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Protein and Phenolic Contents and Antioxidant Activities of 14 Early Maturing Potatoes as Affected by Processing

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Abstract

The effects of processing and genotype (fourteen early potato varieties) were evaluated for their phytochemicals, total phenolics (TPC), total flavonoids (TFC), total anthocyanins (TAC), antioxidant activities measured by ORAC, FRAP and DPPH assays and protein content. While all these profiles were highly dependent on the potato variety and processing, F09085, F10090, French Fingerlings, Purple Fiesta, Red Thumb, Ciklamen and Norland were identified as nutritionally rich in phytochemicals such as TPC, TFC, TAC, higher antioxidant capacities and protein ($p < 0.05$). In general, TPC, TFC and TAC increased after processing and were highest in the retrograded samples as compared to the raw samples, whereas protein contents decreased following processing ($p < 0.05$). Significant and positive correlations were observed between TPC, TAC, TFC, FRAP, ORAC and DPPH assays (R^2, 0.63, 0.83, 0.88, 0.87, 0.69 for uncooked, 0.48, 0.84, 0.76, 0.89, 0.79 cooked and 0.40, 0.87, 0.88, 0.60, 0.68 retrograded samples, respectively, $p < 0.0001$).

Keywords

Potato, Phenolic Content, Anthocyanins, Antioxidant Potential, Protein

1. Introduction

Potato (*Solanum tuberosum* L.) ranks third behind rice and wheat in terms of world food production as food

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energy source and is the world's number one non-grain food commodity [1]. Potatoes are a valuable dietary food due to their diverse functional ingredients including protein, fiber, vitamins, and phytochemicals such as polyphenols [1] [2]. Plant polyphenols including phenolic acids, flavonoids, anthocyanins and other secondary metabolites are natural antioxidants that play a role in the treatment and prevention of cancers, cardiovascular diseases, neurodegenerative diseases and diabetes [3] [4]. There has been great interest in identifying potato varieties rich in antioxidant phytochemicals for the above-mentioned potential health benefits. The content of polyphenols in potatoes appears to be cultivar dependent [2] [5]. A study involving 74 Andean potato cultivars has reported an approximate 11-fold variation in total phenolic content and a high correlation between polyphenol content and antioxidant activities [2]. Although potatoes are known as a high energy carbohydrate source, they also contain good quality protein. Potato protein is nutritionally comparable to whole egg protein and contains higher content of lysine compared to other vegetable protein from pea and cereals [6]. Potato proteins comprise about 50% protease inhibitors, 40% patatin and the rest are high molecular weight proteins [7]. Patatin is a glycoprotein which is a storage protein that also exhibits cultivar-dependent antioxidant activity [8]. Studies involving 32 potato genotypes have shown extensive variations in protein quality and quantity [9]-[11].

Various factors such as genotype, growing conditions, storage, maturity, color of the flesh and skin and processing conditions can affect the content of phytochemicals and protein in potatoes [11]-[13]. Many studies have identified high anthocyanin content in colored potatoes, and have reported varying levels of phenolic and flavonoid contents in different varieties [14] [15]. The presence and absence of anthocyanins are regulated by a dominant gene which controls the pigmentation. Genotype by location differences are observed in the contents of anthocyanin, phytochemicals and total antioxidant activities [15]. Potatoes are also now emerging as an important food crop in many parts of the world which has not traditionally consumed potatoes as a dietary staple, e.g., India and China [16]. Hence nutritional improvements of potatoes for health benefits as well as identifying varieties high in phytochemicals and proteins would likely have a great impact on global health and well-being. There are also conflicting reports of either decrease or increase in the phytochemicals content and their antioxidant activities after various processing methods [13] [14]. Despite many of the studies on phytonutrient content of potatoes [5] [13]-[15], literature is lacking on the effect of processing on phenolic and protein contents as well as antioxidant activities of early maturing potatoes. Early maturing new potatoes have higher amounts of some phytonutrients, including folate [17] than mature potatoes and are often eaten with skin on which will contribute to higher fiber content. Besides, identifying high nutrient early potatoes which can be used in many culinary purposes, will appeal to the health-conscious consumers. Hence, the present study evaluated fourteen early maturing white, yellow, red and purple potato varieties that are adapted to Ontario growing conditions and the effect of processing on their phytochemicals and protein contents as well as antioxidant activities.

2. Materials and Methods

2.1. Potato Sample

A total of 14 potato varieties were tested in this study. Eleven early maturing potato varieties (Adora, bright yellow flesh, lightly netted buff skin; Yellow Star, yellow skin and flesh; Carling Ford, white; Chaleur, white; Dakota Pearl, cream flesh, light yellow skin; Purple Fiesta, dark purple skin and flesh; French Fingerlings, rose pink skin, creamy yellow flesh with some splashes of pink; Ciklamen, red skin and creamy flesh; Red Thumb, red skin and flesh; Maris Peer, creamy flesh and skin; and smart, yellow skin, medium to dark yellow flesh were collected from Grand Bend Produce, 10026 Walker Road, Grand Bend, Ontario. Two advanced potato selections from Agriculture and Agri-Food Canada, F09085 (deep reddish purple flesh and skin), F10090 (deep reddish purple flesh and skin) and Norland (red skin and creamy yellow flesh) were grown at Elora Research Station, University of Guelph, Ontario. These varieties were selected as they are currently available, adapted to Ontario growing conditions, and could be a healthier choice for consumers. The color range was chosen to suit consumer preferences. The potatoes were grown under normal commercially accepted management practices. Fields were irrigated as needed and standard fertilizer practices were followed based on soil test results. Pre-planting soil tests of Conestoga silt loam soil type reported organic matter 2.9% and cation exchange of 17.2 MEQ/100g. The soil pH was 7.7. The field had previously been in barley, fall killed, deep plowed, spring disced and cultivated before planting. Plots were fertilized at the rate of 130 kg N, 180 kg P and 190 kg K per hectare based on soil data recommendation. Initially 46 kg P and 60 kg K were broadcasted followed by the balance of fertilizers applied at planting time. All potatoes were washed and used for analyses as (1) fresh (uncooked), (2)

after boiling (cooked) and (3) boiled and cooled for 48 hrs at 4˚C (retrograded).

2.2. Sample Preparation

Uncooked samples were prepared by gently washing potatoes along with the skin and cutting into small strips (27 mm × 4 mm, LxW) using a vegetable grater and frozen immediately. Cooked samples were prepared by cutting potatoes (with the skin) into four quarters, boiling for 10 minutes in water (until the sample could be pierced through using a fork), and then slicing them into thin pieces using a knife. One set of these cooked samples was refrigerated at 4˚C for 48 hrs, to produce retrograded samples. One-hundred grams of each of uncooked, cooked, and retrograded samples were freeze dried using VIRTIS freeze drier (The Virtis Company, Gardiner, New York 12525). The freeze dried samples were ground using a coffee grinder, passed through a 250 µm sieve, and kept in air-tight plastic bags at room temperature for two days before use for various analyses.

2.3. Total Polyphenol Content Analysis

Samples for total polyphenol content (TPC) was extracted using 80% methanol following a reported protocol [18]. Briefly, dried potato powder (0.5 g) was extracted in 4 ml of 80% methanol for 12 h with continuous shaking at 200 rpm initially. The extract was centrifuged in a bench top centrifuge (4˚C) at 4500 g for 10 min and the supernatant was then collected. The residue was re-extracted for additional 2 h and the pooled supernatant was stored at −30˚C until use. Total polyphenol contents was determined using the Folin-Ciocalteu colorimetric method [19] using BioTek Synergy H4 hybrid reader (Fisher Scientific, Markham, Ontario, Canada). Ten microliters of standards (chlorogenic acid), blank or samples were loaded into a 96 well microplate followed by 95 µl of Folin-Ciocalteu reagent and allowed to stand at room temperature for 5 min. Ninety-five µl sodium carbonate solution (6%) was added and allowed to react at 40˚C in the dark for 30 min, and the absorbance was read at 725 nm. Samples were loaded in triplicates and the average measurement was taken and expressed as mg chlorogenic acid equivalents (CAE) per gram of dry weight. The experiment was repeated at least three times.

2.4. Determination of Total Flavonoid Content

The total flavonoid content (TFC) was determined based on the method of Zou [20]. A 25 µl aliquot of appropriately diluted samples or catechin standard dilutions (0, 15.6, 31.25, 62.5, 125, 250 and 500 mg/L) was mixed with 110 µl of 0.066 M $NaNO_2$ solution in a 96 well-plate. After incubating for 5 min, 15 µl of 0.75 M aluminum chloride solution were added and allowed to react for another 6 min at room temperature followed by the addition of 100 µl of 0.5 M NaOH. The absorbance was read at 510 nm using BioTek SynergyH4 hybrid reader (Fisher Scientific, Markham, Ontario, Canada) and the total flavonoid content was determined from the standard curve and expressed as mg of (+) catechin equivalent (CE) per gram of dry weight.

2.5. Determination of Total Anthocyanin Content

Anthocyanin was extracted twice from 1 g of potato dry matter in 10 ml of methanol: water: acetic acid (80:19:1, v/v/v) in a 15 ml screw-capped plastic tube after vortexing and placing in a rotary shaker for 2 hrs. The supernatant was pooled after centrifuging for 10 mins at 3000 g and concentrated using a rotary evaporater at 35˚C to dryness and stored at −30˚C until use. Total anthocyanin content was determined based on the pH differential method [21]. Twenty-five µl of the standards or samples were mixed in separate wells of a 96-well plate, one with 250 µl of pH 1.0 buffer (0.1 M HCl/4.9 mM KCl) and the other with 250 µl of pH 4.5 buffer (24.8 mM NaOAc). Absorbance was read at 535 and 700 nm using BioTek SynergyH4 hybrid reader (Fisher Scientific, Markham, Ontario, Canada). The net absorbance (A) for the cyanidin chloride standard and the samples were calculated using A = [(A535 − A700)pH 1.0 − (A535 − A700)pH4.5]. The concentration of the anthocyanin was calculated using the linear equation and expressed as mg cyanidin chloride equivalent (CCE) per gram dry weight of potato samples. The mean value was obtained from two separate experiments each consisting of four replications.

2.6. 2, 2-Diphenyl-1-picrylhydrazyl (DPPH) Radical Scavenging Capacity Assay

The DPPH radical scavenging capacity assay was based on the method of Yamaguchi *et al.* [22]. The 96 well

microplate was loaded with 25 µl of either potato extracts or standard (Trolox) followed by 175 µl of 152.15 µM DPPH solution prepared in methanol. The absorbance was read at 515 nm at room temperature after 40 minutes incubation using BioTek SynergyH4 hybrid reader (Fisher Scientific, Markham, Ontario, Canada). The DPPH antioxidant activity was expressed as mg of trolox equivalents (TE) per gram dry weight.

2.7. Ferric Reducing Antioxidant Power (FRAP) Assay

FRAP assay was performed according to the methods of Benzie and Strain (1996) and Tsao, Yang, Xie, Sockovie and Khanizadeh [23] [24]. Ten µl of sample or standard was mixed in the wells of a 96-well plate with 300 µl of freshly prepared FRAP reagent. The FRAP reagent was prepared by mixing 300 mM acetate buffer, pH 3.6, 10 mM 2,4,6-tripyridyl-S-triazine (TPTZ) and 20 mM FeCl3 mixed at 10:1:1 (v/v/v). The plate was incubated at room temperature for 2 h and the absorbance was read at 593 nm using BioTek SynergyH4 hybrid reader (Fisher Scientific, Markham, Ontario, Canada). The final FRAP value was calculated on the basis of 100 µM ascorbic acid being equivalent to a 200 µM FRAP value and expressed as µmol ascorbic acid equivalent (AAE) per gram dry weight.

2.8. Oxygen Radical Absorption Capacity (ORAC)

The oxygen radical absorption capacity was used to measure the antioxidant capacity [25]. Twenty-five microliters of the 100-fold diluted sample extracts or standard were mixed with 150 µl of fluorescein working solution (8.68×10^{-5} mM) in wells of a 96-well plate. The plate was equilibrated for 30 min at 37˚C in a BioTek SynergyH4 hybrid reader (Fisher Scientific, Markham, Ontario, Canada). Reaction was initiated by the addition of 25 µl of a free radical generator AAPH (2, 2'-azobis(2-aminopropane)dihydrochloride, 153 mM) solution and shaking at maximum intensity for 10 s in the plate reader. The multi-detection microplate reader recorded the fluorescence kinetically every minute for 2 h with excitation and emission set at 485 nm and 520 nm respectively. A standard curve was prepared with trolox concentrations ranging from 6.25 to 100 µM. The ORAC values were calculated as the area under the curve (AUC) and expressed as µmoles of trolox equivalent (TE) per gram dry weight of potato dry matter. The experiment was repeated twice with eight replicates per sample.

2.9. Total Protein Determination

Total protein was extracted from 150 mg of freeze-dried potato in 1.5 ml of 62.5 mM Tris-HCl buffer, pH 6.8, with 2% SDS by vortexing at 15 minutes intervals for about 4 h at 4˚C and centrifuging at 8161 g for 5 min [26]. The supernatant was collected and stored at −30˚C until use. Protein content was determined using the microplate assay of DCTM protein determination (Bio-Rad Protein Assay Kit). The experiment was replicated twice with at least eight determinations for each experiment.

2.10. Data Analyses

Data analysis was carried out using GraphPad Prism 6 Software (GraphPad Software Inc., California, USA). Differences among the various treatments were carried out using one-way analysis of variance (ANOVA) and Tukey's multiple comparison test was used to compare the means ($p \leq 0.05$). Pearson correlation was also used to establish a relationship between TPC, TFC, TAC, and FRAP, ORAC and DPPH assays.

3. Results

3.1. Total Phenolic Contents (TPC)

Significant differences were noted in TPC among varieties and after processing (**Figure 1**, $p \leq 0.05$). TPC was analyzed using chlorogenic acid as standard. In general, highest TPC was observed in retrograded potato samples followed by boiled and uncooked samples. F09085, F10090, Red Thumb, Purple Fiesta and French Fingerlings were the varieties which registered the highest TPC in uncooked, boiled and retrograded samples (**Figure 1**). Among the varieties, the highest TPC were obtained in selections F09085 (10.35 mg CAE/g) and F10090 (8.47 mg CAE/g), Red Thumb (8.42 mg CAE/g), Purple Fiesta (6.58 mg CAE/g), and French Fingerlings (5.04 mg CAE/g) after retrogradation (**Figure 1**).

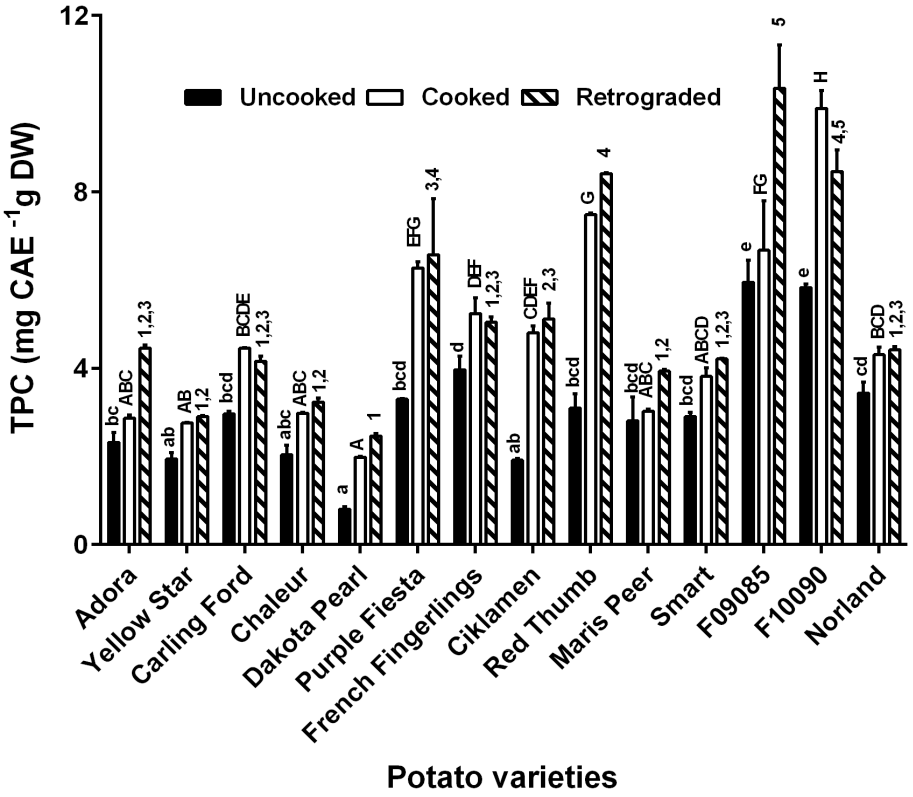

Figure 1. Effect of variety and processing on mean total phenolic contents (TPC) of potatoes as measured on chlorogenic acid equivalents. Each bar represent mean of 8 values, from four replicates and two determination per replicate along with standard error. Bars with different letters of a, A, 1 denote significant differences between uncooked, cooked and retrograded samples, respectively (Tukey's test, $p \leq 0.05$).

3.2. Total Flavonoid Content (TFC)

TFC varied significantly among varieties and with all processing methods (**Figure 2**, $p \leq 0.05$). Selection F10090 registered the highest TFC in all the processing methods with the highest content of 3.92 mg CE/g in boiled samples (**Figure 2**). After F10090, selection F09085, varieties Purple Fiesta, Red Thumb, Norland, French Fingerlings and Ciklamen also had high TFC values. Similar to TPC, TFC was higher in the retrograded samples followed by boiled and uncooked samples.

3.3. Total Anthocyanin Content (TAC)

Anthocyanin contents were detected only in purple/red colored varieties such as Purple Fiesta, French Fingerlings, Ciklamen, Red Thumb, F09085, F10090 and Norland (**Figure 3**). TAC varied significantly among these varieties and after processing ($p \leq 0.05$) with the highest contents in Purple Fiesta followed by F09085, F10090, Red Thumb, Ciklamen, French Fingerlings and Norland after boiling and retrogradation. Boiling and retrogradation increased the TAC in all these varieties with the exception of F09085 and F10090.

3.4. Antioxidant Activities

Antioxidant activities were determined using three chemical model assays, ORAC, FRAP and DPPH. Significant differences were observed among varieties in their antioxidant activities as measured by the three assays among all processing methods ($p \leq 0.05$). In general, the antioxidant activity was highest in retrograded samples followed by boiled and uncooked potatoes. Among the uncooked potatoes, the highest ORAC values ($p \leq 0.05$) were observed in F09085 and F10090 followed by French Fingerlings, Red Thumb, Purple Fiesta, Carling Ford and Norland (**Figure 4**). A similar trend was observed in the ORAC values of boiled and retrograded potatoes

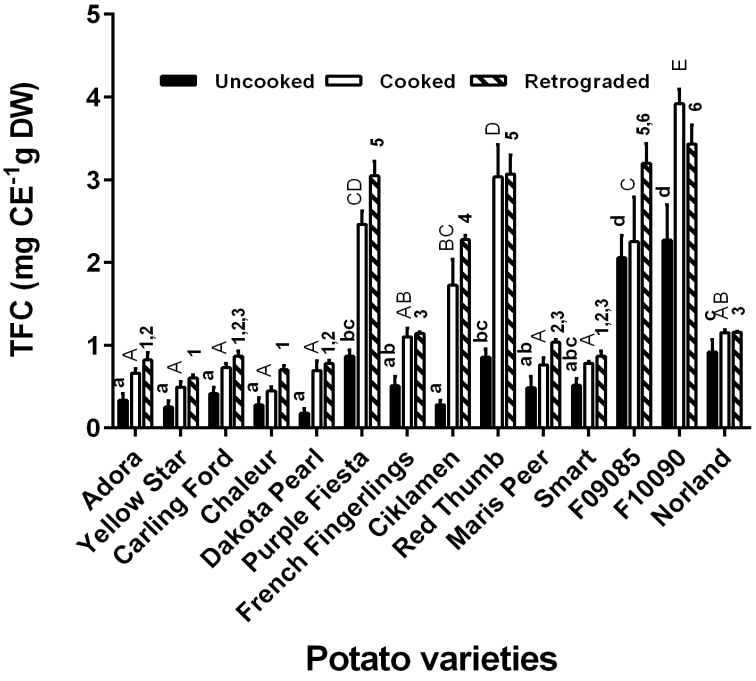

Figure 2. Effect of variety and processing on mean total flavonoid contents (TFC) of potatoes as measured on catechin equivalents (CE). Each bar represent mean of 12 values, from 3 replicates and four determinations per replicate along with standard error. Bars with different letters of a, A, 1 denote significant differences between uncooked, cooked and retrograded samples, respectively (Tukey's test, $p \leq 0.05$).

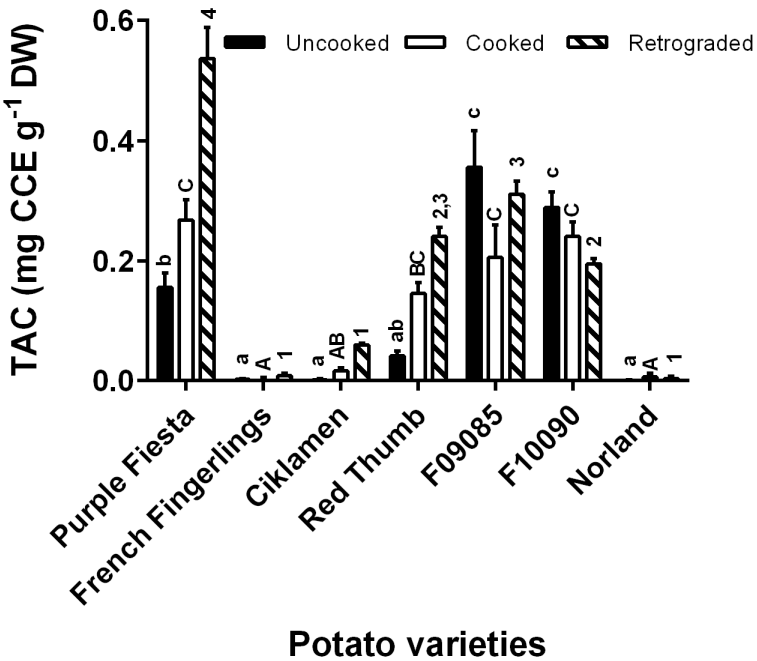

Figure 3. Effect of variety and processing on mean total anthocyanin contents (TAC) of potatoes as measured on cyanidin chloride equivalents (CCE). Each bar represents mean of 10 values with two replicates and five determinations per replicate along with standard error. Bars with different letters of a, A, 1 denote significant differences between uncooked, cooked and retrograded samples, respectively (Tukey's test, $p \leq 0.05$).

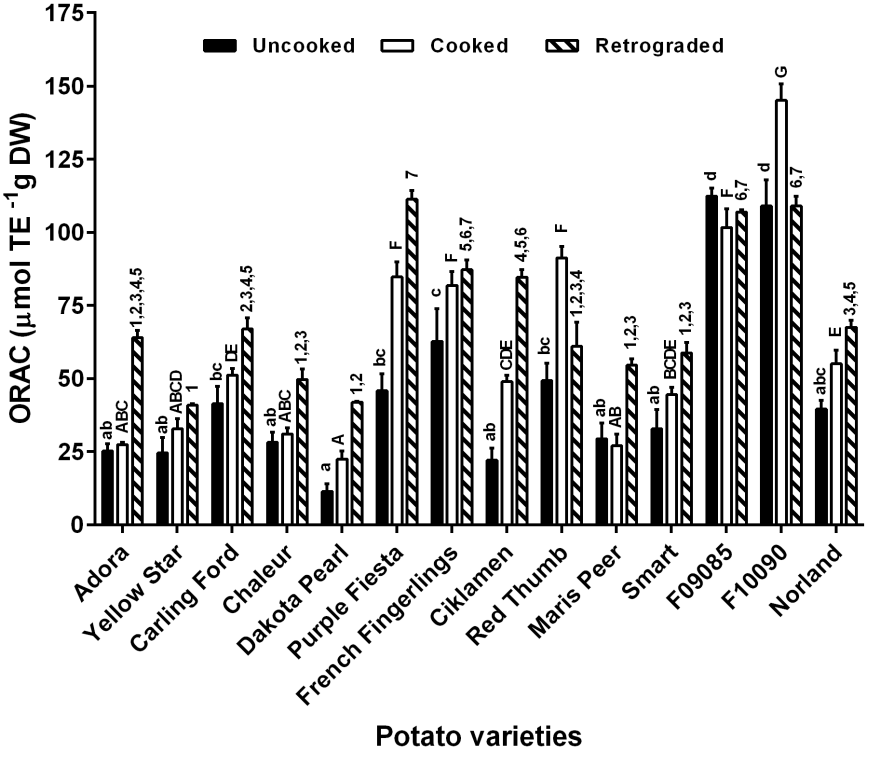

Figure 4. Effect of variety and processing on antioxidant capacity as measured by ORAC on trolox (TE) equivalents. Each bar represents mean of16 values, from four replicates and four determinations per replicate and standard error. Bars with different letters of a, A, 1 denote significant differences between uncooked, cooked and retrograded samples, respectively (Tukey's test, $p \leq 0.05$).

with some exceptions. A range of almost 10-fold difference in ORAC values were observed between the highest F09085 and lowest Dakota Pearl in uncooked values whereas the gap decreased to 6-fold for boiled and 3-fold for retrograded samples. Processing as well as varietal differences also affected the FRAP values significantly (**Figure 5**, $p \leq 0.05$). F10090, F09085, Red Thumb, and Purple Fiesta registered the highest FRAP values in all the three categories of uncooked, boiled and retrograded potatoes ($p \leq 0.05$). A range of 6-fold, 13-fold and 3-fold difference among the varieties between the lowest and highest FRAP values was observed in the uncooked, boiled and retrograded potatoes, respectively. The antioxidant activities of varieties as measured by DPPH, were also significantly different ($p \leq 0.05$). F10090 registered the highest DPPH value both in uncooked and boiled samples whereas Red Thumb had the highest value in the retrograded samples (**Figure 6**). In general, DPPH antioxidant activities were highest in F10090, F09085, Red Thumb, Purple Fiesta, Norland, Ciklamen, French Fingerlings and Adora in all the uncooked, boiled and retrograded samples and the DPPH activities increased following boiling and retrogradation (**Figure 6**). The uncooked, boiled and retrograded samples showed a 31-, 6- and 4-fold differences, respectively, between the lowest and highest DPPH values.

3.5. Protein Content

Protein contents of the varieties differed significantly in all uncooked, boiled and retrograded samples ($p \leq 0.05$). Protein content ranged from 5.7% to 9.0%, 3.2% to 7.4% and 3.3% to 6.7% on dry weight basis in uncooked, boiled and retrograded potatoes, respectively (**Figure 7**). It should be noted that the protein content of uncooked samples was higher in all the varieties compared to boiled and retrograded potatoes. F09085 and French Fingerlings had the highest protein contents in uncooked samples followed by F10090, Dakota Pearl, Ciklamen, Yellow Star, Purple Fiesta and Red Thumb. The remainder of the varieties had similar protein contents in the uncooked samples. In the boiled and retrograded samples, F09085, F10090 and Red Thumb registered the highest protein contents.

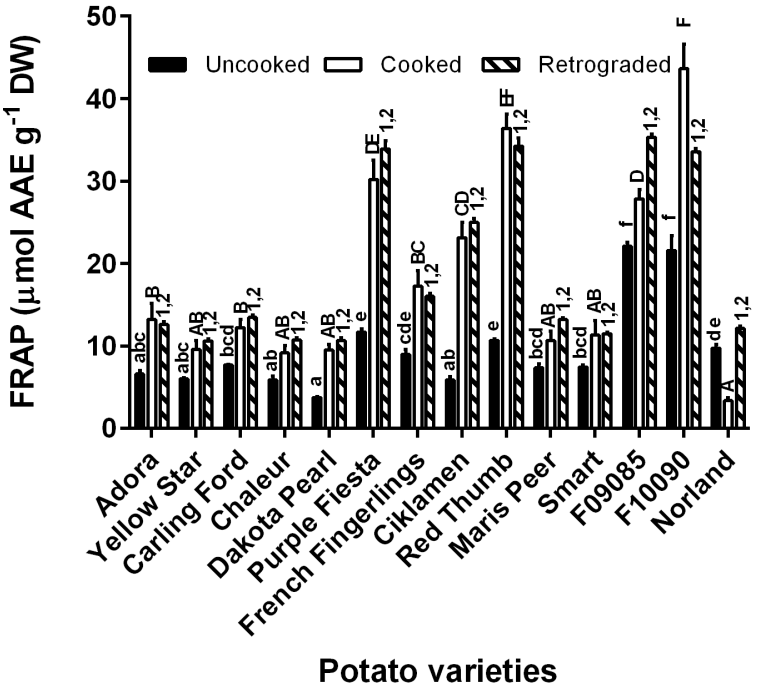

Figure 5. Effect of variety and processing on antioxidant capacity as measured by FRAP on ascorbic acid (AAE) equivalents. Each bar represent mean from 12 values with four replicates and three determinations per replicate and standard error. Bars with different letters of a, A, 1 denote significant differences between uncooked, cooked and retrograded samples, respectively (Tukey's test, $p \leq 0.05$).

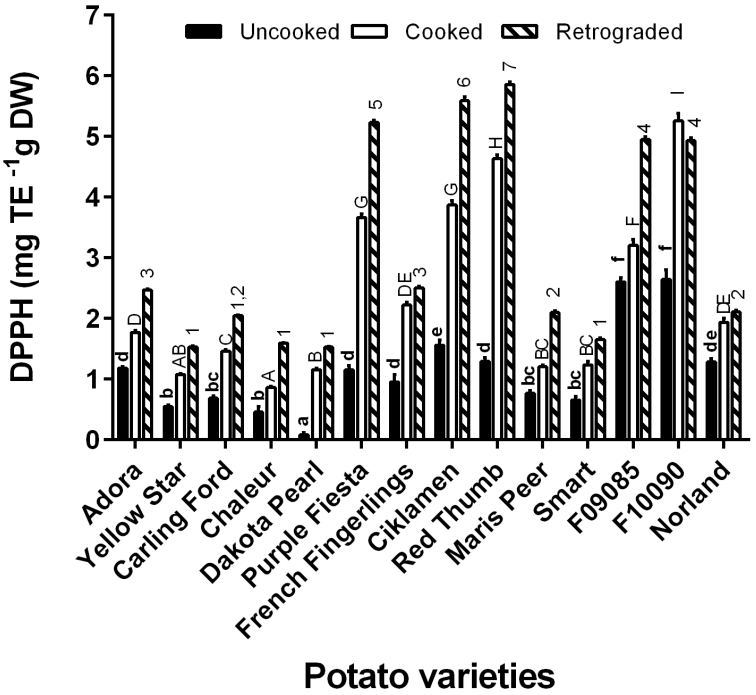

Figure 6. Effect of variety and processing on antioxidant capacity as measured by DPPH on trolox (TE) equivalents. Each bar represents mean of 14 determinations and standard error. Bars with different letters of a, A, 1 denote significant differences between uncooked, cooked and retrograded samples, respectively (Tukey's test, $p \leq 0.05$).

3.6. Correlation of TPC, TFC, and TAC with Antioxidant Activities

Significant positive correlations were observed between TPC, TAC, TFC and ORAC, FRAP and DPPH (**Table 1**). The correlations were high between the antioxidant activities measured by FRAP, ORAC and DPPH with TPC, TAC, TFC, and among FRAP, ORAC and DPPH in the uncooked samples. A similar trend was observed in cooked and retrograded samples with some exceptions. The correlation, even though significant, was not strong between TAC, FRAP, ORAC and DPPH in cooked potatoes. In retrograded samples, a strong correlation was not observed between TAC and ORAC, DPPH and TPC and TAC.

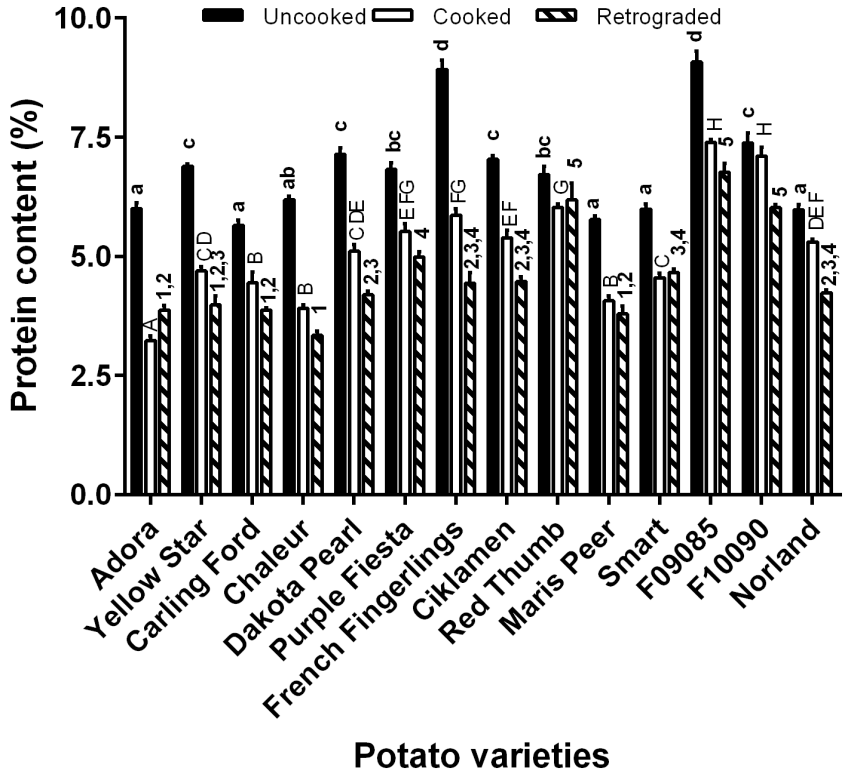

Figure 7. Effect of variety and processing on total protein contents of potatoes. Each bar represents mean of 16 values from two replicates and eight determinations per replicate and standard error. Bars with different letters of a, A, 1 denote significant differences between uncooked, cooked and retrograded samples, respectively (Tukey's test, $p \leq 0.05$).

Table 1. Pearson correlations of bioactives (R^2) to antioxidant potential.

	Uncooked					Cooked					Retrograded				
	TAC	TFC	FRAP	ORAC	DPPH	TAC	TFC	FRAP	ORAC	DPPH	TAC	TFC	FRAP	ORAC	DPPH
TAC (n = 56)		0.74**	0.84**	0.73**	0.70**		0.56**	0.41**	0.44**	0.16*		0.52**	0.61**	0.27*	0.31**
TPC (n = 84)	0.63**	0.83**	0.88**	0.87**	0.69**	0.48**	0.84**	0.76**	0.89**	0.79**	0.40**	0.87**	0.88**	0.60**	0.68**
TFC (n = 84)			0.97**	0.82**	0.75**			0.77**	0.78**	0.84**			0.97**	0.58**	0.87**
FRAP (n = 84)				0.90**	0.76**				0.70**	0.82**				0.56**	0.89**
ORAC (n = 84)					0.68**					0.65**					0.48**

*, ** denote significant differences at $p \leq 0.05$ and 0.0001 respectively. TAC, total anthocyanin content; TPC, total phenolics content; TFC, total flavonoid content; FRAP, ferric reducing antioxidant power; ORAC, oxygen radical absorption capacity; DPPH, 2,2-Diphenyl-1-picrylhydrazyl radical scavenging capacity.

4. Discussion

Epidemiological and experimental studies in cells, animal models of disease and human intervention trials demonstrate that polyphenolic compounds found in fruit and vegetables have the potential to enhance human health and even prevent, mitigate or treat many illnesses due to their antioxidant activities [4]. Many of the studies on phytochemical and antioxidant activities of coloured potatoes were conducted on raw potatoes [27] [28]. Although these types of studies produce valuable information, they do not document phytochemicals and antioxidant activities of potatoes that are consumed by humans. Besides maturity, genotype by environment interaction is reported to be a factor that influences the phytochemical composition [2] [5] [13] [15]. Processing conditions such as cooling, can influence the glycemic impact of cooked potatoes through retrogradation of starch polymers. It has been reported by low field nuclear magnetic resonance (LF-NMR) studies that retrogradation is more extensive in boiled potatoes after 24 - 48 h of cooling than after 1 - 2 h [29]. Since retrogradation of amylose is a rapid process often completed within 48 h [30], we chose 48 h for the cooling time in order to get the maximum effect of retrogradation. Considering the above mentioned factors, in the present study, fourteen early maturing potato varieties including two advanced selections with different skin and flesh colors were evaluated for their bioactive compounds such as TPC, TFC, and TAC, antioxidant activities and protein contents after processing. In general, the selections F09085 and F10090, and varieties, Purple Fiesta, Red Thumb and French Fingerlings registered the highest TPC, and TFC contents whereas highest TAC values were obtained in Purple Fiesta, F09085 and F10090. Among these varieties, Purple Fiesta has the darkest purple color skin and flesh, whereas F09085, F10090 with reddish purple skin and flesh, and Red Thumb have a deep red skin and flesh. French Fingerlings has a rose pink skin with a creamy yellow flesh with some splashes of pink color. Antioxidant activities as measured by FRAP, DPPH and ORAC were higher in F09085, F10090, Purple Fiesta, Red Thumb and French Fingerlings. It should be noted that the colored varieties either with flesh and skin or skin alone had higher TPC, TFC, TAC and higher FRAP, ORAC and DPPH values than yellow or white colored potatoes. Similar differences of higher phenolic contents and antioxidant activities were reported in uncooked yellow or white colored and pigmented potatoes [5] [31]-[33]. Higher correlations observed between TPC and antioxidant activities determined by FRAP, ORAC, DPPH and between FRAP, DPPH and ORAC values in uncooked samples in this study were also reported by other authors [5] [31]-[33].

Processing also affected TPC, TFC, TAC, FRAP and ORAC contents with the highest values often observed in retrograded samples followed by boiling and unprocessed samples. In general, the nutrient value of potatoes decreased after cooking [32]-[36]. However, it has been also reported that depending upon the variety and processing methods, TPC and antioxidant activities may either increase or decrease. For example, in potato clones such as CO97232-2R/Y, CO97215-2P/P and CO97227-2P/PW, the TPC contents increased after baking whereas values decreased following chipping compared to the unprocessed samples [35]. Also it has been reported that boiling of potato resulted in an increase and preservation of total anthocyanin contents as well as antioxidant content as measured by ORAC in red and purple-fleshed potato cultivars compared to raw tubers [15]. Our results also showed a similar trend of increased anthocyanin contents and antioxidant activities in boiled samples. Navarre *et al*. [37] have reported that processing of 3 varieties of new potatoes by various methods such as steaming, microwaving, boiling and baking increased the extractable phenolics and the TPC especially chlorogenic acids and TFC in all three cultivars after cooking. They also reported that the extent of increase was greatest after boiling. Their results also suggested that the increase in these nutrient contents after processing was consistent across all cultivars tested. The increase in TPC, TFC and TAC values could be attributable to greater extraction of these compounds after cooking due to the changes in cell matrix and the inactivation of the enzymes that degrade these components [13] [37]. It was also reported that the antioxidant capacity was increased by all the cooking methods compared to uncooked potatoes [35]. Ramírez-Anaya *et al*. [38] also reported significant increases in antioxidant activities of boiled compared to raw potatoes as measured by DPPH and FRAP.

Significant correlations were observed between TPC, TFC, TAC and FRAP and ORAC values in all the three processing methods in our study. Similar correlations between TPC, TAC and antioxidant activities as measured by ORAC, FRAP, DPPH have also been reported in potatoes by several authors [13] [32] [34] [35]. The lower correlation observed between TAC and ORAC, FRAP and DPPH values suggests that phenolics other than anthocyanins e.g. phenolic acids contribute more to the total antioxidant activities. TPC includes flavonoids, other phenolic acids and all compounds with phenolic features but the specific composition of these phenolic com-

pounds can vary among different potato varieties, thus contributing differently to the antioxidant activity [33] [39]-[41].

Protein content of all varieties decreased by 19% - 47% and 25% - 47%, respectively, in cooked and retrograded samples. It should be noted that in potato, water-soluble protein content varies from 49% - 55% of total protein [42]. Hence it is suggested that the decrease in protein content after boiling may have resulted from leaching of the water-soluble proteins. Potato protein has a high biological value of 90 - 100 and is comparable to egg protein. Even though the protein content of potato is low, its high biological value and large consumption as a staple makes it a moderate nutritional source of proteins. It is also interesting to note that the colored varieties besides their high TPC, TFC, TAC and antioxidant capacities are also high in protein content. The loss of protein from these colored varieties was less (4% - 25%) compared to the white varieties which had a loss of 44% - 47%.

5. Conclusion

The present study identified F09085, F10090, French Fingerlings, Purple Fiesta, Red Thumb, Ciklamen and Norland as the nutritionally richest varieties among the 14 tested Ontario-grown potatoes according to the higher TPC, TFC, TAC contents, higher antioxidant activities and protein content. Potatoes were reported as the third leading source of dietary antioxidants in the North American diet after apples and oranges [43]. Potatoes could make a positive contribution to today's diet as consumers become more conscious and aware of the benefits of foods for health. Potatoes can be an excellent source of dietary antioxidants and energy and could be the basis for the development of functional foods.

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