Nutraceutical Properties of Flour and Tortillas Made with an Ecological Nixtamalization Process

Lilia Irene Rodríguez Méndez, Juan de Dios Figueroa Cárdenas, Minerva Ramos Gómez, and Lilia Leticia Méndez Lagunas

Abstract: The traditional nixtamalization (TN) process, used for obtaining maize-based products, negatively affects bioactive compounds because of its highly alkaline pH. Recently, an ecological nixtamalization (EN) process has been developed that retains the pericarp and maintains the nejayote (wastewater) within the acidic-neutral range. This study examines the effect of pH on the nutraceutical compounds (NC) of maize, such as polyphenolics and anthocyanins (ANT), as well as the effect on the antioxidant capacity (AC). The highest concentration of total phenolics (TP) in the maize kernel was found in the black and yellow genotypes, the highest concentration of ANT in the black genotypes, and the highest concentration of AC in the red and white genotypes. In the flour, TP levels were between 206 to 400 mg GA/100 g, ANT levels were 141 to 407 mg cyanidin-3-glucoside/kg, and AC levels were 2544 to 3001 mg AA/kg. In tortillas, TP levels were 255 to 319 mg GA/100 g, ANT levels were 32 to 342 mg cyanidin-3-glucoside/kg, and AC levels were from 1513 to 2695 mg AA/kg. The reduced loss of soluble solids, the pH, and the formation of compounds with proteins and carbohydrates from the EN process positively affected AC retention.

Keywords: ecological nixtamalization, maize flour, maize tortilla, nutraceutical properties

Practical Application: Ecological nixtamalization can replace traditional nixtamalization; the process demonstrates the ability to retain nutraceutical compounds that are beneficial to health.

Introduction

In Mexico, maize (corn) is primarily consumed in the form of nixtamalized products, most notably the tortilla. In traditional nixtamalization (TN), maize grains are cooked in water with calcium hydroxide (lime) and the wet nixtamal is ground, forming the masa (dough) from which various products are made. TN is not very efficient as it involves a high consumption of water, the production of solid residues, contaminating effluents, an increased cost, and the loss of nutrients such as fats, proteins, dietary fiber, and various nutraceutical compounds (NC) (Maya-Cortés and others 2010). The ecological nixtamalization (EN) process patented by Figueroa and others (2011) was developed to solve some of these drawbacks and inconveniences (Campechano and others 2012).

EN replaces calcium hydroxide with calcium salts. The dough and tortillas made with this process have a better appearance than TN, and excellent sensory properties (Figueroa and others 2011). Rats fed with these tortillas exhibited weight gain and indicated a high-protein efficiency ratio, suggesting that nutritional properties and nutraceuticals are improved by the EN process (Maya-Cortés and other 2010).

In comparison with other grains, maize contains more total phenolic and has a higher antioxidant capacity (AC) (Adom and Liu 2002). The principal phenolic compound found in maize is ferulic acid that represents approximately 85% of the total phenolic and is concentrated in the pericarp of the grain, either in free form or esterified to the hemicelluloses of the cell wall (De la Parra and others 2007). The anthocyanins (ANT), found in the pericarp and aleurone, determine the color of pigmented maize and these water-soluble compounds are potent natural antioxidants due to their ability to trap free radicals (Stavric 1994).

The free, glycosylated, and esterified phenolics in the grain are primarily located in the peripheral layers (pericarp, head, and aleurone cells) and to a lesser extent in the endosperm (Yu and others 2001). The peripheral layers are all lost in the TN process. Alkaline pH, cooking time, elevated temperature during TN, and cooking the tortilla all affect the NCs. These effects have not been evaluated in the EN process. The objective of this study was to evaluate phenolic compounds, anthocyanin content, and AC in the flour and tortillas made with an EN process that uses calcium salts, compared to TN which uses calcium hydroxide.

Materials and Methods

Plant material

Four types of maize were chosen: a white maize hybrid, and 3 pigmented maize landraces with yellow, red, and black colors grown during 2011 in Huitzilan State of Querétaro, Mexico.

Nixtamalization

Traditional nixtamalization (TN). One kilogram maize was added to a 1% calcium hydroxide solution in a proportion of 2:1 (w/v). The mixture was cooked for 30 min and removed from heat and left in a steeping mode for 16. The cooked maize, called nixtamal, was then separated from the cooking water (nejayote),
washed with purified water in a 1:1 ratio with the grain weight in order to eliminate the excess calcium hydroxide, and ground in a stone grinder (Model M100, FUMASA, Querétaro, México) forming masa.

Ecological nixtamalization (EN). The procedure described in Mexican Patent 292391 (figueroa and others 2011) was used to obtain masa. The procedure is similar to the one described above for TN but calcium hydroxide is replaced with calcium carbonate, calcium chloride, or calcium sulfate in a 1% concentration in relation to grain weight (Campechano and others 2012). Each salt was evaluated in separate treatments.

Flour production

The masa obtained from the grinder was dried in a flash dryer (Cinestav, Querétaro, Mexico). The resulting flour was ground in a Pulvex grinder using a hammer head, and sifted through a mesh of 60 (0.5 mm) (Campechano and others 2012). The dried flour was packed into bags and stored in a cold room at 4 °C until use.

Tortilla preparation

The tortillas were prepared by mixing 200 g corn flour with 200 mL water to achieve the proper dough consistency. The masa was flattened with a manual tortilla roller (Tortilladoras Gonzalez, Ltd, Querétaro, México) resulting in 1.2-mm-thick tortillas with diameter of 12.5 cm. The tortillas were cooked on a hot iron surface at 270 °C for 17 s on one side, 50 s to form a thick layer on the opposite side, and turned again to allow puffing for 17 s.

Distribution of anatomical fractions

Ten grains were soaked in water for 1 h at 100 °C. The grains were dried with paper towel in order to remove external moisture. They were then dissected to separate the germ, pericarp, and endosperm. The fractions were dried in a stove for 3 h at 100 °C and then weighted.

pH

AOAC (1990) method 981.12 was used to determine the pH of the nejayote using a digital potentiometer (Model 250, Denver Instrument, Denver, Colo., USA).

Loss of dry matter

The Mexican standard (NMX-FF-034/1-SCFI-2002) was used to determine the loss of dry matter in maize (LDM), expressed in percentage.

Phenolic compounds

Extraction. The method proposed by Bakan and others (2003) was used to extract free phenolics (FP): 30 mL of a methanol/water solution (80:20) was added to a 1.5-g sample and submerged in an ultrasonic bath for 60 min at room temperature. The mixture was centrifuged at 1325 g for 10 min (Model Z513K, Herms, Gosheim, Germany). A methanol/water solution (80:20) was added to the supernatant for a second extraction. The method employed by Sosulski and others (1983) was used for the extraction of bound phenolic (BP).

Quantification. The Folin-Ciocalteau method modified by Singleton and Rossi (1965) was used for the quantification of total phenolics (TP). The standard was gallic acid (GA) and the results are expressed in mg of gallic acid/100 g of sample, d.b.

Anthocyanins

The method described by Abdel-Aal and Huc (1999) was used to extract ANT. 5 mL of acidified methanol with 1% HCl (1 N) was added to a 1 g sample and left to sit for 60 min. The mixture was centrifuged at 2500 x g for 10 min and then separated from the supernatant. The sediment underwent 2 successive extractions and the supernatants were combined and called extract.

For the quantification, a 1.5-mL aliquot of the extract was measured spectrophotometrically at 540 nm, the wavelength at which the ANT exhibits maximum absorption. Total anthocyanin content was calculated with the equation proposed by Abdel-Aal and Huc (1999):

$$A = (\frac{A_{535} - A_{700}}{\xi}) \times (V_x/1000) \times MW \times (1/WT) \times 10^6$$

where $A$ is the anthocyanin concentration, $A_{535}$ and $A_{700}$ are the absorbance of the extract, $\xi$ is the molar extinction coefficient of cyanidin-3-glucoside (25965 cm/mol), $V_x$ is the total volume of the extract (mL), $MW$ is the molecular weight of cyanidin-3-glucoside (449.2 g/mol), and $WT$ is the total weight (d.b). ANT were expressed as mg of cyanidin-3-glucoside/kg d.b.

Antioxidant capacity

The DPPH method developed by Brand Williams and others (1995) was employed to determine AC. The sample was treated as described extraction of phenolic compounds to obtain the extract. The results are expressed in mg of ascorbic acid/kg d.b.

Statistical analysis

A random factorial design with 2 factors was used: genotype (white, yellow, red, and black) and type of salt (calcium hydroxide, carbonate, chloride, and sulfate). Each treatment was carried out in triplicate. An analysis of variance was applied to the data and the Tukey test was used to determine the differences between treatments. Pearson's correlation was used to identify the association between the dependent variables with $\alpha < 0.05$.

Results and Discussion

Nutraceutical compounds in grain

Table 1 shows the major NCs of maize kernels. The amount of total, free, and bound phenolic was higher in the black and yellow genotypes, which is consistent with previously reported values in the range of 25 to 70, 105 to 1343, and 45 to 1760 mg GA/100 g for the white and pigmented genotypes, respectively (De La Parra and others 2007; Del Pozo-Infran and others 2007; Lopez-Martinez and others 2009, 2011; Gutierrez Uribe and others 2010; Mora-Rochin and others 2010; Urias-Peraldi and others 2013).

The genotype significantly affected the phenolic compounds content. The differences observed can be attributed to genetic antecedents, the physical properties of the grain, and the relative relation of the pericarp and endosperm, which are the structures richest in phenolic compounds (Adon and Liu 2002; Salinas-Moreno and others 2003; Mora-Rochin and others 2010; Campechano and others 2012).

The results show that the yellow and black genotypes have a pericarp with proportions of 5.89 and 5.30%, respectively. In contrast, the pericarp of the white genotype has a proportion of 5.61%. These proportions could explain the higher phenolic level in the pigmented maize.

The anthocyanin content (Table 1) was higher in the black and red genotypes. This is consistent with the results of other studies.
Table 1—Nutraceutical properties of raw corn.*

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenols in raw corn (mg gallic acid/100 g d.b.)</th>
<th>Anthocyanins (mg cyanidin-3-glucoside /kg d.b.)</th>
<th>Antioxidant capacity (mg ascorbic acid /kg d.b.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free</td>
<td>Bound</td>
<td>Total</td>
</tr>
<tr>
<td>White</td>
<td>197c</td>
<td>99c</td>
<td>296d</td>
</tr>
<tr>
<td>Yellow</td>
<td>218b</td>
<td>194a</td>
<td>412b</td>
</tr>
<tr>
<td>Red</td>
<td>181c</td>
<td>171b</td>
<td>352c</td>
</tr>
<tr>
<td>Black</td>
<td>264a</td>
<td>205a</td>
<td>469a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>946c</td>
<td>1692c</td>
<td>2736c</td>
</tr>
<tr>
<td></td>
<td>2551b</td>
<td></td>
<td>2460c</td>
</tr>
<tr>
<td></td>
<td>4515a</td>
<td></td>
<td>2974a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2317d</td>
</tr>
</tbody>
</table>

*Means with the same letters in the same column are not significantly different (P ≤ 0.05).

that report a range of 97.5 to 3890 mg cyanidin-3-glucoside/kg (De la Pozo and others 2007; López-Martinez and others 2009). However, the values of the white and yellow genotypes, 5.7 to 1702 mg cyanidin-3-glucoside/kg, were higher than those reported (De la Pozo and others 2007; López-Martinez and others 2009).

The AC of maize kernels (Table 1) was higher in the white and red genotypes. There was a significant difference (α < 0.05) between the genotypes. In general, pigmented maize is reported to have a higher AC than white maize (De la Parra and others 2007; López-Martinez and others 2009) although some references report a high AC in the yellow genotype (López-Martinez and others 2009). Factors such as the degree of maturity and genotype influence the AC of maize.

Correlation analysis indicated a direct association between phenolic compounds (FP, BP, TP) and ANT with values of r(ANT, FP) = 0.73, r(ANT, BP) = 0.73, and r(ANT, TP) = 0.82, respectively. The correlation of phenolic compounds, ANT and AC showed an inverse relationship with values of r(AC, FP) = -0.93, r(AC, BP) = -0.53, r(AC, TP) = -0.79, and r(AC, ANT) = -0.47, respectively.

Nutraceutical compounds in flour

Table 2 shows the phenolic compounds found in flour and the dry matter lost in the nixtamalization process. Significant differences (α < 0.05) were found between the traditional and ecological treatments. Regarding the TN process, various studies have reported values within the range of 20 to 3800, 28 to 680, and 97 to 2720 mg GA/100 g for total, free, and bound phenolics, respectively (De la Parra and others 2007; López-Martinez and others 2009, 2011; Gutiérrez-Uribe and others 2010) which are similar to the findings of this study for the white and pigmented genotypes.

The results show a close relation between the low loss of dry matter and the high concentration of free and bound phenolics, an overall comparison was made between LDM and phenolic compounds (FP, BP, and TP) for all the genotypes and salts. An inverse correlation was found for r(LDM, FP) = -0.16, r(LDM, BP) = -0.30, and r(LDM, TP) = -0.38, which is consistent with the findings of Cabrera Soto and others (2009) for white maize. They found that the germ has the highest proportion of free phenolics while the bound phenolic are located in the pericarp. The TN process promotes the loss of the pericarp and part of the germ (Rosenstrater 2006; Campechano and others 2012) which causes the lixiviation of phenolic compounds.

Moreover, using EN resulted in high levels of free, bound, and total phenolic compounds in all of the genotypes, except for the red genotype. This can be explained by the fact that in EN the pH is about 7, which diminishes the release of ferulic acid into the nejayote. In contrast, during TN the pH in near 11 and the ester bonds between the ferulic acid and the arabinoxyans (pentosans or gums), which are responsible for reticulation, weaken the pericarp and the cellular wall hydrolyzing the ester bond and releasing the ferulic acid (Saulnier and Thibault 1999; Cortes and others 2006; Campechano and others 2012).

A comparison of free phenolic compounds levels in the flour and raw corn found losses of 28 to 52% in TN and 8 to 62% in EN. The amount of bound and total phenolic compounds increased in some genotypes, while in others it decreased in both processes. Although the loss of phenolic compounds was observed in each step of the sequential processing, the TN process was the most damaging to all of the genotypes. The combined effect of alkaline and thermal treatments during nixtamalization and the lixiviation of the phenolic compounds in the cooking solution greatly influenced the total loss of phenolic, while the EN process increased phenolic compounds retention in all genotypes.

The anthocyanin content of the flour (Table 3) revealed significant differences (α < 0.05) between the 2 treatments. The flour obtained from the pigmented genotypes contained more ANT. These results are consistent with the values found by various authors for the white and yellow genotypes (2.5 to 7 mg of cyanidin-3-glucoside/kg) and in pigmented genotypes (22.1 to 2338 mg of cyanidin-3-glucoside/kg) (De la Parra and others 2007; Del Pozo-Insfran and others 2007; López-Martinez and others 2011).

Comparing the flours from both treatments with raw corn reveals an anthocyanin loss of 8 to 85%. Losses greater than 73% have been reported in pigmented genotypes, particularly in red and black genotypes that undergo TN (Salinas-Moreno and others 2003; Cortes and others 2006; De la Parra and others 2007). The nixtamalization process reduces anthocyanin levels, primarily in the pigmented genotypes (Mora-Rochin and others 2010). A variety of factors affect the inhibition or destruction of ANT during nixtamalization: the characteristics of each genotype, nixtamalization duration, pH of the solution, and cooking temperature, with the last 2 destroying the pigment of the pericarp (Markakis 1982).

During nixtamalization, losses of dry matter from 2.5 to 3.2% were found in genotypes with high levels of ANT that underwent EN. In contrast, losses between 4.41 and 7.25% of dry matter were found in the genotypes that underwent TN. The ANT are located in the pericarp and the aleurones and are mostly eliminated in the TN process. The synergistic effect of the alkaline pH and the presence of the gelatinous layer has also been suggested (Cortes and others 2006; De la Parra and others 2007).

Furthermore, ANT are more stable in an acidic medium where the predominant form is the flavilium ion. In an alkaline environment the ion flavilium is susceptible to the nucleophilic attack of water, producing a carbinol pseudo-base (Cuevas-Montiila and others 2008). The use of other salts in EN maintains the pH of the
Table 2—Flour phenolic compounds and nejayote dry matter losses and pH.1*

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Salt</th>
<th>Phenols in flour (mg gallic acid/100 g d.b)</th>
<th>Dry matter losses (%)</th>
<th>Nejayote pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Free</td>
<td>Bound</td>
<td>Total</td>
</tr>
<tr>
<td>White</td>
<td>Ca(OH)2</td>
<td>140</td>
<td>210</td>
<td>351</td>
</tr>
<tr>
<td>White</td>
<td>CaCO3</td>
<td>127 ± f</td>
<td>79 j</td>
<td>206 j</td>
</tr>
<tr>
<td>White</td>
<td>CaCl2</td>
<td>142 ± e</td>
<td>235 b</td>
<td>378 b</td>
</tr>
<tr>
<td>White</td>
<td>CaSO4</td>
<td>167 ± c</td>
<td>182 f</td>
<td>349 ± c</td>
</tr>
<tr>
<td>Yellow</td>
<td>Ca(OH)2</td>
<td>152 ± d</td>
<td>161 g</td>
<td>313 ± ef</td>
</tr>
<tr>
<td>Yellow</td>
<td>CaCO3</td>
<td>201 ± b</td>
<td>184 f</td>
<td>385 ± b</td>
</tr>
<tr>
<td>Yellow</td>
<td>CaCl2</td>
<td>97 ± h</td>
<td>163 g</td>
<td>260 ± h</td>
</tr>
<tr>
<td>Yellow</td>
<td>CaSO4</td>
<td>142 ± e</td>
<td>187 f</td>
<td>329 ± d</td>
</tr>
<tr>
<td>Red</td>
<td>Ca(OH)2</td>
<td>120 ± f</td>
<td>100 j</td>
<td>314 ± d e</td>
</tr>
<tr>
<td>Red</td>
<td>CaCO3</td>
<td>214 ± a</td>
<td>189 ef</td>
<td>309 f</td>
</tr>
<tr>
<td>Red</td>
<td>CaCl2</td>
<td>197 h</td>
<td>198 de</td>
<td>291 g</td>
</tr>
<tr>
<td>Red</td>
<td>CaSO4</td>
<td>97 ± h</td>
<td>136 gh</td>
<td>253 l</td>
</tr>
<tr>
<td>Black</td>
<td>Ca(OH)2</td>
<td>127 ± f</td>
<td>100 h</td>
<td>273 ± h</td>
</tr>
<tr>
<td>Black</td>
<td>CaCO3</td>
<td>139 ± e</td>
<td>261 a</td>
<td>400 ± a</td>
</tr>
<tr>
<td>Black</td>
<td>CaCl2</td>
<td>100 ± b</td>
<td>204 cd</td>
<td>305 ± fg</td>
</tr>
<tr>
<td>Black</td>
<td>CaSO4</td>
<td>112 ± g</td>
<td>256 s</td>
<td>367 ± b</td>
</tr>
</tbody>
</table>

*Means with the same letters in the same column are not significantly different (P < 0.05).

Table 3—Anthocyanins and antioxidant activity in flour and tortillas processed with traditional (with lime) and ecological (calcium salts) nixtamalizations.*

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Salt</th>
<th>Anthocyanins (mg cyanidin-3-glucoside/kg d.b)</th>
<th>Antioxidant capacity (mg ascorbic acid/kg d.b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Free</td>
<td>Bound</td>
</tr>
<tr>
<td>White</td>
<td>Ca(OH)2</td>
<td>382 gh</td>
<td>2179 g</td>
</tr>
<tr>
<td>White</td>
<td>CaCO3</td>
<td>141 h</td>
<td>2911 b</td>
</tr>
<tr>
<td>White</td>
<td>CaCl2</td>
<td>335 h</td>
<td>2809 c</td>
</tr>
<tr>
<td>White</td>
<td>CaSO4</td>
<td>538 h</td>
<td>2544 e</td>
</tr>
<tr>
<td>Yellow</td>
<td>Ca(OH)2</td>
<td>427 gh</td>
<td>2401 f</td>
</tr>
<tr>
<td>Yellow</td>
<td>CaCO3</td>
<td>583 gh</td>
<td>2887 b</td>
</tr>
<tr>
<td>Yellow</td>
<td>CaCl2</td>
<td>644 g</td>
<td>3001 a</td>
</tr>
<tr>
<td>Yellow</td>
<td>CaSO4</td>
<td>608 g</td>
<td>2598 e</td>
</tr>
<tr>
<td>Red</td>
<td>Ca(OH)2</td>
<td>1771 e</td>
<td>2450 f</td>
</tr>
<tr>
<td>Red</td>
<td>CaCO3</td>
<td>1469 f</td>
<td>2692 d</td>
</tr>
<tr>
<td>Red</td>
<td>CaCl2</td>
<td>2046 d</td>
<td>2793 c</td>
</tr>
<tr>
<td>Red</td>
<td>CaSO4</td>
<td>1280 f</td>
<td>2882 b</td>
</tr>
<tr>
<td>Black</td>
<td>Ca(OH)2</td>
<td>3830 b</td>
<td>2745 b</td>
</tr>
<tr>
<td>Black</td>
<td>CaCO3</td>
<td>4107 a</td>
<td>2936 e</td>
</tr>
<tr>
<td>Black</td>
<td>CaCl2</td>
<td>1986 e</td>
<td>2653 d</td>
</tr>
<tr>
<td>Black</td>
<td>CaSO4</td>
<td>3133 c</td>
<td>2829 c</td>
</tr>
</tbody>
</table>

*Means with the same letters in the same column are not significantly different (P < 0.05).

nejayote between 4 and 7 which favors the stability of cyanidin-3-glucoside (Salinas-Moreno and others 2003) and promotes higher anthocyanin retention.

The AC is shown in Table 3. Significant differences (α < 0.05) were found between TN and EN. These results are consistent with those of De la Parra and others (2007) and Gutiérrez-Uribe and others (2010) who encountered values in the range of 1021 to 4427 mg AA/kg.

In all of the genotypes an AC increase of 3 to 27% in the flour, in comparison with raw kernels was observed in EN, except with red maize which decreased 3 to 9%. In contrast, a decrease of 2 to 18% was found in all of the genotypes when using TN, except for the black genotypes which increased 18%. Del Pozo-Infran and others (2007) suggested that the levels of ferulic acids, free, and esterified, are responsible for the AC in pigmented maize. However, an analysis of the correlation between phenolic compounds and ANT with the AC did not show a direct association, except in flour with a black genotype that showed r = 0.84 and r = 0.78, respectively.

An overall mean comparison of the 3 calcium salts was carried out for each genotype of maize. Significant differences (α < 0.05) were found for all of the variables, except for yellow maize where significant differences were not found between the salts and the ANT. These results confirm that the effect of the salts and genotype on phenolics and antioxidant activity is significant.

Nutraesthetic compounds in tortillas

Table 4 shows the phenolic compounds in tortillas. Significant differences (α < 0.05) were found between the treatments. The results were similar to those reported by other studies with the
values for free phenolics from 18 to 50 mg GA/100 g and for bound phenolics between 67 and 158 mg GA/100 g. The data were consistent with previously reported data for tortillas made with pigmented genotypes (De la Parra and others 2007; Del Pozo-Insfran and others 2007; Mora-Rochin and others 2010; López-Martínez and others 2011).

A comparison of the flour and raw corn showed a free phenolics reduction of 59% to 73% for TN, 61% to 79% for EN, and a TP reduction of 31% to 57% for TN and 0% to 41% for EN in both processes bound phenolic compounds increased in some genotypes and decreased in others.

Alkaline nixtamalization reduced the phenolic compounds content more than the cooking process. In the tortilla production process losses were between 5% and 50% depending on the use of lime of calcium salts in the process (Table 4). Del Pozo-Insfran and others (2007) found that there were higher losses of TP (54 to 89%) in nixtamalization than during the preparation of the tortillas (on average 75%). Morin-Rochin and others (2010) experienced phenolic compounds losses between 35% to 44% in the same process.

The highest contribution to the TP was made by the bound phenolics (63% to 90%). Similar values were reported for tortillas made with pigmented genotypes (Cuevas-Montillas and others 2008; De la Parra and others 2007). The presence of bound phenolics can be attributed to the fact that they are most commonly linked by ester bonds to hemi-cellulosic chains, mostly with arabinose residues, and that they also polymerize with lignin though ether bonds (Klepaczka and Fornal 2006).

Additionally, the ferulic acid in the pentose molecules forms specific compounds with proteins by chemically bonding with amino acids (Klepaczka and Fornal 2006). This composition could explain the resistance of bound phenolics to the high temperatures used in tortilla production.

In general, the temperatures in the conversion of raw corn into tortillas, the nixtamalization process using either lime or calcium salts, grinding, drying, mixing, and cooking all influence the concentration of phenolic compounds.

Table 3 presents the results of quantification of anthocyanin in tortillas, which are consistent with the results of other studies. In tortillas made with white and pigmented genotypes the range of the reported values was 2.9 to 1954 mg cyanidin-3-glucoside/kg (De la Parra and others 2007; Del Pozo-Insfran and others 2007; Mora-Rochin and others 2010; López-Martínez and others 2011).

The losses of ANT in tortillas, in relation to raw corn, were 54% to 94% using TN and 24% to 98% with EN, and the losses for flour and tortillas were 20% to 45% and 3% to 46%, respectively. These results were consistent with the findings of López-Martínez and others (2011) who reported losses of 41% to 71% with TN.

Previous research has determined that the concentration and presence of specific polyphenolics in the food matrix have a profound effect on the stability of ANT (Mazza and Mininini 1993; Del Pozo-Insfran and others 2007). ANT are liable pigments that experience degrading reactions particularly during processing and storage. A logarithmic decrease of anthocyanins with an arithmetic increase of temperature was found by Markakis (1982). It has been suggested that the rapid destruction of ANT at high temperatures could be due to the hydrolysis of the 3-glycoside structure that has a protective effect in an unstable anthocyanin. The other suggestion is that hydrolysis of the pyrimid ring results in the production of chalcone, which is responsible for brown color that may develop in a food containing anthocyanin (Markakis 1982; Giusti and Wrolstad 2001).

The stability of anthocyanin is highly variable and depends on its structure as well as on the composition of the matrix where it is found (Giusti and Wrolstad 2001). Two structures are found in maize, acylated and nonglucosylated, which are differentiated by the presence of one or more acyl groups in the anthocyanin molecules that makes them more stable at higher temperatures than the nonglucosylated forms (Pascual and others 2002).

The AC of tortillas (Table 3) decreased from flour to tortilla by 4% to 44% in all of the samples, indicating a thermal effect. A significant statistical difference (α < 0.05) between treatments was found. The TN values were higher than those reported by De la Parra and others (2007) whose results were in the range of 1000 to 1100 mg AA/kg. Del Pozo-Insfran and others (2007), for the white and pigmented genotypes, found values of 26% to 54%, while López-Martínez and others (2011) experienced losses of 5% to 20%.

In the white and yellow genotypes, there was a direct relationship between free phenolics and AC (rPAC) = 0.83. In the red and black pigmented genotypes the bound phenolics, ANT, and AC were directly related with (rPAC) = 0.95, (rANT;AC) = 0.74, indicating that free and bound phenolics as well as ANT, contribute to the AC. Making the tortilla is the last but also an important step involving heat and mass transfer, causing physical (gelatinization), chemical, and structural changes of dough components. Increased temperatures promote the formation of protein cross-links with these compounds and all of these changes affect the retention of the NGs.

An overall mean comparison was carried out for each genotype. Significant differences (α < 0.05) were found for all of the variables, except for yellow maize where no significant differences were found for bound and TP. These results confirm that the effect of the salts and genotype on phenolics and antioxidant activity is significant.

Conclusions

The traditional and EN treatments used in the processing of raw corn affect the NC content in flour and tortillas. An alkaline treatment combined with the thermal effect releases the phenolics and the AN through the pericarp and part of the germ, and they
are subsequently lost in the nejayote. In contrast, the EN process maintains an acidic or neutral medium during nixtamalization which, in turn, conserves a higher proportion of the pericarp, consequently reducing the release of ferulic acid into the nejayote and inhibiting the degradation of ANT. Numerous factors, such as genotype, time, pH, and cooking, affect the stability of the ANT. As expected, the most ANT were found in flour made from pigmented genotypes and the greatest losses were seen in the white and yellow genotypes. In general, the greatest contribution of total phenolic in flour and tortillas alike, was made by bound phenolic which contribute to the increase in antioxidant activity when EN is used. Resistance of the NCS to high temperatures during tortilla making may be due to the fact that EN better maintains the structure. Physical changes like gelatinization that occur while cooking the tortilla could significantly affect the matrix where the NCS are located. This should be examined in further studies. The contribution of phenolic and ANT to antioxidant activity is related more to the genotype than to the type of treatment.

Acknowledgments
The authors are thankful to the Consejo Nacional de Ciencia y Tecnología (CONACYT) for financial support to Ms. Rodríguez (306037). The authors also acknowledge the technical help of Juan Veles and Marcela Gaytan.

Authors' Contributions
Rodriguez did the experimental tests and drafted the manuscript, Figueroa designed and planned the study, Ramos helped in the interpretation of results, Méndez helped in the interpretation and drafting of the manuscript.

References
C: FOOD CHEMISTRY

Physicochemical Characterization and Sensory Analysis of Yeast-leavened and Sourdough Soy Breads (pages C1487-C1494)
Gabriela Yezbick, Jennifer Ann Jarvis, Steven J. Schwartz and Yael Vodovotz
Article first published online: 11 SEP 2015 | DOI: 10.1111/1750-3841.12246

Abstract | Full Article (HTML) | PDF(644K) | References
Request Permissions

The Effect of Fat Replacers on Batter and Cake Properties (pages C1495-C1502)
Vassiliki Palioura and Vassiliki Opranoulou
Article first published online: 3 SEP 2013 | DOI: 10.1111/1750-3841.12235

Abstract | Full Article (HTML) | PDF(662K) | References
Request Permissions

Physicochemical Analysis and Anti-inflammatory Potential of Hyphaene tribuloides L. Fruit (pages C1503-C1508)
Mohamed A. Farag and Paul W. Parke
Article first published online: 11 SEP 2013 | DOI: 10.1111/1750-3841.12253

Abstract | Full Article (HTML) | PDF(343K) | References
Supporting Information | Request Permissions

Discrimination of Swiss Cheese from 5 Different Factories by High Impact Volatile Organic Compound Profiles Determined by Odor Activity Value Using Selected Ion Flow Tube Mass Spectrometry and Odor Threshold (pages C1509-C1515)
Kaitlyn Taylor, Cheryl Wick, Hardy Castada, Kyle Kent and W. James Harper
Article first published online: 8 OCT 2013 | DOI: 10.1111/1750-3841.12249

Abstract | Full Article (HTML) | PDF(247K) | References
Request Permissions

Characterization and Comparison of the Pungent Components in Commercial Zanthoxylum bungeanum Oil and Zanthoxylum schinifolium Oil (pages C1516-C1522)
Zhi-Feng Zhao, Rui-Xue Zhu, Kai Zhong, Qiang He, Ai-Mei Luo and Hong Gao
Article first published online: 8 OCT 2013 | DOI: 10.1111/1750-3841.12236

Abstract | Full Article (HTML) | PDF(639K) | References
Request Permissions

Spray-Dried Structured Lipid Containing Long-Chain Polyunsaturated Fatty Acids for Use in Infant Formulas (pages C1523-C1528)
Supakana Nagachinta and Casimir G. Akoh
Article first published online: 11 SEP 2013 | DOI: 10.1111/1750-3841.12243

Abstract | Full Article (HTML) | PDF(466K) | References
Request Permissions

Nutraceutical Properties of Flour and Tortillas Made with an Ecological Nixtamalization Process (pages C1529-C1534)
Lilia Irene Rodríguez Méndez, Juan de Dios Figueroa Cárdenas, Minerva Ramos Gómez and Lilia Leticia Méndez Lagunas
Article first published online: 11 SEP 2013 | DOI: 10.1111/1750-3841.12241

Abstract | Full Article (HTML) | PDF(177K) | References
Request Permissions

The Influence of Bleaching Agent and Temperature on Bleaching Efficacy and Volatile Components of Fluid Whey and Whey Retentate (pages C1535-C1542)
A.J. Fox, T.J. Smith, P.D. Gerard and M.A. Drake
Article first published online: 16 SEP 2013 | DOI: 10.1111/1750-3841.12251

Abstract | Full Article (HTML) | PDF(509K) | References
Request Permissions

Enrichment of Functional Properties of Ice Cream with Pomegranate By-products (pages C1543-C1550)
Mustafa Çam, Fatma Emreşan, Duygu Aslan and Merve Dinc
Article first published online: 16 SEP 2013 | DOI: 10.1111/1750-3841.12258

Abstract | Full Article (HTML) | PDF(1423K) | References
Request Permissions

E: FOOD ENGINEERING AND PHYSICAL PROPERTIES
### Journal Citation Reports®

#### 2012 JCR Science Edition

**Journal Summary List**

Journals from: search Full Journal Title for 'JOURNAL OF FOOD SCIENCE'

Sorted by: Journal Title  

**Mark Rank**  

<table>
<thead>
<tr>
<th>Abbreviated Journal Title (linked to journal information)</th>
<th>ISSN</th>
<th>JCR Data</th>
<th>Eigenfactor® Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Cites</td>
<td>Impact Factor</td>
<td>5-Year Impact Factor</td>
</tr>
<tr>
<td>J FOOD SCI</td>
<td>17543</td>
<td>1.775</td>
<td>2.160</td>
</tr>
</tbody>
</table>

**Acceptable Use Policy**

Copyright © 2013 Thomson Reuters.