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The effect of harvest dates on the starch properties of various potato cultivars

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Abstract

The effect of harvest dates on the starch properties of six potato cultivars was studied. The focus was on the content of amylose and phosphorus, mean granule size, viscosity analysis by rapid visco analyzer, thermal analysis by differential scanning calorimetry, and chain length distribution of amylopectin. A late harvest date significantly enhanced mean granule size, the phosphorus content, peak viscosity and breakdown. Furthermore, a late harvest date led to significant but slight decreases in amylose content, pasting temperature, and gelatinization temperature. In contrast, harvest date had no influences on gelatinization enthalpy on distribution of the shorter chain lengths of amylopectin. The correlation coefficients were calculated among these starch properties, and starch phosphorus content was found to have positively significant correlations with the peak viscosity and breakdown.

Keywords: Potato starch; Phosphorus content; Pasting properties; Differential scanning calorimetry; Harvest date

1. Introduction

The potato is an important upland crop in Japan. The total annual production of potatoes in Japan was approximately 2.96 million tons in 1999, and about 75% of the total production comes from Hokkaido, the northernmost and second largest island of Japan (Mori, 2001). Potatoes for starch production, which account for 35–40% of the domestic output, are grown exclusively in Hokkaido.

The starch has small amounts of covalently bound phosphate in the amylopectin molecules. Potato starch is unique because it has a higher concentration of phosphate than the starches from other botanical sources (Hizukuri, Tabata, & Nikuni, 1970). A relatively high degree of phosphate substitution in potato starch leads to starch gels with high viscosity (Suzuki, Shibanuma, Takeda, Abe, & Hizukuri, 1994; Veselovsky, 1940; Wiesenborn, Orr, Casper, & Tacke, 1994). Therefore, potato starch is used in fish paste products, as an ingredient in several types of noodles and in the production of glucose and isomerized-glucose syrup.

Starch properties are generally influenced by the cultivars and by environmental factors. The starch properties of potato cultivars vary significantly (Cottrell, Duffus, Paterson, & Mackay, 1995; Ganga & Corke, 1999; Haase & Plate, 1995; Jansen, Flamme, Schüler, & Vandrey, 2001; Kim, Wiesenborn, Orr, & Grant, 1995; Morrison et al., 2000; Sabiniano, Ishibashi, & Hironaka, 1995; Suzuki et al., 1994; Veselovsky, 1940; Wiesenborn et al., 1994), and the developmental stage of a potato also affects starch properties (Geddes, Greenwood, & Mackenzie, 1965; Lui, Weber, Currie, & Yada, 2003;

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Madsen & Christensen, 1996; Sugimoto, Yamashita, Hori, Abe, & Fuwa, 1995). This subject has been investigated to some extent; however, potato cultivars in Hokkaido, as processing materials for starch, have not been thoroughly examined (Sabiniano et al., 1995; Suzuki et al., 1994). Benimaru and Konafubuki are typical cultivars used in the starch industry in Hokkaido (Mori, 2001). In addition, potato cultivars that are primarily used for market sale and food processing are also used for starch production. Generally, in Hokkaido, potatoes are planted in April to May and harvested from August to October. Due to the influence of the harvest date, there may be variations in the properties of starches from potatoes grown in Hokkaido, even within the same cultivar.

The objective of the present study was to determine if some physicochemical properties of potato starches varied among six different cultivars that had been harvested on two dates in Hokkaido.

2. Materials and methods

2.1. Potato samples

Six potato cultivars, Konafubuki, Benimaru, Sakurafubuki, Astarte, Early Starch, Hokkai No. 87, were cultivated in 2001 at the experimental farm at the National Agricultural Research Center for the Hokkaido Region at Memuro, Hokkaido, and used for this study. Konafubuki, Benimaru, Sakurafubuki, Astarte, and Early Starch are the cultivars used for starch production and Hokkai No. 87 is a candidate cultivar for starch production. Seed tubers of these six cultivars were planted on 9 May. All cultivars were grown in rows, 75 cm apart with 30 cm between plants. Tubers were harvested on two dates (early harvest, 29 August; late harvest, 27 September). After harvest, the tubers were stored at 15–20 °C for about 2 weeks and then at 4 °C for 2–3 months until processed for starch.

2.2. Preparation of starch

A composite sample of at least eight potato tubers (one size, 80–120 g) was used for the preparation of starch. The potato tubers were washed carefully with distilled water and cut into small pieces. The diced sample (300 g) was homogenized in a mixer with 400 ml of distilled water. The slurry was successively filtered, twice, through 250 and 106 μm metallic sieves, allowing most of the starch granules to pass. The filtration (starch suspension) was allowed to stand for 2 h. The starch granules were recovered from the extraction by decantation. The remaining starch pellets were successively washed with water, three times, and then dried at 20 °C. The purified starch samples were stored at 4 °C until analyses.

2.3. Amylose content

The blue value (BV) at 680 nm was estimated according to the method as previously described (Noda, Takahata, Sato, Kumagai, & Yamakawa, 1998a; Noda et al., 1998b), using intact starch, rather than defatted starch. The amylose content was calculated from the BV according to the equation of Takeda, Takeda, and Hizukuri (1983). As Suzuki et al. (1994) reported that the average BVs of amylose and amylopectin isolated from two potato cultivars were 0.243 and 1.40, respectively, these BVs were used in the calculation of the amylose content of the potato starch.

2.4. Phosphorus content

Starch granules (0.2 g) were placed in a micro-Kjeldahl flask and heated with 2 ml of HNO_3 until the production of brown smoke ceased. After the solution had cooled, 1.5 ml of 60% perchloric acid and 1.5 ml of HNO_3 was added and the mixture then heated. When white smoke arose, the solution was cooled. Then, 3 ml of distilled water was added and the mixture heated. After the solution had cooled, the volume was made up to 10 ml with distilled water. The phosphorus content in the digestion was measured as inorganic phosphorus, using the vanado-molybdate method to calculate the phosphorus content of starch. For assay, 2 ml of the solution of starch digestion, 3 ml of distilled water, 0.5 ml of 60% perchloric acid, 1.5 ml of a 20 mM ammonium vanado solution containing 2.4% perchloric acid and 3.0 ml of a 3.53% ammonium molybdate solution were mixed, kept for 30 min and the absorbance read at 420 nm.

2.5. Granule size

The granule size distribution of starch was measured using sympatec HELOS particle size analysis. The mean diameter, based on volume distribution was measured.

2.6. Thermal properties by differential scanning calorimetry (DSC)

DSC measurement was conducted using a DSC 6100 (Seiko Instruments, Japan). Approximately 10 mg of starch (dry weight basis) were weighed and placed in a silver pan. Distilled water was then added to make a starch concentration of 30% (dry weight basis, w/w). A sealed pan, with distilled water, was used as a reference. Scans were run at a heating rate of 2 °C/min from 25 to 130 °C.

2.7. Pasting properties by rapid visco analyzer (RVA)

The RVA paste viscosity was determined using the RVA-4 (Newport Scientific Pvt., Ltd., Australia) as follows. Each starch was added to 25 ml of distilled water to create a 4% suspension (dry weight basis, w/w). The suspension was kept at 50 °C for 1 min, heated to 95 °C at 12.2 °C/min, and kept at 95 °C for 2.5 min; it was then cooled to 50 °C at 11.8 °C/min and kept at 50 °C for 2 min.

2.8. Chain length distribution of amylopectin

The shorter chain length of amylopectin was determined by high-performance anion-exchange chromatography (HPAEC), using the DX-300 system (Dionex Co., CA) equipped with a pulsed amperometric detector (PAD). The column used was a CarboPac PA-1 (4 × 250 mm) with CarboPac PA-1 guard column. Each starch was digested by addition of isoamylase from *Pseudomonas amyloderamosa* (Seikagaku Kogyo Co., Japan), according to a previously reported method (Noda, Takahata, & Sato, 1995). A digested sample was injected and eluted with a gradient of sodium acetate (0–2.5 min, increased from 150 to 200 mM; 2.5–10 min, increased from 200 to 250 mM; 10–25 min, increased from 250 to 275 mM; 25–45 min, increased from 275 to 325 mM in 150 mM NaOH with a flow rate of 1 ml/min). The molar distributions of amylopectin chain length (DP 6–17) were estimated, using the values of the relative PAD responses of malto-oligosaccharides (DP 6–17), which were described by Koizumi, Fukuda, and Hizukuri (1991).

2.9. Statistical analysis

The determinations of amylose content were done in triplicate. Other tests were carried out in duplicate. The averages and Duncan *t* test were computed to measure variations among harvest dates. The correlation coefficients among starch properties were also calculated. Calculations were performed using Microsoft Excel 5.0 for Windows.

3. Results and discussion

3.1. Amylose content

The BVs at 680 nm ranged between 0.466 and 0.508 (data not shown). The amylose contents calculated from the BVs were in the range of 17.7% to 23.1% (Table 1). Among six potato cultivars, the average value of the amylose content was the lowest in Hokkai No. 87 (18.1%) and the highest in Early Starch (22.0%). Late harvest date resulted in a significant but minor decrease in amylose content. A manifest increase in the amylose content from 12% to 20% was observed with the maturity of potato tubers (Geddes et al., 1965). Sugimoto et al. (1995) reported that the amylose content tended to increase in the earlier stage of development of potato tubers and that little variation in the amylose content was found in the later stage. In contrast, Lui et al. (2003) demonstrated that the amylose content decreased after the first harvest and remained unchanged during growth of tubers. Christensen and Madsen (1996) observed that the amylose content was constant during the later stage of potato tuber development.

3.2. Phosphorus content

As shown in Table 2, the phosphorus content ranged between 579 and 981 ppm. Benimaru and Hokkai No. 87 had the lowest (593 ppm) and highest (922 ppm) average values of phosphorus content, respectively. In an early study, Hizukuri et al. (1970) reported that potato starches had a markedly higher phosphorus content (456–754 ppm) than those from other botanical sources, such as the sweet potato (89–123 ppm), kuzu (92 ppm), non-waxy rice (137 ppm), and waxy rice (20 ppm). Other researchers found the starch phosphorus content for various potato cultivars to be 630–1240 ppm (Veselovsky, 1940), 609–1031 ppm (Wiesenborn et al., 1994), 367–973 ppm (Suzuki et al., 1994), 430–1096 ppm (Haase & Plate, 1996), 596–1022 ppm (Kim et al., 1995) and 490–1220 ppm (Morrison et al., 2000). These results are

Table 1
Amylose content, phosphorus content and mean granule size of starches in potato cultivars differing in harvest date

Cultivar	Amylose content (%)			Phosphorus content (ppm)			Mean granule size (μm)		
	Early	Late	Cultivar average	Early	Late	Cultivar average	Early	Late	Cultivar average
Konafubuki	20.0	19.5	19.8	732	814	773	34.5	40.7	37.6
Benimaru	21.1	21.0	21.1	588	598	593	42.8	44.3	43.5
Sakurafubuki	22.0	20.9	21.5	652	707	680	43.0	46.2	44.6
Astarte	22.5	21.1	21.8	579	629	604	43.1	46.8	45.0
Early Starch	23.1	20.9	22.0	788	843	816	38.0	43.4	40.7
Hokkai No. 87	18.4	17.7	18.1	863	981	922	36.2	43.4	39.8
Average[a]	21.2a	20.2b		700b	762a		39.6b	44.1a	

[a] Values followed by the same letter in the same row within the same parameter are not significantly different ($P < 0.05$).

Table 2
Starch pasting properties by RVA in potato cultivars differing in harvest date

Cultivar	Peak viscosity (RVU)			Breakdown (RVU)			Pasting temperature (°C)		
	Early	Late	Cultivar average	Early	Late	Cultivar average	Early	Late	Cultivar average
Konafubuki	261	302	282	132	178	155	69.5	67.9	68.7
Benimaru	202	224	213	93	116	105	68.7	67.9	68.3
Sakurafubuki	247	239	243	108	103	106	71.5	70.7	71.1
Astarte	225	239	232	118	137	128	68.6	68.7	68.7
Early Starch	302	329	316	172	214	193	69.5	68.8	69.2
Hokkai No. 87	297	355	326	185	252	219	67.8	67.1	67.5
Average[a]	256b	281a		135b	167a		69.3a	68.5b	

[a] Values followed by the same letter in the same row within the same parameter are not significantly different ($P < 0.05$).

quite similar to the data obtained in this study. The harvest date had a large effect on the starch phosphorus content. Namely, a later harvest date enhanced the starch phosphorus content in every potato cultivar. This is in agreement with the reports of Christensen and Madsen (1996) and Lui et al. (2003). In contrast to the data obtained here, the results from Geddes et al. (1965) suggested no apparent trend in the starch phosphorus content with the maturity of the potato tuber. Hizukuri (1969) and Tester, Debon, Davis, and Gidley (1999) noted that the starch phosphorus content definitely increased as the environmental temperature, during the development of potato tubers, decreased from 25 to 10 °C and from 25 to 20 °C, respectively. Thus, good evidence was obtained to support the concept that lower environmental temperature during the development of potato tubers was associated with higher phosphorus content in starch granules. This is because, in this study, a late harvest represents lower environmental temperatures during the development of the potato tubers than an early harvesting.

3.3. Granule size

It is well known that potato starch contains exceptionally large granules. The present study indicates that the mean granule sizes of potato starches were in the range of 34.5–46.8 μm (Table 1). The results are in agreement with those reported by Morrison et al. (2000) and Jansen et al. (2001). Among six potato cultivars, smaller average values of mean granule sizes were observed in Konafubuki (37.6 μm), and distinctly larger values were found in Benimaru (43.5 μm), Sakurafubuki (44.6 μm), and Astarte (45.0 μm). Later harvesting led to clear increases in the mean granule size of starch. Current research shows that the granule size of starch increases with the increasing weight of a potato tuber (Geddes et al., 1965; Lui et al., 2003; Sugimoto et al., 1995). In addition, in sweet potato, a positive correlation was observed between the weight of tubers and the average size of starch granules (Noda, Takahata, & Nagata, 1992).

3.4. Pasting properties

Table 2 shows the RVA characteristics, which include peak viscosity, breakdown, and pasting temperature, of all potato starch samples. Potato starch is currently known to exhibit higher peak viscosity of starch paste. Although RVA analysis was conducted with a starch suspension of only 4% (w/w) concentration, relatively higher values of peak viscosity (202–355 RVU) and breakdown (93–252 RVU) were noted among the potato starch samples examined. Of the six potato cultivars, the average values of peak viscosity varied from 213 RVU in Benimaru to 326 RVU in Hokkai No. 87. Similarly, in breakdown, the lowest average value was found in Benimaru (105 RVU), and the highest, in Hokkai No. 87 (219 RVU). A lower setback was seen among potato starch samples, with values ranging between 10 and 17 RVU (data not shown). There was a significant variation in pasting temperature, with values ranging between 67.1 and 71.5 °C. Later harvesting enhanced the peak viscosity and breakdown in all cultivars except Sakurafubuki. Statistical analysis revealed that the peak viscosity and breakdown were significantly higher at late harvesting than at early harvesting and that pasting temperature was significantly but slightly lower at late harvesting than at early harvesting. Madsen and Christensen (1996) and Lui et al. (2003) indicated increases in peak viscosity and small decreases in pasting temperature during growth, similarly to our data (see Table 3).

3.5. Thermal properties

The DSC thermogram parameters (onset temperature (T_0), peak temperature (T_p), and enthalpy (ΔH)) of starches for potato samples harvested at two different stages are given in Table 3. The T_0 and T_p of all potato starch samples ranged between 60.4 and 64.7 °C and between 63.5 and 67.7 °C, respectively. In most cases, the T_0 and T_p were 6–7 °C and 3–4 °C lower than the pasting temperature measured by RVA, respectively. There was not a large variation in ΔH, with a range

Table 3
Starch gelatinization properties by DSC in potato cultivars differing in harvest date

Cultivar	T_0 (°C)			T_p (°C)			ΔH (J/g)		
	Early	Late	Cultivar average	Early	Late	Cultivar average	Early	Late	Cultivar average
Konafubuki	63.7	61.9	62.8	66.6	65.1	65.9	20.8	20.0	20.4
Benimaru	61.3	60.4	60.9	64.0	63.5	63.8	19.9	19.3	19.6
Sakurafubuki	64.7	63.1	63.9	67.7	67.0	67.4	20.2	20.1	20.2
Astarte	61.5	61.3	61.4	64.9	64.5	64.7	19.3	19.4	19.4
Early Starch	62.8	62.3	62.6	66.0	65.2	65.6	19.0	20.8	19.9
Hokkai No. 87	61.8	61.6	61.7	64.8	64.6	64.7	19.6	20.4	20.0
Average[a]	62.6a	61.7b		65.7a	65.0b		19.8a	20.0a	

[a] Values followed by the same letter in the same row within the same parameter are not significantly different ($P < 0.05$).

between 19.0 and 20.8 J/g. Similar to pasting temperature, T_0 and T_p were significantly but slightly lower at late harvesting than at early harvesting. ΔH was not significantly affected by the harvest date. Our findings on DSC characteristics were in good agreement with the report of Lui et al. (2003). Environmental temperatures clearly increased the gelatinization temperature and enthalpy by DSC in the potato (Cottrell et al., 1995; Tester et al., 1999). Similar results were obtained in sweet potato (Noda, Kobayashi, & Suda, 2001) and rice (Asaoka, Okuno, Sugimoto, & Fuwa, 1985). The data obtained here suggest that a small alteration in environmental temperature during the development of the potato tuber had no or only slight influences on the gelatinization properties by DSC.

3.6. Chain length distribution of amylopectin

The representative profiles of the molar distributions of amylopectin unit-chain (DP 6–17) determined by HPAEC are presented in Fig. 1. It is well known that the distribution profile of the amylopectin unit-chain differs clearly depending on the plant sources. All potato amylopectins examined in this study peaked at DP 12–14 and had an obvious trough at DP 8. The results were in good agreement with those reported by Koizumi et al. (1991) and Hanashiro, Abe, and Hizukuri (1996). In this investigation, the proportion of unit-chains with DP 6–10 to the sum of those with DP 6–17, on a molar basis, was an indicator of the distribution profile of amylopectin chain length. As shown in Table 4, the proportion ranged between 0.237 and 0.281. A late harvest date did not lead to a significant change in the proportion of unit-chains with DP 6–10. As potato starch contains a relatively large amount of covalently bound phosphate in the amylopectin molecules, attention should be given to the phosphorylated chain. However, according to the report of Takeda and Hizukuri (1982), the phosphate group was attached to longer unit-chains with more than DP 20 of amylopectin. Therefore, unit-chains between DP 6 and 17, which were analyzed in this study, were assumed to be completely non-phosphorylated.

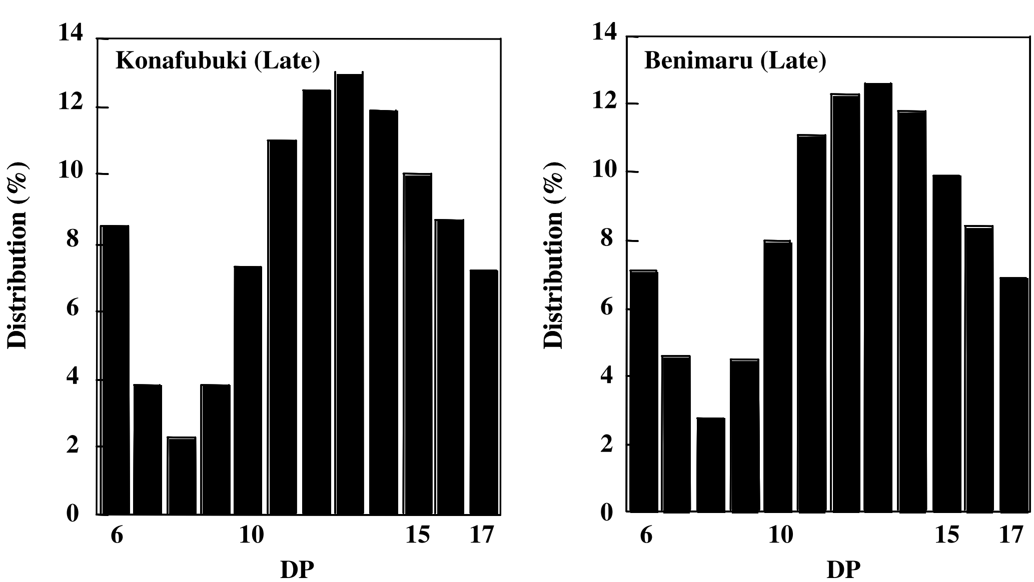

Fig. 1. Molar distributions of amylopectin unit-chains (DP 6–17) for representative potato starches.

Table 4
Amylopectin chain length by HPAEC in potato cultivars differing in harvest date

Cultivar	Proportion of DP 6–10		
	Early	Late	Cultivar average
Konafubuki	0.237	0.257	0.247
Benimaru	0.275	0.271	0.273
Sakurafubuki	0.256	0.257	0.257
Astarte	0.240	0.260	0.250
Early Starch	0.254	0.281	0.268
Hokkai No. 87	0.267	0.272	0.270
Average[a]	0.255a	0.266a	

[a] Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

3.7. Correlation analysis

All possible correlation coefficients among 10 parameters in 12 potato starches are summarized in Table 5. The starch phosphorus content is widely accepted to contribute to the starch pasting properties. For example, higher starch phosphorus content was closely associated with a higher peak viscosity in potato, as indicated by Veselovsky (1940), Wiesenborn et al. (1994) and Suzuki et al. (1994). In this study, the phosphorus content highly and positively correlated with breakdown ($P < 0.01$) and peak viscosity ($P < 0.01$). The amylose content may be the major factor affecting the starch pasting properties, since the extent of starch swelling is assumed to be inhibited by an increase of amylose content. Therefore, starch with lower amylose content has been assumed to exhibit higher peak viscosity and breakdown and lower pasting temperature. The present data indicate that the amylose content is not correlated with peak viscosity. Furthermore, the amylose content is negatively but weakly correlated with breakdown ($P < 0.05$) and is positively but weakly correlated with pasting temperature ($P < 0.05$). Wiesenborn et al. (1994) and Ganga and Corke (1999) found no correlation of amylose content with peak viscosity, using 44 and 24 potato starches, respectively, as in the data from this study. Wiesenborn et al. (1994) also reported that amylose content was positively but weakly correlated with pasting temperature ($P < 0.05$). On the basis of these results, including those reported here, the starch phosphorus content, rather than the amylose content, may have an impact on the starch pasting properties of potato.

The existence of phosphate groups in starch granules has appeared to affect the starch gelatinization properties. Kim et al. (1995) observed a weak positive correlation between the phosphorus content and T_0 in 42 potato starches. Furthermore, Blennow, Bay-Smidt, Olsen, and Møller (2000), reporting on the contribution of the covalently bound phosphate in the starch granules to DSC parameters, using starches from four different plant sources, found a weak correlation between the content of starch-bound phosphate and T_0 or T_p. However, no significant correlation coefficient was obtained between the phosphorus content and each of the DSC parameters, T_0, T_p, and ΔH, in this study. In previous reports, the content of amylopectin short chains played a more important role than the amylose content in accounting for DSC gelatinization properties in sweet potato (Noda et al., 2002; Noda et al., 1998b) and buckwheat (Noda et al., 1998b). Namely, a larger amount of extremely short chains in amylopectin molecules was associated with lower values of T_0, T_p, and ΔH. It would be anticipated that an increase in short outer chains in amylopectin molecules would reduce the efficiency of packing in the starch crystallinity, resulting in lower T_0, T_p, and ΔH. In contrast, in this study, T_0, T_p, and ΔH did not correlate with the proportion of DP 6–10, which probably resulted from the relatively small variations in DSC parameters and the distribution of amylopectin unit-chains.

4. Conclusion

This research demonstrates that the choice of the harvest date had an effect on starch properties. The mean granule size, phosphorus content, peak viscosity and breakdown seem to be more altered than other starch properties as a result of differences in the harvest

Table 5
Correlation coefficients between starch properties for potato starches

	1	2	3	4	5	6	7	8	9
1. Amylose									
2. Phosphorus content	−0.67**								
3. Mean granule size	0.21	−0.35							
4. Peak viscosity	−0.52	0.96**	−0.29						
5. Breakdown	−0.58*	0.92**	−0.20	0.96**					
6. Pasting temperature	0.59*	−0.38	0.09	−0.37	−0.57*				
7. T_0	0.22	0.10	−0.31	0.09	−0.14	0.82**			
8. T_p	0.26	0.06	−0.20	0.05	−0.19	0.86**	0.97**		
9. ΔH	−0.44	0.40	−0.12	0.36	0.28	0.15	0.46	0.37	
10. Proportion of DP 6–10	−0.33	0.29	0.37	0.28	0.37	−0.38	−0.44	−0.51	0.12

* Significant at 0.05 level.
** Significant at 0.01 level.

date. This knowledge may be of use when determining the best times to harvest potatoes to obtain a crop with additional potato starch.

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