Original paper

Comparison of Pasting and Thermal Properties of Starches Isolated from four Processing Type Potato Varieties Cultivated in Two Locations in Hokkaido

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Starches from four processing type potato varieties, cultivated in two locations in Hokkaido prefecture of Japan were evaluated for the effects of variety and growing locations on their physicochemical properties. Amylose and phosphorous contents, average granule size, solubility, swelling power, thermal and pasting properties were evaluated. Pearson's correlation analysis and two-way ANOVA were applied and found that significant differences in amylose content, phosphorous content and average granule size were observed among the four varieties and between the two locations ($p < 0.05$). Swelling power and pasting properties were higher in starches from Kamikawa, while solubility was higher for starches from Tokachi. Higher T_0 and T_p observed for Kitahime in Kamikawa and T_0 , T_p and T_c for Andover and Snowden in Kamikawa suggest presence of more stable crystalline structures in starch granules grown in Kamikawa. Thus, variety and growing locations affected the starch properties, such as thermal and pasting properties significantly ($p < 0.05$).

Keywords: potato, starch, physicochemical properties, pasting properties, thermal properties, growing location

Introduction

Potato (*Solanum tuberosum* L.), 4th most cultivated crop in the world, is mainly utilized by the food industry, for fresh consumption and processing into chips, frozen products and starch. In Japan, 60% of annual production is utilized by processing industry, while around 22% of Hokkaido potato production is annually used for potato crisp and frozen potato product processing (GAIN, 2010).

Starch being the major component of potato dry matter, the characteristics of potato products such as crisps and French fries are determined by cooking, pasting and rheological characteristics of starch (Miranda and Aguilera, 2006). For example, French fries

with crispy crust were produced from tubers with high starch content (Dupont *et al.*, 1992). Cooking, textural, rheological and pasting properties of potato starch are correlated with physicochemical properties such as granule size, granule size distribution, amylose/amylopectin ratio and phosphorous content (Wiesenborn *et al.*, 1994; Kaur *et al.*, 2002a; Kaur *et al.*, 2002b). Furthermore, lower pasting temperature and higher swelling power of potato starch is attributed to extensive phosphorylation of amylopectin molecules (Kaur *et al.*, 2002b). Characteristics of starch granule such as higher degree of crystallinity, higher percentage of small granules and presence of phosphate mono esters increase the gelatinization transition temperatures, and

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presence of irregular or cuboidal shaped large granules increases the enthalpy of gelatinization (Krueger *et al.*, 1987; Yuan *et al.*, 1993; Singh and Singh, 2001).

Physicochemical properties of potato starch are considered to be a cumulative effect of the geno type and the conditions of growing location (Kaur *et al.*, 2002b). Significant variations are reported in pasting behavior and rheological properties of pastes and gels made from starches from various potato varieties (Wiesenborn *et al.*, 1994 ; Hopkins and Gormley, 2000), while Kaur *et al.* (2007) attributed the variations observed in amylose content, pasting properties and thermal properties, to differences in variety and growing location. Liu *et al.* (2003) reported that regions with low temperature, resulted in starches with higher granule size, lower pasting and transition temperatures and Noda *et al.* (2004a) stated that later harvest dates are found to be enhancing the phosphorous content in starches.

It is a clear fact that physicochemical properties of potato starch are subjected to considerable variations depending on the variety and locational differences. Thus, the aim of this study was directed to determine the effects of variety and growing locations on the physicochemical properties of four processing type potato varieties cultivated in two different growing locations in Hokkaido.

Materials and Methods

Materials Four varieties of potato, two early varieties, Andover and Toyoshiro and two late varieties, Snowden and Kitahime, were cultivated in two locations, Tokachi and Kamikawa in Hokkaido prefecture of Japan in 2013.

Starch isolation All samples were subjected to starch extraction immediately after their respective harvest dates. One kilogram of peeled potato was ground using a laboratory scale blender in 10 L of deionized water. The starch slurry was sieved using a series of parallel sieves with aperture sizes of 710, 106 and 75 μm , respectively and allowed to stand still for 2 h. After filtering using a glass filter (26G2, Asahi Glass Co. Ltd.), approximately 3 L of deionized water was added to the residue and allowed to stand for 6 h while stirring using a magnetic stirrer. Followed by filtering, 3 L of deionized water was added and stirred for another 2 h. This was repeated twice before the crude starch was separated. The isolated starch was oven dried at a temperature of 55°C for 4.5 h. Dried starch was ground, sieved through a sieve with an aperture size of 106 μm and stored in air tight plastic containers at 4°C until further analysis. Prior to further analysis moisture content was measured according to AOAC method at 135°C (AOAC, 2000).

Amylose content Amylose content of the isolated starch samples were measured according to the procedure by Yun and Matheson (1990) with modifications as described in Megazyme Amylose/ Amylopectin Assay procedure (K-AMYL 07/11). Amylogulocosidase (EC 3.2.1.3., 3300 U/mL) and glucose oxidase–peroxidase assay kit (cat. No. K-GLUC) required were purchased from Megazyme (Megazyme International Ireland

Ltd.).

Phosphorous content Phosphorous content of the starches was determined by an inductively coupled plasma spectrometer (ICPS – 8100, Shimadzu Co. Ltd.). Two grams of each starch sample was charred in a capped crucible on a Bunsen burner and then ashed in muffle furnace at 550°C for 6 h. Ash samples were heated to complete dryness with 50% (v/v) HCl, dissolved in 2N HCl and transferred into 25 mL volumetric flask with 2N HCl. One milliliter from each sample was transferred into 10 mL test tubes and added 9 mL of deionized water to a final volume of 10 mL. Well mixed samples were analyzed along with a standard series of 0.0, 2.0, 4.0, 10.0 and 20.0 ppm of P in 0.2N HCl.

Particle size and particle size distribution Starch particle size and particle size distribution was determined using a compact laser diffraction particle size analyzer (LA-300, Horiba Instruments Co. Ltd.).

Swelling power and Solubility Swelling power and solubility of the isolated starches were determined using 0.4% dry weight basis (dwb) aqueous suspensions of starch employing the method by Yousif *et al.* (2012) with slight modifications. Starch solutions were heated to 70°C for 30 min in a water bath and cooled to 10°C for 20 min before centrifuged at 3000 g and subjected to gravimetric measurement.

Pasting properties The pasting properties of the starch samples were measured using a rapid visco analyzer (RVA-4, Newport Scientific Pvt. Ltd.). A 6% dwb aqueous suspension of starch was analyzed in triplicates for peak, breakdown, final viscosities and pasting temperature using the method described by Singh *et al.* (2006).

Thermal properties Differential scanning calorimeter (Micro DSC II, Setaram Inc.) was used to determine the thermal properties of starch. Starch solutions of 30% dwb were prepared in metal canisters and kept overnight at room temperature after hermetically sealing. Samples were analyzed in a scanning temperature range of 30 to 95°C at a heating rate of 0.8°C/min, using distilled water as the reference. Enthalpy of gelatinization (ΔH), initiation (T_0), peak (T_p) and conclusion (T_c) temperatures of gelatinization were measured in triplicates.

Statistical analysis SPSS statistical software (version 17.0) was used to analyze the data by analysis of variance (ANOVA). When significant differences were revealed ($p < 0.01$, $p < 0.05$), mean scores were compared by Duncan's multiple range test ($p < 0.05$). Pearson's correlation analysis was conducted to evaluate the relationships among physicochemical properties ($p < 0.01$, 0.05). Two-way ANOVA test was conducted to identify the effects of variety and growing location on starch properties.

Results and Discussion

Physicochemical properties Table 1 summarizes the physicochemical properties of four potato starches grown in Tokachi and Kamikawa. Amylose contents of the starches varied

Solubility values of the starches in this study varied between 23.7 and 38.7% dwb as in Table 1. The results obtained were comparable with the results reported by Kaur *et al.* (2007). Solubility of starches among the four varieties was not significantly

Table 1. Physicochemical properties of starch from four potato varieties grown in two locations in Hokkaido

Location		Tokachi					Kamikawa				
Cultivar	Amylose (% dwb)	P (mg/100g dwb)	AVG (μ m)	Swelling power (g/g dwb)	Solubility (% dwb)	Amylose (% dwb)	P (mg/100g dwb)	AVG (μ m)	Swelling power (g/g dwb)	Solubility (% dwb)	
AD	20.6 $\pm$ 1.0 b	58.4 $\pm$ 0.2 b	42.4 $\pm$ 0.3 b	80.1 $\pm$ 0.6 b*	31.8 $\pm$ 4.4 a	18.4 $\pm$ 1.0 a	59.3 $\pm$ 0.7 a	42.0 $\pm$ 0.2 b	59.8 $\pm$ 1.5 a	24.3 $\pm$ 1.1 a	
TS	20.6 $\pm$ 0.3 b	51.2 $\pm$ 1.1 a	43.2 $\pm$ 0.2 c*	62.2 $\pm$ 5.7 a	36.0 $\pm$ 3.5 b*	23.0 $\pm$ 0.6 c*	71.7 $\pm$ 1.8 b*	41.2 $\pm$ 0.5 a	64.1 $\pm$ 0.3 b	23.7 $\pm$ 2.5 a	
SD	19.1 $\pm$ 0.1 a	69.5 $\pm$ 0.6 c	39.3 $\pm$ 0.3 a	62.8 $\pm$ 2.7 a	38.7 $\pm$ 3.4 b*	20.2 $\pm$ 1.2 b	74.4 $\pm$ 2.8 b	42.7 $\pm$ 0.1 c*	69.0 $\pm$ 2.3 c*	25.0 $\pm$ 1.4 a	
KH	21.2 $\pm$ 0.2 b	85.2 $\pm$ 2.7 d	44.4 $\pm$ 0.1 d	76.4 $\pm$ 5.4 b	36.9 $\pm$ 1.8 b*	22.2 $\pm$ 0.2 c*	96.8 $\pm$ 3.3 c*	47.2 $\pm$ 0.1 d*	75.5 $\pm$ 2.6 d	31.4 $\pm$ 0.9 b	

Abbreviations: AD, Andover; TS, Toyoshiro; SD, Snowden; KH, Kitahime; P, phosphorous content; AVG, average granule size

Values within each column with different superscript letters are significantly different at $p < 0.05$. Values with * superscript are significantly higher than the corresponding location at $p < 0.05$.

different, but the solubility of starches from Toyoshiro, Snowden and Kitahime, between the two locations varied significantly ($p < 0.05$), where starches from Tokachi possessed higher solubility values. Differences observed in solubility values can be attributed to the differences in starch granular size (Singh and Singh, 2001; Kaur *et al.*, 2007).

Pasting properties Table 2 presents the pasting properties of the starches and peak viscosity ranged between 4168 and 7399 cP, which is in well accordance with Kaur *et al.* (2007) and Waterschoot *et al.* (2014). Kitahime reported the highest and Andover reported the lowest value for peak viscosity, while starches isolated from Kamikawa possessed higher values for peak viscosity compared to starches from Tokachi. Breakdown viscosity values for the four varieties in the two locations ranged between 2490 and 5277 cP, where in both locations, Kitahime reported the highest value. Higher breakdown is attributed to the enhanced shear force sensitivity and disintegration resulted by the extensively swollen granules (Kaur *et al.*, 2007). On the other hand, Andover in Kamikawa and Toyoshiro in Tokachi had the lowest breakdown viscosities of 2490 and 2850 cP, respectively and these two accounted for the lowest phosphorous contents in the respective locations. In addition, the late varieties are considered to possess enhanced peak and breakdown viscosities according to Noda *et al.* (2004a), which is confirmed by the comparable observations in Kamikawa in this study. Pasting temperature ranged between 66 and 69°C in this study, standing comparable with the results reported by Noda *et al.* (2004a) and Kaur *et al.* (2007).

Thermal properties Thermal properties of the four starches are presented in Table 3. T_0 varied between 59.6 and 63.4°C, which is in accordance with the results published by Waterschoot *et al.* (2014). Among the four varieties, Kitahime reported the highest and Snowden the lowest value for T_0 , while significantly higher values for T_0 were observed in Kamikawa, compared to their counterparts in Tokachi ($p < 0.05$), except for Toyoshiro. T_0 resembles the initiation of internal structural disordering, which depends on the stability of the amorphous and crystalline regions of starch (Lim *et al.*, 2001; Chung *et al.*, 2014). Higher T_0 observed for Kitahime variety and starches isolated from Kamikawa, might indicate the presence of more stable amorphous regions and more ordered crystalline regions in starch granules.

T_p varied between 62.6 and 66.6°C, which is in well accordance with the results by Waterschoot *et al.* (2014). Toyoshiro in Kamikawa reported the lowest while Kitahime in both locations reported the highest value for T_p . Cottrell *et al.* (1995) and Chung *et al.* (2014) reported that the differences in varietal characteristics among starches and growing locations are considered to exert an impact on T_p . T_p is considered to reflect the stability of the crystalline regions upon structural breakdown during gelatinization (Alvani *et al.*, 2011). Thus, the higher values obtained for T_p , might be due to higher stability of crystalline areas in starch granules.

Results obtained for T_c varied between 68.1 and 73.0°C, being

Table 2. Pasting properties of starch from four different potato varieties grown in two locations in Hokkaido

Location	Tokachi						Kamikawa					
	Cultivar	PV (cP)	BDV (cP)	FV (cP)	SBV (cP)	PT (°C)	PV (cP)	BDV (cP)	FV (cP)	SBV (cP)	PT (°C)	
	AD	6284 ± 16 b*	4437 ± 11 b*	2078 ± 20 c*	222 ± 9 ab*	67.9 ± 0.4 b	4168 ± 10 a	2490 ± 7 a	1860 ± 7 a	182 ± 5 a	69.4 ± 0.0 ab*	
	TS	4236 ± 18 a	2850 ± 20 a	1609 ± 7 b*	223 ± 6 ab	66.4 ± 0.4 a	4622 ± 18 b*	2978 ± 21 b*	1906 ± 4 b*	262 ± 6 b*	68.9 ± 0.4 a*	
	SD	4230 ± 36 a	2918 ± 21 a	1521 ± 15 a	204 ± 1 a*	66.4 ± 0.5 a	5167 ± 7 c*	3348 ± 9 c*	1989 ± 7 c*	176 ± 5 a	68.6 ± 0.0 a*	
	KH	6424 ± 36 c	4482 ± 75 b	2192 ± 55 d	260 ± 4 b	66.4 ± 0.0 b	7399 ± 30 d*	5277 ± 116 d*	2444 ± 55 d*	306 ± 22 c*	69.4 ± 0.4 b*	

Abbreviations: AD, Andover; TS, Toyoshiro; SD, Snowden; KH, Kitahime; PV, peak viscosity; BDV, breakdown viscosity; FV, final viscosity; SBV, setback viscosity; PT, pasting temperature. Values within each column with different superscript letters are significantly different at $p < 0.05$. Values with *superscript are significantly higher than the corresponding location at $p < 0.05$.

Table 3. Thermal properties of starch from four different potato varieties grown in two locations in Hokkaido

Location		Tokachi				Kamikawa			
Cultivar	T_0 (°C)	T_P (°C)	T_C (°C)	ΔH (J/g)	T_0 (°C)	T_P (°C)	T_C (°C)	ΔH (J/g)	
AD	61.6 ± 0.1 b	64.4 ± 0.0 c	70.3 ± 0.0 c	19.1 ± 0.1 c*	62.6 ± 0.1 c*	66.0 ± 0.0 c*	73.0 ± 0.0 d*	18.6 ± 0.2 b	
TS	59.7 ± 0.1 a	62.8 ± 0.0 b	68.1 ± 0.1 a	17.7 ± 0.1 a	59.6 ± 0.0 a	62.8 ± 0.1 a	68.2 ± 0.1 a	17.8 ± 0.0 a	
SD	59.6 ± 0.0 a	62.6 ± 0.0 a	68.6 ± 0.1 b	18.5 ± 0.0 b	61.4 ± 0.0 b*	64.5 ± 0.0 b*	70.1 ± 0.0 b*	18.6 ± 0.1 b	
KH	61.8 ± 0.1 c	65.4 ± 0.0 d	72.2 ± 0.0 d*	19.1 ± 0.1 c*	63.4 ± 0.0 d*	66.6 ± 0.0 d*	72.0 ± 0.0 c	18.7 ± 0.0 b	

Abbreviations: AD, Andover; TS, Toyoshiro; SD, Snowden; KH, Kitahime; T_0 , initiation temperature; T_p , peak temperature; T_c , conclusion temperature; ΔH , gelatinization enthalpy (dwb)

Values within each column with different superscript letters are significantly different at $p < 0.05$.

Values with *superscript are significantly higher than the corresponding location at $p < 0.05$.

Table 4. Pearson's correlation coefficients between physicochemical properties of starch

	AM	P	PV	BDV	FV	SBV	PT	T_0	T_p	T_c	ΔH	SP	S
P	0.180												
	0.637												
PV	0.674	0.480											
	0.484	.979*											
BDV	0.644	0.477	.999**										
	0.516	.985*	.999**										
FV	0.765	0.489	.990**	.983*									
	0.447	.961*	.996**	.994*									
SBV	0.884	0.612	0.712	0.684	0.798								
	0.830	0.782	0.728	0.751	0.737								
PT	0.704	0.593	.987*	.982*	.991*	0.798							
	0.091	0.552	0.669	0.664	0.735	0.630							
T_0	0.699	0.482	.999**	.997**	.995**	0.735	.990*						
	-0.383	0.408	0.584	0.557	0.635	0.128	0.790						
T_p	0.755	0.617	.968*	.959*	.986*	0.857	.994**	.974*					
	-0.453	0.321	0.506	0.478	0.563	0.069	0.778	.995*					
T_c	0.657	0.770	0.915	0.908	0.932	0.856	.967*	0.921	.977*				
	-0.661	0.008	0.210	0.180	0.280	-0.140	0.679	0.911	0.947				
ΔH	0.262	0.651	0.879	0.894	0.818	0.454	0.869	0.864	0.823	0.847			
	-0.558	0.285	0.452	0.418	0.478	-0.194	0.474	0.912	0.906	0.826			
SP	0.581	0.334	.978*	.983*	0.945	0.558	0.932	.971*	0.893	0.816	0.876		
	0.521	.970*	.954*	.954*	0.923	0.610	0.418	0.422	0.333	0.011	0.399		
S	-0.422	0.444	-0.565	-0.572	-0.529	-0.071	-0.436	-0.558	-0.383	-0.192	-0.335	-0.697	
	0.321	0.906	.971*	.965*	.987*	0.685	0.813	0.744	0.683	0.427	0.573	0.864	
AVG	.993**	0.170	0.592	0.559	0.695	0.883	0.634	0.621	0.695	0.605	0.169	0.485	-0.340
	0.269	0.891	.964*	.956*	.981*	0.638	0.804	0.774	0.714	0.461	0.622	0.863	.998**

Upper value- Tokachi, Lower value- Kamikawa

Abbreviations: AM, amylose content; P, phosphorous content; PV, peak viscosity; BDV, breakdown viscosity; FV, final viscosity; SBV, setback viscosity; PT, pasting temperature; T_0 , initiation temperature; T_p , peak temperature; T_c , conclusion temperature; ΔH , gelatinization enthalpy; SP, swelling power; S, solubility; AVG, average granule size

*significant at 0.05 level and **significant at 0.01 level.

comparable with the results presented by Waterschoot *et al.* (2014). Andover reported the highest value and Toyoshiro reported the lowest value for T_c among the four varieties. The varieties in

Kamikawa reported higher T_c values, compared to that of Tokachi. Native crystalline structure of potato starch is considered to be the main determinant of T_0 , T_p and T_c (Parada and Aguilera, 2012), as

Table 5. Two-way ANOVA results for the effects of variety and location on physicochemical properties of potato starch

	Variety	Location	Variety * Location
	<i>p</i> value		
AM	< 0.001	0.053	< 0.001
P	< 0.001	< 0.001	< 0.001
PV	< 0.001	< 0.001	< 0.001
BDV	< 0.001	< 0.001	< 0.001
FV	< 0.001	< 0.001	< 0.001
SBV	< 0.001	0.451	< 0.001
PT	< 0.001	< 0.001	0.007
T_0	< 0.001	< 0.001	< 0.001
T_p	< 0.001	< 0.001	< 0.001
T_c	< 0.001	< 0.001	< 0.001
ΔH	< 0.001	< 0.001	< 0.001
SP	< 0.001	0.026	< 0.001
S	0.007	< 0.001	0.051
AVG	< 0.001	< 0.001	< 0.001

Abbreviations: AM, amylose content; P, phosphorous content; PV, peak viscosity; BDV, breakdown viscosity; FV, final viscosity; SBV, setback viscosity; PT, pasting temperature; T_0 , initiation temperature; T_p , peak temperature; T_c , conclusion temperature; ΔH , gelatinization enthalpy; SP, swelling power; S, solubility; AVG, average granule size

degree of crystallinity in starch granules provides structural stability, and resistance against disordering of internal molecular organization by heating (Barichello *et al.*, 1991).

ΔH is the energy requirement for the physical state transformation during gelatinization, due to the loss of double helical structure in starch and thus an overall measure of quality and quantity of crystallites (Singh *et al.* 2006; Kaur *et al.* 2007). ΔH for the current study varied between 17.7 and 19.1 J/g dwb as in Table 3. The highest value for ΔH was reported by Kitahime and the lowest by Toyoshiro. Values of ΔH for Andover and Kitahime from Tokachi were significantly higher compared to Kamikawa ($p < 0.05$), which resemble the presence of higher content of stable internal granule structures in Kitahime and Andover in Tokachi.

Pearson's correlation for starch properties Pearson's correlation coefficients for physicochemical properties are summarized in Table 4. Amylose content was positively correlated with average granule size in Tokachi ($r = 0.993$, $p < 0.01$), comparable with Geddes *et al.* (1965) and Kaur *et al.* (2004a). Higher swelling power resulted, due to extensive hydration of granules, can be attributed to the significantly positive correlation between swelling power and phosphorous content in Kamikawa ($r = 0.970$, $p < 0.05$), which is in accordance with Kaur *et al.* (2007). Significantly higher positive correlation observed between granule size and solubility in Kamikawa ($r = 0.998$, $p < 0.05$), as reported by Singh and Singh (2001) and Kaur *et al.* (2007),

suggests the increased susceptibility in large granules to disintegration. Peak and breakdown viscosities are positively correlated with phosphorous content ($r = 0.979$, $p < 0.05$; $r = 0.985$, $p < 0.05$, respectively), which causes extensive hydration and subsequent increased susceptibility to disintegration (Hemar *et al.*, 2007). Final viscosity is considered to be directly affected by the apparent amylose content, where a positive, but non-significant correlation was observed between amylose content and final viscosity in this study in Tokachi ($r = 0.765$, $p < 0.05$) and Kamikawa ($r = 0.447$, $p < 0.05$) (Liu *et al.*, 2007). Higher solubility of starches enhances the final viscosity, as a network is formed from leached amylose during cooling, which is further proved by the significantly positive relationship in Kamikawa ($r = 0.987$, $p < 0.05$). Positive correlations observed between pasting temperature and T_0 , T_p and T_c ($r = 0.990$, $p < 0.05$; $r = 0.994$, $p < 0.05$; $r = 0.967$, $p < 0.05$, respectively), as reported by Kaur *et al.* (2007), might indicate the presence of stable amorphous and ordered crystalline regions in granules resisting pasting and gelatinization.

Two-way ANOVA analysis of physicochemical properties of starch Two-way ANOVA test was conducted to identify the effects of varieties and growing locations on the physicochemical properties of potato starch and the results are provided in Table 5. Amylose content was found to have no significant effect from the growing location ($p = 0.053$), in this study as similarly observed by Hase and Plate (1996). Setback viscosity ($p = 0.451$), which is the important parameter of processed potato products, is also independent from effect of growing location. According to the results obtained, it is clear that the majority of the physicochemical properties of potato starch, such as, phosphorous content, granule size, pasting and thermal properties are cumulatively determined by the interaction between variety and growing location.

Conclusions

The physicochemical properties of the starch significantly varied among the varieties as well as the locations. Among the four varieties, Kitahime showed higher contents of amylose and phosphorous, higher values for pasting properties, gelatinization properties, swelling power, solubility and mean granule size in both locations. Andover and Toyoshiro showed lower values for the above parameters in the two locations. The swelling power, pasting and thermal properties were higher in starches isolated from Kamikawa district compared to their counterparts in Tokachi district. The late varieties, Snowden and Kitahime showed higher values for phosphorous content and pasting properties compared to the early varieties, Andover and Toyoshiro. The properties such as pasting, thermal and swelling power of starches were substantially affected both by the variety and the growing location. Thus, potato tubers or starch from different potato varieties or from different locations used in processing can significantly influence quality of the final products.

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