Title: Properties of starch from potatoes differing in glycemic index

Authors: Kai Lin Ek[a], Shujun Wang[b], Jennie Brand-Miller[c] and Les Copeland[a*]

Affiliations:

[a]Department of Plant and Food Science, Faculty of Agriculture and Environment, The University of Sydney, Australia.

[b]Key Lab of Food Nutrition and Safety, Department of Education of China, School of Food Engineering and Biotechnology, Tianjin University of Science & Technology.

[c]Boden Institute of Obesity, Nutrition and Exercise, and the School of Molecular Bioscience, The University of Sydney, Australia.

* Corresponding Author

Les Copeland

The University of Sydney, NSW 2006 Australia

E-mail address: les.copeland@sydney.edu.au

Tel.: + 61 2 8627 1017; fax: + 61 2 8627 1099.

Abstract:

Potatoes are a popular source of dietary carbohydrate worldwide and are generally considered to be a high glycemic index (GI) food. Potato starch characteristics play a key role in determining their rate of digestion and resulting glycemic response. Starches isolated from seven potato cultivars with different GI values, including a low GI cultivar (Carisma), were examined for relative crystallinity, granule size distribution, amylopectin chain length, and thermal and pasting properties. Starch from the Carisma cultivar was more thermally stable and more resistant to gelatinization, with significantly higher ($p<0.05$) pasting temperature and differential scanning calorimetry (DSC) gelatinization onset, peak and conclusion temperatures, compared to the other cultivars. Differences between the potatoes in the other properties measured did not align with the GI ranking. Thermal analysis and starch pasting properties may be useful indicators for preliminary identification of potato cultivars that are digested slowly and have a lower GI.

Keywords: Glycemic index, potato, *Solanum tuberosum* L., starch, thermal properties, pasting properties

1. Introduction

Potatoes are the most important non-grain food commodity produced globally, with production in 2012 reaching 368 million tonnes[1]. They are a major source of carbohydrate in the Western world and consumption is increasing rapidly in developing countries. Annual global consumption is more than 200 million tonnes, with an estimated 74 kg consumed *per capita* in Europe, 53 kg in Australia and 26 kg in Asia[2]. Carbohydrates are the principal energy source in the human diet accounting for 40-80% of energy intake[3].

The terminology and classification of carbohydrates for translation into nutritional characteristics is complex. The FAO/WHO scientific update on carbohydrates in human nutrition suggested the glycemic index (GI) as one of the ways to guide food choices when considering similar carbohydrate-containing foods[4]. The GI is a system of classifying carbohydrate-rich foods based on their blood glucose-raising potential[5]. The carbohydrate in a high GI food is digested and absorbed rapidly and results in high postprandial blood glucose and insulin levels, which over the long term are associated with increased risks of diet-related diseases including type-2 diabetes and cardiovascular disease[6-9]. According to the International Standards Organisation (ISO) Standard[10], foods that have a GI of greater than 70 are classified as high GI, foods with a GI that fall in the range of 56-69 are classified as medium GI, and foods that have a GI of 55 or less are classified as low GI[10].

Potatoes are generally considered a high GI food[11] and some nutritionists have advised substitution with a low GI option[9, 12]. This advice may not apply to all potatoes, as there is considerable natural variability between cultivars in the GI values of potatoes that have been prepared for consumption by similar methods[13, 14].

Starch is the main carbohydrate with blood glucose raising potential (i.e., available carbohydrate) in potatoes. The susceptibility of native starch to enzymic breakdown *in vitro* is influenced by various factors, including amylose content[15], phosphorus content[15, 16], granule size and starch morphology[17], amylopectin chain length profile[15] and the fine structures of branch chains in both amylose and amylopectin[18]. In contrast, the extent of gelatinization and retrogradation of starch in processed or cooked foods is the main determinant of the rate at which it is digested and elicits postprandial blood glucose responses[19, 20].

In a previous study, a low GI potato cultivar, Carisma, with a GI of 53, was identified amongst seven potato cultivars. The other cultivars had GI values ranging from 69 to 103[21]. The GI values were strongly and positively correlated with the extent of *in vitro* enzymatic hydrolysis of starch in the cooked potatoes at 120 min (r = 0.91, p<0.01), but not to dry matter, total starch or dietary fibre content of the potatoes[21]. There were no significant differences in the amylose content among the starches isolated from the seven potato cultivars[21]. In the present study, the properties of starch from Carisma and high GI potatoes were examined to identify characteristics of potato starch that influence their GI values.

2. Materials and Methods

2.1 Potatoes

Potatoes were obtained from growers in South Australia (Carisma, Desiree, Virginia Rose) and Tasmania, Australia (Russet Burbank, Maiflower, Nicola, Bintje).

2.2 Starch extraction

Starch was extracted from potatoes according to the method of Noda *et al*.[22] with modifications, as described by Ek *et al.*[21].

2.3 Phosphorus content

Phosphorus content was determined spectrophotometrically according to the method of Morrison[23].

2.4 Particle size analysis

Particle size of starch granules was quantified as starch surface area using a method based on image analysis of light micrographs. Starch granules (20 mg) were dispersed in 1 mL of deionised water and a few drops of the suspension were placed on a microscope slide with a coverslip and sealed using nail varnish. Images were obtained using a Leica DM 2500M light microscope (Leica, Germany). Five slides were prepared of starch from each potato cultivar and three micrographs were obtained from each slide. Three micrographs were selected randomly from the total of 15 micrographs collected per cultivar giving a triplicate measurement of starch surface area. The micrographs were converted into binary images, a scale in µm was set and granule surface area was measured using ImageJ 1.43u (Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, http://imagej.nih.gov/ij/, 1997-2012) (Figure 1). The output was copied into Excel spreadsheets for data analysis. Classification of the size of starch granules according to surface area was: small (< 500 μm^2), medium (500-1000 μm^2) and large (> 1000 μm^2).

2.5 Starch crystallinity

Relative crystallinity of starch was measured using a Difftech Mini Materials Analyser X-ray diffractometer (GBC Scientific Equipment Pty. Ltd.) according to the method by Wang *et al*[24]. The X-ray generator was equipped with a cobalt anode (λ = 1.78897 Å) operating at 1 kW and 3.36 mA. All starch samples were kept at constant humidity (75%) in a desiccator over a saturated NaCl solution for a week prior to analyses. X-ray diffractograms were acquired at room temperature (20 ± 1°C), the scattering intensity was measured from 4° to 30° as a function of 2θ and at a scanning speed of 0.5°/min and a step size of 0.02°. Traces software v. 6.7.13 (GBC Scientific Equipment Pty. Ltd.) was used to subtract the background representing the amorphous portion of diffractograms. Relative crystallinity was calculated as a ratio of the crystalline area to the total area between 4 to 30°(2θ)[25].

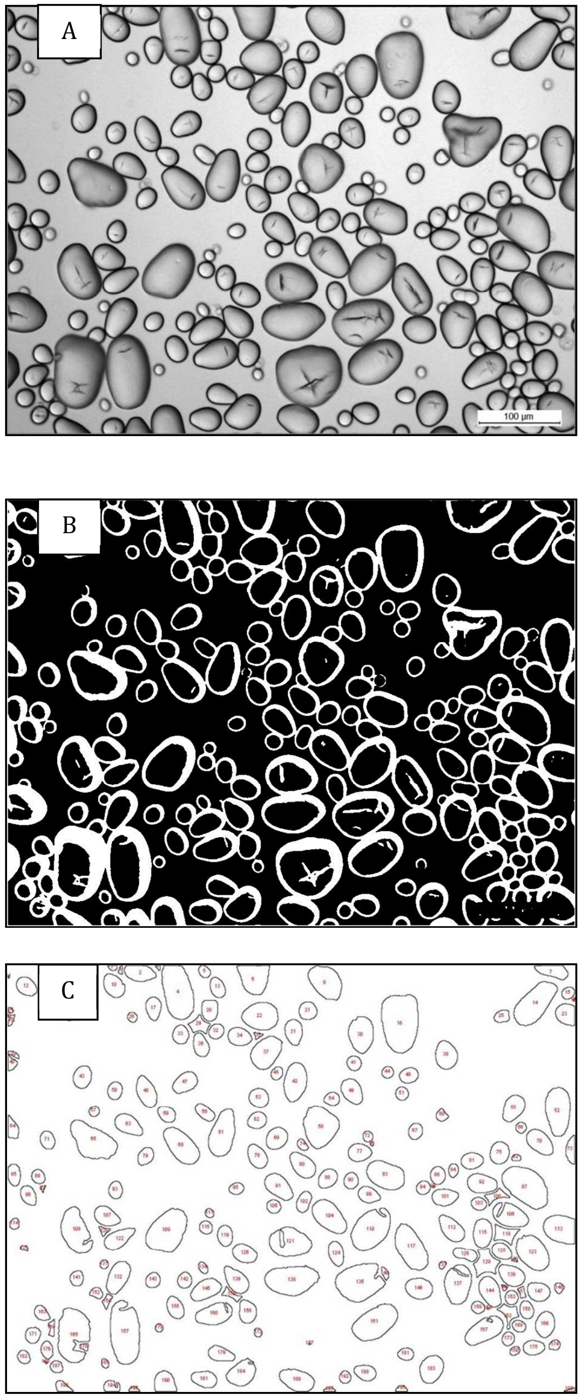

Figure 1: Particle size determination of starch granules by image analysis. Light micrographs of starch granules of cultivar Russet Burbank (A) were converted in binary images (B) and the surface area of the granules was estimated using ImageJ software (C). The scale bar corresponds to 10 μm.

2.6 Amylopectin chain length profile

The amylopectin chain length profile was determined using using high performance anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD), according to the method of Liu *et al.*[15] using isoamylase (280 U/mg, Megazyme International Ireland Ltd. Bray Co., Wicklow, Ireland) to de-branch the starch. Enzymes were inactivated by placing samples in a boiling water bath for 10 min and an aliquot (200 μL) from de-branched samples was diluted with 2 mL of 150 mM NaOH, filtered (0.45 μm nylon syringe filter) and injected into the HPAEC-PAD system (5 μL sample loop) (Dionex Corporation, Sunnyvale, CA, USA). The HPAEC-PAD system consisted of a Dionex HPLC equipped with an ED50 electrochemical detector with a gold working electrode, P680 HPLC pump, TCC-100 column oven, and ASI-100 automated sampler (Dionex Corporation, Sunnyvale, CA, USA). The standard triple potential waveform was employed, with the following periods and pulse potentials: T_1=040 s, with 0.20 s sampling time, E_1 = 0.05 V; T_2 = 0.20 s, E_2 – 0.75 V; T_3 = 0.40s, E_3 = -0.15V. A Dionex CarboPac™ PA1 column with gradient elution (-5 to 0 min, 40% A; 5 min, 60% A; 45 min, 80% A) at a column temperature of 26°C and a flow rate of 1 mL/min (0.5 Hz) was used. Data were collected using Chromeleon software, version 6.80(Dionex Corporation, Sunnyvale, CA). The weight fractions of chain lengths 6-13, 14-18, 19-37, 38-60 were quantified based on the area of peaks. Standards were prepared by dissolving 0.5-1.0 mg from a Shodex STANDARD P-82 kit (Showa Denko K.K. Shodex Group, Kawasaki, Kanagawa, Japan) in distilled water to make 0.1-0.5% solutions.

2.7 Thermal analysis

DSC measurements were made using a Modulated Differential Scanning Calorimeter MDSC 2920 instrument (TA Instruments Inc., Delaware, USA) equipped with a thermal analysis data station and data recording software. Approximately 3 mg of starch from each cultivar was weighed accurately into an aluminium sample pan. Water was added to the starch sample with a microsyringe to obtain a starch:water ratio of 1:2 (w/w) and the pan was hermetically sealed. The detailed procedures for DSC measurements and analysis of the thermal transition parameters are described elsewhere[26].

2.8 Starch pasting properties

Starch pasting properties were analyzed using a Rapid Visco Analyser RVA-4 (Newport Scientific, Warriewood, Australia). Starch samples and deionised water (8% dry starch basis, total weight of 28 g) were weighed directly into a test canister and the mixture was agitated by stirring using the plastic paddle before the canister was inserted into the instrument. The starch suspension was stirred at 960 rpm for the first 10 s then decreased to 160 rpm for the remainder of the experiment. Samples were equilibrated at 50°C for 1min then heated at 6°C/min to 95°C, held at 95°C for 5 mins before cooling at 6°C/min back to 50°C and held for 2 mins. Peak viscosity, trough viscosity and final viscosity were recorded, and breakdown (peak minus trough viscosity) and setback (final minus trough viscosity) were calculated using the Thermocline software provided with the instrument.

2.9 Statistical analyses

All analyses were performed on duplicate starch samples except relative crystallinity determination, which was done as a single test, and granule size analysis which was performed in triplicate. One-way analysis of variance (ANOVA) by Duncan's test ($p<0.05$) was performed using SPSS V. 20 software (SPSS Inc., Chicago, IL).

3. Results

3.1 Physicochemical properties

The chain length profile of amylopectin from all of the potato cultivars had the chain length 13-24 fraction as the highest percentage (47-51%) and chain length 6-12 fraction as the lowest (7-9%). Although small differences were noted among the starches from the seven potato cultivars in their amylopectin chain length distributions, and also in their phosphorus content and relative crystallinity (Table 1), these differences did not differentiate Carisma from other high GI cultivars (Table 1).

Russet Burbank starch had the largest mean granule size, whereas the mean granule size of Maiflower was significantly smaller than that of the other cultivars (Table 1). Maiflower had the highest percentage of small starch granules (90%) and the lowest percentage of large granules (3%). In comparison, Russet Burbank had the lowest percentage of small granules (57%) and highest percentage of large granules (11%). The percentage of small starch granules (82%) and large granules (4%) in Carisma was significantly different from the respective values for Russet Burbank, but did not differ significantly from Maiflower (Figure 2). Although there were significant differences in granule size distributions between the cultivars (Table 1), these did not correspond to the differences in GI values.

3.2 Thermal properties

The potato starches presented well-defined single differential scanning calorimetry (DSC) endotherms (Figure 3). The thermal transition temperatures T_o, T_p and T_c ranged from 60.0 to 66.2°C, 62.8 to 69.3°C and 67.6 to 75.8°C, respectively, and the gelatinization enthalpies ranged from 18.5 to 19.5 Jg^{-1} (Table 2). Carisma starch had the highest values T_o (66.2°C), T_p (69.3°C) and T_c (75.8°C), whereas the lowest respective values were observed for Russet Burbank. The average gelatinization temperature range (T_c - T_o) was 10.0°C. The thermal transition temperatures varied significantly between some of the cultivars, but there were no significant differences in gelatinization enthalpies ($p > 0.05$).

3.3 Starch pasting properties

All seven starches displayed similar pasting profiles, which were typical of potato starch. Pasting temperature ranged from 60.8°C to 70.2°C (Table 3). Carisma starch had the highest pasting temperature (70.2°C), whereas Russet Burbank starch had the lowest (60.8°C), consistent with the ranking of DSC thermal transition temperatures. The starches had similar peak viscosities with the exception of Russet Burbank starch, which was significantly lower than those of the others. Final paste viscosity was lowest for Russet Burbank (3869 cP) and the highest for Carisma (9009 cP). Carisma starch also had the highest trough (7595 cP) and final viscosity (9009 cP).

Table 1. Properties of starches from seven potato cultivars

Cultivar (GI value)^{c}	AM (%)^{c}	P (%)	RC (%)	Mean GSA (μm^2)	AP chain length profile			
					DP 6 – 12	DP 13-24	DP 25-36	DP 37-54
Carisma (53)	25.2 ± 1.7^{a}	0.054 ± 0.005^{cd}	24	314 ± 31^{b}	7.0 ± 0.1^{a}	49.2 ± 0.6^{a}	26.8 ± 0.1^{b}	17.1 ± 0.7^{ab}
Nicola (69)	25.6 ± 1.7^{a}	0.061 ± 0.007^{de}	25	288 ± 53^{ab}	8.4 ± 0.4^{ab}	50.5 ± 4.0^{a}	22.8 ± 3.6^{a}	18.3 ± 0.7^{b}
Desiree (74)	23.1 ± 0.9^{a}	0.032 ± 0.004^{a}	26	438 ± 86^{c}	7.2 ± 0.1^{a}	46.7 ± 0.6^{a}	27.6 ± 0.2^{b}	18.4 ± 0.6^{b}
Russet Burbank (82)	24.4 ± 0.8^{a}	0.047 ± 0.001^{bc}	27	649 ± 74^{d}	8.4 ± 0.6^{ab}	46.6 ± 0.6^{a}	27.5 ± 1.3^{b}	18.5 ± 1.2^{b}
Virginia Rose (93)	27.7 ± 0.8^{a}	0.040 ± 0.000^{ab}	24	259 ± 22^{ab}	7.0 ± 0.3^{a}	47.0 ± 0.8^{a}	27.9 ± 0.5^{b}	18.7 ± 0.2^{b}
Bintje (94)	24.7 ± 1.3^{a}	0.068 ± 0.004^{e}	23	362 ± 54^{bc}	7.2 ± 0.1^{a}	47.3 ± 1.1^{a}	27.6 ± 0.8^{b}	18.0 ± 0.2^{b}
Maiflower (103)	24.1 ± 1.9^{a}	0.042 ± 0.009^{abc}	30	196 ± 58^{a}	9.3 ± 1.5^{b}	47.7 ± 0.3^{a}	26.8 ± 0.7^{b}	16.3 ± 0.6^{a}

[a] Values in a column with the same superscript do not differ significantly (p> 0.05).

[b] Abbreviations: GI, Glycemic Index; AM, amylose; AP, amylopectin; P, phosphorus; RC, relative crystallinity; GSA, granule surface area; DP, degree of polymerization.

[c] GI values and AM content are from Ek *et al*[21].

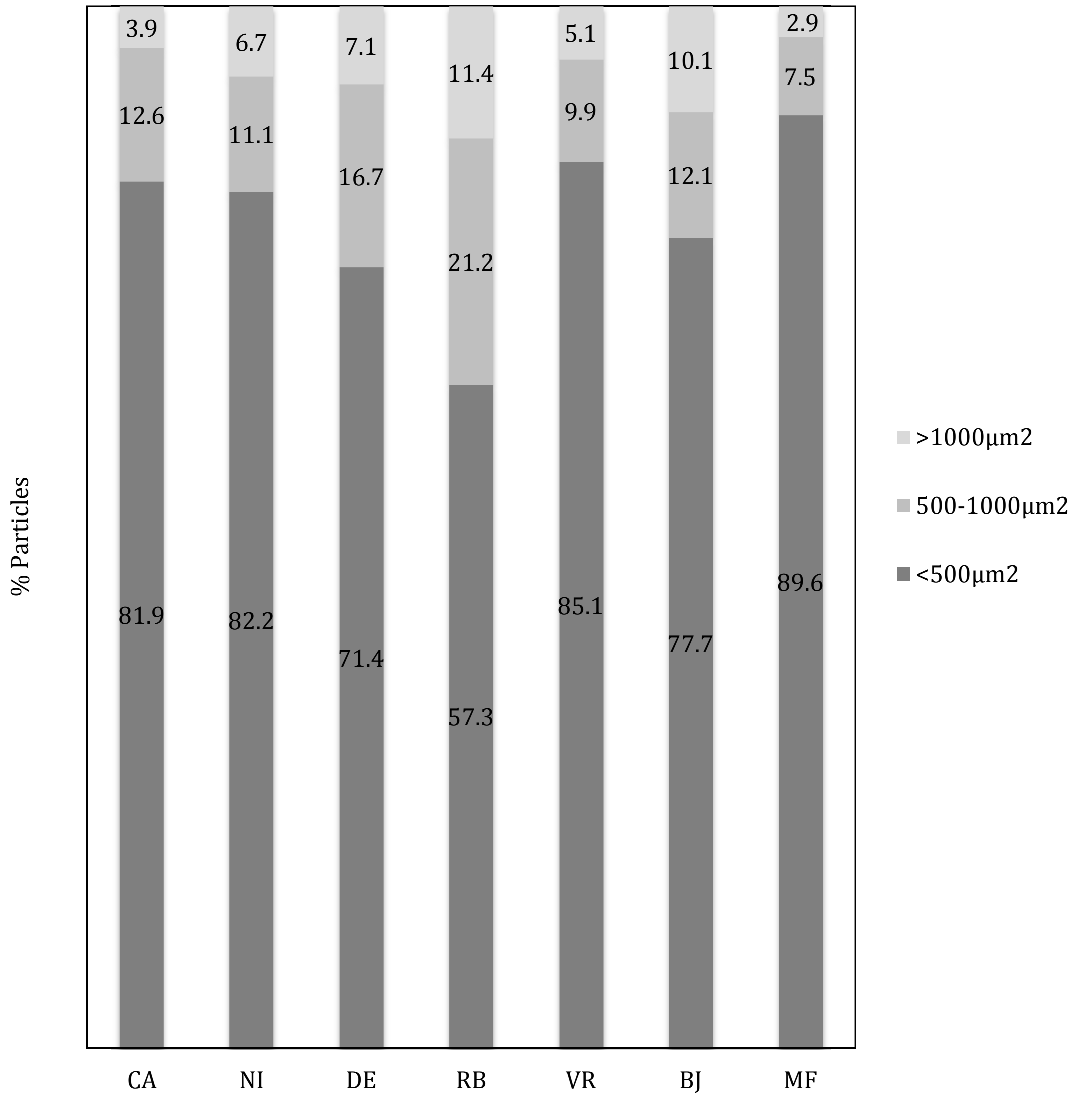

Figure 2: Particle size distribution of starch granules from seven different potato cultivars

Abbreviations: CA, Carisma; NI, Nicola; DE, Desiree; RB, Russet Burbank; VR, Virginia Rose, BJ, Bintje; MF, Maiflower.

Table 2. Thermal properties of starch from seven potato cultivars

Cultivar	Transition temperature (°C)				ΔH (J/g)
	T_o	T_p	T_c	$T_c - T_o$	
Carisma	66.2 ± 0.1^{e}	69.3 ± 0.0^{e}	75.8 ± 0.1^{e}	9.6 ± 0.1^{b}	19.4 ± 0.0^{ab}
Nicola	60.4 ± 0.1^{a}	64.0 ± 0.2^{b}	67.6 ± 0.2^{b}	10.6 ± 0.4^{c}	18.5 ± 0.5^{a}
Desiree	63.7 ± 0.2^{d}	67.1 ± 0.3^{d}	74.4 ± 0.1^{d}	10.7 ± 0.3^{c}	18.7 ± 0.0^{ab}
Russet Burbank	60.0 ± 0.2^{a}	62.8 ± 0.2^{a}	67.6 ± 0.2^{a}	7.6 ± 0.0^{a}	18.7 ± 0.7^{ab}
Virginia Rose	61.4 ± 0.0^{bc}	65.4 ± 0.0^{c}	72.6 ± 0.5^{c}	11.2 ± 0.5^{c}	19.4 ± 0.3^{ab}
Bintje	61.8 ± 0.4^{c}	66.2 ± 0.1^{c}	71.1 ± 1.2^{b}	9.3 ± 0.8^{b}	18.5 ± 0.3^{a}
Maiflower	61.2 ± 0.0^{b}	66.2 ± 0.1^{c}	72.1 ± 0.3^{bc}	10.9 ± 0.3^{c}	19.5 ± 0.1^{b}

[a] Values in a column with the same superscript do not differ significantly ($p > 0.05$).

[b] Abbreviations: T_o = onset temperature; T_p = peak temperature; T_c = conclusion temperature; ΔH = enthalpy change.

Table 3. Pasting properties of starch from seven potato cultivars

Cultivar	PT (°C)	PV (cP)	TV (cP)	BV (cP)	FV (cP)	SB (cP)
Carisma	70.2 ± 0.4^{f}	13128 ± 69^{d}	7595 ± 322^{d}	5533 ± 253^{a}	9009 ± 301^{e}	1415 ± 21^{e}
Nicola	62.8 ± 0.0^{b}	12847 ± 28^{cd}	4088 ± 9^{b}	8759 ± 19^{b}	4876 ± 11^{b}	788 ± 2^{b}
Desiree	66.0 ± 0.0^{e}	10812 ± 370^{b}	5186 ± 70^{c}	5626 ± 440^{a}	6304 ± 31^{d}	1119 ± 39^{d}
Russet Burbank	60.8 ± 0.1^{a}	8521 ± 83^{a}	3215 ± 20^{a}	5306 ± 64^{a}	3869 ± 13^{a}	654 ± 7^{a}
Virginia Rose	64.2 ± 0.2^{d}	13723 ± 141^{e}	4934 ± 199^{c}	8789 ± 59^{b}	5881 ± 214^{c}	947 ± 15^{c}
Bintje	63.4 ± 0.4^{c}	13262 ± 292^{d}	3849 ± 24^{b}	9413 ± 268^{c}	4543 ± 106^{b}	$694 \pm 82b^{ab}$
Maiflower	63.4 ± 0.3^{c}	12478 ± 100^{c}	3907 ± 52^{b}	8571 ± 48^{b}	4671 ± 105^{b}	764 ± 52^{b}

[a] Values in a column with the same superscript do not differ significantly ($p > 0.05$).

[b] Abbreviations: PT, pasting temperature; PV, peak viscosity; TV, trough viscosity; BV, breakdown viscosity; FV, final viscosity; SB, setback.

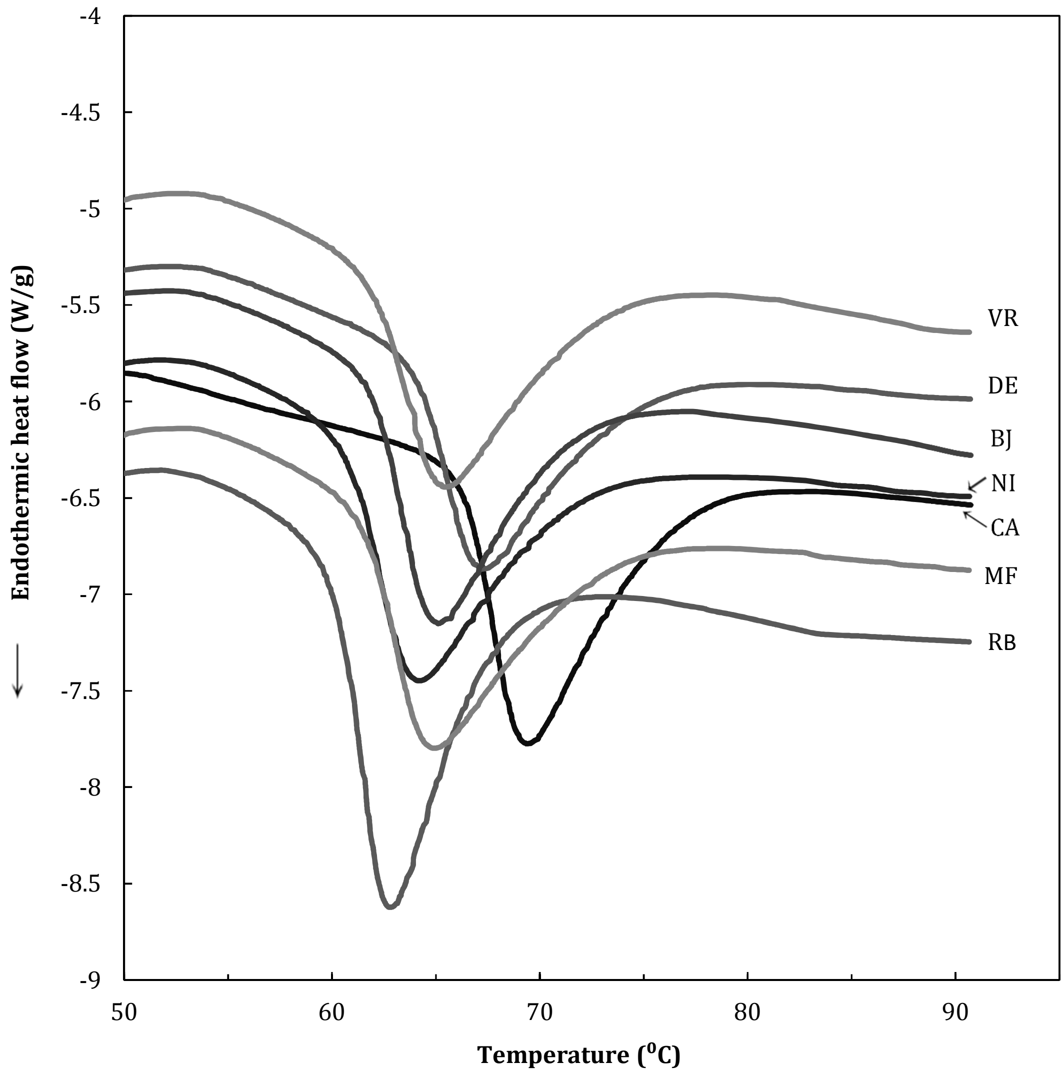

Figure 3: DSC thermograms of starch from seven potato cultivars.

Abbreviations: CA, Carisma; NI, Nicola; DE, Desiree; RB, Russet Burbank; VR, Virginia Rose, BJ, Bintje; MF, Maiflower.

4. Discussion

The present study has shown that starch from the low GI potato cultivar Carisma was more resistant than starch from the high GI cultivars to the effects of hydrothermal treatment in the DSC and RVA. Carisma starch had significantly higher thermal transition temperatures (T_o, T_p and T_c) and starch paste temperature compared to starches from high GI cultivars. Trough and final viscosities, and hence setback viscosity, were also significantly different for Carisma compared to the other cultivars. While there were some differences between the cultivars with respect to starch granule size distribution, amylose content, phosphorus content, relative crystallinity and amylopectin chain length profiles, none of the trends differentiated Carisma from the high GI potatoes.

Higher DSC transition temperatures are thought to result from a higher degree of crystallinity, or more ordered crystalline regions, which impart greater structural stability and make the granules more resistant to gelatinization[27]. Potato starch with less crystalline order was observed to gelatinize at a lower temperature and reach a greater degree of gelatinization at the same temperature than more crystalline potato starch[28]. The same study showed that glycemic response increased with a greater degree of starch gelatinization. The higher gelatinization onset temperature of Carisma starch suggests that the crystalline regions of Carisma starch are more stable than those of the other cultivars. Hence, under the same cooking conditions, the lower glycemic response elicited by Carisma could be because its starch was gelatinized to a lesser extent than starch from the potatoes with a high GI value.

The parameter ΔH measures the energy change due to loss of molecular order and melting of crystallites when hydrogen bonds break within the granule. The value of ΔH has been considered to be an indicator of the quantity and quality of the starch crystalline structure[29, 30]. However, more recent studies have indicated that the DSC endotherm obtained at a water/starch ratio of 2:1 does not represent complete starch gelatinization and corresponds to the energy taken up until the available water becomes limiting[31]. Under these conditions, considerable residual crystallinity and lamellar structure remains at the end of the DSC endotherm[32]. Therefore in the present study, the onset and peak temperatures, but not ΔH, in the DSC endotherm obtained at a water/starch ratio of 2:1 would have been indicative of the quality of the starch crystallinity of the seven potato cultivars.

The pasting profile of Carisma starch was clearly different from that of the other six cultivars (Figure 4), with a significantly higher pasting temperature, higher trough and final viscosities. RVA pasting temperature provides an indication of the temperature at which granule disruption commences. A higher pasting temperature indicates that Carisma starch required more heat for the onset of starch gelatinization during cooking. Continued heating past the temperature of peak viscosity results in the breakdown of swollen granules and realignment of starch polymer molecules, causing a decrease in paste viscosity. Carisma starch had greater resistance to breakdown as indicated by the significantly higher trough viscosity compared to the other starches (Figure 4). The setback viscosity is thought to result from the rearrangement of amylose molecules that have leached from swollen starch granules during cooling, and is indicative of the retrogradation tendency of starch[33]. Carisma starch had significantly higher final and setback viscosities compared to the other starches indicating more viscous retrograded starch paste which could confer resistance to enzymatic digestion. Food matrix viscosity has been observed to affect the enzymatic digestibility of starch and glycemic response[19]. A high level of viscosity slows down propulsive and mixing effects generated by peristalsis, reducing interactions between substrates and digestive enzymes and also the absorption of hydrolysis products thus lowering postprandial glycemia[19].

No significant correlations were observed between amylose and phosphorus contents, and amylopectin chain length distributions, of the seven starches with their respective DSC and RVA properties, nor with the GI values of the potatoes. The lack of such correlations was similar to the results of other studies, which found no significant relationship between amylose and phosphorus content with gelatinization temperature and enthalpy[15, 34]. Smaller granule sizes have been reported to be related to increased DSC transition temperatures and decreased enthalpy of gelatinization[35]. However, in the present study, Maiflower starch had a significantly smaller mean granule size compared to Carisma starch but did not show higher transition temperatures. Higher amylose content, fewer short amylopectin branch chains and smaller granule size were reported to be associated with higher pasting temperature, higher setback viscosity and higher peak viscosity temperature[36-38], however these associations were not observed in the present study.

Recent work has shown that the fine structural features of both amylose and amylopectin significantly influence the *in vitro* digestion rate of starch in cooked rice grains. Longer chain lengths of amylose branches, a smaller relative amount of long to short amylopectin branches and a smaller ratio of longer amylose branches to short amylopectin branches increased *in vitro* digestion rate[18]. In the present study no relationship was found between amylose content, amylopectin chain length profile and GI value, but further aspects of the fine structures of branch chains in amylose and amylopectin (for example, spacing between branch points) were not investigated and could be possible factors that influence starch granule resistance to gelatinization during cooking, starch digestibility and consequently the GI value. It is also possible that due to fine structural differences the glucan chains of Carisma starch are less disordered and therefore less susceptible to amylolysis when hydrothermally treated in the potato tissue[39].

Potato cultivars differ in the size and shape of tuber cells, and the strength of cell wall structures[40-41]. Hence, the physical properties of the tuber may also influence the GI and *in vitro* digestibility of starch in cooked potatoes. Cell walls are considered to be a limiting factor for starch hydrolysis in foods[19, 42]. Cell walls could act as a physical barrier for heat conductance during cooking and thereby reduce the extent of starch gelatinisation. They can also limit the extent of starch swelling, and the rate of starch hydrolysis by restricting enzyme access. Nevertheless, the significantly different hydrothermal properties of isolated Carisma starch indicate that the characteristics of the starch are likely to be a major determinant of digestibility.

5. Conclusions

Starch from the low GI potato cultivar Carisma was more resistant to the effects of hydrothermal treatment in the DSC and RVA than starch from the high GI cultivars used for comparison in this study. Carisma starch was also more resistant to shear and breakdown, and formed a stronger retrograded starch paste than the starches from the high GI potatoes. Further examination of these properties, which could be associated with the fine structure of amylose and amylopectin and the way these molecules are organized in the granules, may provide insights into why the starch in cooked Carisma potatoes has greater resistance to enzymatic hydrolysis, and elicits a lower postprandial blood glucose response than other potatoes. The importance and popularity of potatoes as a food crop dictate the need to identify and develop cultivars that are digested slowly and have a low GI. This study suggests that thermal analysis and starch paste properties could be used as an aid in identifying and developing cultivars that are digested slowly and have a low GI.

Acknowledgements

K.E. was supported by a scholarship from Agrico Holland, the Mitolo Group (Australia) and Glycemic Index Foundation Limited. The authors thank the Mitolo Group and Agronico for supplying the potato cultivars used in this study. The authors acknowledge the scientific and technical assistance from Mr Dennis Dwarte from the Australian Centre for Microscopy and Microanalysis (ACMM), The University of Sydney in the development of the particle size analysis method.

References

1 FAOSTAT, http://faostat3.fao.org/home/index.html#DOWNLOAD, (accessed 20/08/2013).

2 FAOSTAT, http://faostat3.fao.org/home/index.html#DOWNLOAD, (accessed 20/08/2013).

3 FAO. *Carbohydrates in human nutrition,* Report of a Joint FAO/WHO Expert Consultation, Rome, 1998.

4 J. Mann, J. H. Cummings, H. N. Englyst, T. Key, S. Liu, G. Riccardi, C. Summerbell, R. Uauy, R. M. Van Dam, B. Venn, H. H. Vorster and M. Wiseman, *Eur. J. Clin. Nutr.,* 2007, **61**, S132-S137.

5 D. J. Jenkins, T. M. Wolever, R. H. Taylor, H. Barker, H. Fielden, J. M. Baldwin, A. C. Bowling, H. C. Newman, A. L. Jenkins and D. V. Goff, *Am. J. Clin. Nutr.*, 1981, **34**, 362-366.

6 S. M. Liu, W. C. Willett, M. J. Stampfer, F. B. Hu, M. Franz, L. Sampson, C. H. Hennekens and J. E. Manson, *Am. J. Clin. Nutr.*, 2000, **71**, 1455-1461.

7 D. D. S. Ludwig, *JAMA, J. Am. Med. Assoc.,* 2002, **287**, 2414-2423.

8 D. Mozaffarian, T. Hao, E. B. Rimm, W. C. Willett and F. B. Hu, *N. Engl. J. Med.*, 2011, **364**, 2392-2404.

9 W. Willett, J. Manson and S. M. Liu, *Am. J. Clin. Nutr.*, 2002, **76**, 274S-280S.

10 ISO 26642:2010(E). *Food products –Determination of the glycaemic index (GI) and recommendation for food classification*, 2010.

11 L. M. Aston, D. Jackson, S. Monsheimer, S. Whybrow, T. Handjieva-Darlenska, M. Kreutzer, A. Kohl, A. Papadaki, J.A. Martinez, V. Kunova, M.A. Van Baak, A. Astrup, W.H.M. Saris, S.A. Jebb and A.K. Lindroos, *Obes. Rev.*, 2010, **11**, 92-100.

12 J. Brand-Miller, J. McMillan-Price, K. Steinbeck and I. Caterson, *J. Am. Coll. Nutr.*, 2009, **28 Suppl**, 446S-449S.

13 K. L. Ek, J. Brand-Miller and L. Copeland, *Food Chem.*, 2012, **133**, 1230-1240.

14 C. J. K. Henry, H. J. Lightowler, C. M. Strik and M. Storey, *Br. J. Nutri.*, 2005, **94**, 917-921.

15 Q. Liu, R. Tarn, D. Lynch and N. M. Skjodt, *Food Chem.*, 2007, **105**, 897-907.

16 Z. H. Lu, R. Y. Yada, Q. A. Liu, B. Bizimungu, A. Murphy, D. De Koeyer, X. Q. Li and R. G. Pinhero, *Food Chem.*, 2011, **126**, 1246-1253.

17 S. Dhital, A. K. Shrestha and M. J. Gidley, *Carbohydr. Polym.*, 2010, **82**, 480-488.

18 Z. A. Syahariza, S. Sar, J. Hasjim, M. J. Tizzotti, and R.G. Gilbert, *Food Chem,* 2013, **136**, 742-749.

19 J. Singh, A. Dartois and L. Kaur, *Trends in Food Sci. Tech.*, 2010, **21**, 168-180.

20 S. Wang and L. Copeland, *Food Funct.,* 2013*,* **4**, 1564-1580.

21 K. L. Ek, S. Wang, L. Copeland and J. Brand-Miller, *Br. J. Nutr.,* 2014, **111***,* 699-705.

22 T. Noda, S. Tsuda, M. Mori, S. Takigawa, C. Matsuura-Endo, K. Salto, W. H. A. Mangalika, A. Hanaoka, Y. Suzuki and H. Yamauchi, *Food Chem.*, 2004, **86**, 119-125.

23 W. R. Morrison, *Anal. Biochem.*, 1964, **7**, 218-224.

24 S. J. Wang, J. L. Yu, Q. H. Zhu, J. G. Yu and F. M. Jin, *Food Hydrocolloids,* 2009*,* **23**, 426-433.

25 S. Nara and T. Komiya, *Starch - Stärke*, 1983, **35**, 407-410.

26 S. J. Wang, P. Sharp and L. Copeland, *Food Chem.*, 2011, **126**, 1546-1552.

27 V. Barichello, R.Y. Yada, R.H. Coffin and D.W. Stanley, *J. Food Sci.*, 1990, **55**, 1054-1059.

28 J. Parada, and J.M. Aguilera, *Food Res. Int.,* 2012*,* **45**, 238-243.

29 R. F. Tester and W. R. Morrison, *Cereal Chem.*, 1990, **67**, 551-557.

30 D. Cooke and M. J. Gidley, *Carbohydr. Res.*, 1992, **227**, 103-112.

31 S. Wang and L. Copeland, *J. Agri. Food Chem.*, 2012, **60**, 6439-6446.

32 P. J. Jenkins and A. M. Donald, *Carbohydr. Res.*, 1998, **308**, 133-147.

33 A. A. Karim, M. H. Norziah, and C. C. Seow, *Food Chem.*, 2000, **71**, 9-36.

34 A. A. Karim, L. C. Toon, V. P. L. Lee, W. Y. Ong, A. Fazilah and T. Noda, *J. Food Sci.,* 2007, **72**, C132-C138.

35 N. Singh and L. Kaur, *J. Sci. Food Agri.*, 2004, **84**, 1241-1252.

36 L. Kaur, J. Singh, O. J. McCarthy and H. Singh, *J. Food Eng.*, 2007, **82**, 383-394.

37 M. Schirmer, A. Hochstotter, M. Jekle, E. Arendt, and T. Becker, *Food Hydrocolloids,* 2013*,* **32**, 52-63.

38 I. S. M. Zaidul, H. Yamauchi, S. Takigawa, C. Matsuura-Endo, T. Suzuki and T. Noda, *Food Chem.*, 2007, **105**, 164-172.

39 R. Tahir, P. R. Ellis, T. Y. Bogracheva, C. Meares-Taylor and P J. Butterworth, *Biomacromolecules*, 2011, **12**, 123-133.

40 A. Bordoloi, L. Kaur and J. Singh, *Food Chem.,* 2012, **133**, 1092-1100.

41 P. Colonna, V. Leloup, and A. Buleon, *Eur. J. Clin. Nutr.,* 2009, **46**, S17-S32.

42 N. Singh, L. Kaur, R. Ezekiel and H. S. Guraya, *J. Sci. Food Agric.*, 2005, **85**, 1275-1284.