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Short communication

Starch phosphorus content in potato (*Solanum tuberosum* L.) cultivars and its effect on other starch properties

Takahiro Noda [a,*], Nisha Sulari Kottearachchi [b], Shogo Tsuda [a], Motoyuki Mori [a], Shigenobu Takigawa [a], Chie Matsuura-Endo [a], Sun-Ju Kim [a], Naoto Hashimoto [a], Hiroaki Yamauchi [a]

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

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Abstract

The research presented herein provides valuable data with respect to the phosphorus content of starches from many potato (*Solanum tuberosum* L.) cultivars using an energy-dispersive X-ray fluorescence technique. In all starches examined, the phosphorus content ranged from 308 to 1244 ppm. Furthermore, the estimation of the starch characteristics of representative samples differing manifestly in their phosphorus content indicated that enhancing the starch phosphate resulted in significant increases in the swelling power, peak viscosity, and breakdown and significant but small increases in the onset and peak temperatures of gelatinization. Other starch quality parameters, such as the amylose content, median granule size, and the gelatinization enthalpy, did not change significantly due to the degree of phosphate substitution of starch.

Keywords: Potato starch; Phosphorus content; Cultivar; Peak viscosity; Gelatinization temperature

1. Introduction

Covalently bound phosphate in amylopectin molecules is ubiquitous in storage starches isolated from root and tuber crops (Hizukuri, Tabata, & Nikuni, 1970). Among root and tuber starches, potato (*Solanum tuberosum* L.) starch contains the largest quantity of organic phosphate (Hizukuri et al., 1970). The unique traits of potato starch paste are due to its extremely high degree of phosphate substitution. Potato starches from many cultivars show variations in the physicochemical characteristics, including the phosphorus content, to some extent (Kim, Wiesenborn, Orr, & Grant, 1995; Noda et al., 2004; Wiesenborn, Orr, Casper, & Tacke, 1994). Since modifying the starch properties of potato by raising or lowering its phosphorus content suggests the possibility of its use in the making of value-added products, the measurement of the phosphorus content of potato starch is a promising means. However, wet chemical analysis, which is the conventional method for determining the phosphorus content of starch, requires a considerable amount of time and labor. Recent work in our laboratory has indicated that an energy-dispersive X-ray fluorescence (ED-XRF) technique can be utilized to analyze the phosphorus content rapidly and reliably (Noda et al., 2006).

The objective of the present study was to investigate the starches isolated from many potato cultivars with regard to their phosphorus content using the ED-XRF technique. Representative starches differing in their degree of phosphate substitution were further evaluated for their fundamental properties, such as the amylose content, granule size distribution, swelling power, rapid viso-analyzer (RVA) pasting properties, and differential scanning calorimetry (DSC) gelatinization properties. Another objective of this study was to discuss the effect of a marked alteration in the phosphorus content of potato starch on these starch properties.

* Corresponding author. Tel.: +81 155 62 9278; fax: +81 155 62 2926.
E-mail address: noda@affrc.go.jp (T. Noda).

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2. Materials and methods

2.1. Potato samples

A total of 475 potato cultivars, lines, and genotypes were collected from Japan and other countries. The above materials were grown at the experimental farm of the National Agricultural Research Center for the Hokkaido Region at Memuro, Hokkaido, Japan. Sixty-nine genotypes were cultivated in the 2003 growing season, and 466 were cultivated in 2004. Two-year trials were limited to 60 genotypes during the 2003 and 2004 growing seasons. Starches were isolated from these potato samples by a previously reported method (Noda et al., 2004). The starch granules were then stored at 4 °C in airtight containers.

2.2. Potato starch analysis

For the selected starches, several starch characteristics, namely, the amylose content, granule size distribution, RVA paste viscosity, and DSC thermal properties, were determined as previously reported (Noda et al., 2004). For the measurement of the swelling power, 20 mg starch in dry weight basis was directly weighed into a screw-cap test tube, and 5 ml distilled water was added. The capped tubes were then placed on a vortex mixer for 10 s and incubated in a 70 °C water bath for 20 min with frequent mixing by inverting at 2 min intervals. The tubes were then cooled in a water bath at 20 °C for 5 min and centrifuged at 9000*g* for 15 min at 10 °C, and the supernatant was removed with suction. The swelling power was calculated as the weight of the swelled starch residue per 1 g of dry starch. The experiment to estimate the swelling power was conducted in triplicate.

3. Results and discussion

To assess the ED-XRF technique for routine analysis, we estimated the phosphorus content of starches from 69 potato cultivars grown in 2003 and from 466 cultivars grown in 2004. The frequency distribution of the phosphorus content of potato starches studied is shown in Fig. 1. The mean value of the phosphorus content of all the starches was 716 ppm with a median of 703 ppm. The phosphorus content ranged between 308 and 1244 ppm, being well in accordance with the previous reports (Kim et al., 1995; Noda et al., 2004; Wiesenborn et al., 1994). Sixty cultivars were studied using samples grown in 2003 and 2004 seasons to evaluate the constancy between two cultivated years. The correlation between the two-year phosphorus content of potato starches from these 60 cultivars is presented in Fig. 2. A highly significant correlation was observed between the phosphorus content of the cultivars from 2003 and the cultivars from 2004 ($r = 0.798$; $n = 60$). Thus, the differences related to the cultivar used are more pronounced than the differences due to the year the cultivars were grown with regard to the phosphorus content of potato starch. According to the phosphorus content, we selected eight low-phosphorus starches (LPS) (308–395 ppm), nine medium-phosphorus starches (MPS) (711–716 ppm), and seven high-phosphorus starches (HPS) (1110–1244 ppm). Measurements of the amylose content, granule size distribution, swelling power, RVA pasting properties, and DSC gelatinization properties of these 24 starches that differed largely in the degree of phosphate substitution were carried out to evaluate the contribution of the phosphate to these characteristics.

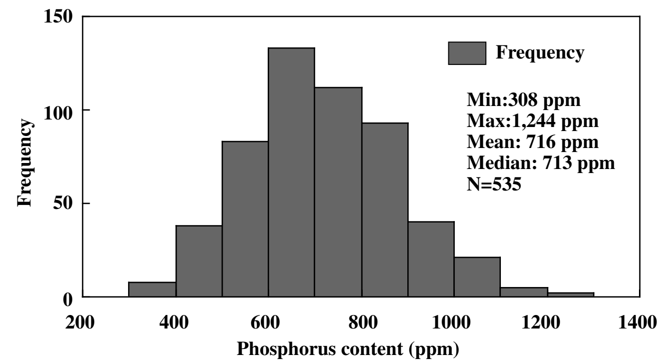

Fig. 1. Frequency distribution of the phosphorus content of 535 potato starches.

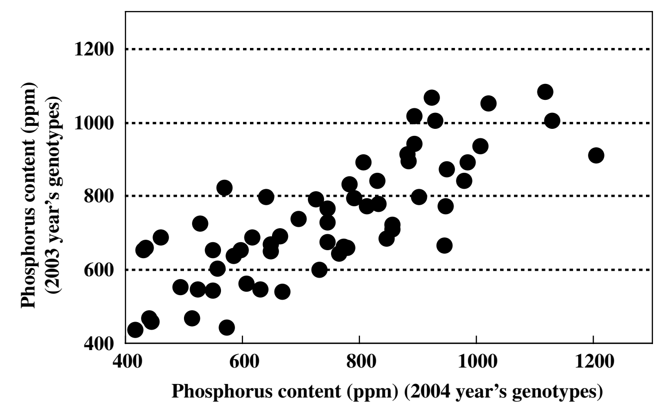

Fig. 2. Linear correlations between the phosphorus content of starches from potatoes growing during the years 2003 and 2004.

The amylose content, median granule size, and swelling power of the LPS, MPS, and HPS are shown in Table 1. LPS had the highest mean value of the amylose content (23.6%), followed by MPS (22.1%) and HPS (21.7%). The mean value of the median granule size was the highest for LPS (37.7 μm) and the lowest for HPS (34.3 μm). However, the differences in the mean values of the amylose content and median granule size were not significant among LPS, MPS, and HPS. The mean value of the swelling power at 70 °C was significantly higher for HPS (63.6 g/g) than for MPS (48.5 g/g) and LPS (40.6 g/g). Vasanthan, Bergthaller, Driedger, Yeung, and Sporns (1999) Yusuph, Tester, Ansell, and Snape (2003) indicated no relationship or a small one between the starch phosphorus content and swelling power in several potato starches. However, the ranges in the phosphorus content among samples used in these studies were relatively small. In this study, we have reached the conclusion that a higher phosphorus content resulted in higher swelling power when potato

Table 1
Chemical composition, median granule size, and swelling power of representative potato starches

Genotype (Year grown)	Phosphorus content (ppm)	Amylose content (%)	Median granule size (μm)	Swelling power at 70 °C (g/g)
LPS				
Schwalbe (04)	361	25.6	39.9	35.4
Sidra (04)	385	25.2	35.9	36.2
Norin No. 2 (04)	376	20.5	35.4	38.4
Koniku No. 4 (04)	308	23.3	36.4	41.6
Koniku No. 10 (04)	395	24.3	37.7	46.6
Koniku No. 16 (04)	361	25.5	40.6	49.2
Koniku No. 24 (04)	358	22.4	41.7	43.7
Hokkai No. 58 (04)	371	21.7	34.0	34.0
Mean ± SD ($n = 8$)[a]	364c	23.6a	37.7a	40.6a
MPS				
Firmula (04)	713	18.4	39.4	46.3
Jagakittzu Prapuru (04)	712	23.8	34.6	44.7
Nagasaki Murasaki (04)	716	24.7	37.3	42.5
Parnassia (04)	712	23.7	41.2	52.0
V-2 (04)	713	23.5	33.1	42.8
Hokkai No. 5 (04)	714	20.6	31.3	54.2
Hokkai No. 40 (04)	711	21.3	36.1	62.1
86092-9 (04)	716	20.3	40.5	42.9
90056-12 (04)	716	22.9	28.5	49.2
Mean ± SD ($n = 9$)[a]	714b	22.1a	35.8a	48.5a
HPS				
Atlantic (04)	1129	21.8	40.6	62.2
I-853 (04)	1110	22.7	42.6	62.2
P10167-2 (04)	1244	18.2	36.8	69.4
Wouseon (04)	1177	22.7	29.9	78.8
Chokei No. 115 (04)	1121	20.4	34.2	73.6
Inca Red (03)	1206	26.2	26.6	45.1
Touya (03)	1117	20.1	29.7	53.9
Mean ± SD ($n = 7$)[a]	1158a	21.7a	34.3a	63.6b

[a] Different letters within each column show significant difference at $p < 0.05$.

starches with marked variation in their phosphorus content were used. Table 2 presents the results of the pasting and gelatinization properties tested by RVA and DSC, respectively, of LPS, MPS, and HPS. As the phosphorus content of potato starch increased, the peak viscosity and breakdown increased to their highest levels. The mean values of the peak viscosity and breakdown of HPS were 1.79 (399 RVU) and 2.34 (272 RVU) times the values of LPS, respectively. Potato starches with a higher phosphorus content exhibit a higher peak viscosity (Noda et al., 2004; Wiesenborn et al., 1994) and breakdown (Noda et al., 2004). We analyzed the RVA pasting properties of potato starch samples with a markedly different phosphorus content, and the results definitely agreed with the above data. The DSC data indicated that the mean values of the onset temperature of gelatinization (T_o) were significantly higher for MPS (64.6 °C) and HPS (65.5 °C) than for LPS (63.2 °C). As for the peak temperature of gelatinization (T_p), HPS had a significantly higher mean value (68.5 °C) than LPS (65.7 °C) and MPS (66.9 °C). However, the differences in the mean values of T_o and T_p were not particularly large (below 2.5 °C) among LPS, MPS, and HPS. Few or no effects of the phosphorus content on T_o and T_p were observed by Kim et al. (1995); Noda et al. (2004) and Yusuph et al. (2003). Blennow, Bay-Smidt, Olsen, and Møller (2000) indicated that T_o and T_p correlated positively but weakly with the phosphorus content. The phosphorus content did not have an impact on ΔH in this study, which agrees with previous reports (Blennow et al., 2000; Kim et al., 1995; Noda et al., 2004; Yusuph et al., 2003). Muhrbeck and Eliasson (1991) and Wischmann et al. (2005) reported that the ΔH of the starches with a higher phosphorus content was lower than that of starches with a lower phosphorus content; however, the sample numbers used in their studies were fewer than eight.

4. Conclusions

Trials were carried out over 2 years using 535 potatoes from 475 cultivars to characterize the phosphorus content of starch in potato tubers using an ED-XRF technique. On the basis of the degree of phosphate substitution, 8 LPS (308–395 ppm), 9 MPS (711–716 ppm), and 7 HPS (1110–1244 ppm) were selected from all starches used and analyzed for their amylose content, median granule size, swelling power, RVA pasting properties, and DSC gelatinization properties. Significant differences in the amylose content and median granule size were not observed among LPS, MPS, and HPS. HPS showed significantly higher swelling power than MPS and LPS. From the RVA data, the peak viscosity and breakdown were respectively in the order of: HPS > MPS > LPS. The DSC data indicated significant but small increases in the values of T_o and T_p with an increase in the starch phosphorus content, whereas the level of starch

Table 2
RVA pasting properties and DSC gelatinization properties of representative potato starches[a]

Genotype (Year grown)	RVA pasting properties		DSC gelatinization properties		
	Peak viscosity (RVU)	Breakdown (RVU)	T_o (°C)	T_p (°C)	ΔH (J/g)
LPS					
Schwalbe (04)	194	89	63.1	66.3	21.0
Sidra (04)	191	86	63.7	65.7	20.3
Norin No. 2 (04)	205	95	63.1	64.6	20.4
Koniku No. 4 (04)	240	144	63.2	65.3	20.5
Koniku No. 10 (04)	237	140	62.3	65.0	20.4
Koniku No. 16 (04)	268	165	62.6	65.6	22
Koniku No. 24 (04)	233	119	65.3	68.2	21.3
Hokkai No. 58 (04)	213	95	62.4	65.2	20.0
Mean ± SD ($n = 8$)[b]	223c	116c	63.2b	65.7b	20.7a
MPS					
Firmula (04)	306	181	64.5	66.2	18.9
Jagakittzu Prapuru (04)	332	198	66.0	68.0	19.8
Nagasaki Murasaki (04)	320	186	66.2	67.8	20.1
Parnassia (04)	344	217	64.9	66.4	18.7
V-2 (04)	295	158	66.8	69.4	20.8
Hokkai No. 5 (04)	333	215	63.4	65.9	22.3
Hokkai No. 40 (04)	309	201	63.2	66.1	20.6
86092-9 (04)	314	190	63.4	66.4	22.0
90056-12 (04)	281	158	63.4	66.6	20.2
Mean ± SD ($n = 9$)[b]	315b	189b	64.6a	66.9b	20.4a
HPS					
Atlantic (04)	419	301	64.5	67.1	20.4
I-853 (04)	434	303	66.7	70.1	21.6
P10167-2 (04)	373	257	66.2	69.5	19.8
Wouseon (04)	397	288	64.9	68.6	20.6
Chokei No. 115 (04)	401	283	64.1	66.7	20.2
Inca Red (03)	381	225	67.8	70.8	21.6
Touya (03)	391	246	64.4	66.7	19.5
Mean ± SD ($n = 7$)[b]	399a	272a	65.5a	68.5a	20.5a

[a] Values are means of two determinations.
[b] Different letters within each column show significant difference at $p < 0.05$.

phosphorus did not have a significant impact on ΔH. These results provide useful and important information for potato breeders and researchers.

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