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Morphological, Nutritive Composition, Thermal, In Vitro Digestibility and Crystallinity Properties of Starch Extracted From Potato Tubers Stored For a Short Term

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Abstract

This study aimed to examine the physicochemical properties of potato starch and determine the effect of short term potato storage which ranged from 2 to 10 months on the potato starch. The research results showed the ash content, swelling factor, and peak viscosity decreased with the tuber storage duration, while the other properties such as granule morphology, amylose, protein, resistant starch (RS), etc. remained the same. Ash content reduced about 19.5 – 40.5 % during storage. This was believed to be the reasons why the swelling factor and peak viscosity decreased. After up to 10 months storage, starch granules still exhibited smooth and intact surface. It contained 22 – 26 % amylose and 0.47 – 0.58 % protein. The gelatinization occurred at around 60 °C. The relative crystallinity was23 – 30%. In vitro digestibility tests showed 65 – 80% RS, indicating one of the highest RS level in the starch available in the market.

Keywords: potato storage; starch; pasting, in vitro digestibility; swelling factor

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Introduction

In addition to French fries and chips, starch is one main product of potatoes, which ranges from 66% to 80% in tubers on a dry weight basis, varying with cultivar and plant growth stage [1]. Potato starch is unique compared to cereal starches (corn, wheat, rice, etc.), because of larger granule size (5 - 100 μm), longer amylose and amylopectin chain length, presence of phosphate ester groups on amylopectin, ability to exchange certain cations with corresponding effects on viscosity behavior, ability to form a thick visco-elastic gel upon heating and subsequent cooling in water, and poor thermal and shear stability of the gel [2]. Because of these typical properties, potato starch are typically used as thickeners and stabilizers in foods such as puddings, custards, soups, sauces, gravies, pie fillings, and salad dressings, and to make noodles and pastas. The most advantage of the potato starch is it is an enzyme-resistant starch (RS) which is not hydrolyzed to D-glucose in the small intestine within 120 min of being consumed, but which is fermented in the colon. RS has received more and more attention due to its great physiological benefits to human health, such as increased laxation, reduced risk of getting digestive tract cancers, lowering postprandial glucose response, and lowering blood lipid levels, prevention of gall stone formation, etc. Due to its ability to increase fat oxidation and reduce fat storage in adipocytes, RS has recently been promoted in the popular press as a "weight loss wonder food" and can be applied clinically [3].Studies have shown that a minimum intake of RS (5 - 6 gram/day) appears to be needed in order for beneficial reductions in insulin response to be observed.

After being harvested, potato tubers are stored and consumed all year around. During storage, potato tubers utilize their own stored resources for metabolic processes [4], leading to degradation of starch molecules. Starch degrades via phosphorolytic and hydrolytic reactions into glucose, fructose and sucrose. Storage conditions, such as temperature, relative humidity, atmospheric conditions, light and ventilation, impact various biological processes in the tubers such as respiration, transpiration, cold induced sweetening and incidence of pests and diseases [4, 5]. Light was reported to increase the content of chlorophyll, chlorogenic acid, glycoalkaloids and other substances in the tubers that may have positive effects on resistance against pathogens [6, 7, 8]. Low temperature at 3 - 4 °C induce sweetening and result in high concentrations of the reducing sugars, i.e. glucose and fructose [9], which cause an undesirable dark brown color in the processed potato products. In addition, stresses of relative humidity and CO2concentration can also result in reducing sugar accumulation during the storage.

The storage of potato is essential to meet the market requirement in starch industry. Research has been extensively conducted on quality control of potato tubers during storage, but there is a lack of available results on the effect of storage duration on potato starch quality. This

study was to (1) evaluate the physicochemical properties of the starch from the dominant potato variety, Russet Burbank, which was grown in the Prairie Procinces, Canada, and (2) determine the effect of short term potato storage on the physicochemical characteristics of the starch.

Materials and Methods

Materials

Twelve samples of potato starch were provided by Manitoba Starch Products Inc., Carberry, Manitoba, Canada. The starches were produced by wet extraction from potatoes of Russet Burbank grown in years 2008 – 2011 in Carberry, Manitoba, Canada (latitude 49°52' North and longitude 99°21' West). The potatoes were harvested in August & September and were stored at about 7 °C for 2, 5, 10 months respectively prior to the starch extraction. All the starch samples came dried, sealed in plastic bags and were stored at room temperature until the tests were conducted.

Granule morphology and shape observation

Granule morphology of the starch granule was examined by scanning electron microscopy (SEM). The starch powder was sprinkled on double-sided adhesive tapes mounted on aluminum stubs, and coated with gold using a Balzers SCD 030 sputter coater (BAL-TEC RMC, Tucson, AZ). Images were obtained using a JEOL JSM-6300 Scanning Electron Microscope (JEOL USA, Peabody, MA) while using an accelerating voltage of 15 keV.

Amylose, protein and ash analysis

Iodine colorimetric method was used to measure the amylose content. 20 mg starch sample was weighed and dissolved with 10 ml 0.5N KOH solution. The solution was brought into 100 ml volumetric flask and diluted to the mark with distilled water. Then 10 ml of the solution was pipetted into a 50 ml volumetric flask. 5 ml of 0.1N HCl and 0.5 ml of iodine reagent was added. Then the volume of the starch solution was brought into 50 ml. The absorbance of the blue color was measured at 625 nm after 5 min. Amylose content was calculated by a standard curve plotted for a mixture of amylose and amylopectin from potato. Amylose data was obtained from two replicates. Protein was conducted using TruSpec Nitrogen Determinator (Model: 630-100-200, Leco Corporation, USA) for each starch sample. 150 – 200 mg sample was weighed into a tin foil cup and loaded into a carousel (autoloader) and dropped into a primary furnace where it combusted at 950 °C. The products of combustion were then passed through a secondary furnace at 850 °C for further oxidation. The combustion gases were collected in a ballast tank and then flowed to the detector. N2 was determined by thermal conductivity detection. The protein content was calculated by using the equation of N x 6.25. Protein measurements were performed in duplicate samples. Ash analysis was conducted following the [10] with minor modifications. 2 grams sample was weighed into a previously heated and tared crucible cup and pre-ashed above a gas flame in a fume hood. After that, the crucibles were put into a muffle furnace. The temperature of the muffle furnace was brought up to 550 °C for 6-8 hours. The crucible cups were then put into a desiccator, cooled down to the room temperature and weighed. The ash content was calculated by the equation 1. Three replicates measurements were performed for each sample.

$$Ash\ (\%) = Ash\ (g)/Sample\ (g) \times 100\% \quad (1)$$

Gelatinization characteristics

Thermal properties of the starch samples were determined with a Differential Scanning Calorimeter (DSC, TA Instruments, TzeroTM). 2.5 – 3.5 mg sample was weighed into the sample pans (TzeroTM). Moisture content was adjusted to 70% by adding distilled water. The pans were hermetically sealed, equilibrated at room temperature for 2 h and heated from 30 °C to 90 °C at a heating rate of 10°C/min. The gelatinization onset temperature (TO), peak temperature (TP), gelatinization temperature at conclusion (TC) and enthalpy change (ΔH) were recorded. Each test was performed in triplicate samples.

Swelling factor

Swelling factor (SF) measurement followed the direct method of Tester & Morriosn (1990) with minor modifications. 100 –150mg starch was weighed into a 10 ml screw-cap test tube. 5ml distilled water was added. The capped tubes were inverted several times to mix the contents, and then placed into a water bath to incubate for 40min with frequent mixing by inverting. The temperatures of the water bath were set up at 50, 60, 70, 80, and 95 °C, respectively. The tubes were then cooled in a water bath at 20 °C for 5min. 0.5ml of 1mg/ml blue dextran (Pharmacia, Mr 2×106) solution was added. The content was mixed by gently inverting several times, and then centrifuged at 1500g for 10min. The supernatant was removed with gentle suction. The absorbance of the supernatant (As) and reference (Ar) which contained no starch were measured at 620 nm. The starch was assumed to contain 12 % moisture and the density was 1.4g/ml at room conditions. The calculation of SF was carried out by the following equation 2.

$$SF = 1 + 7700 \times (1 - {}^{A_r}/_{A_s})/W \quad (2)$$

Where W is the weight of the starch samples. The experiment to estimate the swelling power was conducted in duplicate samples.

X-ray diffraction and crystallinity

The starch samples were analyzed with an X-ray diffractometer (Siemens D5000, Germany) between 2θ = 4° and 2θ = 30° with a step size 2θ = 0.02° and a scan speed of 1 sec/step. X-ray from Cu-Kα radiation (λ = 0.15410 nm) was used at 40 kV and 40 mA. The starch sample was packed into a quartz cell. The diffractometer was equipped with 1° divergence slit and a 0.1 mm receiving slit. The overall degree of crystallinity was quantified as the ratio of the area of crystalline reflections to the overall diffraction area. X-ray diffraction processing software of Jade 7.0 Material Data (Material Data Inc., Livermore, Calif., U.S.A.) was used to do the analysis. Each sample was tested in duplicate.

In vitro starch digestibility

In vitro starch digestibility of the potato starch was determined by using approved [11] with assay kit (Megazyme International Ireland Ltd., Bray, Ireland). 100 mg starch was incubated with pancreatic α-amylase (120 Ceralpha Units) and amyloglucosidase (12 U) in 4 mL of 0.1M sodium maleate buffer (pH 6.0) at 37°C with continuous shaking (200 strokes/min) for 16 hr. After incubation, ethanol (95%) was added to inactivate the enzyme and the sample was centrifuged at 1,500 g for 10 min to separate resistant starch and non-resistant starch. Glucose content of the supernatant was measured by a glucose oxidase-peroxidase reagent. Two replicate measurements were conducted for each sample.

Rapid viscosity analysis

The pasting property of the starch was obtained from RVA with 2.5 grams starch dispersed in 25 ml of distilled water. A heating and cooling cycle was programmed in the following manner. The sample was heated from 50°C to 95 °C for 3 min, held at 95 °C for 2 min and cooled to 50 °C within 3 min. Peak viscosity was recorded.

Starch flow ability analysis

Critical orifice diameter (COD) and angle of repose (θ) tests were performed using a Flodex Powder Flow ability Tester (Hanson Research Corporation, Northridge, CA). COD was measured based on the ability of a starch powder to fall freely through an orifice of known diameter in a plate. 50 grams of starch powder was poured into the flat-based cylindrical hopper fitted with one of a series of plates having orifices in the diameter range 4 – 34mm. 1 min was allowed to wait for the powder to settle down. Then the orifice surface shutter at the base of the hopper was opened. The powder was allowed to flow down. The COD was defined as the hole diameter through which the starch did not flow, i. e. the largest diameter of the hole, where an arch was formed. The angle of repose (θ) was determined by measuring the cone height vs the base formed by pouring 50 grams of starch powder falling through a stainless steel funnel placed from a height of 5 cm from the table surface until a stable cone was produced. The angle of repose (θ) was established using the equation 3. Each θtest was performed in triplicate.

$$Tan\theta = (2 \times Height)/Base\ Diameter \quad (3)$$

Statistical analysis

The experimental design was a completely randomized design with two or three replications. Mean values with standard deviations were compared using the Turkey's multiple comparison test using SAS (SAS Inst., Inc., Cary, N.C., U.S.A.) at a 5% significance level with a null hypothesis of H0: μ1 = μ2 = … = μn; and H0: μ1 = μ2 = ... = μm, where μ is a mean of each property, n is potato storage duration (0, 2, 5, and 10 months), and m is harvest year (2008, 2009, 2010, and 2011).

Results and Discussion

Granule morphology and shape observation

Both starch granuale morphology and size are important factors for starch properties. [12] reported that the morphology of the starch granules influence starch functionality, such as in vitro digestibility, since the enzyme hydrolysis takes place first on the surface of starch granules, while the granule size influences starch properties such as ash content, amylose content, phosphorus content, gel firmness, and freeze-thaw stability, etc., which further affect the processibility and the qualities of the starch-based food products.[13] indicated that both dried and cooked starch noodles made from small-size granule fractions were significantly better than those made from their initial starch preparations and much better than those made from the large-size granule fractions. The scanning electron micrographs of starches are presented in **Figure .1** with 2009 (10-month) and 2011 (2-month) being selected as representatives. Figure.1 shows that both starches exist in the form of granules, which are spherical to oval in shape with a smooth surface. The size of the starch granule ranges from 10 to 70 μm. The morphology is similar to one another. No obvious differences are observed. The storage duration does not seem to affect the starch granules.

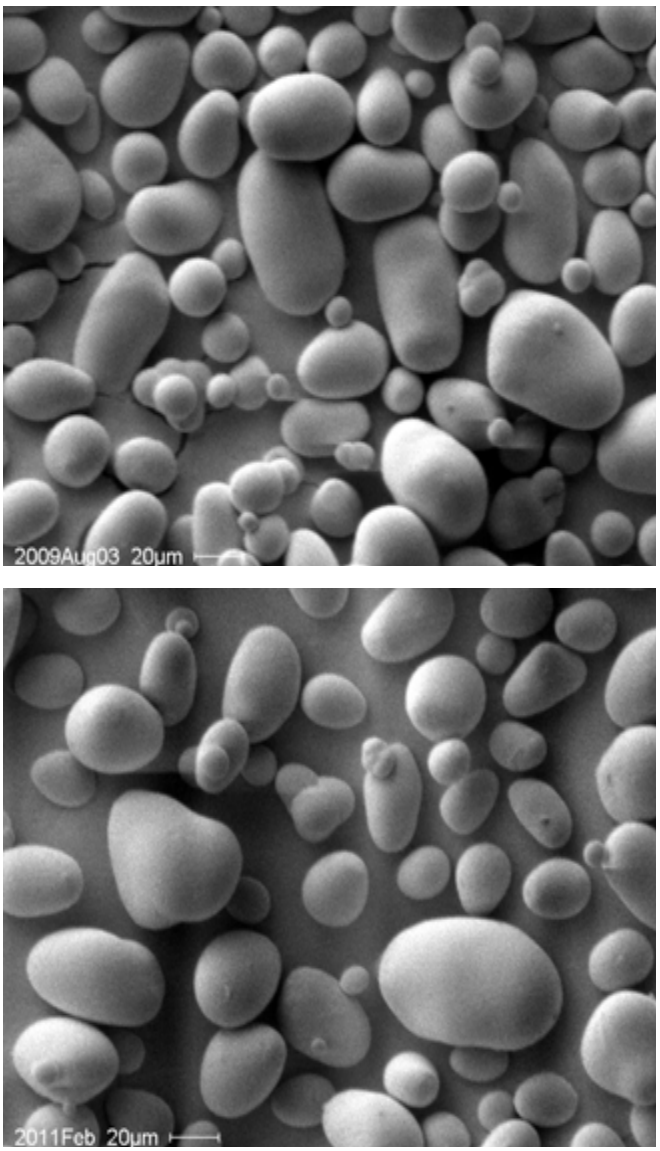

Figure.1Scanning electron micrographs of potato starch granules (Samples of 2009 10-monthand 2011 2-month being representatives)

Amylose, protein and ash analysis

Figure.2A shows amylose, protein and ash content in the starch samples. The results indicate the amylose content of the potato starch ranges from 22 – 26% (amylose/starch, w/w), with neither of harvest year nor storage duration affecting the amylose content. Potato starches produced in other places in Canada, such as New Brunswick and Alberta were reported to contain 30 – 39% amylose [12, 14] which is higher than present results. [5] indicated that the starch of potatoes grown in India contains amylose in the range of 13.4 – 27.6 %, showing an obvious variation. They attributed this difference to potato genotype, environmental condition, and cultural practice, etc. Amylose content was reported to have positive correlation with starch properties, such as gumminess, chewiness, and % granules of 60 - 80 μm size, etc. [15]. Amylose content was also reported to have positive relationship with resistant starch (Shi & Gao, 2011), because amylose molecules combined easily to form solid crystal structure, so high amylose were conducive to formation of resistant starch.

Figure.2B indicates the protein content of the potato starch is in a range of 0.47 – 0.58% (w/w) which is higher than the reports by [16, 17] who respectively reported that potato starch contained 0.3% and 0.07-0.09% (dry base) protein. ANOVA shows the production year and tuber storage duration did not affect the protein content.

Ash content of the potato starch samples is shown in Fig.2C. The results indicates the ash content of the potato starch is in a range of 0.24 – 0.44% (w/w) which is higher than those reported by [2], who reported that potato starch contained 0.18% ash. Ash content demonstrated a decrease with the potato storage duration. For example, the starch of 2008 reduced ash content from 0.41 to 0.33% with the potato storage increasing from 2 to 10 months. The reduction accounted for 19.5 %. The reductions also occurred in the starches of 2009 and 2010, which were respectively 34.2 % and 40.5 %. Potato tubers consumed inorganic materials during the storage duration, leading to the reduction of ash content. Interestly, the ash decrease only happened when the potato tubers were stored for up to 10 months. No significant ash changes were observed when the potatoes were stored for 5 months.

Gelatinization characteristics

DSC graph of the potato starch is presented in **Figure 3** with 2008 (10-month) being a representative, which indicates the starch started gelatinization at 58.93 °C and ended at 75.49 °C. The process absorbed 15.94 J/g energy. The gelatiniation peak temperatures (Tp) are exhibited in Fig.4A. ANOVA indicates the TP of 2008 harvest year increased from 65.6 °C up to 67.5 °C ($P \leq 0.05$) with the storage duration increasing, while the TP of 2009 harvest year decreased from 67.4 °C down to 65.9 °C ($P \leq 0.05$). Meanwhile, the TP of 2010 and 2011 harvest years did not significantly changed ($P \leq 0.05$). The reason is unclear. [18] Conducted a potato storage experiment and observed that the TP shifted to lower temperature after one month storage and then the shifting became negligible when the potato was stored for more than two months.

Figure 4B shows the gelatinization enthalpy, indicating no significant changes were observed ($P > 0.05$). Several factors were reported to affect the starch phase transition characteristics. [19] attributed the differences in the phase transition characteristics to the starch granule crystalline structure. They observed that starches with higher crystallinity have higher gelatinization enthalpy. [20] revealed that starches with long branch amylopectin has higher gelatinization enthalpy. Based on these discussions, it can be deduced that the potato starch of present studies contains the same crystalline region and branch chains. Further tests are needed to confirm the conclusions.

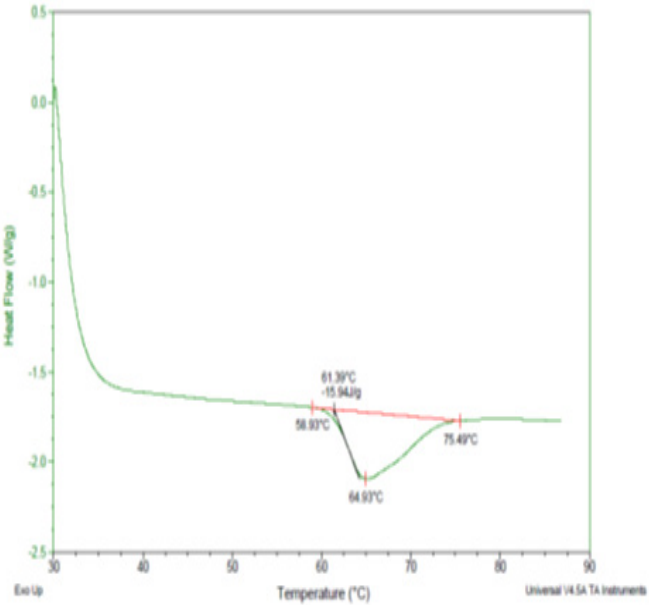

Figure.2 DSC graph of potato starch (sample of 2008 10-month)

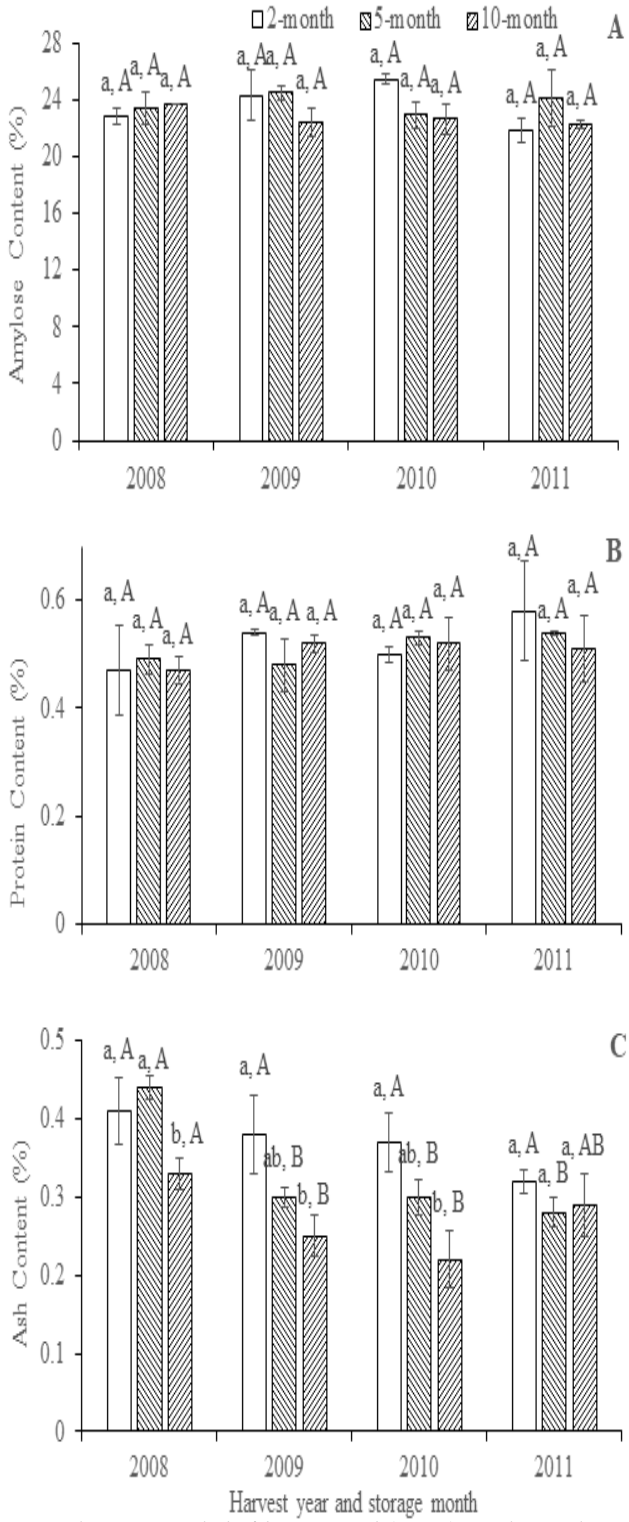

Figure. 3 Amylose, protein, and ash of the potato starch (%, w/w). Same letters indicate the same group at 5% significance. *a* and *b* are for the comparison of within year, and *A* and *B* is for between year.

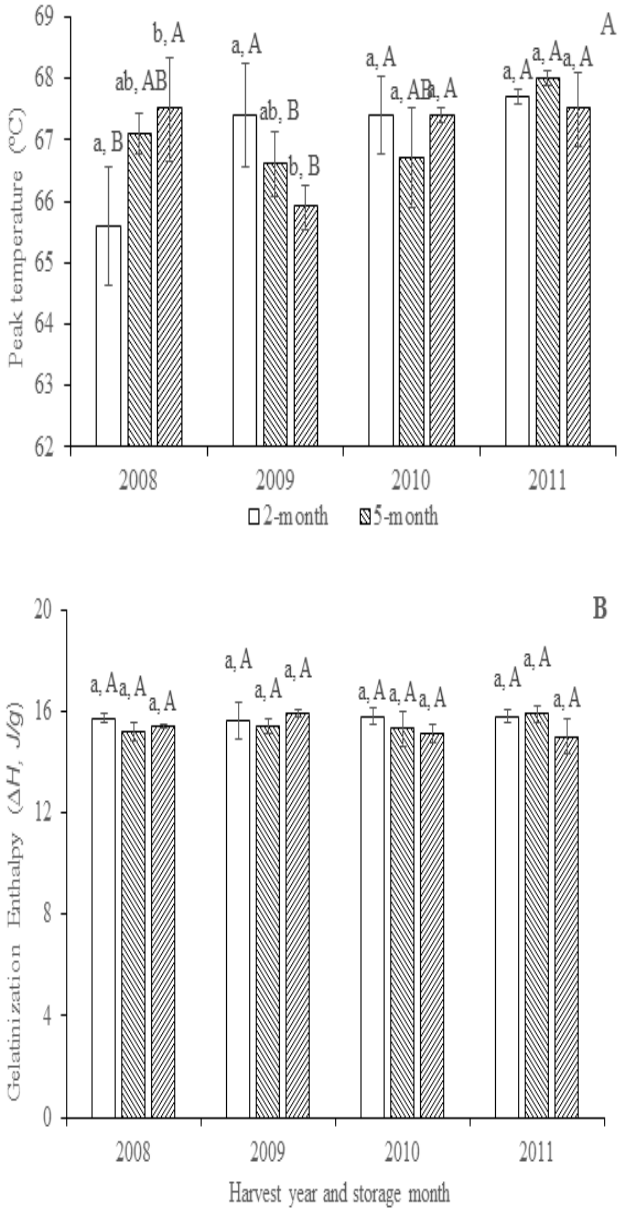

Figure. 4 Gelatinization peak temperature (Tp, °C) and gelatinization enthalpy (ΔH, J/g). Same letters indicate the same group at 5% significance. a and b are for the comparison of within year, and A and B is for between year.

Swelling factor

Swelling factor (SF) reflects ability of starch to hydrate under specific cooking temperature [21]. The SF results are summarized in **Table 1. Figure.5** shows effect of storage duration on potato starch SF, with 2008 sample being a representative. SF of the starches rapidly increased from around3.0 to greater than 70.0 when the cooking temperature enhanced from 50 to 95 °C, indicating the temperature substantially improved the starch hydration capacity. When temperature was increased from 50 up to 95 °C, the starch granules underwent gelatinization, during which amylose and amylopectin were leached into the water, leading to more hydrogen bondings were established between the water molecules and starch molecules. **Table 1** also shows the SF decreased with the potato storage duration increasing. In order to clearly demonstrate this trend, **Figure 5** is built up and exhibits, at 60 °C, the starch SF decrases from 24.4 down to 18.1 with the storage duration increasing from 2-month to 10-month, accounting for a reduction of 25.8 %. This phenomena happened in other starch smples. Amylopectin is reported to be in favor of swelling, while amylose is considered as an inhibitor of starch swelling [22]. However, Figure 3A does not show significant changes on amylose content during the storage. [23] considered SF cannot be expressed as a simple function of amylopectin or amylose content. It could also be attributed to the variation of minor components, such as the phosphorus content and the fine structure of starches. Negatively charged phosphate ester groups weaken the internal structure of the granules, and the crystallinity of the starch regulates the swelling. Anyway, comparing with other starch, such as rice starch which has SF of around 40 at 95 °C [24], Table 1 reflects potato starch has greater hydration and swelling ability during heating.

X-ray diffraction and crystallinity

The X-ray diffraction pattern of the starch indicates the potato starch displays B-type crystalline pattern, which is not shown up here. The relative crystallinity of samples calculated from X-ray diffraction pattern is summarized in **Table 2**, indicating the sample contains 23 – 30% crystalline lattice. The crystallinity of the starch remains almost consistent regardless of storage duration and harvest year. Amylopectin is generally considered to be responsible for the starch crystallinity. Figure.1 A does not show significant change in amylose or amylopectin content, which may explain why the crystallinity keeps consistant during the storage duration. [25] suggested the relative crystallinity was inversely correlated to the proportion of short chains (DP 10-13) in amylopectin. The crystallinity reduced with an increase in the proportion of DP 10-13. However, [24] announced a positive correlation between the crystallinity and the short chains in amylopectin. Current results are comparable with the reported data of about 30% for normal and waxy potato starches [26], but less crystalline than rice and corn, which respectively contain 30 – 34 % [24] and 33 – 42% [26].

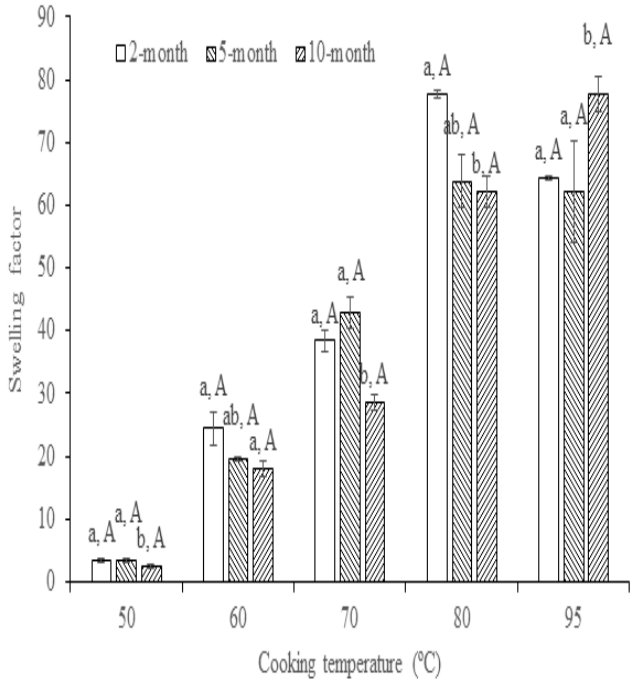

Fig. 5 Effect of storage duration on potato starch swelling factor (2008). Same letters indicate the same group at 5% significance. a and b are for the comparison of within year, and A and B is for between year.

Storage Duration	2008	2009	2010	2011
At 50 °C				
2-month	3.5±0.32^{aA}	3.0±0.21^{aA}	3.6±0.40^{aA}	3.4±0.90^{aA}
5-month	3.3±0.30^{aA}	3.3±0.93^{aA}	2.6±0.04$^{b\ A}$	1.8±0.04^{bB}
10-month	2.6±0.32$^{b\ A}$	2.1±0.56$^{b\ A}$	2.7±0.06$^{b\ A}$	2.90±0.01^{aA}
At 60 °C				
2-month	24.4±2.68^{aA}	18.9±1.21^{aA}	21.2±2.84^{aA}	14.3±0.89$^{a\ B}$
5-month	19.5±0.34$^{ab\ A}$	19.4±3.0^{aA}	15.6±1.57^{bB}	15.3±1.42$^{a\ B}$
10-month	18.1±1.20^{aA}	19.7±3.03^{aA}	18.8±0.63$^{ab\ A}$	13.3±0.45$^{a\ B}$
At 70 °C				
2-month	38.4±1.77^{aA}	37.3±0.89^{aA}	33.4±0.99$^{a\ AB}$	27.9±1.03$^{a\ B}$
5-month	42.9±2.44^{aA}	42.9±1.71^{aA}	33.2±0.72$^{a\ B}$	31.4±1.67$^{a\ B}$
10-month	28.6±1.13$^{b\ A}$	31.7±0.77$^{b\ A}$	33.5±0.84^{aA}	28.9±1.73^{aA}
At 80 °C				
2-month	77.6±0.66^{aA}	61.6±2.47^{aA}	73.1±2.15^{aA}	48.5±5.08$^{a\ B}$
5-month	63.8±4.16$^{ab\ A}$	67.3±0.59$^{a\ A}$	74.5±2.93^{aA}	56.8±1.17$^{b\ B}$
10-month	62.2±2.57$^{b\ A}$	72.8±0.07$^{a\ B}$	67.9±4.33^{aA}	43.8±0.64$^{a\ C}$
At 95 °C				
2-month	64.3±0.26^{aA}	76.1±1.16^{aA}	73.5±1.48^{aA}	81.8±0.63$^{a\ B}$
5-month	62.2±8.11^{aA}	75.1±6.66$^{a\ A}$	71.8±1.07^{aA}	74.5±2.33$^{a\ A}$
10-month	77.6±2.81$^{b\ A}$	72.9±7.55^{aA}	72.6±5.54^{aA}	72.6±0.45$^{a\ A}$

Table 1: Swelling factors of starches at specific temperatures*
*Values are means ± standard deviation (n = 2).Same letters indicate the same group at 5% significance. a and bare for the comparison of within columns, and A and B are for between columns.

Storage Duration	2008	2009	2010	2011
At 50 °C				
2-month	3.5±0.32^{aA}	3.0±0.21^{aA}	3.6±0.40^{aA}	3.4±0.90^{aA}
5-month	3.3±0.30^{aA}	3.3±0.93^{aA}	2.6±0.04$^{b\ A}$	1.8±0.04^{bB}
10-month	2.6±0.32$^{b\ A}$	2.1±0.56$^{b\ A}$	2.7±0.06$^{b\ A}$	2.90±0.01^{aA}
At 60 °C				
2-month	24.4±2.68^{aA}	18.9±1.21^{aA}	21.2±2.84^{aA}	14.3±0.89$^{a\ B}$
5-month	19.5±0.34$^{ab\ A}$	19.4±3.0^{aA}	15.6±1.57^{bB}	15.3±1.42$^{a\ B}$
10-month	18.1±1.20^{aA}	19.7±3.03^{aA}	18.8±0.63$^{ab\ A}$	13.3±0.45$^{a\ B}$
At 70 °C				
2-month	38.4±1.77^{aA}	37.3±0.89^{aA}	33.4±0.99$^{a\ AB}$	27.9±1.03$^{a\ B}$
5-month	42.9±2.44^{aA}	42.9±1.71^{aA}	33.2±0.72$^{a\ B}$	31.4±1.67$^{a\ B}$
10-month	28.6±1.13$^{b\ A}$	31.7±0.77$^{b\ A}$	33.5±0.84^{aA}	28.9±1.73^{aA}
At 80 °C				
2-month	77.6±0.66^{aA}	61.6±2.47^{aA}	73.1±2.15^{aA}	48.5±5.08$^{a\ B}$
5-month	63.8±4.16$^{ab\ A}$	67.3±0.59$^{a\ A}$	74.5±2.93^{aA}	56.8±1.17$^{b\ B}$
10-month	62.2±2.57$^{b\ A}$	72.8±0.07$^{a\ B}$	67.9±4.33^{aA}	43.8±0.64$^{a\ C}$
At 95 °C				
2-month	64.3±0.26^{aA}	76.1±1.16^{aA}	73.5±1.48^{aA}	81.8±0.63$^{a\ B}$
5-month	62.2±8.11^{aA}	75.1±6.66$^{a\ A}$	71.8±1.07^{aA}	74.5±2.33$^{a\ A}$
10-month	77.6±2.81$^{b\ A}$	72.9±7.55^{aA}	72.6±5.54^{aA}	72.6±0.45$^{a\ A}$

Table 2: Crystallinity (%), Resistant starch content (%, db), Peak viscosity (cP), Critical orifice diameter (COD) and Angle of repose (θ, degree) of the potato starch samples (%)*

* Values are means ± standard deviation. Same letters indicate the same group at 5% significance. a and b are for the comparison of within columns, and A and Bare for between columns.

In vitro digestibility

Table 2 shows that RS content of the starch samples is in the range of 65 – 80% (db), which is slightly higher than the values reported by [27] and [28], who indicated that the potato starches from New Brunswick and Alberta, Canada, contains 67 – 73% and 66 – 72 % RS, respectively. Generally speaking, starch granules containing higher amylose show higher RS content. However, as mentioned above, present potato starch contains 22 – 26 % amylose, less than those of [27] and [28], indicating that there must be some additional factors affecting the RS. Table 2 also shows the RS content of 2008 decreased from 75.9 % to 66.5 % with the storage duration from 2 – 10 months. However, RS of other years did not significantly change.

Pasting properties

Pasting properties of the starch samples are demonstrared in Table 2. The peak viscosities are observed in the range of 5748 – 8664 cP, which is higher than most starch products available in the market.[2] selected six varieties of potatoes which grown in Alberta, Canada, and conducted potato starch pasting testing. They reported peak viscosity was in the range of 1786 - 3069 cP. [28] selected thirteen potato varieties, which were grown in New Brunswick and Alberta, Canada, to conduct the pasting testing. They announced most of the peak viscosity was in the range of 7000 - 8000 cP with a few being less than 6000 cP. Present data is close to Lu's results. Table 2 also shows the peak viscosity had a decrease trend with the storage duration increasing from 2 to 10 months. Phosphorus content in the starch is believed to have impact on the peak viscosity. Higher phosphorus will result in higher viscosity [28]. Figure.1C indicates the ash content, including phosphorus, decreased with increasing of the storage duration. This may be explain why the peak viscosity decreased with increasing of the storage duration.

Starch flowability analysis

According to USP 30-NF 25, for repose angles (θ) between 25 – 30° powder flow is excellent, among 31 – 35° the flow is good and within the range of 36 – 40° the flow is fair. Data shown in Table 2 indicates that the starch powders had angle of repose (θ) < 20 degree, demonstrating excellent flowability. However, we found the starch powders did not flow excellently. Instead, the starch powders were sticky and cohered into lumps. Tomas & Kleinschmidt (2009) pointed out when particle sizes are less than 100 μm, inter-particle adhesion forces, including van der Waals forces, exceed the gravitational forces by several orders of magnitude resulting in poor flowability. Our previous study shows that90% (volume) of the present starch granules were smaller than 69 μm in diameter. The poor flowing behaviour of the starch samples is consistent to Tomas & Kleinschmidt's theory (2009).[29]announced the angles of repose were higher for starches with higher moisture content. For maize starch, the angle of repose increased from 52° to 56°, for wheat starch from 42° to 56°, and from 38° to 58° for potato starch.COD was also reported in Table 2. In fact, COD is not a measure of powder flowability, but of the ability of a powder to form an arch. It is helpful when working the starch with a capsule dosator nozzle system. The size of the diameter of the dosator nozzles should be of the COD, or even smaller, so that the powder forms an arch inside the nozzle preventing the powder from running out during plug transfer to the capsule body [30]. Table 2 shows the COD of the potato starch ranged from 14 – 20 mm.

Conclusions

In conclusion, the ash content, swell factor, and peak viscosity decreased with the storage duration. Inorganic materials were consumed during the potato tuber storage, leading to the decrease of ash content. Phosphorus belongs to inorganic materials and is significantly correlated with pasting properties. Therefore, the decrease of ash consequently resulted in decreases of peak viscosity. Present studies exhibited that the potato starch produced in Manitoba, Canada, contains less amylose, but higher crystallinity than others produced in New Brunswick and Alberta, Canada. Even after a 10-month storage, in vitro digestibility indicated that potato starch still is a good resistant starch source. Swelling factor studies showed the potato starch has greater swelling power than starches of other crops such as rice and wheat, indicating good functionality for the food industry.

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