Effect of different calcium sources on the antioxidant stability of tortilla chips from extruded and nixtamalized blue corn (*Zea mays* L.) flours.

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Abstract

This research aimed to develop tortilla chips (TC) high in antioxidants from extruded and nixtamalized blue corn flours prepared with calcium hydroxide $Ca(OH)_2$ and calcium lactate $C_6H_{10}O_6Ca$. Tortilla chips were made with extruded flours [0.1% $Ca(OH)_2$; 0.9% $C_6H_{10}O_6Ca$; without calcium] and nixtamalized flours [1% $Ca(OH)_2$; 2.95% $C_6H_{10}O_6Ca$] using the frying process. Total anthocyanin, total phenolics content, antioxidant activity, color, texture, and oil content were determined. The color of tortilla chips from extruded flours (TCEF) showed high values of the parameters *a** and *b** indicating a reduction in the blue color. These color parameters were significantly different from those observed in tortilla chips from nixtamalized flours (TCNF), which tended to be more blue. The TCEF retained 15% anthocyanins, 34% phenolics, and 54% antioxidant activity. Pearson's correlation analysis indicated that anthocyanins and phenolics correlated significantly with antioxidant activity and color. TCEF with both calcium sources showed higher fracturability compared with that of TCNF. Oil absorption showed an opposite effect, with lower oil content in TCEF. Nixtamalization and extrusion with $C_6H_{10}O_6Ca$ resulted in flours and TC high in anthocyanins and antioxidant activity, representing an alternative production process for corn snack high in antioxidants.

Keywords: calcium lactate; calcium hydroxide; anthocyanins; antioxidant activity; polyphenols.

1 Introduction

Tortilla chips have become one of the most popular snacks among American consumers, and its market has been growing worldwide and gaining importance in the snack industry. This snack is used in salads, guacamole, salsas, and combined with other typical Latin American foods. To make tortilla chips more colorful and attractive, artificial colorants are used, which is a serious concern to consumers. A substitute for synthetic food dyes is the naturally pigmented corn, such as the blue corn. The new trend among consumers is to look for healthier snacks, and tortilla chips made from blue corn are a viable option. The blue color in the corn is caused by anthocyanins, which are mainly found in the aleurone layer and pericarp (Salinas-Moreno et al., 1999). Anthocyanins are flavonoids which have potent antioxidant activity and are known to provide health benefits such as cancer and cardiovascular disease prevention (Brouillard, 1982; He & Giusti, 2010). Anthocyanins are soluble in water, unstable at basic pH, and are affected by high temperatures during processing (Patras et al., 2011).

Traditionally, tortilla chips are made from nixtamalized corn tortillas, which are baked and then fried, giving it an alkaline flavor (Kawas & Moreira, 2001). The nixtamalization process includes cooking and steeping of corn grains in calcium hydroxide [$Ca(OH)_2$] solution for 8 to 24 h; the cooking liquor (nejayote) is drained, and the grains are washed to remove the remaining pericarp and excess lime and milled to form a dough (masa) or dried for the production of instant flour which is used to make tortillas (Serna-Saldívar et al., 1993; Ruiz-Gutiérrez et al., 2012). However, the nixtamalization of blue corn has as a disadvantage of causing anthocyanin degradation due to the influence of the alkaline pH (Bordignon et al., 2009) of the lime solution. The use of other calcium sources that produce neutral or low pH could minimize the degradation of these compounds. Some investigations have evaluated the use of other alkaline compounds for corn cooking (Robles et al., 1988; Maya-Cortés et al., 2010; Botelho et al., 2013) searching for ways to minimize environmental pollution and preserve the quality of nixtamalized products. In addition, another study showed the use of calcium lactate ($C_6H_{10}O_6Ca$) for white corn nixtamalization, which produces tortillas with good texture and color (Ruiz-Gutiérrez et al., 2012); $C_6H_{10}O_6Ca$ could be an alternative method for blue corn nixtamalization because it does not produce high alkaline pH, and thus it may minimize anthocyanin damage during the nixtamalization and other processes producing high-antioxidant products with natural pigments. Similarly, an alternative technology to produce instant flours and snack products is the extrusion-cooking process, which is a low-cost, energy-efficient, and eco-friendly technology (Harper, 1981). Although some studies have evaluated the effect of using $Ca(OH)_2$ in the cooking and extrusion process on the physicochemical properties and quality attributes of flour and snack products (Zazueta-Morales et al., 2002; Cortés-Gómez et al., 2006; Del Pozo-Insfran et al., 2006; De la Parra et al., 2007), no report has been made on the effect of using $C_6H_{10}O_6Ca$ in the cooking and processing of blue corn tortilla chips on the contents of anthocyanins, polyphenols, antioxidant activity, and changes in the color and texture of corn

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products. The combination of the extrusion cooking process with $C_6H_{10}O_6Ca$, as described above, could be an alternative for blue corn nixtamalization to obtain instant flours and snacks higher in antioxidants. This study aimed to produce tortilla chips high in antioxidants from extruded and nixtamalized blue corn flours prepared with $Ca(OH)_2$ and $C_6H_{10}O_6Ca$.

2 Materials and methods

2.1 Chemicals and reagents

Folin-Ciocalteu's phenol reagent, gallic acid, 1,1-diphenyl-2-picrylhydrazyl ($DPPH^•$), and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) were acquired from Sigma-Aldrich Chemical Co. (St. Louis, MO). The other analytical grade solvents used inthe extractions were purchased from J.T. Baker (México City, México).

2.2 Materials

Blue corn (*Zea mays* L.) from the region of Babícora, Chihuahua State, México, was used. Commercial food grade calcium hydroxide [$Ca(OH)_2$] and calcium lactate [$C_6H_{10}O_6Ca$] were used.

2.3 Flour preparation for extrusion

Blue corn kernel was milled once using a hammer mill (Pulvex model 200, México) equipped with a 5 mm sieve. From this milling, 93% of the milled corn was retained on 40-mesh sieve (420 μm), and only 1.0% of milled corn passed through 100-mesh sieve (149 μm). Individual lots of milled blue corn were mixed separately with $Ca(OH)_2$ and $C_6H_{10}O_6Ca$ to obtain concentrations of 0.1% and 0.9%, respectively. Then, each lot was hydrated to reach 30% moisture. An extruded control (EF control) without any calcium source was prepared in the same way. Each lot was packed in a polyethylene bag, tempered, and stored for 14 h at 4 °C.

2.4 Extrusion process

The corn flours were extruded using a single-screw extruder (CINVESTAV-IPN, Querétaro, México) with a barrel (length, 428 mm; diameter, 25 mm) and three independent electrically heated zones. Screw compression ratio was 1:1, die diameter was 4 mm, and the system was operated with a 30 Hz speed screw and a constant feed rate (30 g/min). Blue corn for each treatment of $Ca(OH)_2$ or $C_6H_{10}O_6Ca$ was extruded with temperatures at 50, 70, and 80 °C in the feed, compression and die end barrel zones, respectively. The extrudates were dried at 45 °C for 48 h in an oven (Felisa, México) until a moisture content of 0.09-0.11 kg/kg dried matter was reached. These extrudates were milled using a hammer mill with a 0.8 mm mesh and sieved using a 60-mesh sieve; around 1.80 and 6.87% of the extruded flours obtained passed through 100-mesh sieve (149 μm). The extruded flours (EF) were stored in hermetically sealed plastic bags in the dark at 4 °C.

2.5 Nixtamalization process

Two different nixtamalized blue corn flours (NF) were prepared; one was cooked in a solution of 1% $Ca(OH)_2$, and the other was cooked in a solution of 2.95% $C_6H_{10}O_6Ca$ at the ratio of 1:3 kernel/solution at 90 °C for 40 min followed by 15 h of steeping. The cooking liquor was discarded, and the cooked grain (nixtamal) was washed twice with distilled water to remove the excess lime or calcium lactate. The nixtamal was ground using a stone mill (FUMASA, México) and dried using a flash dryer with input and output temperatures of 295 °C and 90 °C, respectively. The dehydrated flours were milled using a hammer mill (Pulvex model 200, México) with a 0.8 mm mesh and sieved using a 60-mesh sieve; around 48.75 and 52.91% of the nixtamalized flours obtained passed through 100-mesh sieve (149 μm). The sifted flour was stored in the dark at 4 °C in hermetically plastic bags for analysis.

2.6 Tortilla chips preparation

Tortilla chips from nixtamalized flour (TCNF) and tortilla chips from extruded flour (TCEF) were prepared by mixing separately 300 g of each flour with 0.05% of carboxymethyl cellulose and 300 mL of water to achieve an adequate masa consistency for the production of tortillas (50-51% moisture content). The fresh masa was shaped using a manual machine (Máquinas González, Monterrey, N.L., México) obtaining flat disks of 12.5 cm in diameter and 0.8 mm thickness. The tortillas were cooked on a hot griddle at 260±10 °C for 30 s on one side, followed by 30 s on the other side avoiding the puffing of the tortilla, and finally, the tortillas were cooled to room temperature. The tortillas were cut into 4 pieces, placed on trays, and dried in a convection oven (Southbend, USA) at 100 °C for 10 min until a moisture content of 9 - 10% was reached. Next, they were fried using a domestic fryer (Oster, USA) at 180 °C for 1 min. The tortilla chips (TC) were placed between paper towels to blot excess oil and allowed to cool for 20 min. They were stored in the dark at 4 °C in hermetic plastic bags.

2.7 Color measurements

The color of tortilla chips was measured using a Konica Minolta CR-400/410 (Minolta Co., Osaka, Japan) colorimeter. The L^* (luminosity), a^* (green to red) and b^* (blue to yellow) parameters were determined through 20 measurements on each sample (Ruiz-Gutiérrez et al., 2012). A white tile standard ($L = 97.99$, $a = 0.0125$, $b = 1.31$) was used as a reference (standard). The total color difference (ΔE) was calculated using the following Equation 1:

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2} \tag{1}$$

where $\Delta L = L_{std} - L_{sample}$; $\Delta a = a_{std} - a_{sample}$; and $\Delta b = b_{std} - b_{sample}$.

2.8 pH measurements in flours

The pH values were determined in a suspension with 10 g of flour and 100 mL of distilled water recently boiled and cooled. The suspension was stirred with a magnetic bar for 20 min at 1500 rpm and 25 °C (American Association of Cereal

Chemistryists, 2000), the pH was measured during agitation using a pH meter (Corning model Pinnacle, Corning, Inc., New York) calibrated with standard buffers. The analysis was carried out in triplicate.

2.9 Total anthocyanin content

Total anthocyanins were determined according to a previously described method (Abdel-Aal & Hucl, 1999). The samples of tortilla chips (1.5 g) were homogenized with 12 mL of an acidified methanol solution (methanol and 1 N HCl, 85:15, v/v). The solution was mixed and adjusted to pH 1 with 4 N HCl, agitated for 30 min, and then centrifuged at 3200 × *g* (Thermo IEC model CL3-R, USA) for 45 min. The supernatant was poured into a 25 mL volumetric flask and brought to volume with acidified methanol. The absorbance was measured at 535 nm using a spectrophotometer (PerkinElmer model Lambda 25 UV/VIS, USA), and a reagent blank was used. The total anthocyanin content was expressed as milligrams of cyanidin 3-glucoside equivalents per 100 g of sample and was calculated by the following Equation 2:

$$C = \left(\frac{A}{\varepsilon}\right) \times \left(\text{total volume of extract}\right) \times \text{MW} \times \left(\frac{1}{\text{sample}}\text{wt}\right) \times 10 \qquad (2)$$

where *C* is the concentration of total anthocyanin (milligrams of cyanidin 3-glucoside equivalents per 100 g of sample), ε is the molar absorptivity (cyanidin 3-glucoside, 25,965 $\text{cm}^{-1}\,\text{M}^{-1}$), and MW is the molecular weight of cyanidin 3-glucoside (449.2). This determination was performed in triplicate for each extract.

2.10 Total phenolic content

Total phenolic content was determined using the Folin-Ciocalteu colorimetric method with some modifications (Singleton et al., 1999). A calibration curve of gallic acid using deionized water as solvent was used. The extracts were prepared according to (Dykes et al., 2005) using 1.5 g of sample homogenized with 25 mL of (1% HCl/methanol, v/v) and agitated for 2 h. The extracts were centrifuged at 3200 × *g* (Thermo IEC model CL3-R, USA) for 30 min and decanted. Thirty microliters of extract, 3 mL of deionized water, and 200 μL of Folin-Ciocalteu's phenol reagent were mixed and allowed to stand for 10 min at room temperature. The reaction was neutralized with 600 μL of a 20% sodium carbonate solution. The mixture was incubated for 20 min at 40 °C in a water bath and then cooled on ice. The absorbance was measured at 760 nm using a spectrophotometer (PerkinElmer model Lambda 25 UV/VIS, USA). The results were expressed as milligrams of gallic acid equivalents per 100 g of sample (mg GAE/100 g). This determination was performed in triplicate for each extract.

2.11 Determination of antioxidant activity

Antioxidant activity was determined using the 2,2-diphenyl-1-picrylhydrazyl ($\text{DPPH}^{\bullet}$) free radical method (Brand-Williams et al., 1995). The extracts were prepared using a procedure similar to that described for determination of phenolic content, except for the fact that only methanol was used. An aliquot of 3.9 mL of 60 μM DPPH in methanol was added to 0.1 mL of extract. The mixture was shaken vigorously and allowed to stand at room temperature in the dark for 3 h, at which time absorbance at 515 nm was measured using a spectrophotometer (PerkinElmer model Lambda 25 UV/VIS, USA.). The results were expressed as micromoles of Trolox equivalents per gram of sample (μmol TE/g). This determination was performed in triplicate for each extract.

2.12 Texture

The texture of tortilla chips was evaluated using a texturometer (TA-XT2, Texture Analyzer plus, UK) and a 5.0 mm-diameter ball probe with a cylindrical plate of 15.0 mm (internal diameter) and 18.0 mm (external diameter). The probe travelled at 4.0 mm/s. The first peak of the force versus distance was measured and called fracturability (FR), that is, the force (N) required for breaking the TC; about 30 samples from each treatment were tested.

2.13 Oil content

Total oil content of tortilla chips was determined by hexane extraction using a Soxhlet system, according to the AOAC official method 920.39 (Association of Official Analytical Chemists, 1998). The test was performed in triplicate.

2.14 Statistical analysis

Experimental treatments were performed in duplicate, and the data obtained for color parameters (L^*, a^*, b^*), total color difference (ΔE), anthocyanin content, phenolic content, antioxidant activity, texture expressed as fracturability (FR), and oil content were subjected to analysis of variance using the MINITAB, version 13.20 (MINITAB, 2000, PA, USA). Differences between the means were evaluated using the Tukey´s test, with $P \leq 0.05$. Correlation analysis was performed between the color parameter and antioxidant activity with anthocyanin and phenolic content using Pearson's correlation analysis ($P \leq 0.05$).

3 Results and discussion

3.1 Color

The L^* parameter showed significant differences between TCEF control and TCNF with $C_6H_{10}O_6Ca$ at 2.95%, which had the lowest L^* value (Table 1). Similar L^* values have been reported for nixtamalized blue corn tortilla chips (Del Pozo-Insfran et al., 2007). The low L^* values are caused by the characteristic blue color of the corn. Additionally, the color changes during the frying process, which causes darkening due to the Maillard reaction or caramelization (Maga & Liu, 1993; Buttery & Ling, 1995).

The a^* parameter of TCEF was not significantly affected under the conditions evaluated (Table 1). However, significant differences between TCEF and TCNF were found with both calcium sources. Furthermore, TCNF with $Ca(OH)_2$ had the lowest a* value, tending to be less red in color, and it showed significant differences from TCNF with $C_6H_{10}O_6Ca$, which

Table 1. Color results of blue corn tortilla chips.

Tortilla chips	[Conc] (%)	Color[a]				pH^b
		L*	a*	b*	ΔE	
TCEF $Ca(OH)_2$	0.10	31.433±0.279ab	11.440±0.608a	6.7835±0.0124b	67.756±0.172a	6.57±0.02b
TCEF $C_6H_{10}O_6Ca$	0.90	32.020±0.362ab	11.400±0.368a	8.3688±0.0017a	67.320 ±0.417a	5.66±0.02e
TCEF Control	0.00	33.302±1.208a	11.979±0.440a	7.6696 ±0.5733ab	66.098±1.048a	6.24±0.04c
TCNF $Ca(OH)_2$	1.00	31.285±0.431ab	5.420 ±0.325c	3.4900±0.1838c	66.962±0.397a	6.82±0.01a
TCNF $C_6H_{10}O_6Ca$	2.95	30.250±0.424b	7.785±0.361b	2.1800±0.1556d	68.193 ±0.378a	6.10±0.01d

[a]Mean values ± standard error from duplicate treatments. Means with different letters represent a significant difference according to the Tukey´s test ($P < 0.05$). [b]pH values of extruded and nixtamalized blue corn flours.

showed a more saturated red color. It is clear that this tendency must be interpreted together with the behavior of the parameter *b**, which showed a greyish tendency for TCEF with $C_6H_{10}O_6Ca$. It was significantly different from TCEF with $Ca(OH)_2$.

Both TCEF with $C_6H_{10}O_6Ca$ and $Ca(OH)_2$ did not exhibit significant differences from TCEF control. Nevertheless, significant changes were observed between TCEF and TCNF with either calcium source. TCNF with $C_6H_{10}O_6Ca$ had the lowest *b** values, indicating that these tortilla chips tended to be blue in color. Similar *b** values have been reported for nixtamalized blue corn tortilla chips (Del Pozo-Insfran et al., 2007). The differences in the color (ΔE) of the tortilla chips were not significant between the treatments (Table 1).

3.2 Total anthocyanin content

Figure 1 shows the anthocyanin content of blue corn flours and TC for the different treatments. All EF had higher anthocyanin content than that of NF ($P < 0.05$).

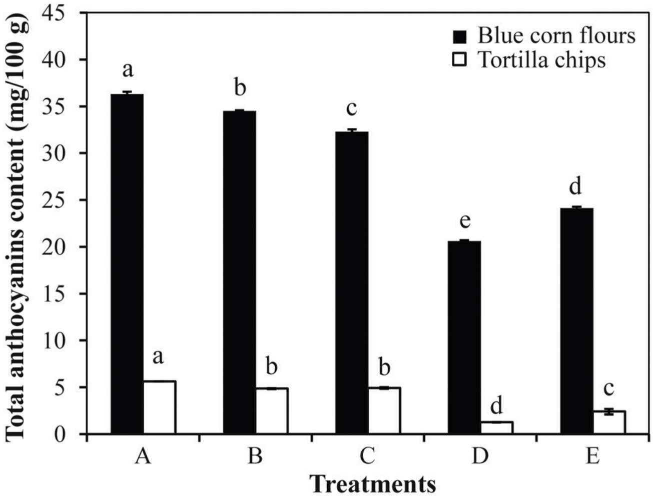

Figure 1. Total anthocyanin content of blue corn tortilla chips. A: TCEF control, B: TCEF $Ca(OH)_2$ 0.1%, C: TCEF $C_6H_{10}O_6Ca$ 0.9%, D: TCNF $Ca(OH)_2$ 1.0%, E: TCNF $C_6H_{10}O_6Ca$ 2.95%. Means between bars and treatments with different letters represent a significant difference according to the Tukey´s test ($P < 0.05$).

This is probably due to the fact that the structural transformation of anthocyanin into chalcones that occurs during extrusion is less frequent than the thermal alkaline effect exerted during the nixtamalization process retaining color and more of these bioactive compounds in the EF. The lowest total anthocyanin content was observed for NF with $Ca(OH)_2$, which was significantly different from that of NF with $C_6H_{10}O_6Ca$. This is due to the alkaline pH of the cooking solution during nixtamalization of pigmented corns, during which anthocyanins are degraded (Cortés-Gómez et al., 2006; Del Pozo-Insfran et al., 2007; Salinas-Moreno et al., 2003) and free phenolic compounds are released during the removal and solubilization of the pericarp (Cortés-Gómez et al., 2006; Pflugfelder et al., 1988). According to our results, nixtamalization with $C_6H_{10}O_6Ca$ caused a decrease in the pH of the flours (Table 1), resulting in high total anthocyanin content. All TCEF had higher total anthocyanin contents than those of TCNF. TCEF control had the highest total anthocyanin content, which was significantly different from those of TCEF and TCNF. TCEF showed no significant differences between the two calcium sources. On the other hand, the lowest anthocyanin content was found for TCNF with $Ca(OH)_2$. All TCEF retained approximately 15% of the initial anthocyanin content from their EF, while both TCNF retained, on average, 8% of the total anthocyanin content. Similar results of anthocyanins losses of 91.07% and 78% in tortilla chips from nixtamalized blue corn have been reported (De la Parra et al., 2007; Del Pozo-Insfran et al., 2007). Therefore, TC processing causes a significant loss in the anthocyanin content due to exposure to high temperatures during the cooking and frying of tortilla.

3.3 Total phenolic content and antioxidant activity

Figure 2 shows remarkable changes in the phenolic content of EF and NF, and EF showed higher phenolic content than that of NF ($P < 0.05$).

This could be attributed to the short-time thermal extrusion that minimized the damage in the total phenolic content in the flour (Mora-Rochín et al., 2010), whereas the nixtamalization process caused physical loss of the pericarp and leaching of phenolics into the cooking liquor (Del Pozo-Insfran et al., 2007; Pflugfelder et al., 1988; López-Martínez et al., 2011), resulting in lower phenolic content in NF. All TCEF showed significantly higher phenolic content than that of TCNF. TCEF control had the highest phenolic content ($P < 0.05$). Despite the highest total phenolic content observed in EF, the average retention in TCEF was lower (34%) than that in the TCNF (48%). This reduction of phenolic content could be due to the thermal conditions during

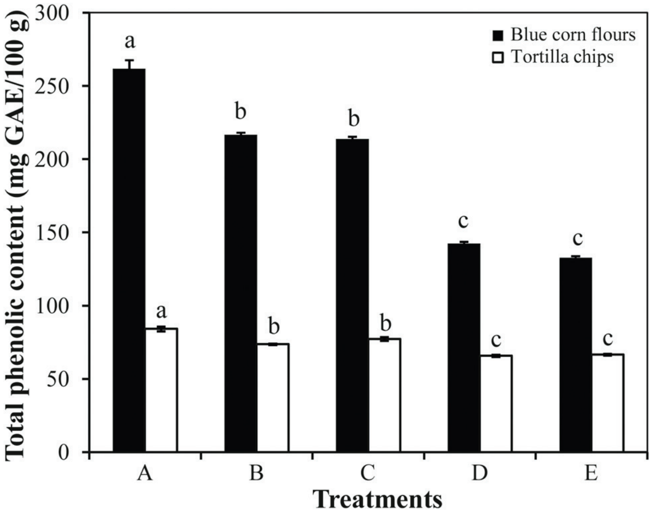

Figure 2. Total phenolic content in blue corn tortilla chips. A: TCEF control, B: TCEF $Ca(OH)_2$ 0.1%, C: TCEF $C_6H_{10}O_6Ca$ 0.9%, D: TCNF $Ca(OH)_2$ 1.0%, E: TCNF $C_6H_{10}O_6Ca$ 2.95%. Means between bars and treatments with different letters represent a significant difference according to the Tukey´s test ($P < 0.05$).

cooking and frying. The differences in the phenolic content retention between TCEF and TCNF are probably due to less starch damage in NF because of starch gelatinization during cooking and frying, minimizing the loss of these components. Figure 3 shows the antioxidant activity of the blue corn flours and their respective tortilla chips for the different treatments.

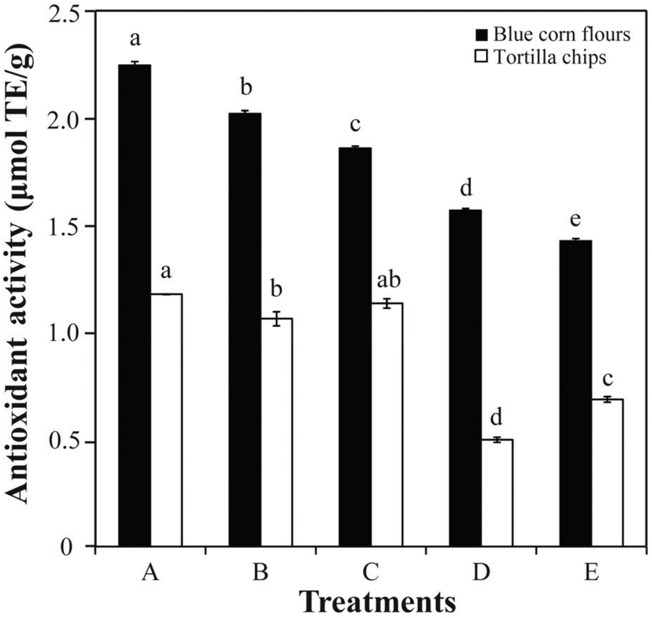

Figure 3. Antioxidant activity of blue corn tortilla chips. A: TCEF control, B: TCEF $Ca(OH)_2$ 0.1%, C: TCEF $C_6H_{10}O_6Ca$ 0.9%, D: TCNF $Ca(OH)_2$ 1.0%, E: TCNF $C_6H_{10}O_6Ca$ 2.95%. Means between bars and treatments with different letters represent a significant difference according to the Tukey´s test ($P < 0.05$).

It shows a notable decrease in antioxidant activity for the TC compared with those of their respective flours. This can be attributed to the fact that during baking and frying, the bioactive compounds such as polyphenols and anthocyanins are degraded, affecting the antioxidant activity (Lapidot et al., 1999). Some studies have reported that the presence of polyphenolics such as catechin and free forms of ferulic acid in corn flours contribute to the antioxidant activity (De la Parra et al., 2007; López-Martínez et al., 2009). The antioxidant activity was high for the extruded flours, and TCEF. These were significantly different from flours and TCNF. This can be due to the fact that during the extrusion process, the bioactive compounds are minimally exposed to heat, resulting in extruded flours with higher content of these compounds. This may also due to the small variation in the pH (pH 5.66) of the flour with $C_6H_{10}O_6Ca$ and the pH (6.57) of the flour with $Ca(OH)_2$), which resulted in greater retention of antioxidant activity in TC. During nixtamalization, some of these compounds are lost by the severity of thermal-alkaline process and by the leaching of these same compounds to the nejayote, causing a decrease in the antioxidant content (Del Pozo-Insfran et al., 2007; López-Martínez et al., 2011) and therefore a decrease in the antioxidant activity of the flours and TCNF, which showed a significant reduction of 60% of NF, on average. Correlation analysis between the values of the bioactive compounds, phenolics, and anthocyanins and the antioxidant activity and color of tortilla chips was performed for the different treatments (Table 2). The color parameters a^* and b^* were significantly correlated with the presence of anthocyanins and phenolics and antioxidant activity, reaching values of $R = 0.86\text{-}0.98$, while the antioxidant activity was significantly correlated with the anthocyanin and phenolic content, with values of $R = 0.90\text{-}0.99$, indicating that the antioxidant activity of the tortilla chips is mainly due to the presence of these bioactive compounds.

3.4 Texture

The texture characteristics of the blue corn tortilla chips, expressed as fracturability, are shown in Table 3. The TCEF with $Ca(OH)_2$ showed the highest resistance to fracture (hardness), which was significantly higher than that of the TCEF with $C_6H_{10}O_6Ca$. This difference can be attributed to the formation of complexes of the starch with the calcium resulting in a more compact (Zazueta-Morales et al., 2002) molecule and therefore harder tortilla chips. This texture difference between both calcium sources could be due to the lower ionization of $C_6H_{10}O_6Ca$ than that of $Ca(OH)_2$, which did not result in the release of Ca^{2+} (Sánchez-Madrigal et al., 2014). In general, the force of fracture of TCEF is higher than that of TCNF; TCNF with $C_6H_{10}O_6Ca$ showed the lowest peak force values. These results are due to the starch changes during extrusion of corn to obtain the flours, such as dextrinization, which is the major mechanism of starch fragmentation during the extrusion process (Gómez & Aguilera, 1984). Although nixtamalization process causes starch damage and decreases the average molecular weight of starch affecting the structural characteristics of products (Kervinen et al., 1984; Pan et al., 1998), the starch remaining after nixtamalization favors the development of tortilla chips with good texture properties. The texture properties of TC is related to the removal of moisture during the baking process at high temperatures to obtain TCNF, which leads to the formation of larger air cells and cracks in the

Table 2. Coefficients of correlation of the different determinations in blue corn tortilla chips.

Determinations	a*	b*	ΔE	TA	TP	AA
a*	0.612					
b*	0.760*	0.866*				
ΔE	–0.912*	–0.239	–0.459			
TA	0.667*	0.989*	0.893*	–0.310		
TP	0.808*	0.868*	0.861*	–0.544	0.918*	
AA	0.638*	0.983*	0.908*	–0.271	0.994*	0.906*

*Significant correlation ($P < 0.05$). ΔE: color difference; TA: total anthocyanins; TP: total phenolics; AA: antioxidant activity.

Table 3. Texture and oil content of blue corn tortilla chips with different calcium sources.

Tortilla chips	[Conc] (%)	Texture FR (N)	Oil content (%)
TCEF $Ca(OH)_2$	0.10	16.2±0.196a	13.38±0.924b
TCEF $C_6H_{10}O_6Ca$	0.90	12.7±0.088bc	14.55±0.306b
TCEF Control	0.00	14.2±0.651b	13.33±0.716b
TCNF $Ca(OH)_2$	1.00	11.6±0.439cd	17.14±0.066a
TCNF $C_6H_{10}O_6Ca$	2.95	10.3±0.459d	17.30±0.173a

[a]Mean values ± standard error from duplicate treatments. Means with different letters represent a significant difference according to the Tukey´stest ($P < 0.05$).

structure resulting in a TCNF with low fracture force values. This is because at high temperatures large cracks are formed due to the quick vaporization and diffusion of moisture through the pores (Kayacier & Sing, 2003).

3.5 Oil content

The oil content of the TC is shown in Table 3. TCEF of blue corn shows low values of oil absorption, with no significant differences between treatments. However, they were different from both TCNF ($P < 0.05$), which showed the highest oil contents, with no significant difference between treatments ($P > 0.05$). The lower oil absorption of TCEF may be due to greater starch gelatinization before frying (Serna-Saldívar et al., 1993); starch gelatinization and its consequent swelling of the granules inhibit oil absorption, thereby reducing the oil content (Fan et al., 1997). In addition, the higher oil absorption in the TCNF could be due to the fact that the nixtamalized flours had greater number (48.75-52.91%) of small particles (<149 µm) than that of the extruded flours since the coarse particles have the function to produce fissures in the product that allow water to escape during frying and reduce oil absorption during cooling (Moreira et al., 1997). Other authors found that high oil absorption in chips was due to the formation of great number of small pores (Dueik et al., 2012). The small pores formed trapped more air during frying resulting in a higher capillary pressure during cooling causing high final oil content in TC (Moreira et al., 1997).

4 Conclusions

All TCEF retained the majority of the properties evaluated better than TCNF. Significant changes were found in the anthocyanin and phenolic content, antioxidant activity, and color parameters (*a** and *b**) during the processing of tortilla chips. The anthocyanin and phenolic content showed high correlation with the antioxidant activity and color of TC, which indicated a direct relation between the antioxidant activity and the physical and chemical properties of TC. TCEF showed high resistance to fracture, but it also showed lower oil retention, which favors the stability of the tortilla chips. A higher anthocyanin content and antioxidant activity chips were found for both flours and tortilla in the nixtamalization and extrusion processes with $C_6H_{10}O_6Ca$, which shows an alternative process to produce naturally colored flours and tortilla chips with higher antioxidant content.

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