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Antioxidant properties of commercial, regular- and whole-wheat spaghetti

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ABSTRACT

Whole grains contain more vitamins, minerals, natural antioxidants and dietary fibre than regular, refined grain products. Therefore, consumption of whole grain products is associated with beneficial health effects. The present investigation evaluated the antioxidant properties of 10 samples of regular- and whole-wheat spaghetti that are commercially available. The methods employed were total phenolic content (TPC), 2,2-diphenyl-1-picryhydrazyl (DPPH) free radical scavenging activity, oxygen radical absorbance capacity (ORAC) and ferulic acid content by HPLC analysis. The effects of cooking on the antioxidant properties of spaghetti were also studied. Whole wheat spaghetti exhibited significantly higher levels of total phenolic content (1389 μg/g) than regular wheat spaghetti (865 μg/g); however, TPC in both regular and whole wheat spaghetti was 48–78% of the original content after cooking. There were no significant differences in ORAC values (34.3–100.4 μmol Trolox equivalents/g) or DPPH scavenging activity (1.0–2.3 μmol Trolox equivalents) among whole wheat and regular spaghetti. Whole wheat spaghetti (234 μg/g) had significantly higher content of ferulic acid than regular spaghetti ($p < 0.05$). TPC and ferulic acid content were found to be good indicators of the antioxidant capacity of spaghetti with both indices demonstrating the superiority of whole wheat over regular pasta products. The current findings on spaghetti add to the mounting evidence on the potential health benefits to be derived from consuming whole grain products.

1. Introduction

Wheat is the dominant cereal grain used in the production of a variety of food products. Wheat varieties differ in their characteristics; the high gluten content of hard wheat makes it suitable for production of bread and other baked products while the yellow endosperm of durum wheat gives pasta its colour. Durum wheat semolina is preferred for production of spaghetti, macaroni and other pasta products (Marconi & Carcea, 2001), although farina and flour from common wheat are occasionally used. Regular semolina is obtained by repeated grinding and sieving of the durum resulting in maximum yield of the granular endosperm product and little amounts of bran powder (Donnelly & Ponte, 2000). In whole wheat semolina, the bran is included. Pasta production starts with adding water to semolina (regular and whole wheat) followed by mixing, extrusion, trimming and drying (Dalbon, Grivon, & Pagani, 1996). Manufacturers employ high-temperature drying technology to obtain better quality pasta in a short period thereby increasing productivity (Anese, Nicoli, Massini, & Lerici, 1999).

Whole wheat products contain more vitamins, minerals, antioxidants and dietary fibre than regular, refined ones (Baic, 2005). The difference in the level of these constituents can be as high as 75% when compared to refined cereals. Cardiovascular disease factors such as serum lipids and lipoprotein have been shown to decrease in the Neapolitan area where there is high consumption of pasta, compared to the northern regions (Mariani-Constantini, 1988). Cardiovascular disease refers to atherosclerosis which is the atheromatous plaque that is formed by the massive accumulation of esterified cholesterol (Goldstein & Brown, 1977). Diverse factors can enhance the development of atheromatous plaque including smoking, high blood pressure, diabetes mellitus and elevated blood lipid levels. Human cells including the aortic smooth muscle cells have low-density lipoprotein (LDL) pathway that regulates the uptake, storage and synthesis of cholesterol and therefore prevents overaccumulation of sterol in the cells (Goldstein & Brown, 1977). Atherosclerosis takes place when this mechanism is disrupted by for example dietary factors such as increased intake of saturated fatty acid and also genetic factor (Goldstein & Brown, 1977; Mustad et al., 1997). Whole wheat pasta not only prevents chronic diseases such as cardiovascular disease, cancer and diabetes, but also helps maintain body weight by further lowering the glycemic responses (Baic, 2005).

Halvorsen et al. (2006) and Shahidi (1997, 2000) concluded that cereals, spices and herbs, nuts and seeds, berries, fruits and vegeta-

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bles are important sources of antioxidants in human diet. Antioxidant capacity of whole wheat products is relatively high and even similar to that of fruits or vegetables on a per serving basis (Slavin, 2003). Compounds in wheat known to exhibit antioxidant properties can be divided into polar phytochemicals primarily, phenolics (Beta, Nam, Dexter, & Sapirstein, 2005; Mpofu, Sapirstein, & Beta, 2006; Zielinski & Kozlowska, 2000) and nonpolar phytochemicals, primarily carotenoids (Adom, Sorrell, & Liu, 2002; Hentschel et al., 2002). The insoluble fibre in durum wheat bran contains 0.5–1.0% phenolic acids (Slavin, 2000). The fibre is broken down in the colon by microbial enzymes releasing the bound phenolic acids thereby providing antioxidant protection (Slavin, 2003). Ferulic acid and caffeic acid are examples of the phenolic acids found in durum wheat bran (Lintas, 1988; Onyeneho & Hettiarachchy 1992; Slavin, 2000). In durum wheat, ferulic acid is esterified to the primary alcoholic group of the arabinose side chains (Lintas, 1988). The mechanisms of ferulic acid and caffeic acid in inhibiting cancer are to prevent formation of carcinogens from precursor compounds or the reaction of carcinogen with important cellular macromolecules (Slavin, 2000). Other antioxidants including phytic acid, vitamin E and selenium are also present in significant amounts in grains. The mechanism of antioxidant activity of phytic acid is that it chelates with metals and thus reduces the damage from Fe-catalysed redox reactions while vitamin E avoids oxidative damage to polyunsaturated fatty acids in the cell membrane (Slavin, 2003). Selenium acts as a cofactor to glutathione peroxidase, an enzyme that works against oxidative reactions and reduces excessive cell proliferation (Slavin, 2003).

Some antioxidants formed during processing contribute to the total antioxidant activity of the grain products (Slavin, 2003). Non-enzymatic browning reactions such as the Maillard reaction can generate some products that display antioxidant properties (Amarowicz, 2009; Manzocco, Calligaris, Mastrocola, Nicoli, & Lerici, 2001). The colour change and antioxidant properties may have either a simple positive correlation or a complex correlation (Manzocco et al., 2001). Pasta had antioxidant or pro-oxidant properties depending on temperature, time and moisture conditions during the drying process (Anese et al., 1999). Food antioxidants are lost in significant amounts as a result of food processing, storage, home handling and cooking (Nicoli, Anese, Parpinel, Franceschi, & Lerici, 1997). The antioxidant capacity, role in disease prevention and levels generally consumed of several whole grain products have been reported (Marquart, Wiemer, Jones, & Jacob, 2003; Seal, 2006; Slavin, 2000, 2003). Whole grain pasta products have become available on the market; however, there is little or no literature on the antioxidant profile of spaghetti derived from whole durum wheat versus semolina. The aim of the present investigation was to conduct a comparative study on the antioxidant properties among brands of regular and whole wheat spaghetti. The effect of cooking on the phenolic content was also investigated.

2. Material and methods

2.1. Samples

Ten samples of commercial spaghetti were purchased from major supermarkets in Winnipeg (Manitoba, Canada). The regular spaghetti samples contained semolina as the main ingredient. They included Catelli and Splendor (Ronzoni Foods Canada Corporation, Montreal, QC), Primo (Primo Foods Inc., Toronto, ON), No Name (Loblaws Inc., Calgary, AB) and Safeway (Canada Safeway Limited, Calgary, AB) (Fig. 1). Catelli Smart, containing inulin as added fibre to impart the same benefits of whole wheat), was included as a control among the whole wheat spaghetti even though it is made from semolina. It has the same appearance, texture and flavour as that of regular spaghetti. The whole wheat spaghetti samples

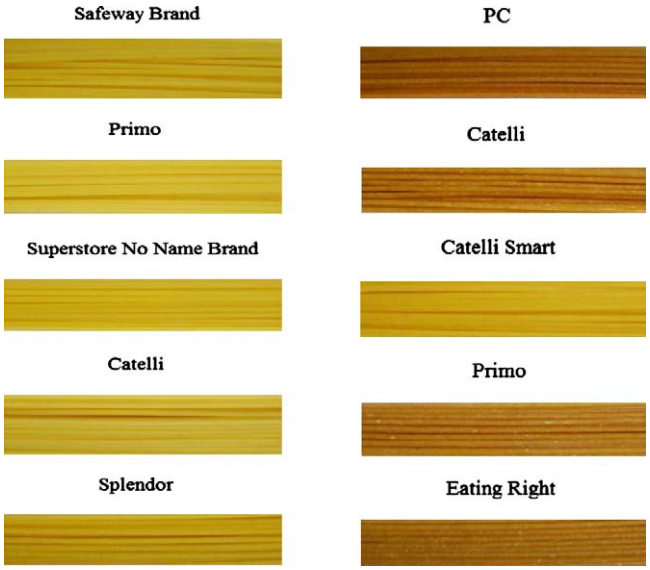

Fig. 1. Regular spaghetti (left) compared to whole wheat spaghetti (right). Catelli Smart was used as control sample among the whole wheat spaghetti since fibre, in the form of inulin, was added to its semolina to simulate the effects of bran found in whole wheat.

included Catelli (Ronzoni Foods Canada Corporation, Montreal, QC), Primo (Primo Foods Inc., Toronto, ON), President's Choice (PC) (Loblaws Inc., Calgary, AB), and Eating Right (Lucerne Foods, Calgary, AB) (Fig. 1). The spaghetti brands were selected such that they had almost the same ingredients with the exception of Catelli Smart which had inulin added, and PC which had durum whole wheat semolina listed as the only ingredient. Trolox, fluorescein and potassium phosphate monobasic used in the ORAC assay were purchased from Fisher Acros Organics (Morris Plains, NJ, USA). AAPH, rutin, Folin–Ciocalteu's phenol reagent, ferulic acid standard, and DPPH were purchased from Sigma–Aldrich (St. Louis, MO).

2.2. Sample preparation

Samples were divided into uncooked and cooked spaghetti. Cooked samples were prepared as follows: 750 mL of water was brought to boil; 17 g of regular or whole wheat spaghetti and half teaspoon of salt were then added. The spaghetti was cooked for 12 min and 20 s. The period was determined by tasting the cooked samples until they achieved *al dente*. Cooked spaghetti samples were frozen prior to freeze-drying (Thermo Electron Corporation, Waltham, MA). A sample mill (Black and Decker, Hunt Valley, MD) was used to grind the spaghetti so as to pass through a screen of 0.5 mm.

2.3. Extraction procedure

The extraction of antioxidant components in uncooked and cooked spaghetti was adapted from methods by Li, Pickard, and Beta (2007). Finely ground spaghetti (1 g) was extracted with ethanol (95%) and 1 M HCl/95% ethanol (w/v, 15/85) (10 mL). The mixture was shaken for 1 h at ambient temperature in a dark room using a wrist action shaker (Burrell, Pittsburgh, PA) and centrifuged at 7800*g* (10,000 rpm, SS-34 Rotors, RC5C Sorvall Instruments) at 5 °C for 15 min. The supernatant was collected using a pipette and transferred into a sample vial. The extractions were done in triplicate. The supernatants were stored in the dark at −20 °C for DPPH radical scavenging activity, total phenolic content (TPC) and oxygen radical absorbance capacity (ORAC) analyses.

2.4. Total phenolic content determination

The TPC of the extracts from spaghetti samples were measured following modifications of the Folin–Ciocalteu method (Li et al., 2007). The Folin–Ciocalteu's phenol reagent was first diluted 10 times and 200 μL of extract added to 1.5 mL of the diluted Folin–Ciocalteu's phenol reagent. Sodium carbonate solution (60 g/L) (1.5 ml) was then added to the mixture. The reaction was allowed to take place at room temperature for 120 min. The absorbance of the solution was measured at 725 nm against a blank of distilled water. Ferulic acid was used as a standard and the results were reported in μg ferulic acid equivalents/g. All analyses were conducted in triplicate.

2.5. DPPH radical scavenging activity assay

The DPPH assay was used following the modifications of Beta et al. (2005). Sixty μmol/L of DPPH radical was prepared in 95% ethanol. DPPH solution (3.04 mL) was then added to 160 μL of the spaghetti extracts and the reaction allowed to take place for 30 min. Absorbance (A) of the solution was measured at 515 nm against a blank of 95% ethanol at t = 30 min. DPPH radical scavenging activity (%) of both samples and Trolox standards was calculated using the formula: $(1 - [A_{sample}/A_{control,t=0}] \times 100)$. A standard curve was created (Trolox concentration vs. %DPPH radical scavenging activity). The Trolox standards were used at 0, 125, 250, 375, and 500 μM. Based on the equation of the standard curve and the %DPPH radical scavenging activity of the samples, the concentration of the samples were calculated. Results were reported in μmol Trolox equivalent/g. All analyses were conducted in triplicate.

2.6. ORAC assay

The ORAC values were obtained following modifications of the procedure described in the literature (Huang, Ou, Hampsch-Woodill, Flanagan, & Prior, 2002). The measurement was taken using an FLx800 microplate fluorescence reader (BioTek Instruments, Inc., Winooski, VT) with fluorescence filters at excitation wavelength of 485/20 nm and an emission wavelength of 528/20 nm. The instrument was monitored by the software, KC4 3.0, version 29. A dilution factor of 500 from the supernatant fluid was used for the samples, rutin was used at 10 μM as a control, and Trolox standards were used at 0, 6.25, 12.5 and 50 μM. The remainder of the procedure was according to Li et al. (2007). The calculation of antioxidant capacity was based on the method used by Huang et al. (2002). A regression equation between the Trolox concentration and the net area under the fluorescence decay curve was constructed. The formula to obtain area under curve (AUC) was as follows:

$$\mathrm{AUC} = 0.5 + \frac{f_1}{f_0} + \cdots + \frac{f_i}{f_0} + \cdots + \frac{f_{49}}{f_0} + 0.5\frac{f_{50}}{f_0}$$

where f_0 = initial fluorescence reading at 0 min and f_i = fluorescence reading at time i min. Net AUC = AUC (blank) − AUC (sample). The final ORAC values were expressed as Trolox equivalent and determined according to the standard curve. All analyses were conducted in duplicate.

2.7. Extraction procedure prior to HPLC analysis

For analysis of the predominant phenolic acid, an HPLC method adapted from Li et al. (2007) was used. Sixty millilitres of 4 M NaOH were added to finely ground spaghetti and the mixture was incubated at ambient temperature for 4 h. Nitrogen was infused into the mixture for 5 min every hour during incubation. The mixture was acidified to pH 1.5–2.5 using ice-cold HCl (6 M) prior to centrifugation at 5 °C for 20 min at 7800g (10,000 rpm, SS-34 Rotors, RC5C Sorvall Instruments). The supernatant was extracted three times using ethyl acetate (70 mL). The organic phase was then dehydrated with sodium sulphate and further dried by using a rotary vacuum evaporator (RE-51 Rotary evaporator, Yamato Scientific America, Inc., Santa Clara, CA). Five millilitre of 50% methanol was added. The hydrolysate was filtered through a 0.45 μm PTFE filter prior to HPLC analysis.

2.8. HPLC analysis

Ferulic acid was quantified in the spaghetti samples by using Waters model 600 pump and controller with Waters 2489 UV/visible detector (Waters Corp., Milford, MA). Analysis was performed with a Gemini 5μ C18 110A column (150 mm × 4.60 mm) (Phenomenex®, Torrance, CA). A gradient of solvent A (1% acetic acid in water) and solvent B (1% acetic acid in methanol) was used for 22 min at a flow rate of 0.5 mL/min. The gradient was as follows: at 0 min 20% B, 4 min 23% B, 8–14 min 25% B, 14–19 min 27% B, 19–22 min 20% B. Detector was set at 320 nm. Identification of ferulic acid in the spaghetti samples was achieved by comparison of the retention time of the ferulic acid standard and samples spiked with the ferulic acid standard. The HPLC analyses were done in duplicate.

2.9. Statistical analysis

All data were converted to dry weight basis and reported as means of duplicate or triplicate analyses. One-way analysis of variance of results (i.e., phenolic content, DPPH and ORAC values) was performed using SAS statistical software version 9.1 (SAS Institute Inc., Cary, NC). Significant differences among sample means for uncooked – regular, uncooked – whole wheat, uncooked – versus cooked – regular and uncooked – versus cooked – whole wheat spaghetti were tested using Fisher's least significant difference (LSD) test at $p < 0.05$.

3. Results and discussion

3.1. Total phenolic content and antioxidant activity of uncooked, regular versus whole wheat spaghetti

Total phenolic content (TPC) was expressed as micrograms of ferulic acid equivalent per gram (μg/g) of spaghetti. Ferulic acid, the major phenolic acid in wheat, was used as a standard as previously reported (Beta et al., 2005; Mpofu et al., 2006). TPC of regular wheat spaghetti brands (Table 1) was significantly lower than that of whole wheat spaghetti brands (Table 2) ($p < 0.05$). Regular and whole wheat spaghetti had an average TPC of 865 and 1389 μg/g, respectively. Among the brands examined, TPC decreased to about 62% of the content found in whole wheat during production of regular spaghetti. Assuming at least an 8% loss during durum wheat milling (Borrelli, Troccoli, Di Fonzo, & Fares, 1999), the outer layers of wheat, particularly the 10% outer layers (Beta et al., 2005), are well-known to be concentrated in TPC. Regular spaghetti from different brands had TPC ranging from 718 to 927 μg/g. Primo and Splendor had the highest and lowest TPC, respectively; however, Catelli, Primo, No Name and Safeway did not show any significant differences at $p < 0.05$. Contrary to regular wheat, whole wheat spaghetti from different brands ranged from 1263 to 1529 μg/g for Catelli and Primo, respectively (Table 2). Catelli Smart, the control sample among the whole wheat spaghetti, exhibited TPC levels similar to those found in regular spaghetti, an indication that the inulin fibre lacked the phenolic phytochemical constituents in the bran of durum wheat.

Table 1
TPC, DPPH radical scavenging activity and oxygen radical absorbance capacity of uncooked regular pasta from different brands.[a]

Sample name	TPC (μg equivalent of ferulic acid/g)		DPPH (μmol equivalent of Trolox/g)		ORAC (μmol equivalent of Trolox/g)	
Catelli	892	a	0.94	d	34.3	d
Primo	927	a	1.60	b	87.9	b
Splendor	718	b	1.28	c	100.4	a
No Name	897	a	1.77	b	52.6	c
Safeway	892	a	2.32	a	59.5	c
LSD	61.33		0.19		10.19	

[a] LSD, least significant difference at $p = 0.05$ level of probability. Mean values for regular spaghetti samples having similar letters in the same column are not significantly different.

Table 2
Total phenolic content, DPPH radical scavenging activity and oxygen radical absorbance capacity of uncooked whole wheat pasta from different brands.[a]

Sample name	TPC (μg equivalent of ferulic acid/g)		DPPH (μmol equivalent of Trolox/g)		ORAC (μmol equivalent of Trolox/g)	
Catelli Smart –control	773	d	1.14	b	83.7	b
Catelli	1263	c	1.36	b	94.9	a
PC	1342	b,c	1.87	a	63.7	c
Primo	1529	a	1.08	b	79.8	b
Eating Right	1423	a,b	1.71	a	83.8	b
LSD	113.20		0.28		10.88	

[a] LSD, least significant difference at p = 0.05 level of probability. Mean values for whole wheat spaghetti samples having similar letters in the same column are not significantly different.

The DPPH and peroxyl radical scavenging activities of spaghetti were expressed as micromole Trolox equivalents per gram (μmol Trolox equiv/g) of spaghetti. There were no significant differences in average DPPH radical scavenging activity for regular (Table 1) and whole wheat (Table 2) spaghetti brands. The average DPPH radical scavenging activities for uncooked regular and whole wheat spaghetti were 1.6 and 1.5 μmol Trolox equiv/g, respectively. Significant differences were observed among spaghetti brands in each of the two categories, with the Safeway and PC brand displaying the highest DPPH radical scavenging activity among the regular and whole wheat samples, respectively. DPPH radical scavenging activity ranged from 0.94 to 2.32 μmol Trolox equiv/g and decreased in the order: Safeway > Primo > No Name > Splendor > Catelli for regular spaghetti. DPPH radical scavenging activity ranged from 1.08 to 1.87 μmol Trolox equiv/g among the whole wheat brands. In the latter category, PC and Eating Right had the highest DPPH scavenging capacity that did not differ significantly at $p < 0.05$. In a study by Amarowicz, Karamac, Weidner, Abe, and Shahidi (2002), DPPH radical scavenging of wheat caryopses and embryos was tested. The range fell between 0.6 and 0.8, measured at 20 min at 517 nm and the concentration of the extracts were 2 mg/0.1 mL (Amarowicz et al., 2002). The range of absorbance of the spaghetti samples were 0.3–0.6, measured at 30 min at 515 nm and the concentration of the extracts were 100 mg/0.16 mL. The lower absorbance or higher DPPH radical scavenging activity of the spaghetti samples is likely due to higher concentration of the extracts.

Similar to the DPPH free radical scavenging activity, the ORAC values were expressed as micromole Trolox equivalent per gram (μmol Trolox equiv/g) of spaghetti. ORAC values ranged from 34 for Catelli to 100 μmol Trolox equiv/g for Splendor among the regular brands (Table 1). Primo had higher ORAC values than No Name and Safeway both of which did not differ significantly in their peroxyl free radical scavenging. Whole wheat spaghetti had ORAC values ranging from 64 for PC to 95 μmol Trolox equiv/g for Catelli. There were no significant differences in ORAC values obtained for Catelli Smart (control), Primo and Eating Right.

The average ORAC values for regular (67 μmol Trolox equiv/g) and whole wheat (81 μmol Trolox equiv/g) (Tables 1 and 2) spaghetti were not significantly different; however, differences ($p < 0.05$) in ORAC values were observed among the individual brands of regular or whole wheat spaghetti with Catelli (regular) and PC (whole wheat) scoring the lowest values in the two categories. Liyana-Pathirana and Shahidi (2007) reported ORAC values of 48 ± 2 and 100 ± 1 μmol Trolox equiv/g for semolina and whole grain, respectively for one Canadian Western Amber Durum wheat. The respective values were somewhat similar to the averages found in this investigation on regular and whole wheat spaghetti although genetic and environmental factors and processing conditions also affect the antioxidant levels of wheat (Mpofu, Beta, & Sapirstein, 2007; Zhou & Yu, 2004). We substantiate the study by Liyana-Pathirana and Shahidi (2007) by emphasizing the potential and full health benefits to be derived from the consumption of whole grain products containing natural antioxidants such as whole wheat pasta.

While TPC was highest for Primo, there was no consistent trend between the total phenolic content and the overall antioxidant activity (DPPH radical scavenging activity and ORAC values) of the regular and whole wheat spaghetti may be due not only to the underlying mechanisms of the assays employed but also to the varying degrees of reactivity of several components in the extracts. Overall, Primo had high to medium levels of antioxidant capacity among the regular spaghetti samples. PC and Eating Right had higher DPPH radical scavenging activity than other whole wheat brands. Primo also maintained high to medium levels of antioxidant capacity among the whole wheat spaghetti samples.

3.2. Ferulic acid content of uncooked, regular- and whole-wheat spaghetti

HPLC chromatograms of the ferulic acid standard and samples (regular and whole wheat spaghetti) are shown in Fig. 2. Ferulic acid was detected in two of the regular brands and in all of the whole wheat spaghetti samples (Table 3). The ferulic acid content in No Name and Safeway regular spaghetti brands were 44 and 54 μg/g respectively. Ferulic acid was not detected in Catelli, Primo and Splendor. The control (Catelli Smart), with added inulin fibre to imitate the bran in whole wheat, had negligible amounts of ferulic acid. Whole wheat spaghetti samples had ferulic acid contents ranging from 214 to 273 μg/g. Whole wheat spaghetti samples

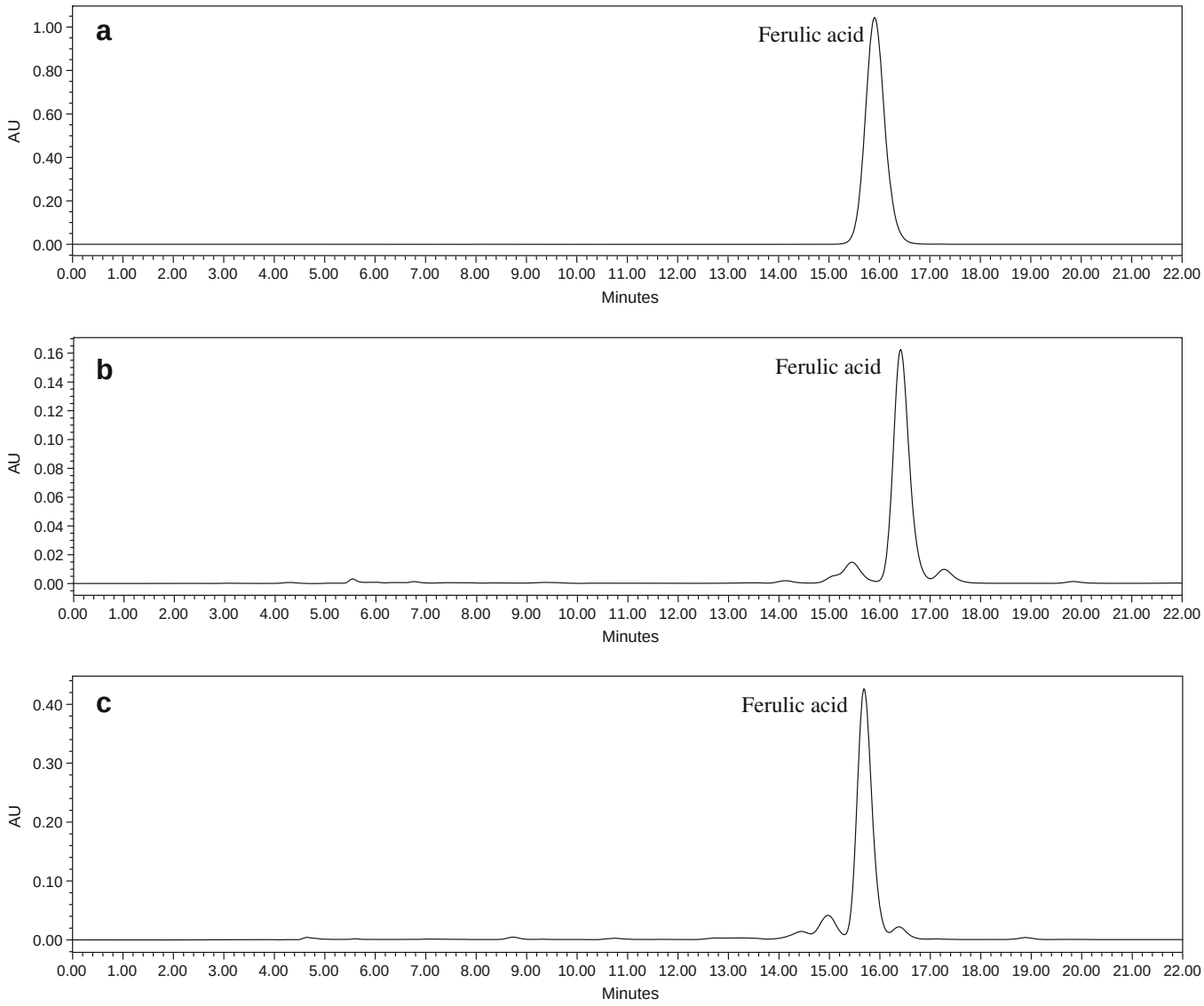

Fig. 2. (a) HPLC chromatograph for ferulic acid standard measured at 320 nm; (b) HPLC chromatograph showing the dominant ferulic acid peak for No Name regular spaghetti measured at 320 nm; (c) HPLC chromatograph showing the dominant ferulic acid peak for Primo whole wheat spaghetti measured at 320 nm.

Table 3
Ferulic acid content of uncooked regular and whole wheat pasta from different brands[a].

Regular	Ferulic acid content (μg/g)		Whole wheat	Ferulic acid content (μg/g)	
Catelli	nd		Catelli Smart (C)	6	d
Primo	nd		Catelli	215	c
Splendor	nd		PC	273	a
No Name	54	a	Primo	214	c
Safeway	44	a	Eating Right	234	b
LSD	9		LSD	10	

[a] LSD, least significant difference at $p = 0.05$ level of probability. For each brand, mean values of cooked and uncooked spaghetti having similar letters in the same column are not significantly different.

had significantly higher ferulic acid content than regular and the inulin-enriched spaghetti samples ($p < 0.05$). The results on ferulic acid content were generally in agreement with the average values of the TPC discussed above.

In one study, the free and esterified ferulic acid content for whole grain of Canadian Western Amber Durum was 46.43 ± 0.13 μg/g (Liyana-Pathirana & Shahidi, 2007). In another study, Jennah Khetifa (red spring durum) and Cham1 (white spring durum) had total ferulic acid contents of 148 and 303 μmol of ferulic acid/100 g of grain, respectively (Adom et al., 2002). Weidner, Amarowicz, Karamac, and Dabrowski (1999) found values of 1.99, 13.51, 1.33 and 16.83 μg/g for free, soluble esters, soluble glycosides and total content of ferulic acids in wheat (cv. Alba) caryopses. They also found values of 2.00, 24.91, 3.47 and 30.38 μg/g for free, soluble esters, soluble glycosides and total content of ferulic acids in wheat (cv. Elena) (Weid-

Table 4
Total phenolic content of uncooked vs. cooked regular pasta from different brands[a].

Regular	μg equivalent of ferulic acid/g		Whole wheat	μg equivalent of ferulic acid/g	
Uncooked Catelli	892	a	Uncooked Catelli Smart (C)	773	a
Cooked Catelli	509	b	Cooked Catelli Smart (C)	530	b
LSD	60		LSD	108	
Uncooked Primo	927	a	Uncooked Catelli	1236	a
Cooked Primo	443	b	Cooked Catelli	831	b
LSD	74		LSD	117	
Uncooked Splendor	718	a	Uncooked Primo	1529	a
Cooked Splendor	564	b	Cooked Primo	844	b
LSD	47		LSD	119	

[a] LSD, least significant difference at $p = 0.05$ level of probability. For each brand, mean values of cooked and uncooked spaghetti having similar letters in the same column are not significantly different.

ner et al., 1999). However, whole wheat spaghetti products averaged 234 μg/g in ferulic acid levels (free and bound ferulic acids). Since genetic and environmental variation in ferulic acid content is recognised among wheat varieties (Adom et al., 2002; Mpofu et al., 2006), it is likely that durum wheat pasta products will vary in phenolic composition. Processing durum into semolina led to considerable losses of ferulic acid such that it could not be detected in other regular brands. Addition of fibre other than the cereal bran is unlikely to restore the phenolic constituents in the final semolina product.

3.3. Effects of cooking on total phenolic content of regular and whole wheat spaghetti

Since there was no significant difference in antioxidant activity between the regular and whole wheat spaghetti samples, the effect of cooking on antioxidant properties was evaluated by determining the total phenolic content (TPC) only for Catelli, Primo and Splendor. Both regular and whole wheat spaghetti showed significant differences in TPC before and after cooking (Table 4). There was a 39% overall decrease in TPC of regular and whole wheat spaghetti after cooking. The average TPC differed significantly ($p < 0.05$) for uncooked (846 μg/g) and cooked (505 μg/g) regular brands. Catelli Smart, the inulin fibre-enriched spaghetti had a 31% decrease in TPC after cooking. TPC decreased significantly ($p < 0.05$) from 1529 to 844 μg/g after cooking Primo whole wheat spaghetti. There is very little literature on phenolic content and antioxidant properties of processed durum wheat, particularly the recently introduced whole wheat pasta products. The ferric reduction-antioxidant capacity of four commercial brands of regular spaghetti decreased after cooking (Halvorsen et al., 2006). The antioxidant components (mmol of electrons/hydrogen atoms donated in the redox reaction per 100 g sample), calculated as percentage of the nonprocessed food ranged from 42% to 63% for spaghetti cooked by steaming. Although the redox-active compounds in methanol/water (9:1, v/v) extracts were not identified in the study (Halvorsen et al., 2006), it is likely that they were phenolic constituents. Other compounds exhibiting antioxidant activity are known to be present in significant amounts in whole grain products. Harris, Quaife, and Swanson (1950) confirmed that cereal products are among the most important sources of vitamin E. For example, wheat spaghetti had tocopherol content of 1.20 mg/100 g of fresh material and 1.3 mg/g of extracted lipid while other food groups such as fruits had lower tocopherol content (0.23–0.72 mg/100 g of fresh material). Based on the ability to inhibit the peroxyl-radical-induced reaction, vitamin E minimises oxidation by free radicals that can cause destruction to the cell membranes of the human body. Given that it is not very stable especially in the presence of reducing agents such as oxygen and light (Leskova et al., 2006), vitamin E will likely undergo destruction during drying and cooking of spaghetti.

Browning reactions in grain-based products may also contribute to antioxidant properties due to the development of melanoidins during the high temperature drying of pasta (Manzocco et al., 2001; Slavin, 2003). These compounds likely survived the final cooking process. The antioxidant properties of pasta depend on the temperature, time and moisture conditions of the drying process (Anese et al., 1999). High antioxidant activity is often associated with the formation of brown melanoidins in Maillard reaction (Manzocco et al., 2001). Maillard reaction can easily occur under certain conditions which apply high temperature and equilibrium relative humidity values ranging from 30% to 12%; however, very high temperature is needed before brown products including melanoidins occur and off-flavours are detected (Anese et al., 1999). Anese et al. (1999) found that anti-radical activity decreases at earlier stages and increases at later stages in both low and high temperature drying. However, high temperature drying for a longer duration resulted in sharper increase in anti-radical activity. Intermediate and advanced Maillard reaction products (MRPs) are generally known to have antioxidant and antimutagenic properties while other studies report on their pro-oxidant and mutagenic properties (Anese et al., 1999). The latter proposed that high molecular weight, brown MRPs were likely involved in the chain breaking activity of pasta supporting the idea that heat-induced antioxidants compensate for the thermal loss of the naturally-occurring phenolic compounds. Further investigations on the health implications of the Maillard reaction in pasta drying as well as the characterization of MRPs in cooked spaghetti are still needed.

4. Conclusion

Whole wheat spaghetti brands exhibited significantly higher contents of phenolic compounds and ferulic acid than regular spaghetti brands; however, they were no significant differences in mean DPPH and peroxyl radical scavenging activities between the two categories. The discrepancies between the trends of the total phenolic content and the antioxidant capacity was likely caused by the presence of other antioxidant components such as the Maillard reaction products formed during pasta drying. A 40% reduction in total phenolic content of both regular and whole wheat spaghetti brands was observed after cooking.

References

Adom, K. K., Sorrell, M. E., & Liu, R. H. (2002). Phytochemical profiles and antioxidant activity of wheat varieties. *Journal of Agricultural and Chemistry, 51*, 7825–7834.
Amarowicz, R. (2009). Antioxidant activity of Maillard reaction products. *European Journal of Lipid Science and Technology, 111*, 109–111.
Amarowicz, R., Karamac, M., Weidner, S., Abe, S., & Shahidi, F. (2002). Antioxidant activity of wheat caryopses and embryos extracts. *Journal of Food Lipids, 9*, 201–210.
Anese, M., Nicoli, M. C., Massini, R., & Lerici, C. R. (1999). Effects of drying processing on the Maillard reaction in pasta. *Food Research International, 32*, 193–199.

Baic, S. (2005). Whole grains – The way to go. . .. In *The food fact sheet by the British Dietetic Association* (pp. 1–2). UK: The British Dietetic Association.

Beta, T., Nam, S., Dexter, J. E., & Sapirstein, H. D. (2005). Phenolic content and antioxidant activity of pearled wheat and roller mill fractions. *Cereal Chemistry, 82*, 390–393.

Borrelli, G. M., Troccoli, A., Di Fonzo, N., & Fares, C. (1999). Durum wheat lipoxygenase activity and other quality parameters that affect pasta color. *Cereal Chemistry, 76*, 335–340.

Dalbon, G., Grivon, D., & Pagani, M. A. (1996). Pasta continuous manufacturing process. In K. E. Kruger, R. B. Matso, & J. W. Dick (Eds.), *Pasta and noodle technology* (pp. 13–58). Minneapolis: American Association of Cereal Chemists International.

Donnelly, B. J., & Ponte, J. G. (2000). Pasta: Raw materials and processing. In K. Kulp & J. G. Pointe (Eds.), *Handbook of cereal science and technology* (pp. 647–666). Boca Raton: CRC Press.

Goldstein, J. L., & Brown, M. S. (1977). The low-density lipoprotein pathway and its relation to atherosclerosis. *Annual Review of Biochemistry, 46*, 897–930.

Halvorsen, B. L., Carlsen, M. H., Phillips, K. M., Bøhn, S. K., Holte, K., Jacobs, D. R., et al. (2006). Content of redox-active compounds (i.e., antioxidants) in foods consumed in the United States. *American Journal of Clinical Nutrition, 84*, 95–135.

Harris, P. L., Quaife, M. L., & Swanson, W. J. (1950). Vitamin E content of foods. *Journal of Nutrition, 40*, 367–381.

Hentschel, V., Kranl, K., Hollmann, J., Lindhauer, M. G., Bohm, V., & Bitsch, R. (2002). Spectrophotometric determination of yellow pigment and evaluation of carotenoids by high-performance chromatography in durum wheat grain. *Journal of Agricultural and Food Chemistry, 50*, 6663–6668.

Huang, D., Ou, B., Hampsch-Woodill, M., Flanagan, J. A., & Prior, R. L. (2002). High-throughput assay of oxygen radical absorbance capacity (ORAC) using a multichannel liquid handling system coupled with a microplate fluorescence reader in 96-well format. *Journal of Agricultural and Food Chemistry, 50*, 4437–4444.

Leskova, E., Kubikova, J., Kovacikova, E., Kosicka, M., Porusbka, J., & Holcikova, K. (2006). Review, vitamin losses: Retention during heat treatment and continual changes expressed by mathematical models. *Journal of Food Composition and Analysis, 19*, 252–276.

Li, W., Pickard, M. D., & Beta, T. (2007). Evaluation of antioxidant activity and electronic taste and aroma properties of antho-beers from purple wheat grain. *Journal of Agricultural and Food Chemistry, 55*, 8958–8966.

Lintas, C. (1988). Carbohydrates of durum wheat. In G. Fabriani & C. Lintas (Eds.), *Durum chemistry and technology* (pp. 124–130). Minneapolis: American Association of Cereal Chemist International.

Liyana-Pathirana, C. M., & Shahidi, F. (2007). The antioxidant potential of milling fractions from breadwheat and durum. *Journal of Cereal Science, 45*, 238–247.

Manzocco, L., Calligaris, S., Mastrocola, D., Nicoli, M. C., & Lerici, C. R. (2001). Review of non-enzymatic browning and antioxidant capacity in processed foods. *Trends in Food Science and Technology, 11*, 340–346.

Marconi, E., & Carcea, M. (2001). Pasta from nontraditional raw materials. *Cereal Foods World, 46*, 522–529.

Mariani-Constantini, A. (1988). Image and nutritional role of pasta in changing food patterns. In G. Fabriani & C. Lintas (Eds.), *Durum wheat: Chemistry and technology* (pp. 283–298). Minneapolis: American Association of Cereal Chemist International.

Marquart, L., Wiemer, K. L., Jones, J. M., & Jacob, B. (2003). Whole grain health claims in the USA and other efforts to increase whole-grain consumption. *Proceedings of the Nutrition Society, 62*, 151–160.

Mpofu, A., Sapirstein, H. D., & Beta, T. (2006). Genotype and environmental variation in phenolic content, phenolic acid composition and antioxidant activity of hard spring wheat. *Journal of Agricultural and Food Chemistry, 54*, 1265–1270.

Mpofu, A., Beta, T., & Sapirstein, H. (2007). Effects of genotype, environment and genotype × environment interaction on the antioxidant properties of wheat. In L. Yu (Ed.), *Wheat antioxidants* (pp. 24–41). New Jersey: John Wiley & Sons Inc..

Mustad, V. A., Etherton, T. D., Cooper, A. D., Mastro, A. M., Pearson, T. A., Jonnalagadda, S. S., et al. (1997). Reducing saturated fat intake is associated with increased levels of LDL receptors on mononuclear cells in healthy men and women. *Journal of Lipid Research, 38*, 459–468.

Nicoli, M. C., Anese, M., Parpinel, M. T., Franceschi, S., & Lerici, C. R. (1997). Loss and/or formation of antioxidants during food processing and storage. *Cancer Letter, 114*, 71–74.

Onyeneho, S. N., & Hettiarachchy, N. S. (1992). Antioxidant activity of durum wheat bran. *Journal of Agricultural and Food Chemistry, 40*, 1496–1500.

Seal, C. J. (2006). Whole grains and CVD risks. *Proceedings of the Nutrition Society, 65*, 24–34.

Shahidi, F. (1997). Natural antioxidants: An overview. In F. Shahidi (Ed.), *Natural antioxidants: Chemistry, health effects, and applications* (pp. 1–11). Illinois: The American Oil Chemists Society (AOCS) Press.

Shahidi, F. (2000). Antioxidants in food and food antioxidants. *Nahrung, 44*, 158–163.

Slavin, J. (2000). Mechanism for the impact of whole grain foods on cancer risk. *Journal of the American College of Nutrition, 19*, 300–307.

Slavin, J. (2003). Why whole grains are protective: Biological mechanisms. *Proceedings of the Nutrition Society, 62*, 129–134.

Weidner, S., Amarowicz, R., Karamac, M., & Dabrowski, G. (1999). Phenolic acids in caryopses of two cultivars of wheat, rye and triticale that display different resistance to pre-harvest sprouting. *European Food Research and Technology, 210*, 109–113.

Zielinski, H., & Kozlowska, H. (2000). Antioxidant activity and total phenolics in selected cereal grains and their different morphological fractions. *Journal of Agricultural and Food Chemistry, 48*, 2008–2016.

Zhou, K., & Yu, L. (2004). Antioxidant properties of bran extracts from Trego wheat grown at different locations. *Journal of Agricultural and Food Chemistry, 52*, 1112–1117.