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Physicochemical and Nutritional Properties of Starch and Dry Matter from Organically and Conventionally Grown Potatoes

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ABSTRACT

The chemical composition, gelatinization, retrogradation, pasting, and *in vitro* starch digestibility of starch and dry matter obtained from Goldrush, Norland and Yukon Gold potatoes grown under organic and conventional conditions were investigated. The crystalline structure of potato starch was also examined using wide-angle X-ray diffraction. Total protein content of potato dry matter was significantly higher in organically grown potatoes. The free glucose levels were significantly higher in dry matter obtained from conventionally grown tubers. Phosphorus content of starch isolated from organic potatoes was significantly lower than that found in starch from conventionally grown potatoes. From rapid visco analysis (RVA), peak viscosity was significantly higher for all starches and dry matter from conventionally produced potatoes. Significant differences were found in peak time of starch and final viscosity of dry matter with respect to production method. Differential scanning calorimetry (DSC) showed some significant differences between production methods in onset temperature, peak temperature, conclusion temperature and enthalpy of gelatinization of starch. Retrograded potato starch and dry matter from conventionally produced potatoes had significantly larger enthalpy values than organic. Comparing digestibility *in vitro*, slowly digestible starch content of raw organic potato starch was significantly greater than that of raw conventional starch, while resistant starch content of raw organic starch was significantly lower than that of raw conventional starch. Rapidly digestible starch content of cooked conventional dry matter was significantly higher than that of cooked organic dry matter, yet resistant starch content was significantly lower than that found in the cooked organic dry matter.

Keywords: chemical composition, crystalline structure, gelatinization, *in vitro* starch digestion, organic, pasting, potato, retrogradation

INTRODUCTION

Organic food has increased in popularity in recent years, owing to its perceived nutritional benefits, reduced environmental impact, and because of safety concerns surrounding pesticide residues in food and water. In Canada, the number of farms producing certified organic products increased from 2230 in 2001, to 3555 in 2006, while there were 11937 farms in 2006 growing organic (uncertified) products (Kendrick 2008). In 2005, certified organic potatoes were grown on 497 ha in Canada; the largest area was in British Columbia (185 ha), followed by Prince Edward Island (84 ha) and Saskatchewan (74 ha) (Macey 2006). Canadian retail consumers spent $2.7 million on organic potatoes in 2006 (Macey 2007).

Organic potato production relies on many of the same methods used in conventional production but specific techniques are set under national legislation (Canadian General Standards Board 2006a). Permitted substances that can be used in organic potato production are quite different from conventional (Canadian General Standards Board 2006b). Organic producers cannot use any manufactured fertilizer blends and the major fertility elements, nitrogen, phosphorus and potassium, are provided by use of many natural, organic products, manures and composts, or from mined, crushed sources, and by crop rotation. The differences in soil management practices, fertility sources, pest and weed management, crop rotations and other inputs may affect quality aspects of the tuber grown.

Studies have been undertaken to examine different qualities of organic potatoes, such as yield, ascorbic acid and mineral content (Warman and Havard 1998), sensory quality (Thybo *et al*. 2001), glycoalkaloid levels (Wszelaki *et al*. 2005), protein profiles (Lehesranta *et al*. 2007), traceability markers (Camin *et al*. 2007), and metabolic profiles (Maggio *et al*. 2008). There is little information on the properties of starch and dry matter isolated from organic potatoes. Starch comprises between 66 and 80% of the potato dry matter, and therefore has a significant impact on the nutritional, cooking and textural qualities of potatoes (Li *et al*. 2006). Potato starch is used in papermaking, as sizing agents for textiles, and in the development of biodegradable plastics, in addition to its use in food products (Li *et al*. 2006). If organic production of potatoes alters the structure and properties of starch, the end use of the starch could be affected. The nutritional quality and taste of organic potato developed in Canada could be different compared to conventional potatoes.

Three potato cultivars Goldrush, Norland and Yukon Gold grown under organic and conventional conditions were selected for this study. Goldrush has medium to high dry matter, white flesh, with excellent boiling and baking quality. Norland has medium dry matter, white flesh, with fair boiling and baking quality, and Yukon Gold has high dry matter, light yellow flesh, with very good boiling and baking quality (PEI Agriculture, Fisheries and Aquaculture 2007). The efforts through research to produce high quality potato should focus on understanding the structure and functional properties of potato starch. Thus, the objective of this study was to evaluate the chemical composition, pasting, gelatinization and retrogradation properties, and *in vitro* starch digestibility of starch and dry matter obtained from different varieties of potato grown under organic and conventional conditions in Canada.

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MATERIALS AND METHODS

Materials

Three potato varieties, Goldrush, Norland and Yukon Gold, were grown under conventional and organic conditions in Prince Edward Island, Canada, in 2007, as outlined below. Pancreatin from porcine pancreas (P-7545, activity 8×USP/g), invertase (I-4504) and other chemicals were purchased from Sigma Chemical Company (St. Louis, MO, USA). Thermostable α-amylase (E-BLAAM), amyloglucosidase (E-AMGDF) and glucose oxidase-peroxidase assay kit were purchased from Megazyme (Megazyme International Ireland Ltd., Bray, Ireland).

Potato production

Separate experiments using either conventional inputs or allowable organic inputs were conducted at Agriculture & Agri-Food Canada Research Centre's Harrington Farm, Harrington, PEI, in 2007. The soil in each experiment was a fine sandy clay loam with a pH of 6.5 and a slight slope. Plots grown conventionally were included in a barley-ryegrass-potato crop sequence. Fertilizer 15-15-15- 0.2B was banded at the rate of 1120 kg/ha. The herbicide metribuzin (Sencor) applied pre-emergence provided weed control, and imidacloprid (Admire) applied in-furrow at planting provided adequate control of the Colorado beetle. Blight was controlled by use of chlorothalonil (Bravo) applied as needed based on provincial blight forecasts. Plots grown organically were in a similar crop rotation managed in an organic system without synthetic inputs for several years. Commercial composted chicken manure (4-4-4% N-P-K) was applied broadcast at 5 t/ha before planting. Weeds were controlled by flaming emerged weeds at ground crack before potato emergence, followed by between the row cultivation and hilling. Spinosad (Entrust) prevented significant damage from the Colorado potato beetle and copper sulphate (Kocide) was applied to manage late blight infection. All plots were planted using a modified 2-row potato planter. Plots were 7.6 m in length with 4 replications, and were planted May 30.

Each experiment contained the potato cultivars Goldrush, Norland and Yukon Gold which are all mid-season cultivars of comparable maturity level.

Starch isolation

Potato starch was obtained following the method of Liu *et al.* (2003). Dry starch was ground with a mortar and pestle, passed through a 125 μm sieve and stored in plastic bags at room temperature until use. Moisture content was calculated as the ratio of the mass lost upon drying to the original sample mass, multiplied by 100. Drying of 1 g duplicate samples took place in a forced air oven (105°C) for 3 h.

Dry matter

Potato dry matter was obtained by freeze-drying, following the method of Liu *et al*. (2002). Tuber dry matter contents ranged from 21.3 ± 0.6% to 25.7 ± 1.2%. Lyophilized samples were ground to powder with a mortar and pestle, passed through a 250 μm sieve and stored in plastic bags at room temperature until use. Moisture content was determined as described for starch.

Proximate analysis

Total starch and free glucose contents of dry matter were measured using AACC method 76.13 (AACC, 2000). Free glucose content was obtained from blank samples (no enzyme added). Total protein content of dry matter (N×6.25) was determined by combustion using a nitrogen analyzer (ThermoQuest CE Instrument, NA 2100, ThermoQuest Italia S.P.A., Ann Arbor, MI). Apparent amylose content of starch was determined by iodine colorimetry according to Williams *et al*. (1970). Phosphorus content of starch was obtained using a modified kjeldahl digest, according to the method of Thomas *et al*. (1967). All analyses were conducted in duplicate.

Wide angle X-ray diffraction

X-ray diffractograms were obtained with a Rigaku RPT 300 PC X-ray diffractometer (Rigaku-Denki Co., Tokyo, Japan) at 40 kV and 100 mA. The scanning range was 3-50°, and scan speed was 2.0°/min. The starch samples were prepared in thin-walled (0.01 mm) glass capillary tubes (1.0 mm in diameter). Moisture content of starch ranged from 7.7 ± 0.0% to 8.9 ± 0.0%.

Amylose leaching

Amylose leaching was determined according to the method of Chung *et al*. (2008). Starches (20 mg, db) in water (10 mL) were heated at 60, 75, and 90°C in sealed tubes for 30 min. The tubes were then cooled to room temperature and centrifuged at 2000 × *g* for 10 min. Supernatant was withdrawn and its amylose content was determined as described above. Amylose leaching was expressed as the mass of leached amylose divided by starch mass, multiplied by 100. Analysis was performed in duplicate.

Rapid visco analysis (RVA)

Pasting properties of starch and potato dry matter were determined using a Rapid Visco^{TM} Analyzer RVA-4 (Newport Scientific Pty. Ltd., Warriewood, NSW, Australia) with the STD 2 profile. The standard 2 profile consisted of a 1 min hold at 50°C, a temperature ramp of 6°C/min to 95°C, a 5 min hold at 95°C, and a temperature ramp of 6°C/min to 50°C, followed by a 2 min hold at 50°C. The paddle speed was 960 rpm for the first 10 s of the experiment, and then 160 rpm for the remainder of the experiment. A 2.00 g sample size was used, with distilled water added to give a final mass of 27 g (6.4% dry starch basis). Pasting temperature, peak time, peak viscosity and final viscosity were measured from the pasting curves of potato starch and dry matter. The reported values are the means of duplicate measurements.

Differential scanning calorimetry (DSC)

Thermal analyses were done with a differential scanning calorimeter (TA Instruments 2920 Modulated DSC, New Castle, DE, USA) equipped with a refrigerated cooling system (RCS). Potato starch and dry matter were evaluated for gelatinization and retrogradation properties.

***Gelatinization*:** Starch and dry matter (12 mg, dry weight) were added to high volume pans, and distilled water was added to give a moisture content of 70%. Pans were sealed and equilibrated 16 h at room temperature prior to heating in the DSC. Pans were heated from 5 to 190°C at a rate of 10°C/min. The DSC was calibrated with indium and an empty pan was used as a reference. The enthalpy (ΔH) of phase transitions was measured from endotherms in the DSC thermograms using software (Universal Analysis ver. 4.1D, TA Instruments) based on the mass of dry solid. Onset, peak and conclusion temperatures of endotherms were measured from the thermograms using Universal Analysis software.

***Retrogradation*:** After heating to 190°C, samples were cooled to 5°C and stored at 5°C for 14 days. The sample was re-heated to 190°C at 10°C/min. The enthalpy (ΔH) of phase transitions was measured from endotherms in the DSC thermograms using software (Universal Analysis ver. 4.1D, TA Instruments) based on the mass of dry solid. Onset, peak and conclusion temperatures of endotherms were measured from the thermograms using Universal Analysis software.

The reported values are means of duplicate measurements.

In vitro starch digestibility

Starch hydrolysis was determined following the method described by Englyst *et al*. (1992) with modifications. Porcine pancreatic α-amylase (0.45 g) was dispersed in water (4 mL), and centrifuged at 1500 × *g* for 12 min. The supernatant (2.7 mL) was transferred to a beaker, and amyloglucosidase (0.3 mL) and invertase (2 mg in 0.2 mL) were added to the solution. This enzyme solution was freshly prepared for each digestion analysis.

Native and cooked potato starch and dry matter were used in

Table 1 Proximate analysis of potato starch and dry matter [a].

Variety	Production type	Apparent amylose in starch (%, w/w)	Phosphorus in starch (%, w/w) × 10^{-2}	Total starch in dry matter (%, w/w)	Free glucose in dry matter (%, w/w)	Total protein in dry matter (%, w/w)
Goldrush	Conventional	33.0 ± 0.0	9.5 ± 0.2	73.6 ± 0.1	1.2 ± 0.0	10.6 ± 0.5
	Organic	32.5 ± 0.3	6.7 ± 0.4	73.2 ± 2.2	0.7 ± 0.0	14.6 ± 1.3
Norland	Conventional	31.4 ± 0.0	9.5 ± 0.2	73.6 ± 3.2	1.1 ± 0.0	12.8 ± 0.8
	Organic	30.8 ± 0.3	7.0 ± 0.2	70.3 ± 2.4	0.6 ± 0.0	13.1 ± 0.3
Yukon Gold	Conventional	33.1 ± 0.2	8.0 ± 0.1	69.3 ± 1.6	0.9 ± 0.1	11.2 ± 0.1
	Organic	31.7 ± 0.0	5.7 ± 0.2	74.1 ± 0.8	0.5 ± 0.0	12.2 ± 0.3
p-value, *t*-test (Conventional versus Organic)			p = 0.000	p = 0.800	p = 0.000	p = 0.028
p-value, Mann-Whitney		p = 0.128				

[a] values represent means ± standard deviation, $n = 2$

this experiment. Immediately following RVA analysis, cooked starch and dry matter samples were removed from the aluminum canister, dried overnight in a forced air oven at 40°C, ground to powder with a Tekmar analytical mill A-10 (Tekmar, Cincinnati, OH), and passed through a 150 µm sieve. Samples were stored at room temperature in sealed containers until analysis.

The starch or dry matter (100 mg) and 4 mL of 0.5 M sodium acetate buffer (pH 5.2) were added to test tubes. Enzyme solution (1 mL) and 15 glass beads (2 mm diameter) were added to each tube and incubated in a shaking water bath (37°C, 200 strokes/ min). Aliquots (0.1 mL) were taken at intervals and mixed with 1 mL of 50% ethanol. Glucose content of the hydrolysates was measured by the glucose oxidase-peroxidase reagent.

According to the Englyst method, rapidly digestible starch (RDS) was defined as starch that was digested within 20 min, slowly digestible starch (SDS) was defined as starch digested during the period between 20 min and 120 min, and resistant starch (RS) was defined as the starch undigested within 120 min. The reported values are means of duplicate measurements.

Statistics

All statistical results were obtained using Minitab® 14 (Minitab Inc., State College, PA). Normality of data was assessed with the Anderson-Darling test. Two-sample *t*-test was performed on normally distributed data, and significant differences between means of conventional and organic samples were evaluated based on $p < 0.05$. For non-normally distributed data, Levene's test was used to ensure equality of variances, followed by the Mann-Whitney test for significant differences between medians ($p < 0.05$). Mean values and standard deviations of duplicate samples are reported for each variety.

RESULTS AND DISCUSSION

Proximate analysis of potato dry matter and starch

Total starch content of dry matter ranged from 69.3% for Yukon Gold, to 74.1% for organic Yukon Gold (**Table 1**). Starch content followed the order: organic Yukon Gold > Goldrush = Norland > organic Goldrush > organic Norland > Yukon Gold. No clear trend was observed between organic and conventionally produced potatoes with respect to total starch content, which is in agreement with the findings of Maggio *et al*. (2008). This indicates that the production regime is not a major factor in starch yield.

Free glucose values were low in the dry matter (**Table 1**). Values ranged between 0.5% (organic Yukon Gold) and 1.2% (Goldrush). Free glucose content was significantly lower in the dry matter obtained from organic potatoes by approximately 50% ($p < 0.05$). Maggio *et al*. (2008) found no significant difference in glucose content of potatoes grown under organic and conventional farming practices, although they reported a significant decrease in glucose content in tubers fertilized with greater amounts of nitrogen. In our study, fertilization of the organic and conventional tubers was different, which could have led to changes in glucose content of the dry matter.

Total protein content of potato dry matter ranged from 10.6% in Goldrush to 14.6% in organic Goldrush (**Table 1**). Protein content followed the order: organic Goldrush > organic Norland > Norland > organic Yukon Gold > Yukon Gold > Goldrush. Dry matter from organic potatoes had significantly greater protein content ($p < 0.05$). Recent studies have also found an increased protein content in organically grown potatoes compared to conventional (Camin *et al*. 2007; Maggio *et al*. 2008). Profiling of proteins in tubers grown under conventional and organic fertilization suggested an increase in proteins involved in the stress response in organic potatoes (Lehesranta *et al*. 2007).

Apparent amylose content of starch is reported in **Table 1**. It ranged from 30.8% in organic Norland starch to 33.1% for Yukon Gold. Amylose content seemed to be slightly lower in the organic starches, with a 1.7% difference between Goldrush and organic Goldrush, a 2.0% difference between Norland and organic Norland, and a 4.0% difference between Yukon Gold and organic Yukon Gold. This same trend was seen in the amylose content measured potentiometrically (data not shown).

Total phosphorus content of potato starch ranged from 5.7×10^{-2} % in organic Yukon Gold, to 9.5×10^{-2} % for conventionally grown Goldrush and Norland (**Table 1**). Phosphorus content was significantly lower in starch obtained from organically grown potatoes ($p < 0.05$). Researchers have reported higher levels of phosphorus in the tissue of organically grown potatoes compared to conventionally grown tubers (Warman and Havard 1998; Wszelaki *et al*. 2005), while others have reported lower levels of phosphorus in organic potatoes (Lehesranta *et al*. 2007). Different types of fertilizers and fertilization regimes could lead to these variations.

X-ray diffraction

Fig. 1 shows the X-ray diffraction patterns of starches obtained from conventionally and organically grown potatoes. The patterns were B-type, exhibiting the characteristic peaks at reflection angles (2θ) of 5.5, 17.2, and 22.1°, consistent with a typical potato starch pattern (Zobel 1988). These similar results indicate that the semi-crystalline structure of starch was not altered by the potato production method used.

Amylose leaching of potato starch

Amylose leaching values at 60, 75 and 90°C are shown in **Table 2**. Amylose leaching increased with temperature, with the rapid increase at 75 and 90°C a result of granular swelling, melting of crystallites and starch gelatinization. Values ranged from 5.2 to 16.1% (Norland), 6.5 to 16.5% (Goldrush), and 6.9 to 16.3% (Yukon Gold) for the conventionally grown potatoes, and 4.3 to 14.5% (organic Norland), 5.3 to 15.4% (organic Goldrush), and 5.7 to 15.2% (organic Yukon Gold) for the organic potatoes. The lower amylose leaching values for the organic potato starch could be a result of the lower (not significantly) amylose content of these starches (**Table 1**), although amylose leaching values were only significantly different at 90°C ($p < 0.05$).

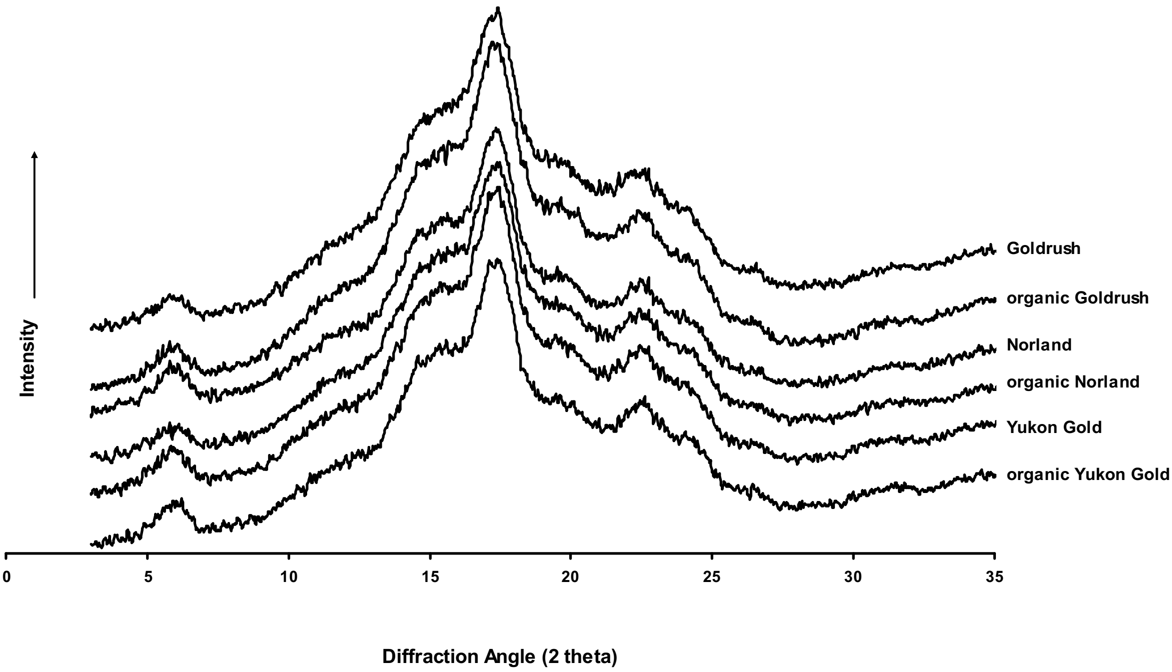

Fig. 1 X-ray diffractograms of starch isolated from conventionally and organically grown potatoes.

Table 2 Amylose leaching of potato starch [a].

Variety	Production Type	Amylose leaching (%, w/w)		
		60°C	75°C	90°C
Goldrush	Conventional	6.5 ± 0.9	10.5 ± 0.5	16.5 ± 0.1
	Organic	5.3 ± 0.3	10.5 ± 0.5	15.4 ± 0.2
Norland	Conventional	5.2 ± 0.3	9.8 ± 0.7	16.1 ± 0.6
	Organic	4.3 ± 0.9	7.5 ± 0.3	14.5 ± 0.4
Yukon Gold	Conventional	6.9 ± 1.2	10.3 ± 0.2	16.3 ± 1.3
	Organic	5.7 ± 0.2	9.1 ± 1.0	15.2 ± 0.2
p-value, *t*-test (Conventional versus Organic)		p = 0.069	p = 0.115	p = 0.005

[a] values represent means ± standard deviation, *n* = 2

Pasting properties of potato starch and dry matter

A comparison between Rapid Visco Analysis (RVA) pasting curves of conventional and organic Norland and Goldrush potato starch is shown in **Fig. 2**. The difference in peak viscosity between organic and conventional potato starch can be seen. Yukon Gold potato starches exhibited similar pasting curves (data not shown in **Fig. 2**).

Pasting temperature, peak time, peak viscosity and final viscosity of potato starch and dry matter are shown in **Table 3**. Pasting temperature of starch ranged from 64.0°C for Yukon Gold to 66.2°C for organic Norland, while the pasting temperature of dry matter was slightly higher, between 65.7°C (Goldrush) and 67.8°C (organic Norland).

Peak time for starch pasting ranged from 4.2 min (Yukon Gold) to 5.7 min (organic Norland) (**Table 3**). Peak time for pasting of the dry matter samples was higher, between 7.2 min (Yukon Gold) and 8.8 min (Goldrush). Organic starch exhibited a higher peak time than conventional starch ($p < 0.05$).

Peak viscosity of potato starch followed the order: Goldrush > Norland > Yukon Gold > organic Goldrush > organic Yukon Gold > organic Norland (**Table 3**). Starch from conventionally grown potatoes showed a significantly higher peak viscosity, by 1567 cP (Norland), 1219 cP (Goldrush), and 707 cP (Yukon Gold) ($p < 0.05$). This could reflect the higher phosphorus content in the starches of conventionally grown potatoes (**Table 1**). In fact, regression analysis showed a linear relationship between phosphorus content and starch RVA peak viscosity, with an r^2 value of 0.80 (data not shown), which is in agreement with the observations of Hemar *et al.* (2007). The phosphate esters in potato amylopectin impart a negative charge to potato starch, which results in repulsion between starch chains, leading to rapid swelling and high peak viscosity (BeMiller 2007); a larger amount of phosphate esters would result in even higher peak viscosity. Peak viscosity of dry matter was lower than that of starch, reflecting the lower starch content of dry matter, and the presence of other components, such as proteins, free sugars and fibres, which competed for water, causing a reduction in starch granule swelling. A higher peak viscosity was recorded for dry matter from conventionally grown potatoes ($p < 0.05$), likely due to the effect of phosphorus content of potato starch.

Final viscosity values were higher for potato starch compared to dry matter, and generally, were higher in samples from conventionally grown potatoes (**Table 3**). Values ranged from 1629 cP (organic Yukon Gold) to 2091 cP (or-

Table 3 Rapid Visco Analysis (RVA) pasting properties of potato starch and dry matter [a].

Variety	Type [b]	Pasting Temperature (°C)		Peak Time (min)		Peak Viscosity (cP)		Final Viscosity (cP)	
		Starch	Dry matter	Starch	Dry matter	Starch	Dry matter	Starch	Dry matter
Goldrush	C	64.3 ± 0.4	65.7 ± 0.1	4.7 ± 0.1	8.8 ± 1.6	7634 ± 25	1381 ±15	2062 ± 11	1535 ± 33
	O	64.2 ± 0.3	66.4 ± 0.6	4.8 ± 0.0	7.9 ± 0.1	6415 ± 43	1295 ± 5	1815 ± 1	1140 ± 11
Norland	C	66.0 ± 0.0	67.6 ± 0.0	4.5 ± 0.0	7.9 ± 0.2	7355 ± 37	1380 ± 9	1966 ± 1	1345 ± 9
	O	66.2 ± 0.4	67.8 ± 0.3	5.7 ± 0.0	8.7 ± 0.3	5788 ± 5	1347 ± 30	2091 ± 40	1100 ± 5
Yukon Gold	C	64.0 ± 0.0	66.0 ± 0.0	4.2 ± 0.0	7.2 ± 0.1	6853 ± 47	1462 ± 52	1752 ± 29	1388 ± 44
	O	64.4 ± 0.0	67.2 ± 0.0	4.6 ± 0.0	8.2 ± 0.2	6146 ± 28	1283 ± 5	1629 ± 9	1271 ± 3
p-value, *t*-test (C versus O)				p = 0.049	p = 0.403	p = 0.000	p = 0.001	p = 0.454	p = 0.001
p-value, Mann-Whitney		p = 0.575	p = 0.262						

[a] values represent means ± standard deviation, *n* = 2

[b] type refers to production type: Conventional (C) and Organic (O)

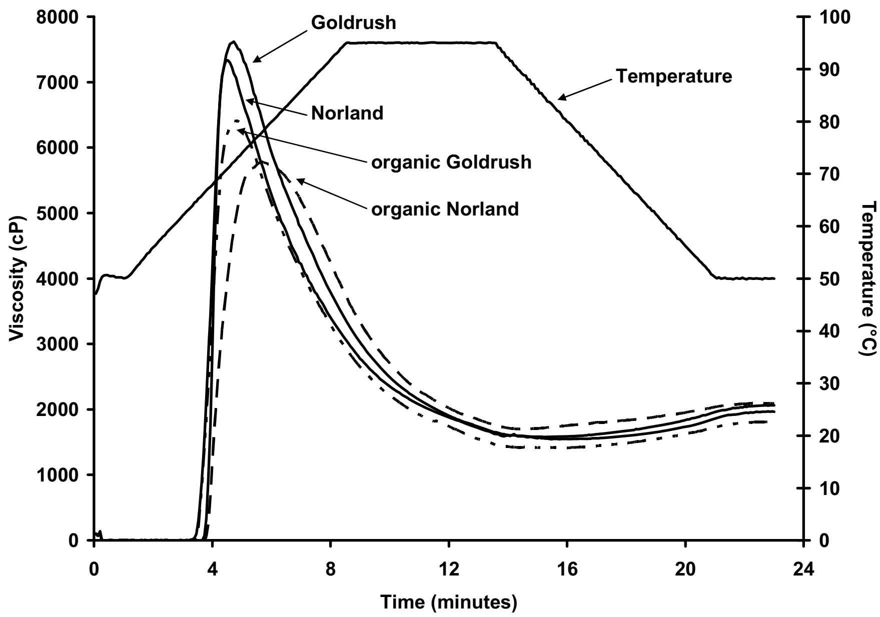

Fig. 2 Rapid Visco Analysis (RVA) pasting curves of Goldrush and Norland potato starches.

ganic Norland) for starches, and 1100 cP (organic Norland) to 1535 cP (Goldrush) for dry matter. In the case of starch and dry matter, the trend towards greater apparent amylose content of conventional starch (**Table 1**) could result in more entanglement of linear chains upon cooling in the RVA, leading to a higher final viscosity (Batey 2007). This greater association of amylose chains on cooling may indicate the formation of a more stable retrograded structure in cooked conventional potato starch and dry matter. Additionally, the higher protein content of organic potato dry matter (**Table 1**) would inhibit entanglement of amylose chains, leading to a lower final viscosity.

Gelatinization of potato starch and dry matter

Starch and dry matter were heated in excess water to gelatinize starch, which resulted in a typical endotherm in the Differential Scanning Calorimetry (DSC) thermograms (Liu *et al.* 2007). Onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy (ΔH) of gelatinization are shown in **Table 4**. Gelatinization onset temperature (T_o) for isolated starch ranged from 61.9°C for organic Goldrush starch, to 64.5°C for Norland and Yukon Gold starches, and was significantly higher for conventional starch ($p < 0.05$). Onset temperature for gelatinization of starch in the potato dry matter was higher than that for isolated starch, likely due to the presence of protein and fibre, the competition of other components for water, and reduced water migration (Liu *et al.* 2007). The onset temperature for the dry matter varied from 63.6°C (Goldrush) to 67.4°C (organic Norland). T_o for organic dry matter was slightly higher than that for conventional dry matter, which could reflect the higher protein content of the organic dry matter (**Table 1**).

Peak temperature (T_p) for isolated starch ranged between 66.6°C (organic Goldrush) and 69.5°C (Yukon Gold), with a significantly lower T_p for starch obtained from organic potatoes compared to conventional ($p < 0.05$) (**Table 4**). Dry matter peak temperatures showed similar variation, ranging between 69.0°C (Goldrush) and 72.1°C (organic Norland). The peak temperature of gelatinization of starch in the dry matter tended to be higher in the organic samples, similar to the trend seen in the onset temperature.

Conclusion temperature (T_c) of the gelatinization endotherm of isolated starch varied from 79.8°C (organic Goldrush) to 82.8°C (Yukon Gold), with the T_c for starch obtained from organic potatoes significantly lower than that of the conventional tubers ($p < 0.05$) (**Table 4**). T_c for gelatinization of starch in dry matter ranged from 80.0°C (organic Goldrush) to 82.2°C (conventional and organic Norland). There was no apparent trend in gelatinization conclusion temperature between organic and conventional potato dry matter.

Gelatinization enthalpy for isolated starch followed the order: organic Goldrush > organic Norland > Norland > organic Yukon Gold > Goldrush > Yukon Gold (**Table 4**). Enthalpy of starch obtained from organic potatoes was significantly higher than that of conventional ($p < 0.05$). ΔH of starch gelatinization in dry matter followed the order: organic Norland > Goldrush > Yukon Gold > organic Yukon Gold > Norland > organic Goldrush. There was no clear trend in enthalpy between organic and conventional potato dry matter.

Overall, organic starch appeared to gelatinize at a slightly lower temperature than conventional starch, possibly due to the lower apparent amylose content of organic starch. Organic starch exhibited a greater enthalpy of gelatinization, possibly a reflection of a greater double helix con-

Table 4 Differential Scanning Calorimetry (DSC) gelatinization properties of potato starch and dry matter [a].

Variety	Type [b]	Onset temperature T_o (°C)		Peak temperature T_p (°C)		Conclusion temperature T_c (°C)		Enthalpy ΔH (J/g)	
		Starch	Dry matter	Starch	Dry matter	Starch	Dry matter	Starch	Dry matter
Goldrush	C	63.5 ± 1.0	63.6 ± 0.4	68.8 ± 1.1	69.0 ± 0.5	82.5 ± 1.3	81.3 ± 1.0	17.3 ± 1.3	12.9 ± 0.2
	O	61.9 ± 0.1	65.5 ± 0.6	66.6 ± 0.1	70.8 ± 0.1	79.8 ± 0.3	80.0 ± 2.7	20.1 ± 0.1	12.0 ± 1.5
Norland	C	64.5 ± 0.1	66.7 ± 0.0	69.2 ± 0.0	71.8 ± 0.0	81.8 ± 0.1	82.2 ± 0.9	18.6 ± 0.0	12.3 ± 0.2
	O	64.1 ± 0.1	67.4 ± 0.0	68.3 ± 0.2	72.1 ± 0.2	80.2 ± 0.6	82.2 ± 0.5	19.4 ± 0.3	13.6 ± 0.5
Yukon Gold	C	64.5 ± 0.1	65.0 ± 0.0	69.5 ± 0.3	69.8 ± 0.1	82.8 ± 0.0	81.1 ± 0.3	15.5 ± 0.2	12.6 ± 0.2
	O	63.3 ± 0.0	65.6 ± 0.4	68.3 ± 0.1	70.8 ± 0.3	80.5 ± 0.5	81.4 ± 0.5	17.8 ± 0.2	12.4 ± 0.0
p-value, *t*-test (C versus O)			p = 0.175		p = 0.137	p = 0.000		p = 0.028	p = 0.949
p-value, Mann-Whitney		p = 0.045		p = 0.031			p = 0.936		

[a] values represent means ± standard deviation, $n = 2$

[b] type refers to production type: Conventional (C) and Organic (O)

tent and crystalline order in the organic starch (Cooke and Gidley 1992). Dry matter from organic potatoes exhibited a slight increase in onset and peak temperatures than dry matter from conventional potatoes, likely due to higher protein content in organic dry matter, which would compete with starch for water (**Table 1**).

Thermal properties of retrograded starch and dry matter

Gelatinized potato starch and dry matter were stored for 14 days at a temperature of 5°C, to study changes occurring upon retrogradation. Onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy (ΔH) of melting the retrograded structures in starch and dry matter are shown in **Table 5**. Onset temperatures were quite similar for both retrograded starch and dry matter, with an average T_o of 46.1°C and 46.5°C for dry matter and starch, respectively.

Peak temperature for melting the retrograded starch ranged between 64.0°C (organic Norland, organic and conventional Yukon Gold) and 66.3°C (Norland), while T_p for the retrograded dry matter was found at a slightly higher temperature, between 65.8°C (Yukon Gold) and 68.1°C (Norland) (**Table 5**). No clear trend was observed in the peak temperatures of retrograded organic and conventional samples.

Conclusion temperature for melting of the retrograded starch was found between 83.6°C (organic Norland) and 86.0°C (Goldrush), while T_c for the retrograded dry matter ranged from 83.1°C (Yukon Gold and organic Yukon Gold) to 85.4°C (Norland) (**Table 5**). No clear trend was observed in the conclusion temperatures of retrograded organic and conventional samples.

Enthalpy of melting the retrograded isolated starch ranged between 8.1 J/g and 9.3 J/g, for organic Yukon Gold and Yukon Gold starches, respectively (**Table 5**). The retrograded dry matter had a lower melting enthalpy, from 5.8 J/g to 7.0 J/g, reflecting the lower starch content of dry matter, as well as the interference of other components on starch retrogradation. Enthalpy values were significantly lower for the retrograded organic starch and dry matter, the opposite of the trend seen in gelatinization enthalpy of starch. It appears that retrograded starch from conventionally produced potatoes has greater molecular order compared to that from organically produced potatoes, possibly a result of higher (not significantly) apparent amylose content, leading to an increase in enthalpy (Gidley *et al.* 1995). This result provides further evidence for the formation of a more stable retrograded structure in cooked conventional potato starch and dry matter, as seen in the higher RVA final viscosity of these samples.

In vitro starch hydrolysis of raw and cooked starch

Both raw and cooked dried starch were subjected to *in vitro* hydrolysis for 120 min, with aliquots removed at 20 min and 120 min to evaluate the quantity of rapidly digestible starch (RDS) and slowly digestible starch (SDS), respectively. Raw potato starch had low levels of RDS (0.9 to 2.8%), as shown in **Table 6**. Cooked starch, which was obtained from the RVA analysis, showed much higher levels of RDS, ranging from 68.9% to 74.1%. In the cooked starch, granules have already swelled, gelatinized and ruptured, allowing the hydrolytic enzymes quick access to glycosidic bonds, resulting in a rapid rise in glucose. There was no apparent difference between RDS values obtained for raw and cooked organic and conventional starch ($p > 0.05$).

Slowly digestible starch (SDS), or starch that was hydrolyzed to glucose after 20 min and before 120 min, was higher in the raw potato starch (**Table 6**). Values ranged from 12.8% (Norland) to 19.1% (organic Yukon Gold) in the raw starch, compared with 4.0% (Norland) to 5.1% (organic Norland) in the cooked starch. SDS content of raw organic starch was significantly greater than that of raw conventional starch ($p < 0.05$), while no clear pattern was seen in the SDS content of cooked starch.

Resistant starch (RS) levels, as shown in **Table 6**, were much higher in raw potato starch than in cooked. Raw potato starches contained between 80.0% (organic Yukon Gold) and 85.5% (Norland) resistant starch, or starch that was remaining after 120 min of hydrolysis. These values are somewhat higher than that reported by Englyst *et al.* (1992), who found an *in vitro* RS content of 75% in raw potato starch. This discrepancy could be a result of differences in

Table 5 Thermal properties of retrograded potato starch and dry matter [a].

Variety	Type [b]	Onset temperature T_o (°C)		Peak temperature T_p (°C)		Conclusion temperature T_c (°C)		Enthalpy ΔH (J/g)	
		Starch	Dry matter	Starch	Dry matter	Starch	Dry matter	Starch	Dry matter
Goldrush	C	46.5 ± 0.0	46.4 ± 0.1	64.5 ± 1.0	65.9 ± 0.5	86.0 ± 2.5	83.7 ± 1.3	9.2 ± 0.3	6.1 ± 0.4
	O	46.5 ± 0.1	46.3 ± 0.0	64.3 ± 0.7	66.8 ± 0.3	84.7 ± 0.6	83.7 ± 0.7	8.4 ± 0.4	5.8 ± 0.1
Norland	C	46.7 [c]	46.3 ± 0.0	66.3 ± 2.7	68.1 ± 0.7	85.7 ± 0.3	85.4 ± 0.5	8.6 ± 1.2	6.5 ± 0.1
	O	46.3 ± 0.1	46.3 ± 0.0	64.0 ± 0.2	67.9 ± 0.0	83.6 ± 0.8	83.7 ± 0.2	8.2 ± 0.5	5.8 ± 0.0
Yukon Gold	C	46.6 ± 0.1	44.7 ± 0.0	64.0 ± 0.1	65.8 ± 0.3	84.0 ± 0.1	83.1 ± 0.3	9.3 ± 0.1	7.0 ± 0.0
	O	46.4 ± 0.1	46.3 ± 0.0	64.0 ± 0.6	67.0 ± 0.6	85.3 ± 0.2	83.1 ± 0.3	8.1 ± 0.5	5.8 ± 0.3
p-value, *t*-test (C versus O)		p = 0.005			p = 0.297	p = 0.340	p = 0.373		p = 0.010
p-value, Mann-Whitney			p = 0.749	p = 0.471				p = 0.045	

[a] values represent means ± standard deviation, $n = 2$
[b] type refers to production type: Conventional (C) and Organic (O)
[c] one value of T_o obtained for this sample

Table 6 Starch nutritional fractions of raw and cooked potato starch [a].

Variety	Type [b]	RDS [c] (%)		SDS [d] (%)		RS [e] (%)	
		Raw	Cooked	Raw	Cooked	Raw	Cooked
Goldrush	C	1.7 ± 0.3	68.9 ± 0.5	15.0 ± 0.9	4.8 ± 1.1	83.4 ± 0.7	26.3 ± 0.9
	O	2.8 ± 0.7	73.4 ± 1.3	16.0 ± 1.2	4.3 ± 1.6	81.3 ± 1.0	22.4 ± 0.8
Norland	C	1.7 ± 0.1	72.0 ± 1.6	12.8 ± 0.8	4.0 ± 2.1	85.5 ± 0.8	23.9 ± 0.7
	O	2.5 ± 0.6	69.4 ± 1.6	15.9 ± 0.8	5.1 ± 2.1	81.5 ± 0.3	25.4 ± 0.5
Yukon Gold	C	2.2 ± 0.3	73.2 ± 1.8	15.8 ± 0.2	4.8 ± 1.2	82.1 ± 0.4	22.0 ± 1.2
	O	0.9 ± 0.1	74.1 ± 1.6	19.1 ± 0.3	4.7 ± 1.3	80.0 ± 0.4	21.2 ± 0.8
p-value, *t*-test (C versus O)		p = 0.447	p = 0.345	p = 0.001	p = 0.809	p = 0.000	p = 0.192

[a] values represent means ± standard deviation, $n = 2$
[b] type refers to production type: Conventional (C) and Organic (O)
[c] rapidly digestible starch
[d] slowly digestible starch
[e] resistant starch

Table 7 Starch nutritional fractions of raw and cooked potato dry matter [a].

Variety	Type [b]	RDS [c] (%)		SDS [d] (%)		RS [e] (%)	
		Raw	Cooked	Raw	Cooked	Raw	Cooked
Goldrush	C	0.2 ± 0.3	56.4 ± 1.8	17.9 ± 0.3	5.3 ± 2.3	55.5 ± 0.1	12.0 ± 0.8
	O	1.2 ± 0.9	52.5 ± 0.7	19.9 ± 1.4	4.9 ± 1.3	52.2 ± 1.8	15.8 ± 0.8
Norland	C	1.2 ± 0.2	54.2 ± 1.0	15.1 ± 1.0	4.8 ± 1.4	57.3 ± 0.9	14.6 ± 0.4
	O	0.4 ± 0.6	52.0 ± 0.6	14.6 ± 0.7	4.3 ± 1.5	55.3 ± 0.2	14.0 ± 1.4
Yukon Gold	C	1.4 ± 0.2	55.6 ± 0.8	18.4 ± 0.4	4.3 ± 0.8	49.5 ± 0.4	9.3 ± 0.3
	O	1.1 ± 0.3	54.1 ± 0.7	19.1 ± 1.1	5.7 ± 1.1	53.9 ± 1.0	14.3 ± 0.5
p-value, *t*-test (C versus O)		p = 0.864	p = 0.000		p = 0.773		p = 0.002
p-value, Mann-Whitney				p = 0.260		p = 0.237	

[a] values represent means ± standard deviation, $n = 2$
[b] type refers to production type: Conventional (C) and Organic (O)
[c] rapidly digestible starch
[d] slowly digestible starch
[e] resistant starch

potato varieties, and enzyme source and activity. The low digestibility of raw potato starch granules has been attributed to their large granule size, B-type crystalline structure, and the presence of phosphate esters (Noda *et al.* 2008). Cooked starches contained 21.2% (organic Yukon Gold) to 26.3% (Goldrush) resistant starch. RS values were significantly greater in the raw conventional starch compared to the raw organic starch ($p < 0.05$); however, no trend was seen in the RS content of cooked starches ($p > 0.05$).

In vitro starch hydrolysis in raw and cooked potato dry matter

Both raw and cooked (dried) dry matter were subjected to *in vitro* hydrolysis for 120 min, with aliquots removed at 20 min and 120 min to evaluate the quantity of rapidly digestible starch (RDS) and slowly digestible starch (SDS), respectively. Generally, RDS content was low in the raw potato dry matter (0.2-1.4%) and much higher in the cooked dry matter (52.0-56.4%) (**Table 7**). RDS content was significantly higher in the cooked conventional dry matter compared to cooked organic dry matter ($p < 0.05$).

Slowly digestible starch content of the raw potato dry matter (14.6-19.9%) (**Table 7**) was similar to that of the raw potato starch (**Table 6**). As seen in the starch, SDS values tended to be higher in the raw organic dry matter compared to the raw conventional dry matter, yet no clear pattern was observed in the cooked dry matter. SDS content of the cooked potato dry matter (4.3-5.7%) was similar to that of the cooked potato starch (4.0-5.1%, **Table 6**).

Resistant starch content of raw potato dry matter was much higher than that of cooked dry matter, as presented in **Table 7**. Raw dry matter had resistant starch contents of 49.5% (Yukon Gold) up to 57.3% (Norland), while RS content of cooked dry matter ranged from 9.3% (Yukon Gold) to 15.8% (organic Goldrush). No apparent differences were seen in RS content of raw potato dry matter. However, RS content of cooked potato dry matter from organic potatoes was significantly higher than that of cooked conventional dry matter ($p < 0.05$), indicating the potential for reduced starch digestibility, which could have a positive impact on human health.

CONCLUSIONS

Potato production method influences the chemical composition of potato starch and dry matter, pasting and thermal properties, and digestibility, which could directly affect cooking quality, sensory attributes and nutritional quality of potato products. Phosphorus content of starch isolated from organic potatoes was significantly lower than that found in starch from conventionally grown potatoes, while free glucose levels were significantly higher in dry matter obtained from conventionally grown tubers. Total protein content of potato dry matter was significantly higher in organically grown potatoes. RVA peak viscosity was higher for starch and dry matter from conventionally grown potatoes, likely a reflection of the higher phosphorus content of the starch. Some thermal properties were significantly different for conventional and organic samples, indicating possible differences in starch molecular order. Slowly digestible starch (SDS) content of raw organic starch was significantly higher than conventional, while RS content was significantly lower than conventional. Rapidly digestible starch (RDS) content was significantly higher in cooked dry matter from conventional potatoes, while RS content was significantly higher in cooked dry matter from organic potatoes.

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