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Processed Sweet Corn Has Higher Antioxidant Activity

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Processed fruits and vegetables have been long considered to have lower nutritional value than the fresh produce due to the loss of vitamin C during processing. Vitamin C in apples has been found to contribute <0.4% of total antioxidant activity, indicating most of the activity comes from the natural combination of phytochemicals. This suggests that processed fruits and vegetables may retain their antioxidant activity despite the loss of vitamin C. Here it is shown that thermal processing at 115 °C for 25 min significantly elevated the total antioxidant activity of sweet corn by 44% and increased phytochemical content such as ferulic acid by 550% and total phenolics by 54%, although 25% vitamin C loss was observed. Processed sweet corn has increased antioxidant activity equivalent to 210 mg of vitamin C/100 g of corn compared to the remaining 3.2 mg of vitamin C in the sample that contributed only 1.5% of its total antioxidant activity. These findings do not support the notion that processed fruits and vegetables have lower nutritional value than fresh produce. This information may have a significant impact on consumers' food selection by increasing their consumption of fruits and vegetables to reduce the risk of chronic diseases.

KEYWORDS: Phenolics; antioxidant; phytochemicals; ferulic acid; grains; processing; sweet corn

INTRODUCTION

Cardiovascular disease and cancer are ranked first and second, respectively, as the leading causes of death in the United States. Approximately 35% of deaths due to cancer in the United States are related to diet (*1*). Regular consumption of fruits, vegetables, and grains is associated with reduced risk of chronic diseases such as cancer, coronary heart disease, diabetes, Alzheimer's disease, cataract, and age-related functional decline (*2*, *3*). Therefore, dietary modification is a practical strategy for the prevention of chronic diseases. The original aim of Recommended Dietary Allowances (RDA) to prevent clinical nutrient deficiencies has been shifted to focus on prevention of diseases such as cancer, coronary heart disease, and birth defects (*4*). The U.S. Department of Agriculture (USDA) has recommended eating 6−11 servings of grain products daily, and these foods comprise the base of the USDA food guide pyramid. This recommendation is designed to increase public awareness of the health benefits of grain consumption. Many of the protective compounds in whole grains are also found in fruits and vegetables, but some of these plant compounds such as phenolics, including ferulic acid, are unique to grains.

In the United States, the farm value of sweet corn for processing ranks second only to tomatoes, and the total U.S. acreage of processing sweet corn harvested in 1997 was 464,220 acres. Approximately 52% of the acreage was devoted to sweet corn for canning. Sweet corn is generally consumed as processed in canned sweet corn, tortillas, and bakery and snack foods. Because most of the grain-based products consumed are heat-processed, it is imperative to know its nutritional quality after processing. It is a conventional wisdom that processed fruits and vegetables have a lower nutritional values than their respective fresh commodities due to the loss of vitamin C content in the processing (*6*−9). Our research group found vitamin C in apples contributed <0.4% of the total antioxidant activity, indicating most of the activity comes from the natural combination of phytochemicals (*10*). This suggests that processed fruits and vegetables may retain their antioxidant activity despite the loss of vitamin C. In another previous study, we demonstrated that thermal processing of tomatoes significantly increased the bioaccessible lycopene content and the total antioxidant activity, whereas no significant change on total phenolics content was observed (*11*). However, lycopene is the predominant phytochemical present in tomatoes and its total phenolics content is low. It is not clear how thermal processing affects the quality of phenolic-rich produce. Therefore, the objective of this study was to evaluate the effect of thermal processing on the antioxidant activity of sweet corn by assessing contents of total phenolics, vitamin C, and ferulic acid and the total antioxidant activity of the raw and thermally processed sweet corn.

MATERIALS AND METHODS

Chemicals. Folin−Ciocalteu reagent, hydrochloric acid, ferulic acid, and α-keto-γ-methiolbutyric acid (KMBA) were obtained from Sigma Chemical Co. (St. Louis, MO). Sodium hydroxide, acetonitrile, and methanol were purchased from Fisher Scientific (Pittsburgh, PA). Gallic

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acid and metaphosphoric acid were purchased from ICN Biomedical Inc. (Costa Mesa, CA). Hexane and ethyl acetate were purchased from Mallinckrodt (Paris, KY). 2,2′-Azobis(amidinopropane) (ABAP) was obtained from Wako Chemicals (Richmond, VA). Ethanol was purchased from Pharmaco Products (Brookfields, CT). All reagents used were of analytical grade.

Sample Preparation. Yellow sweet corn (*Zea mays*) was purchased from a local supermarket. Twenty-five ears were dehusked, and the kernels were removed from the cobs and placed into a container. The collected corn kernels were mixed to obtain a homogeneous sample before being packaged in 8.8 cm (H) by 6.2 cm (D) cans. Six replicates were subjected to six different treatments: raw, cooked at 115 °C for 10, 25, or 50 min (commercial processing condition for canned corn is at 115 °C for 25 min); and cooked at 100 and 121 °C for 25 min. The raw treatment consisted of storing the corn kernels in sealed cans without any thermal treatment. The other treatments involved retort heating of the canned corn in the pilot plant of the Department of Food Science, Cornell University. The temperatures and retort times were automatically monitored by the retort controller. All samples in each treatment were stored at −40 °C until use.

Extraction. *Extraction of Soluble Phytochemicals.* Soluble free and conjugated phytochemicals in sweet corn were extracted according to the method reported previously (*10*). Briefly, 50 g of sweet corn kernels was weighed and homogenized with 80% ethanol (1:2 w/w) for 5 min using a chilled Waring blender. Samples were then homogenized further using a Polytron homogenizer for an additional 3 min to obtain a thoroughly homogenized sample. The homogenates were centrifuged at 2200*g* for 15 min. After centrifugation, the 80% ethanol supernatant was separated from the residue. The residues were saved for extraction of bound phytochemicals. The supernatants were evaporated under vacuum at 45 °C. The free phytochemical sweet corn extracts were frozen at −40 °C until analysis

Extraction of Bound Phytochemicals. Bound phytochemicals of sweet corn were extracted according to a modification of the method reported previously (*12*). Briefly, 2 g of samples of the sweet corn residues after free phytochemical extraction were flushed with nitrogen gas and hydrolyzed directly with 4 N NaOH at room temperature for 1 h with shaking. After the solution was acidified to pH 2 with concentrated HCl, hexane was added to defat. Then bound phytochemicals were extracted six times by ethyl acetate. The solvent was evaporated under vacuum at 45 °C to obtain the bound phytochemical extracts of sweet corn that were frozen at −40 °C until analysis. Extracts from free phenolic extractions were used for soluble conjugated phenolic extractions using the method described above.

Determination of L-Ascorbic Acid Content. Total L-ascorbic acid content was determined using the 2,6-dicholorophenol (DIP) titrimetric method adapted from the *Official Methods of Analysis of the Assocation of Official Analytical Chemists* (*13*). All values were expressed as mean ± SD micrograms of ascorbic acid per gram of corn for three replications. The $D_{115°C}$ value of vitamin C was calculated as the time in minutes at 115 °C to have 90% reduction in vitamin C content.

Determination of Total Phenolic Content. Samples were analyzed spectrophotometrically for total phenolic contents using a modified Folin−Ciocalteu colorimetric method (*10*, *14*). Results were reported as mean ± SD for three replications. The principle of this assay is the reduction of the Folin−Ciocalteu reagent (FCR) in the presence of phenolates, resulting in the production of molybdenum−tungsten blue that is measured spectrophotometrically with a DU series 600 spectrophotometer. All sweet corn extracts were diluted with Milli-Quartz water to a 1:5 dilution in order to obtain readings that fall within the standard curve concentration range of 0.0−600.0 μg of gallic acid/mL. For each analysis, 125 μL of the standard gallic acid solution or 1:5 diluted sweet corn extract was added to 0.5 mL of Milli-Quartz water in a test tube. Then 125 μL of FCR was added, and the sample was mixed well to ensure that the FCR reacted completely and rapidly with the oxidizable phenolates in the sample. Each sample was then allowed to stand for 6 min before addition of the alkali sodium carbonate. Following that, 1.25 mL of a 7% sodium carbonate aqueous solution was added to raise the pH for phenols to be oxidized rapidly to phenolates only in alkaline condition. One milliliter of water was then added to each sample to adjust the final volume to 3 mL. After 90 min, at room temperature, the intensity of the blue color was measured at 760 nm versus the prepared blank in comparison with standards prepared similarly with known gallic acid concentrations. All values were expressed as mean (microgram gallic acid equivalents per gram of corn) ± SD for three replications.

HPLC Analysis of Ferulic Acid. Free and bound sweet corn extracts were diluted with acidified methanol (pH 2) prior to analysis. Ferulic acid was isolated on a Supelcosil LC-18-DB, 150 × 4.6 mm, 3 μm, column with isocratic elution of 20% actonitrile in water adjusted to pH 2 with trifluoroacetic acid at flow rate of 0.6 mL/min. Detection was at a wavelength of 280 nm with a Waters 484 UV−visible detector (Waters Corp., Milford, MA). Detector signals were acquired and integrated by Waters Millenium software (Waters Corp.). Peak identification of free ferulic acid in sample extracts was based on retention time and cochromatography of authentic ferulic acid standard (ICN Biomedical Inc.). Ferulic acid concentrations in samples were calculated by extrapolation on the calibration curve. Ten microliter injections were used for all analyses. The recovery of ferulic acid analysis was 105.13 ± 5.23% ($n = 3$).

Quantification of the Total Antioxidant Activity. The total antioxidant activity of the free and bound phytochemical extracts from sweet corn was measured by using a modified total oxyradical scavenging capacity (TOSC) assay (*10*, *15*). Antioxidant activity was assessed at four different time points (15, 30, 45, and 60 min) and six different extract concentrations to determine the TOSC value. The TOSC value for each concentration of sweet corn sample was calculated using the integration of the area under the kinetic curve. The TOSC value for each concentration was quantified according to the equation

$$\mathrm{TOSC} = 100 - (\int \mathrm{SA}/\int \mathrm{CA} \times 100)$$

where ∫SA is integrated area from the sample reaction and ∫CA is the integrated area from the control reaction. For the sweet corn extract of each treatment, the median effective dose (EC_{50}) was determined from the dose−response curve of concentration of sweet corn versus TOSC. Using the median effective dose for each treatment, the TOSC value was determined and expressed as micromole vitamin C equivalents per gram of sweet corn. All TOSC values are presented as mean ± SD for three replicates.

Statistical Analysis. Statistical analyses were conducted using SigmaStat version 1.0 (Jandel Corp., San Rafael, CA). Differences among treatments were determined using a *t* test. For relationship plots, significance of the relationship was determined by regression analysis of variance.

RESULTS

Vitamin C content declined with increased heating time at 115 °C, which is consistent with previous results (*6*−*9*). The raw sweet corn had the highest vitamin C content (0.24 ± 0.02 μmol of vitamin C/g of corn). After heating at 115 °C for 10, 25, and 50 min (commercial processing conditions for canned sweet corn are at 115 °C for 25 min), the vitamin C contents dropped to 0.20 ± 0.01, 0.18 ± 0.01, and 0.13 ± 0.02 μmol of vitamin C/g of corn with significant decreases by 16.7% ($p < 0.05$), 25.0% ($p < 0.05$), and 45.8% ($p < 0.01$), respectively (**Figure 1A**). After heating at 100, 115, and 121 °C for 25 min, the vitamin C content dropped to 0.22 ± 0.01, 0.18 ± 0.01, and 0.14 ± 0.01 μmol of vitamin C/g of corn with significant decreases by 8.3% ($p < 0.05$), 25.0% ($p < 0.05$), and 41.7% ($p < 0.01$) compared with unprocessed raw sweet corn, respectively (**Figure 1B**).

The total free phenolic content of the raw sweet corn was 250.0 ± 2.0 μg/g of corn. With thermal processing at 115 °C for 10, 25, and 50 min, the total free phenolic contents in the heat-treated sweet corn were 311.7 ± 15.9, 335.0 ± 18.0, and 337.7 ± 31.9 μg/g of corn with increases by 24.0, 32.0, and 36.0%, respectively ($p < 0.05$; **Figure 2A**). With thermal processing for 25 min at 100, 115, and 121 °C, the total free

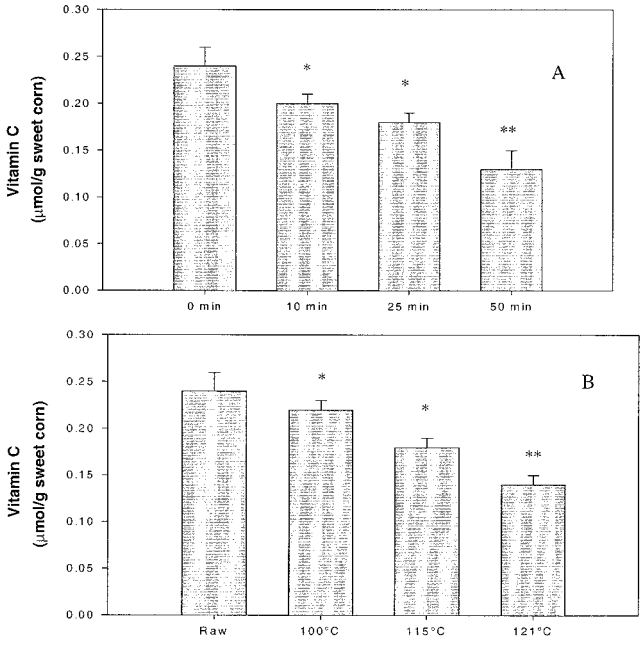

Figure 1. Effect of heat processing at 115 °C for 0, 10, 25, and 50 min (A) and at 100, 115, and 121 °C for 25 min (B) on vitamin C content in sweet corn (mean ± SD, $n = 3$). Significantly different from the control group: *, $p < 0.05$; **, $p < 0.01$.

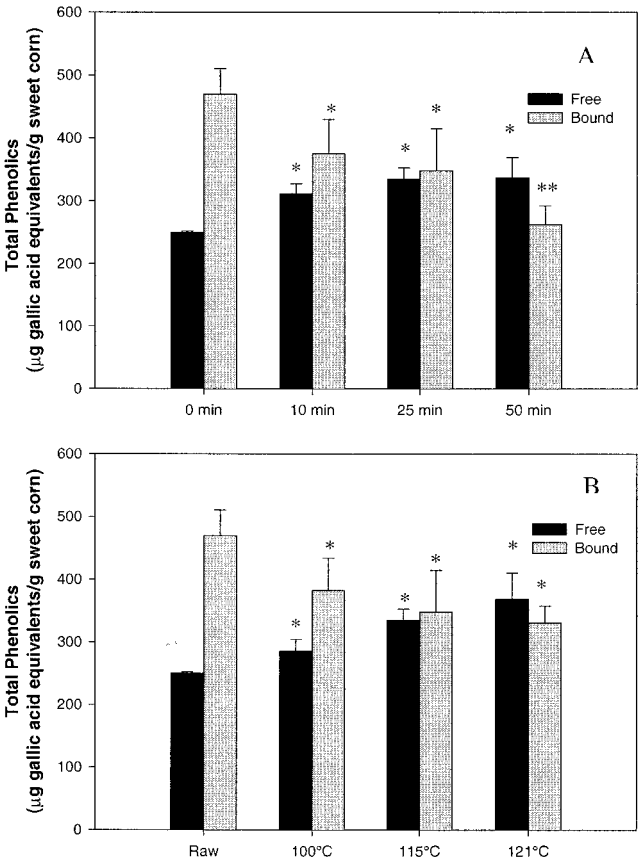

Figure 2. Effect of thermal processing at 115 °C for 0, 10, 25, and 50 min (A) and at 100, 115, and 121 °C for 25 min (B) on total free and bound phenolics content in sweet corn (mean ± SD, $n = 3$). Significantly different from the control group for total bound phenolics: *, $p < 0.05$; **, $p < 0.01$.

phenolic contents were 285.5 ± 18.9, 335.0 ± 18.0, and 368.7 ± 41.8 μg/g of corn with significant increases by 16.0, 32.0, and 48.0%, respectively ($p < 0.05$; **Figure 2B**). On the other hand, the bound phenolic content of the raw sweet corn sample was 470.0 ± 40.6 μg/g of corn. With thermal processing at 115 °C, the total bound phenolic contents in the 10, 25, and 50 min heat-treated sweet corn samples were 375.4 ± 54.3, 348.4 ± 66.8, and 262.3 ± 30.1 μg/g of corn with decreases by 19.2% ($p < 0.05$), 25.5% ($p < 0.05$), and 44.7% ($p < 0.01$), respectively (**Figure 2A**). With thermal processing for 25 min at 100, 115, and 121 °C, the total bound phenolic contents were 382.6 ± 51.9, 348.4 ± 66.8, and 330.9 ± 27.0 μg/g of corn with significant decreases by 19.2% ($p < 0.05$), 25.5% ($p < 0.05$), and 29.8% ($p < 0.05$), respectively (**Figure 2B**). The decrease in bound phenolic content across both heating time and heating temperature parameters was statistically significant between the raw sweet corn and the heat-treated sweet corn samples.

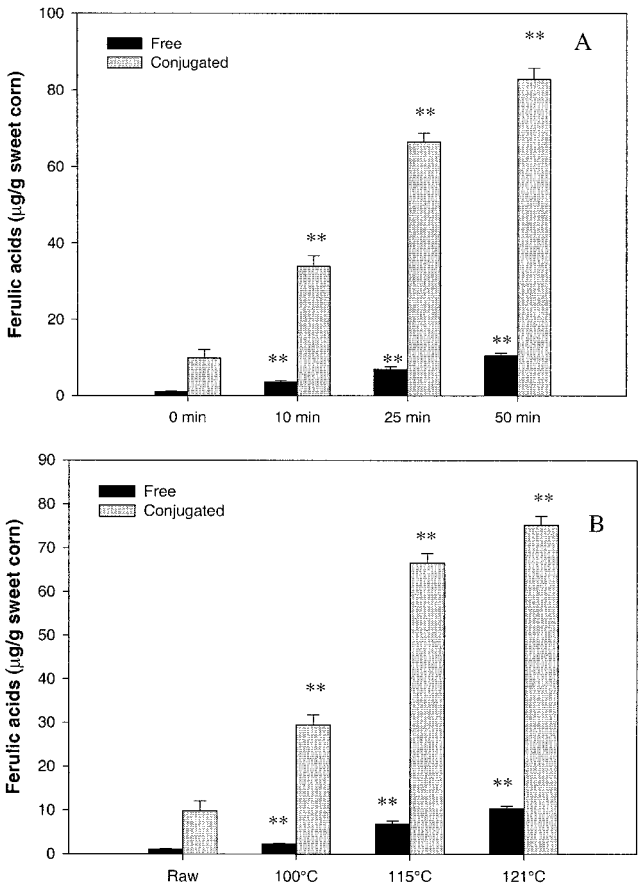

Figure 3. Effect of thermal processing at 115 °C for 0, 10, 25, and 50 min (A) and at 100, 115, and 121 °C for 25 min (B) on free and conjugated ferulic acid contents in sweet corn (mean ± SD, $n = 3$). Significantly different from the control group: **, $p < 0.01$.

The free ferulic acid content of the raw sweet corn was 1.05 ± 0.09 μg/g of corn. With thermal processing at 115 °C, the free ferulic acid contents in the 10, 25, and 50 min heat-treated sweet corn were 3.57 ± 0.38, 6.85 ± 0.74, and 10.45 ± 0.62 μg/g of corn with significant increases by 239.9, 553.3, and 896.3%, respectively (**Figure 3A**). With thermal processing for 25 min at 100, 115, and 121 °C, the free ferulic acid contents were 2.36 ± 0.15, 6.85 ± 0.74, and 10.35 ± 0.56 μg/g of sweet corn with significant increases by 124.8, 553.3, and 886.6%, respectively (**Figure 3B**). The increase in free ferulic acid content across both heating time and heating temperature parameters was statistically significant between the raw sweet corn and the heat-processed sweet corn ($p < 0.01$).

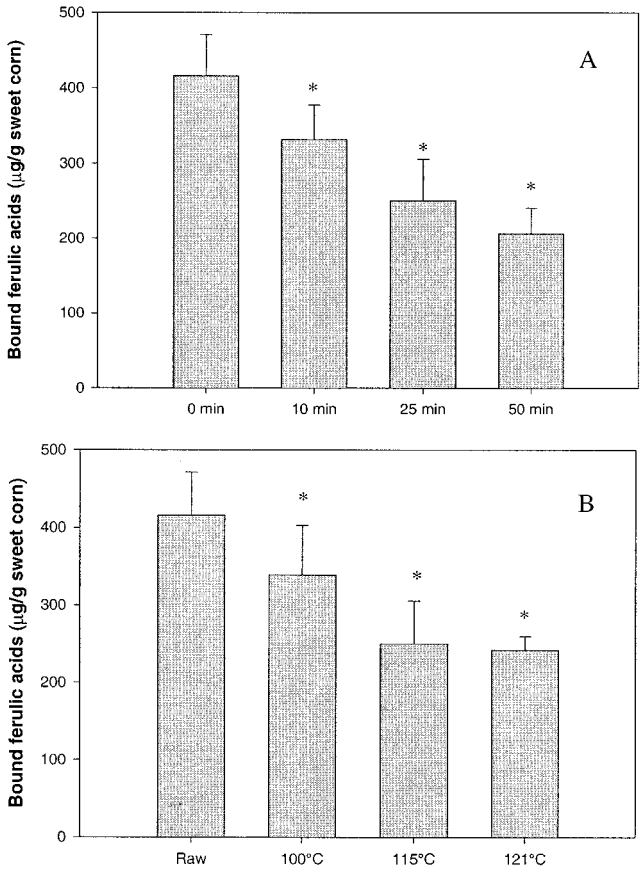

Figure 4. Effect of thermal processing at 115 °C for 0, 10, 25, and 50 min (A) and at 100, 115, and 121 °C for 25 min (B) on bound ferulic acid content in sweet corn (mean ± SD, $n = 3$). Significantly different from the control group: *, $p < 0.05$.

The soluble conjugated ferulic acid content of the raw sweet corn was 9.85 ± 2.26 μg/g of corn. With thermal processing at 115 °C, the conjugated ferulic acid contents in the 10, 25, and 50 min heat-treated sweet corn were 34.00 ± 2.66, 66.50 ± 2.23, and 82.86 ± 2.89 μg/g of corn with significant increases by 245.2, 575.1, and 741.2%, respectively (**Figure 3A**). With thermal processing for 25 min at 100, 115, and 121 °C, the conjugated ferulic acid contents were 29.52 ± 2.23, 66.50 ± 2.23, and 75.23 ± 2.04 μg/g of sweet corn with significant increases by 199.7, 575.1, and 663.8%, respectively (**Figure 3B**). The increase in conjugated ferulic acid content across both heating time and heating temperature parameters was statistically significant between the raw sweet corn and the heat-processed sweet corn ($p < 0.01$).

On the other hand, the bound ferulic acid content of the raw sweet corn sample was 415.87 ± 55.22 μg/g of sweet corn. With thermal processing at 115 °C, the total bound phenolic contents in the 10, 25, and 50 min heat-treated sweet corn samples were 331.25 ± 45.74, 250.14 ± 55.41, and 206.21 ± 34.35 μg/g of sweet corn with decreases by 20.3, 39.9, and 50.5%, respectively (**Figure 4A**). With thermal processing for 25 min at 100, 115, and 121 °C, the bound ferulic acid contents were 338.80 ± 64.22, 250.14 ± 55.41, and 241.83 ± 17.75 μg/g of corn with decreases by 18.5, 26.0, and 29.6%, respectively (**Figure 4B**). The decrease in bound ferulic acid content across both heating time and heating temperature parameters was statistically significant between the raw sweet corn and the heat-treated sweet corn samples ($p < 0.05$).

Thermal treatment at 115 °C increased the total antioxidant activity of the free phytochemical sweet corn extracts. The raw

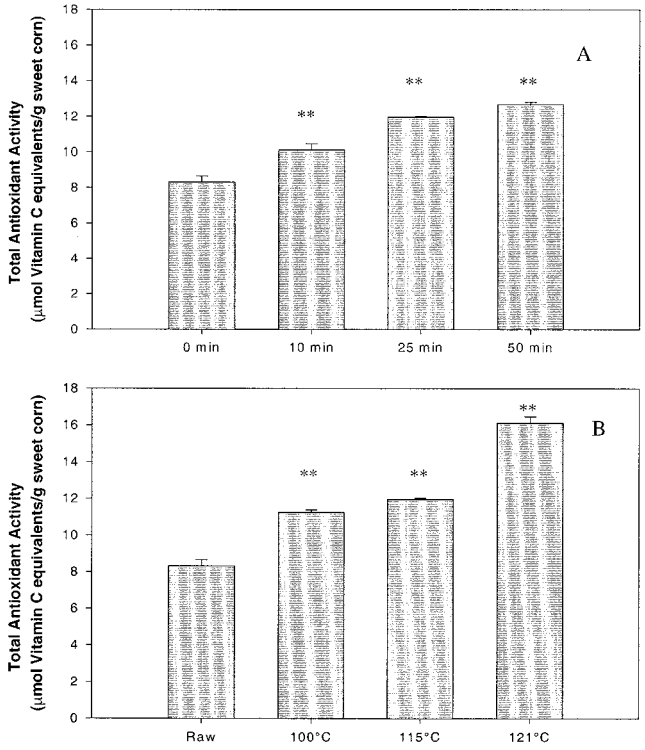

Figure 5. Effect of thermal processing at 115 °C for 0, 10, 25, and 50 min (A) and at 100, 115, and 121 °C for 25 min (B) on total antioxidant activity in free phytochemical sweet corn extracts (mean ± SD, $n = 3$). Significantly different from the control group: **, $p < 0.01$.

sweet corn was found to have a total antioxidant activity of 8.3 ± 0.3 μmol vitamin C equivalents/g of corn (**Figure 5A**). With heat treatment at 115 °C, the total antioxidant activities of the 10, 25, and 50 min sweet corn increased to 10.1 ± 0.3, 12.0 ± 0.1, and 12.7 ± 0.1 μmol vitamin C equivalents/g of corn, respectively. There were significant increases by 21.9, 44.0, and 52.6% in total antioxidant activity of free phytochemical extracts in the 10, 25, and 50 min samples with thermal processing at 115 °C in comparison to the raw samples, respectively ($p < 0.01$; **Figure 5A**). With thermal processing for 25 min at 100, 115, and 121 °C, the total antioxidant activities of free phytochemical extracts were 11.3 ± 0.1, 12.0 ± 0.1, and 16.1 ± 0.4 μmol vitamin C equivalents/g of corn with significant increases by 35.4, 44.0, and 94.0%, respectively ($p < 0.01$; **Figure 5B**). The increase in the total antioxidant activity between the raw and heat-processed sweet corn across both heating time and temperature parameters was found to be statistically significant ($p < 0.01$). Thermal treatment at 115 °C decreased the total antioxidant activity of the bound phytochemical sweet corn extracts. The raw sweet corn sample was found to have a total antioxidant activity of 25.49 ± 0.44 μmol vitamin C equivalents/g of corn (**Figure 6A**). With thermal treatment at 115 °C, the total antioxidant activities in the 10, 25, and 50 min bound phytochemical sweet corn samples decreased to 19.92 ± 0.03, 18.37 ± 0.30, and 12.79 ± 0.16 μmol vitamin C equivalents/g of corn, respectively. There were decreases by 21.9, 27.9, and 49.8% in total antioxidant activity in the 10, 25, and 50 min samples with thermal processing at 115 °C in comparison to the raw samples, respectively ($p < 0.01$; **Figure 6A**). With thermal processing for 25 min at 100, 115, and 121 °C, the total antioxidant activities in bound phytochemical extracts were 22.00 ± 0.44, 18.37 ± 0.30, and 15.10 ± 0.05 μmol vitamin C equivalents/g of corn with significant decreases by 13.7, 27.9, and 40.8%, respectively (*p*

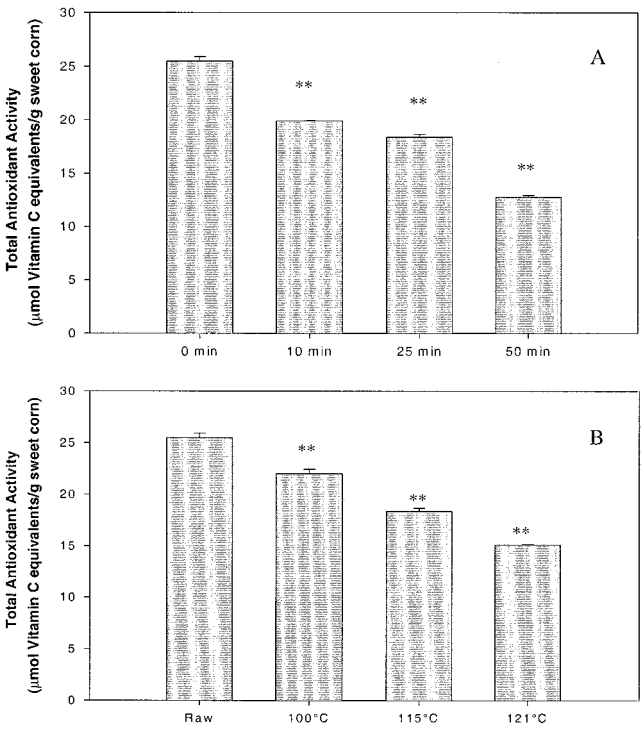

Figure 6. Effect of thermal processing at 115 °C for 0, 10, 25, and 50 min (A) and at 100, 115, and 121 °C for 25 min (B) on total antioxidant activity in bound phytochemical sweet corn extracts (mean ± SD, $n = 3$). Significantly different from the control group: **, $p < 0.01$.

< 0.01; **Figure 6B**). The decrease in the total antioxidant activity in bound phytochemical extracts between the raw and thermally processed sweet corn across both heating time and temperature parameters was found to be statistically significant ($p < 0.01$).

DISCUSSION

Processed fruits and vegetables have long been perceived to have lower nutritional value than the fresh commodities because of the decline in vitamin C (*6*−*9*). We also observed the loss of vitamin C in thermally processed sweet corn across the heating time parameter of 25 min at 100, 115, and 121 °C and across the temperature parameter at 115 °C, with an estimated $D_{115°C}$ value (the time taken for 90% reduction of the initial vitamin C content at 115 °C) as 218 min. This result is consistent with a kinetic study of the loss of vitamin C in canned peas, which showed a $D_{121°C}$ value of 246 min (*7*) and in thermally processed tomatoes with a $D_{88°C}$ value of 276 min (*11*). Loss of vitamin C occurs primarily by chemical degradation involving oxidation of ascorbic acid to dehydroascorbic acid (DHAA) and 2,3-diketogulonic acid and further polymerization to other nutritionally inactive products (*16*). Because heat is known to speed the oxidation process of ascorbic acid, thermal processing results in a loss of vitamin C content in fruits and vegetables (*16*). Our group had found that vitamin C contributed <0.4% of the total antioxidant activity in apples (*10*). This finding suggested that thermally processed sweet corn might retain or increase its total phenolics and thus total antioxidant activity despite the loss of vitamin C.

The present results supported our hypothesis, for there were significant increases in the content of total free phenolics in sweet corn following thermal treatment with both increased heating times and temperatures. Correspondingly, the bound phenolic content decreased as they were released from esterified and insoluble bound forms. Phenolic acids occur in plants as metabolic intermediates (*17*). Of all the cereal grains tested, sweet corn contained the highest levels of insoluble-bound phenolic acids, comprising 69.2% of total phenolic content (*18*). Thermal processing may release more bound phenolic acids from the breakdown of cellular constituents. Although disruption of cell walls also releases the oxidative and hydrolytic enzymes that can destroy the antioxidants in fruits and vegetables (*17*), thermal processing at 100, 115, and 121 °C will deactivate these enzymes to avoid the loss of phenolic acids.

trans-Ferulic acid is the predominant phenolic acid comprising 73.2% of the total phenolic acid content of corn flour (*19*). In addition, *trans*-ferulic acid is the predominant phenolic acid liberated from soluble esters and glycosides (*18*). Therefore, ferulic acid was analyzed as a marker to demonstrate the effect of heat treatment on the release of conjugated and bound phenols in sweet corn. Phenolic acids of corn are in free, esterified, and insoluble bound forms with the insoluble bound phenolic acids being the predominant fraction. Some phenolic acids are linked covalently to amine functionalities (*19*), and some are linked to glycosides by ester bonds (*20*). Some of the ferulic acids released by processing are incorpoarated into the solubilized feruloylated oligosaccharides, and some are present as free ferulic acids. Our results showed that heat treatment had increased the free and conjugated ferulic acid contents in sweet corn due to the release of bound ferulic acid across both the heating time and heating temperature parameters. However, the released free ferulic acid content observed was low due to its reactivity, and its occurrence as solubilized feruloylated oligosaccaharides was higher. Heat only solubilizes feruloylated oligosaccharides, and subsequent treatment would be needed to release ferulic acid in its free form. The ester linkage survived the heating temperatures used, and thus ferulic acid remained esterified to neutral sugars. Further hydrolysis of the extracts of soluble phytochemicals yielded an ∼8−10-fold higher amount of ferulic acids. Thus, it is reasonable to assume the major portion of the released ferulic acids was in the form of conjugated glycosides. This assumption is supported by the fact that a thermal pretreatment at 160 °C increased solubilization of feruloylated oligosaccaharides from maize bran by 80% and solubilized ferulic acids did not occur in the free form (*20*). In that study, feruloyl esterases were needed to release ferulic acid in the free form. Additionally, the levels of soluble conjugated phenolic acids in the cereal flours were 2−5 times greater than the free phenolic acid levels (*18*). Some phenolic acids may be linked covalently to amine functionalities. Thus, ferulic acid occurs most frequently as the soluble conjugated form instead of its free form. A more severe heat treatment is required to release ferulic acid in its free form as an autohydrolysis reaction generally occurs at temperatures of >180 °C (*20*). Additionally, ferulic acid sugar esters have a better suppressive effect on low-density lipoprotein (LDL) oxidation than free ferulic acid (*21*). 5-*O*-Feruloyl-L-arabinosefuranose (FAA) is a more polar and hydrophilic compound than ferulic acid due to the conjugated sugar. Affinity of the LDL particle for the ferulic acid ester is important to show the antioxidant activity in LDL oxidation system. It was also shown that antioxidative activities of 5-*O*-feruloyl-L-arabinosefuranose and *O*-(5-*O*-feruloyl-α-L-arabinofuranosyl)−(1→3)-*O*-*β*-D-xylopyranosyl-(1→4)-D-xylopyranose in vitro were stronger than that of ferulic acid in its free form (*22*). Therefore, due to increased solubilization of ferulic acid sugars with both increased heating time and temperatures, heat treatment should enhance the antioxidant activity of sweet corn.

The increase in total antioxidant activity of the heat-processed sweet corn could be explained by the increased amount of solubilized ferulic acid esters, a major bound phenolic acid in sweet corn, and the increased release of other bound phenolics released from the matrix with thermal processing. Another reason for improved antioxidant activity could be due to the additive and synergistic effects of other phytochemicals such as phenolics and flavonoids (*10*). Correspondingly, the antioxidant activity of the bound phytochemical extracts decreased with heating time and temperature as more antioxidative phytochemicals were presumably released.

Our results clearly showed total free phenolic content, free ferulic acid content, and total antioxidant activity increased significantly following thermal processing of sweet corn despite the decline in vitamin C content. Our findings imply that thermal processing enhances the antioxidant activity of sweet corn by increasing free ferulic acid and total free phenolic contents. The phytochemicals in grains have not received as much attention as the phytochemicals in fruits and vegetables. Our results will increase awareness among consumers of the health benefits of consuming grain. We suggest consumers obtain their phytochemicals from a variety of sources (fruits, vegetables, and grains) to achieve optimum health benefits because grains have unique phytochemicals that are complementary to the phytochemicals present in fruits and vegetables. These phytochemicals include ferulic acid and caffeic acid that are more concentrated in grains than in fruits and vegetables. Bound phytochemicals, mainly in β-glycosides, cannot be digested by human enzymes and could survive stomach and small intestine digestion to reach the colon, providing site-specific health benefits (*23*). This is consistent with the findings that grain consumption has been associated with reduced risk of colon cancer (*5*). In 15 of 18 epidemiological studies, grain intake provided protection against colorectal and gastric cancers (*5*). Our findings are against the notion that processed fruits and vegetables have lower nutritional values than their unprocessed counterparts. This work could have a direct impact on consumers' food selection by increasing their awareness of the health benefits of processed fruits and vegetables and by encouraging them to obtain their phytochemical sources from a variety of sources including fruits, vegetables, and grains.

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