation of 6-year-old Korean ginseng starches studied by DSC. *Lebensmittel-Wissenschaft und-Technologie – Food Science and Technology, 38*, 59–65.

Madsen, M. H., & Christensen, D. H. (1996). Changes in viscosity properties of potato starch during growth. *Starch/Starke, 48*, 245–249.

Matveev, Y. I., van Soest, J. J. G., Nieman, C., Wasserman, L. A., Protserov, V. A., Ezernitskaja, M., et al. (2001). The relationship between thermodynamic and structural properties of low and high amylose maize starches. *Carbohydrate Polymers, 44*, 151–160.

Mitch, E. L. (1984). Potato starch: Production and uses. In R. L. Whistler, J. N. BeMiller, & E. F. Paschall (Eds.), *Starch: Chemistry and technology* (pp. 479–490). New York: Academic Press.

Mori, M. (2001). Breeding of potato varieties to meet changing demand. *Farming Japan, 35*, 10–15.

Morrison, I. M., Cochrane, M. P., Copper, A. M., Dale, M. F. B., Duffus, C. M., Ellis, R. P., et al. (2000). Potato starches: Variation in composition and properties between three genotype grown at two different sites and in two different years. *Journal of the Science of Food and Agriculture, 81*, 319–328.

Murakami, N., Asama, K., Itoh, H., & Itoh, T. (1978). Studies on starch in potato breeding I. Variations in diameter of starch granule and inorganic constituents among various potato varieties, and effects of fertilizer levels on these characteristics. *Journal of Japanese Society for Starch Science (Denpun Kagaku), 25*, 178–185 (in Japanese with English abstract).

Noda, T., Takigawa, S., Endo, C. M., Kim, S.-J., Hashimoto, N., Yamauchi, H., et al. (2005). Physicochemical properties and amylopectin structures of large, small, and extremely small potato starch granules. *Carbohydrate Polymers, 60*, 245–251.

Noda, T., Tsuda, S., Mori, M., Takigawa, S., Endo, C. M., Hashimoto, N., et al. (2004a). Properties of starches from potato varieties grown in Hokkaido. *Journal of Applied Glycoscience, 51*, 241–246.

Noda, T., Tsuda, S., Mori, M., Takigawa, S., Endo, C. M., Saito, K., et al. (2004b). The effect of harvested dates on the starch properties of various potato cultivars. *Food Chemistry, 86*, 119–125.

Sugimoto, Y., Yamashita, Y., Hori, I., Abe, K., & Fuwa, H. (1995). Developmental changes in the properties of potato (*Solanum tuberosum* L.) starches. *Journal of Applied Glycoscience (Oyo Toshitsu Kagaku), 42*, 345–353 (in Japanese with English summary).

Suzuki, A., Shibanuma, K., Takeda, Y., Abe, J., & Hizukuri, S. (1994). Structure and pasting properties of potato starches from jaga kids purple '90 and red '90. *Journal of Applied Glycoscience (Oyo Toshitsu Kagaku), 41*, 425–432.

Wiesenborn, D. P., Orr, P. H., Casper, H. H., & Tacke, B. K. (1994). Relationship between potato starch paste behavior and selected physical/chemical properties. *Journal of Food Science, 58*, 644–648.

Zaidul, I. S. M., Yamauchi, H., Kim, S. J., Hashimoto, N., & Noda, T. (2007). RVA study of mixtures of wheat flour and potato starches with different phosphorus content. *Food Chemistry, 102*, 1105–1111.