Physicochemical, nutritional and sensory properties of deep fat-fried fortified tortilla chips with broccoli (*Brassica oleracea* L. convar. *italica* Plenck) flour

ALMA VÁZQUEZ-DURÁN – ANDRÉS GALLEGOS-SOTO – HUGO BERNAL-BARRAGÁN – MERCEDES LÓPEZ-PÉREZ – ABRAHAM MÉNDEZ-ALBORES

Summary

The incorporation of broccoli trimmings into tortilla chips and their effect on the physicochemical, compositional, nutritional and sensory properties was studied. Broccoli flour was added to the formulation at levels of 2%, 4% and 8%. Triangular samples were processed in a lab-scale sheeter, baked, air oven-dried and finally deep fat-fried in fresh canola oil. The addition of broccoli flour significantly increased the protein (from 8.1% to 9.5%), crude fibre (from 1.9% to 3.1%), lysine (from 25.55 $g\cdot kg^{-1}$ protein to 35.11 $g\cdot kg^{-1}$ protein) and calcium contents (from 0.45 $g\cdot kg^{-1}$ to 0.73 $g\cdot kg^{-1}$) in the fortified tortilla chips. Additionally, the final oil content of tortilla chips was significantly lower (10.5%) in comparison with standard deep fat-fried products. Acceptance test indicated that 76% of participants would definitely prefer either control or tortilla chips prepared with up to 4% broccoli flour, when taste, price, appearance, texture and low fat content were the principal factors influencing the preference. From these results, it is concluded that broccoli flour could be incorporated into an innovative formulation to produce tortilla chips with improved physicochemical and nutritional properties.

Keywords

broccoli by-products; fortified tortilla chips; nutritional properties

Roughly, one-third of the edible parts of food produced for human consumption gets lost or is wasted, which is globally about 1.3 billion ton per year, including over 1 million tons of vegetable cutbacks [1]. These plant-derived waste by-products are inexpensive, available in large quantities, and are known to contain significant amounts of valuable components that remain unexploited, such as: protein, dietary fibre, saccharides, antioxidants, vitamins, bioactive and chemoprotective compounds.

Broccoli (*Brassica oleracea* L. convar. *italica* Plenck) is a vegetable that belongs to genus *Brassica*, family *Brassicaceae*. In Mexico, broccoli production is estimated at 335 000 tons per year [2] and the country is considered the seventh largest worldwide broccoli producer. Broccoli provides protein, fat, fibre, saccharides, and minerals. Additionally, it has been reported as one of main sources of natural antioxidants (phenolics, carotenoids, and vitamins) and chemoprotective substances (glucosinolates and their degradation products, isothiocyanates). Recently, broccoli consumption increased due to numerous beneficial effects in human health, as a high intake of cruciferous vegetables was found to be commonly associated with a reduced risk of cancer [3]. Several researchers also pointed out that regular

Alma Vázquez-Durán, Andrés Gallegos-Soto, Hugo Bernal-Barragán, Agronomy Department (UANL–FA), Autonomous University of Nuevo Leon, Agropecuary Sciences Campus, Avenida Francisco Villa s/n, Colonia Ex Hacienda el Canada, CP 66050, General Escobedo, Nuevo Leon, Mexico.

Mercedes López-Pérez, Unidad Irapuato (CINVESTAV–IPN), Center for Research and Advanced Studies of the National Polytechnic Institute, Km 9.6, Libramiento Norte, Carretera Irapuato-Leon, CP 36821, Irapuato, Guanajuato, Mexico.

Abraham Méndez-Albores, Superior Studies Department at Cuautitlan (UNAM–FESC), National Autonomous University of Mexico, Campus 4, Multidisciplinary Research Unit, Km 2.5 Carretera Cuautitlan-Teoloyucan, CP 54714, Cuautitlan Izcalli, Estado de Mexico, Mexico.

Correspondence author:

Alma Vázquez–Durán, tel.: (+52) 8113404399; fax: (+52) 8113404399, e-mail: vazquezd.alma@yahoo.com.mx

or intensive intake of horticultural products may reduce the risk of chronic degenerative diseases [4, 5]. Unfortunately, it was estimated that, during production, up to 70% of the total weight of the broccoli plant is discarded and, during processing, a loss of up to 50% of the initial broccoli head weights takes place, yielding large quantities of waste.

Due to the increasing consumer demand for convenient, healthy and "natural" foods, various attempts were carried out with the aim to improve the nutritional value of products by changing their nutritional composition. Corn chips and tortilla chips are two of the most popular snack foods in USA and Mexico, accounting for 80% of the maize-based snacks consumed worldwide [6]. Maize is the main ingredient of chips; however, it is low in protein content and is also deficient in some essential amino acids. Regularly, maize chips and tortilla chips are deep fat-fried in hot oil or fat, resulting in products that have a high fat content [7]. Excess consumption of fat and oils, in particular those containing saturated fats, increases the risk of obesity, coronary heart disease, diabetes, hypertension and cancer [8]. At present, there is a growing demand for healthier or lower-fat products, and this is driving the development of new formulations for producing low-fat snacks with acceptable physicochemical, nutritional and sensory properties at a reasonable price. Information about the use of broccoli to produce a "functional food" (a food that, by virtue of physiologically active components, provides a health benefit beyond basic nutrition) remains still meager in the food industry. Consequently, this research presents data on utilization of broccoli residues to produce functional tortilla chips with improved physicochemical, compositional, nutritional and sensory properties.

MATERIALS AND METHODS

Vegetable sample

Dehydrated broccoli wastes were kindly provided from a dried foods factory Deshidratadora La Cascada (Queretaro, Mexico). Samples were milled in an electric plate-style mill type C-11-1 (Glen Mills, Clifton, New Jersey, USA) and sieved (number 60, 0.25 mm) to provide ground material with a particle size of $< 250\,\mu$m.

Nixtamalized maize flour

Mexican traditional nixtamalization process was used to produce fresh nixtamalized maize flour [9]. Briefly, 20 kg whole white maize (commercial hybrid AS-900) was mixed with 40 l of tap water and 140 g of calcium hydroxide (JT Baker, Xalostoc, Mexico). The maize was cooked in a kettle for 20 min and steeped for 12 h at room temperature (24 °C). The steep liquor (nejayote) was removed and the cooked maize was washed with 40 l of tap water to remove excess lime and pericarp tissue. The nixtamal (cooked grain) was stone-ground (FUMASA, Model MN-400, Puebla, Mexico) to provide masa (corn dough). Subsequently, the masa was passed through a flash dryer to obtain dehydrated flour, the dryer conditions being 260 °C for the inlet air temperature, 90 °C for the exhaust air, and 4 s of residence time. Finally, the nixtamalized maize flour was ground in a mill Model 200 (Molinos Pulvex, Mexico City, Mexico) using a hammer head and a 0.5 mm mesh screen.

Sample preparation (formulation)

For the preparation of control samples, a combination of 990 g nixtamalized maize flour, 10 g of food grade granulated sodium chloride (La Fina, Coatzacoalcos, Mexico), and 1 600 g deionized water were mixed together in a Professional 600 series stand mixer (KitchenAid, St. Joseph, Michigan, USA) for 5 min at 7.33 rad·s^{-1}. Fortification process was conducted by substituting 2%, 4% and 8% of the initial weight of the nixtamalized maize flour in the formulation with broccoli flour. The resulting masses with about 65% moisture content were kept in thermally insulated plastic containers at room temperature, and allowed to rest for 1 h for proper hydration.

Preparation of tortilla chips

Triangular chips of approximately 18 cm^2 area were made using a Rondo STE 64C lab-scale sheeter (Rondo; Moonachie, New Jersey, USA). The final thickness of tortilla chips was set to 1.2 mm and was controlled by adjusting the roller gap of the sheeter-roller. Chips were baked for 20 s on each side on a griddle at 270 °C. The temperature was measured with a non-contact portable infrared thermometer Fluke-572 (Fluke; Melrose, Massachusetts, USA). The moisture content of the baked tortilla chips was around 57%. Subsequently, tortilla chips were air oven-dried at 50 °C for 6 h.

Deep fat-frying process

Baked tortilla chips were deep fat-fried in a professional 3 l stainless fryer model 35030 (Hamilton Beach, Picton, Canada). The unit was filled with fresh canola oil (ACH Foods Companies, Mexico City, Mexico). The oil temperature for frying was 190 °C, and samples (ten triangular pieces per batch) were fried during 7 s. The fried samples were drained on paper towels, cooled to room temperature, and packaged in hot seal polyethylene terephthalate/aluminum/polyethylene (PET/Al/PE) pouches flushed with N_2 gas.

Physicochemical analysis

pH

The pH value was determined according to the 943.02 AOAC method [9]. Briefly, 10 g of sample were suspended in 100 ml of recently boiled distilled water. The suspension was shaken (25 Hz, 25 °C, 30 min) using an orbital shaker model 21704-10 (Cole-Parmer, Vernon Hills, Illinois, USA). After 10 min, the supernatant liquid was decanted and the pH value was immediately determined using a pH meter model PC45 (Conductronic, Puebla, Mexico). Determinations were performed in triplicate.

Colour

Tortilla chips were subjected to surface colour analysis with a Konica Minolta model CR-410 colorimeter (Konica Minolta, Tokyo, Japan). The colorimeter was calibrated with a white porcelain plaque (L = 97.02, a = 0.13, b = 1.77). Three derived functions, total colour difference (ΔE), chroma (C^*) and hue angle (h) were computed from the L, a and b readings, as follows:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

$$C^* = \sqrt{a^2 + b^2} \quad (2)$$

$$h = \arctan \frac{b}{a} \quad (3)$$

where L is luminosity, 0 = black, 100 = white, and parameters a (from green to red) and b (from blue to yellow) are the two chromatic components that range from –120 to 120.

Compositional analysis

The following analyses were performed in triplicate: moisture content (drying at 105 °C for 24 h); ash (incineration at 550 °C); crude protein (micro-Kjeldahl, N × 6.25); crude fat (defatting in a Soxhlet equipment with hexane); and crude fibre (acid and alkaline hydrolysis), following the AOAC official methods 925.10, 923.03, 960.52, 920.39C and 962.09E, respectively [10]. Energy content was calculated from the macronutrient composition analysed for each sample using the conversion factors of 17 $kJ\cdot g^{-1}$ for protein, 17 $kJ\cdot g^{-1}$ for saccharides, and 37 $kJ\cdot g^{-1}$ for lipids [11]. To ensure close comparison without the influence of rounded conversion factors, values of 16.74 $kJ\cdot g^{-1}$, 16.74 $kJ\cdot g^{-1}$, and 37.66 $kJ\cdot g^{-1}$ were used for protein, saccharide and lipids, respectively.

Nutritional properties

Lysine

Lysine analysis was performed using the method described by LÓPEZ-CERVANTES et al. [12] using high performance liquid chromatography (Waters Associates, Milford, Massachusetts, USA), equipped with a Waters Nova-pak C18 reverse phase column (4 μm, 3.9 mm × 150 mm) maintained at 38 °C. Samples (50 mg) were hydrolysed at 110 °C with 10 ml of 6 $mol\cdot l^{-1}$ HCl for 24 h. The hydrolysed sample was filtered and the extract was diluted 200 times with MilliQ water (EMD Millipore, Billerica, Massachusetts, USA). A 300 μl aliquot of the extract was dried and derivatized with the same amount of 9-fluorenylmethylchloroformate. Standard as well as samples (20 μl) were injected into HPLC and eluted with a mobile phase of 30 $mmol\cdot l^{-1}$ ammonium phosphate (pH 6.5) in 15:85 (v/v) methanol:water; 15:85 (v/v) methanol:water; and 90:10 (v/v) acetonitrile:water at a flow rate of 1.2 $ml\cdot min^{-1}$. The gradient program employed was as reported previously [12]. Lysine was detected using a fluorescence detector (Waters model 2475), the excitation and emission wavelengths being 270 nm and 316 nm, respectively. Analyses were done in triplicate.

Tryptophan

Tryptophan analysis was performed using the colorimetric method described by NURIT et al. [13]. Flour samples were defatted with hexane in a Soxhlet-type continuous extractor for 6 h. After hexane evaporation, 80 mg of the powder was digested using 3 ml of 4 $mg\cdot ml^{-1}$ papain solution in 0.165 $mol\cdot l^{-1}$ sodium acetate. The tubes were incubated at 65 °C for 16 h, allowed to cool to room temperature, and centrifuged at 3600 ×g for 10 min. Subsequently, one milliliter of the supernatant was carefully transferred to a clean tube, and 3 ml of a colorimetric reagent (0.1 $mol\cdot l^{-1}$ glyoxylic acid in 3.5 $mol\cdot l^{-1}$ H_2SO_4 + 1.8 $mmol\cdot l^{-1}$ $FeCl_3 \times 6H_20$ + 15 $mol\cdot l^{-1}$ H_2SO_4) was added. Samples were vortexed, incubated at 65 °C during 30 min, and then allowed to cool to room temperature before reading their optical density at 560 nm in a Beckman-Coulter DU-530 UV-visible spectrophotometer (Beckman-Coulter, Brea, California, USA). A calibration curve was constructed using standard tryptophan (Sigma-Aldrich, St. Louis, Missouri, USA). Analyses were done in triplicate.

In vitro protein digestibility

In vitro protein digestion (*PD*) was performed using the 982.30G AOAC method [10]. A multi-enzyme cocktail, consisting of a mixture of porcine pancreatic trypsin type IX, porcine intestinal peptidase grade I, bovine pancreatic α-chymotrypsin type II, and bacterial protease (Sigma-Aldrich), was used. Sodium caseinate was used as a control (10 g suspended in 200 ml distilled water and adjusted to pH 8 with NaOH). Flour samples and distilled water were used to prepare 10 ml of an aqueous protein suspension (10 mg N) with pH adjusted to 8.0, while stirring in a water bath at 37 °C during 1 h. The multi-enzyme cocktail was maintained in an ice bath and adjusted to pH 8.0. While stirring, 1 ml of the multi-enzyme solution was added to the protein suspension and, 10 min after addition, 1 ml of bacterial protease was added and then transferred to 55 °C bath for 9 min. Exactly 19 min after reaction, vials were transferred back to a 37 °C bath. The rapid pH drop was recorded automatically over a 20 min period using a pH meter (Conductronic). Samples were analysed in triplicate. Percentage of *PD* was calculated as follows:

$$PD = 234.84 - 22.56\ (\text{pH value}) \quad (4)$$

where 234.84 is the intercept and 22.56 is the slope of the linear regression equation.

Mineral analysis

Calcium determination was performed according to the 985.35 AOAC official method [10] with minimal modifications. Briefly, tortilla chips were dried in a vacuum oven at 40 °C during 48 h, then milled and sieved (number 60, 0.25 mm) to provide ground material with a particle size of < 250 μm. Samples (1–2 g) placed into ashing crucibles were calcinated in a furnace model FE-360 (Felisa, Zapopan, Mexico) for 5 h at 480 °C. Samples were removed and allowed to cool to room temperature, 5 ml concentrated HCl plus 0.7 ml concentrated HNO_3 were added, and then heated at 150 °C in a hot plate model LMS-1003 (Lab Tech, Namyangju, South Korea) for 1 h. Cooled samples were transferred into 100 ml volumetric flasks and brought to the sign with distilled water. Subsequently, 1 ml was transferred into a 40 ml volumetric flasks and 0.4 ml of 10 mg·ml^{-1} La_2O_3 solution was added to eliminate phosphorus interference, flasks were brought to the sign with distilled water. A calibration curve was constructed using standard stock solutions of calcium carbonate. Calibration curve solutions as well as samples were vaporized in an air-acetylene flame by using a Solaar S Series AA Atomic Absorption Spectrometer (Thermo Scientific, Waltham, Massachusetts, USA). Absorbance was measured at a wavelength of 422.7 nm. Samples were analysed in triplicate.

Consumer preference and sensory evaluation

A panel of 100 untrained judges was selected from students and professors of the Food Engineering Department of the National Autonomous University of Mexico (both sexes, 18 to 50 years old). The selection criteria for the panelists were based on the participant interest, taste/odour and texture perception, besides that they all declared to enjoy eating maize-based snacks and to consume them on a regular basis (at least twice every month). In preliminary evaluations, panelists were asked to evaluate their preference for the fortified tortilla chips. Three options were considered: definitely, probably, and might prefer. Additionally, panelists were also asked: What factors influence your decision to prefer tortilla chips similar to these samples?

For the sensory test, tortilla chips were offered to candidates in individual booths under sensory controlled laboratory conditions (24 °C, 50–60% relative humidity). Control chips were always offered before fortified tortilla chips. Participants receiving a separate set of samples (2 pieces from each treatment) with the following sensory attributes being evaluated: aroma, appearance, oral texture, taste, and aftertaste. For aroma evaluation, tortilla chips were placed in small (16.5 × 14.9 cm) sealed ziploc plastic bags and smelled twice. Tortilla chips appearance was judged under 250 W incandescent white bulbs installed in each individual booth. For taste judgment, samples were not swallowed and purified water was offered for oral rinsing; however, samples of tortilla chips were consumed for aftertaste analysis and the results were recorded after 30 s of consumption. Sensory attributes were assessed using a 9-point hedonic scale. A sensory score of 5 or above was deemed acceptable and a sensory score below 5 was considered unacceptable. Consumer preference and sensory tests were repeated three times on different dates.

Experimental design and statistical analysis

The experiment was conducted as a completely randomized design, the four experimental conditions were carried out with three replicates. Data were assessed by analysis of variance (ANOVA) and means comparisons were performed according to the Tukey test using the Statistical Analysis System (SAS Institute, Cary, North Carolina, USA). A significance value of $p < 0.05$ was used to distinguish significant differences between treatments.

RESULTS AND DISCUSSION

Tab. 1 shows the physicochemical, compositional, and nutritional properties of the nixtamalized maize and broccoli flours. Results on these properties were quite similar to those reported previously by other researchers [14, 15]. As presented in Tab. 1, broccoli is an excellent source of protein (27.1%), crude fibre (11.5%), ash (6.3%), saccharides (64.6%), and is low in lipids (2%). Moreover, among these important nutritive compounds, broccoli contains high amounts of the essential amino acid lysine (130.75 $g\cdot kg^{-1}$ protein). Consequently, flour characteristics of broccoli remains play an important role in their utilization. Regarding minerals, broccoli flour had the highest calcium content (4.09 $g\cdot kg^{-1}$), almost 9 times higher than that of the nixtamalized maize flour (Tab. 1). Farnham et al. [16] reported calcium contents up to 4.35 $g\cdot kg^{-1}$ for the broccoli hybrid Arcadia. Lucarini et al. [17] reported a value of 3.50 $g\cdot kg^{-1}$ for calcium content in a single sample of broccoli (unidentified cultivar) purchased from a store. Data on calcium content are in agreement with the values found by those researchers.

Physicochemical properties

Some physicochemical properties of tortilla chips are listed in Tab. 2. Regarding the moisture content (before frying), significant differences were not observed between treatments, the average content for oven-dried tortilla chips was 10.2%. Once the tortilla chips were fried, the moisture content of the samples fortified with broccoli flour was not significantly different than the control; however, frying (at 190 °C for 7 s) reduced the moisture content to 3.5%. Tortilla chips are known to contain both free and bound water, free water on the surface evaporates rapidly in the first seconds of the frying process, thus tortilla chips have a significantly reduced moisture content. Al-Okbi et al. [18] reported moisture contents in the range of 2.4% to 7.0% for tortilla chips prepared with 30% rice bran (fried at 160 °C for 1 min in sunflower oil). Those moisture content values are in close agreement with our results. On the other hand, the pH values of tortilla chips showed significant differences, mainly due to broccoli incorporation. In general, as the broccoli content increased in the formulation, lower pH values were registered (Tab. 2). Tortilla chips fortified with 2% broccoli flour presented no significant differences on pH in comparison with control chips, in these samples the average value was 6.07. On the contrary, tortilla chips fortified with 4% and 8% broccoli flour presented a slightly lower average pH value (5.96). This fact was a consequence of the broccoli addition into the formulation, since broccoli flour presented a pH value of 5.48 (Tab. 1). Campas-Baypoli et al. [15] reported no differences in pH of three different flours prepared from broccoli crop remains (florets, leaves and stalks); the average pH values for these flours were 5.18, 5.31 and 5.47, respectively. On the other hand, Torres et al. [19] reported pH values of 6.47 and 5.77 for tortilla chips prepared with 1% lime using traditional and commercial nixtamalization processes. These pH values are in accordance with our results, taking into account that, in this research, the amount of calcium hydroxide used to prepare the nixtamalized flour was 0.7% (w/w).

Surface colour analysis

Results on colour of tortilla chips containing different levels of broccoli flour are also presented in Tab. 2. Significant differences were detected for

Tab. 1. Physicochemical properties, proximate analysis, nutritional properties and mineral contents of nixtamalized maize and broccoli flours.

Properties	Flour	
	Nixtamalized maize	Broccoli
Physicochemical properties		
Moisture content [%]	10.0 ± 0.6	12.2 ± 0.2
pH	6.10 ± 0.004	5.48 ± 0.009
Proximate composition		
Proteins [%]	8.1 ± 0.1	27.1 ± 0.4
Lipids [%]	4.3 ± 0.0	2.0 ± 0.2
Ash [%]	1.3 ± 0.0	6.3 ± 0.2
Crude fibre [%]	2.2 ± 0.1	11.5 ± 0.5
Saccharides [%]	86.3	64.6
Nutritional properties		
Lysine [$g\cdot kg^{-1}$]	23.76 ± 0.22	130.75 ± 1.22
Tryptophan [$g\cdot kg^{-1}$]	5.09 ± 0.09	11.14 ± 0.18
In vitro protein digestibility [%]	83.5 ± 0.3	77.2 ± 0.2
Minerals		
Calcium [$g\cdot kg^{-1}$]	0.47 ± 0.03	4.09 ± 0.10

Mean values of three replicates ± standard error are presented. Proximate and mineral composition are expressed on dry basis. Lysine and tryptophan contents are expressed per kilogram of proteins. Saccharides were determined by difference: 100 - Σ(protein + lipid + ash).

Tab. 2. Physicochemical properties of deep fat-fried fortified tortilla chips.

Properties	Control	Broccoli addition		
		2%	4%	8%
Moisture content [%]				
Before frying	10.1 ± 0.1 [a]	10.3 ± 0.1 [a]	10.1 ± 0.2 [a]	10.2 ± 0.3 [a]
After frying	3.4 ± 0.1 [a]	3.5 ± 0.1 [a]	3.5 ± 0.0 [a]	3.4 ± 0.1 [a]
pH	6.10 ± 0.006 [a]	6.04 ± 0.004 [a]	6.00 ± 0.010 [b]	5.91 ± 0.003 [b]
Colour				
Luminosity *L*	76.26 ± 1.28 [a]	70.87 ± 1.06 [b]	68.84 ± 1.03 [b]	62.33 ± 0.97 [c]
ΔE	28.49 ± 0.35 [a]	32.75 ± 0.24 [b]	34.76 ± 0.47 [b]	39.58 ± 0.25 [c]
Chroma *C**	19.47 ± 0.85 [a]	19.78 ± 1.15 [a]	20.16 ± 0.67 [a]	19.02 ± 1.25 [a]
Hue angle *h*	85.02 ± 0.18 [a]	85.82 ± 0.21 [a]	86.88 ± 0.19 [a]	81.92 ± 0.48 [b]

Mean values of three replicates ± standard error are presented. Means with the same letter in the same row are not significantly different (Tukey´s test, $p > 0.05$).

luminosity (L), total colour difference (ΔE) and the hue angle (h). In general, increasing the level of broccoli resulted in lowering the brightness. Thus, the lowest luminosity (62.33) was registered for tortilla chips fortified with 8% broccoli flour. Conversely, control chips presented the highest L value (76.26). Regarding this, Rababah et al. [20] reported an average L value of 76.20 for extruded maize chips, and similar values were also reported for maize chips fortified with 3% broad bean or chickpea flour. Additionally, Xu and Kerr [21] reported ΔE, chroma and hue angle values in the range from 19.42 to 30.09, from 24.6 to 25.6, and from 83.1 to 85.3, respectively, for deep fat-fried maize chips made by continuous vacuum drying. These physicochemical data are in close agreement with those obtained in this research.

Compositional properties

Tab. 3 shows the proximate composition of tortilla chips. As the broccoli content increased in the formulation, higher protein values were registered, while significant differences were observed for the four addition levels. In comparison to the control, tortilla chips fortified with 2%, 4% and 8% broccoli flour had an increased protein content by 2.5%, 4.9% and 17.3%, respectively. Stojceska et al. [22] reported an increase in protein content by up to 25.2% in cereal-based ready-to-eat expanded snacks added with 20% cauliflower. Rababah et al. [20] reported protein contents of 8.6%, 8.0% and 10.5% for maize chips fortified with 9% broad bean, chickpea and isolated soya protein, respectively. These results are consistent with the values found in this research. Regarding the lipid content, there were no significant differences among the addition levels, the average content was 10.3% (Tab. 3). Lujan-Acosta and Moreira [23] reported 26.3% oil content for tortilla chips prepared from nixtamalized maize flour, and 14.5% for sun-dried tortilla chips. Esturk et al. [24] reported oil contents in the range from 22.6% to 36.9% for deep fried tortilla chips added with carboxymethyl cellulose. Other authors reported oil contents of 19.4% for tortilla chips added with 30% rice bran, and 33.4% for deep fat-fried maize chips [18, 21]. It is well known that oil content is significantly affected by the type of pre-treatment, frying oil temperature, frying time and by flour particle size. Also, there is a strong negative correlation between moisture content and oil uptake in tortilla chips. As more moisture is removed from the samples during frying, the oil content increases. In this research, the size of pores formed in tortilla chips due to the thermal treatment (baking and oven-drying) could be one reason for less oil uptake. As a result, the number of small pores and the network of cavities inside tortilla chips were reduced by drying prior to frying. In the case of ash content, there were no significant differences between control and fortified tortilla chips added with up to 4% broccoli flour; in these samples, the average ash content was 2.0% (Tab. 3). However, ash content significantly increased in tortilla chips fortified with 8% broccoli (2.4%). Méndez-Albores et al. [25] reported ash content values up to 1.8% in maize tortillas produced by a modified nixtamalization process. On the other hand, as the broccoli flour content increased in the formulation, higher crude fibre values were registered. In comparison to the control, tortilla chips fortified with 2%, 4% and 8% broccoli flour, their crude fibre became increased by 15.8%, 36.8% and 63.2%, respectively. This notable increase in ash and fibre contents of tortilla chips was principally due to the incorporation of broccoli to the formulation, since broccoli flour presented the highest content of ash (6.3%) and crude fibre (11.5%). CAMPAS-BAYPOLI et al. [15] reported ash and fibre crude contents of 7.9% and 11.7% for broccoli flours prepared with florets. These results are quite similar to those reported in this research. Furthermore, there were no significant differences in the saccharide and energy content of tortilla chips, the average values for these parameters were 79.0% and 18 538 kJ·kg^{-1}, respectively (Tab. 3).

Nutritional properties

Tab. 3 shows some nutritional properties of tortilla chips. There were no significant differences in tryptophan content and in vitro protein digestibility of tortilla chips with the four addition levels. However, as the broccoli flour content increased in the formulation, higher lysine contents were observed. Samples produced with incorporation of 2% and 4% broccoli flour had an increased lysine content by approximately 35%. The maximum increment (49.1%) was observed in tortilla chips produced with 8% broccoli; these samples had the contents of lysine and tryptophan of 35.11 g·kg^{-1} and 5.22 g·kg^{-1} in the protein fraction, which corresponds to 65% and 54% of FAO profile, respectively [26].

Mineral analysis

As a result of the inclusion of broccoli flour, there was a significant increase in the calcium content of tortilla chips. As the broccoli content increased, higher levels of the mineral were registered (Tab. 3). In comparison to the control, samples prepared with the incorporation of 2%, 4% and 8% broccoli flour, had a calcium content increased by 22.2%, 44.4% and 62.2%, respectively. Several authors reported that the calcium content in raw maize ranges from 0.071 g·kg^{-1} to 0.085 g·kg^{-1} [27, 28], and that the calcium content increases considerably during nixtamalization [29]. However, the retained calcium content depends on several factors such as the amount of calcium hydroxide added initially, the cooking time-temperature, the time for which the grain is left to soak in the lime solution after boiling, and the frequency and intensity of the washing process used to remove the excess lime from the cooked maize. In general, commercial flours are usually lime-treated with only one hour of steeping [30]. Consequently, the calcium content is very low in comparison with that of products of the traditional process, where the calcium content may reach values of up to 2.49 g·kg^{-1} [31]. For instance, the commercial nixtamalized maize flour Maseca (Grupo Maseca, Nuevo Leon, Mexico) usually contains 0.49 g calcium per kilogram of flour. This value is quite similar to the calcium content obtained in

Tab. 3. Proximate analysis, nutritional properties and mineral content of deep fat-fried fortified tortilla chips.

Properties	Control	Broccoli addition		
		2%	4%	8%
Proximate composition				
Proteins [%]	8.1 ± 0.1 ^{a}	8.3 ± 0.1 ^{b}	8.5 ± 0.1 ^{c}	9.5 ± 0.0 ^{d}
Lipids [%]	10.1 ± 0.0 ^{a}	10.3 ± 0.1 ^{a}	10.2 ± 0.0 ^{a}	10.5 ± 0.1 ^{a}
Ash [%]	1.9 ± 0.0 ^{a}	2.0 ± 0.0 ^{a}	2.1 ± 0.0 ^{a}	2.4 ± 0.0 ^{b}
Crude fibre [%]	1.9 ± 0.1 ^{a}	2.2 ± 0.1 ^{b}	2.6 ± 0.0 ^{c}	3.1 ± 0.1 ^{d}
Saccharides [%]	79.9 ^{a}	79.4 ^{a}	79.2 ^{a}	77.6 ^{a}
Energy [kJ·kg^{-1}]	18535 ^{a}	18560 ^{a}	18522 ^{a}	18535 ^{a}
Nutritional properties				
Lysine [g·kg^{-1}]	23.55 ± 0.47 ^{a}	30.89 ± 0.86 ^{b}	32.54 ± 1.02 ^{b}	35.11 ± 0.81 ^{c}
Tryptophan [g·kg^{-1}]	5.00 ± 0.07 ^{a}	5.16 ± 0.01 ^{a}	5.19 ± 0.04 ^{a}	5.22 ± 0.04 ^{a}
In vitro protein digestibility [%]	84.2 ± 0.1 ^{a}	82.9 ± 0.6 ^{a}	82.6 ± 0.2 ^{a}	81.8 ± 0.9 ^{a}
Minerals				
Calcium [g·kg^{-1}]	0.45 ± 0.03 ^{a}	0.55 ± 0.01 ^{b}	0.65 ± 0.02 ^{c}	0.73 ± 0.02 ^{d}

Mean values of three replicates ± standard error are presented. Means with the same letter in the same row are not significantly different (Tukey´s test, $p > 0.05$). Proximate and mineral composition are expressed in dry basis. Saccharides were determined by difference: 100 - Σ(protein + lipid + ash).

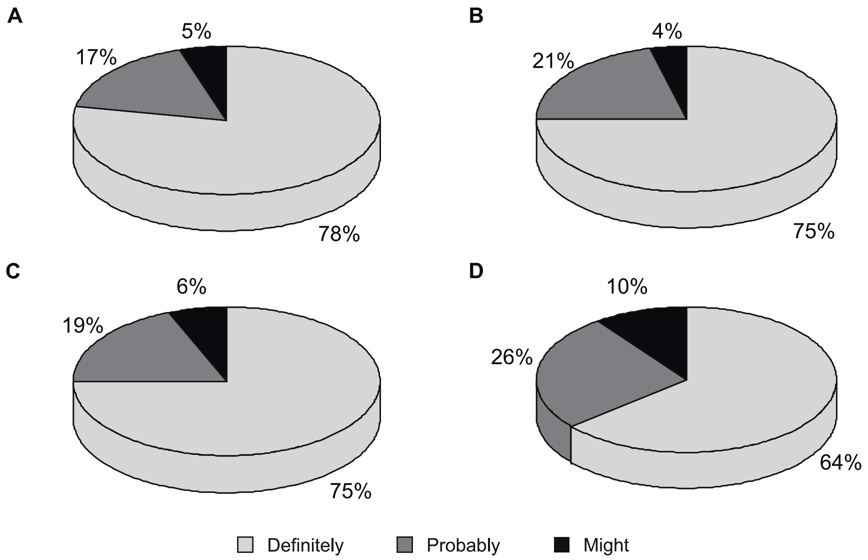

Fig. 1. Consumer preferences of deep fat-fried fortified tortilla chips.

A – control, B – 2% broccoli, C – 4% broccoli, D – 8% broccoli.

the control chips (0.45 g·kg^{-1}). Broccoli is a good vegetable source of calcium and the efficiency of absorption from most vegetable sources is the same or better than that from dairy products, unless high amounts of inhibitors, such as oxalic acid or phytic acid, are present [32, 33]. Thus, tortilla chips fortified with broccoli flour could be an important alternative source of calcium in segments of the population that consume limited amounts of this mineral.

Preference survey and sensory analysis

Results of the preference evaluation showed that approximately 76% of panelists definitely, 19% probably, and 5% might prefer control and tortilla chips prepared with up to 4% broccoli. In comparison, 64% of panelists definitely, 26% probably, and 10% might prefer tortilla chips prepared with 8% broccoli flour (Fig. 1). Interestingly, a high percentage of panelists indicated they would definitely prefer tortilla chips prepared with the incorporation of broccoli flour. Nevertheless, as the chips offered in this research were served without additional flavouring agents, this may have reduced the preference, in particular of those samples prepared with the highest content of broccoli flour. Moreover, it should be noted that 94% of the panelists indicated that they consider taste as the principal factor to be considered when buying tortilla chips. Additionally, 86% of the panelists pointed out that price is also a concern when they choose tortilla chips. Besides, when asked which

Tab. 4. Sensory evaluation of deep fat-fried fortified tortilla chips.

Attributes	Control	Broccoli addition		
		2%	4%	8%
Aroma	8.92 ± 0.23 a	8.57 ± 0.25 a	8.69 ± 0.32 a	7.54 ± 0.22 b
Appearance	9.01 ± 0.11 a	8.92 ± 0.33 a	8.78 ± 0.28 a	8.86 ± 0.33 a
Oral texture	7.45 ± 0.14 a	7.33 ± 0.27 a	7.28 ± 0.41 a	7.16 ± 0.48 a
Taste	9.11 ± 0.09 a	9.15 ± 0.19 a	8.89 ± 0.39 a	7.75 ± 0.51 b
Aftertaste	6.45 ± 0.17 a	6.51 ± 0.09 a	6.17 ± 0.21 a	5.57 ± 0. 44 b
Overall acceptability	8.18 a	8.09 a	7.96 a	7.38 b

Mean values of three replicates ± standard error are presented. Means with the same letter in the same row are not significantly different (Tukey´s test, $p > 0.05$).

other factors directly influence their decision to select chips, 85% indicated appearance or even texture, 83% indicated low fat content, and 74% a healthy diet.

Results from the subsequent sensory test are summarized in Tab. 4. In terms of overall acceptability, control and tortilla chips prepared with up to 4% broccoli flour had somewhat higher scores (8.18, 8.09 and 7.96) than tortilla chips prepared with 8% broccoli incorporation (7.38). These results were more closely linked with attributes such as aroma, taste and aftertaste. Also, some comments suggested that tortilla chips prepared with 8% broccoli had less of the typical flavour associated with nixtamalized products. While tortilla chips prepared with up to 4% broccoli flour had more of a nixtamalized maize flavour, tortilla chips with 8% broccoli addition had a flavour more closely associated to the vegetable (broccoli). Likability was not the only consideration for consumers; as noted, a majority of consumers are trying to eat "healthier products". A key aspect of that is how well the concept of a "healthier product" is communicated on the package and in the store [21]. In our research, even without additional information, tortilla chips prepared with the incorporation of broccoli flour had a reasonable preference. In general, panelists found that tortilla chips prepared with up to 4% broccoli flour had better aroma, appearance, oral texture, taste and aftertaste. However, with the right communication, consumers may better appreciate tortilla chips fortified with 8% broccoli flour, since vegetable consumption may provide potential health benefits.

CONCLUSION

The results obtained in this research on incorporation of broccoli by-products into tortilla chip formulations bring information on its effect on the physicochemical, compositional, nutritional and sensory properties of the product. Addition of broccoli at levels of up to 8% increased protein, fibre, lysine and calcium contents in the finished product by 17.3%, 63.2%, 49.1% and 62.2%, respectively. The taste panel acceptability score showed that broccoli by-products could be added to a level of up to 4% without compromising aroma, appearance, oral texture, taste and aftertaste of the chips. This issue will be addressed in future trials where the flavour of the chips containing up to 8% broccoli flour could be further improved by coating or spraying with selected flavours. As there is a growing market for low-fat snacks along with foods that contain significant amounts of nutrients, antioxidants, bioactive and chemoprotective compounds, the incorporation of broccoli trimmings may be a means for producing tortilla chips for targeted markets. However, more research on possible effect of thermal treatment (baking and frying) on acrylamide formation in tortilla chips enriched with broccoli flour, needs to be conducted as well.

Acknowledgements

The authors are grateful to Nydia Corina Vásquez-Aguilar and Eliud Gerardo Piña-Sandoval for their technical help. We also thank the Autonomous University of Nuevo Leon, San Nicolas de los Garza, Mexico, for financial assistance for this research through the Support Program for Scientific and Technological Research (PAICyT) grant IT970-11.

REFERENCES

1. Global food losses and waste. Extent, causes and prevention. Rome: Food and Agriculture Organization of the United Nations, 2011. Available at <http://www.fao.org/docrep/014/mb060e/mb060e00.pdf>
2. Servicio de Información Agroalimentaria y Pesquera. In: Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación [online]. Mexico: Agrifood and Fishery Information Service (SIAP), 2011 [cit. 01 November 2013]. <http://www.siap.gob.mx/index.php?option=com_wrapper&view=wrapper&Itemid=350>
3. Moreno, D. A. – Carvajal, M. – López-Berenguer, C. – García-Viguera, C.: Chemical and biological characterisation of nutraceutical compounds of broccoli. Journal of Pharmaceutical and Biomedical Analysis, *41,* 2006, pp. 1508–1522. DOI: 10.1016/j.jpba.2006.04.003.
4. Sun-Waterhouse, D. – Melton, L. D. – O'Connor, C. J. – Kilmartin, P. A. – Smith, B. G.: Effect of apple cell walls and their extracts on the activity of dietary antioxidants. Journal of Agricultural and Food Chemistry, *56*, 2008, pp. 289–295. DOI: 10.1021/jf072670v.
5. Jew, S. – AbuMweis, S. S. – Jones, P. J. H.: Evolution of the human diet: linking our ancestral diet to modern functional foods as a means of chronic disease prevention. Journal of Medicinal Food, *12*, 2009, pp. 925–934. DOI: 10.1089/jmf.2008.0268.
6. Camire, M. E. – Camire, A. – Krumhar, K.: Chemical and nutritional changes in foods during extrusion. Critical Reviews in Food Science and Nutrition, *29*, 1990, pp. 35–57. DOI: 10.1080/10408399009527513.
7. Moreira, R. G. – Castell-Perez, M. E. – Barrufet, M.: Deep fat frying: fundamentals and applications. Gaithersburg: Springer, 1999. 350 pp. ISBN: 0834213214.
8. Saguy, I. S. – Dana, D.: Integrated approach to deep fat frying: engineering, nutrition, health and consumer aspects. Journal of Food Engineering, *56*, 2003,

pp. 143–152. DOI: 1016/S0260-8774(02)00243-1.

9. Serna-Saldívar, S. O. – Gómez, M. H. – Rooney, L. W.: Technology, chemistry and nutritional value of alkaline-cooked corn products. In: Pomeranz, Y. (Ed.): Advances in cereal science and technology. St Paul: American Association of Cereal Chemists, 1990, pp. 243–307.
10. Horwitz, W. (Ed.): Official methods of analysis of AOAC International. 17th ed. Gaithersburg: Association of Official Analytical Chemists International, 2000. 2200 pp. ISBN 0-035584773.
11. Food energy: Methods of analysis and conversion factors. FAO Food and Nutrition Paper 77. Rome: Food and Agricultural Organization of the United Nations, 2003. <http://www.fao.org/docrep/006/y5022e/y5022e00.htm>
12. López-Cervantes, J. – Sánchez-Machado, D. I. – Rosas-Rodríguez, J. A.: Analysis of free amino acids in fermented shrimp waste by high-performance liquid chromatography. Journal of Chromatography A, *1105,* 2006, pp. 106–110. DOI: 10.1016/j.chroma.2005.08.040.
13. Nurit, E. – Tiessen, A. – Pixley, K. V. – Palacios-Rojas, N.: Reliable and inexpensive colorimetric method for determining protein-bound tryptophan in maize kernels. Journal of Agricultural and Food Chemistry, *57*, 2009, pp. 7233–7238. DOI: 10.1021/jf901315x.
14. Vaca-García, V. M. – Martínez-Rueda, C. G. – Mariezcurrena-Berasain, M. D. – Dominguez-López, A.: Functional properties of tortillas with triticale flour as a partial substitute of nixtamalized corn flour. LWT – Food Science and Technology, *44*, 2011, pp. 1383–1387. DOI: 10.1016/j.lwt.2011.01.024.
15. Campas-Baypoli, O. N. – Sánchez-Machado, D. I. – Bueno-Solano, C. – Núñez-Gastélum, J. A. – Reyes-Moreno, C. – López-Cervantes, J.: Biochemical composition and physicochemical properties of broccoli flours. International Journal of Food Science and Nutrition, *60*, 2009, pp. 163–173. DOI: 10.1080/09637480802702015.
16. Farnham, M. W. – Grusak, M. A. – Wang, M.: Calcium and magnesium concentration of inbred and hybrid broccoli heads. Journal of the American Society for Horticultural Science, *125*, 2000, pp. 344–349.
17. Lucarini, M. – Canali, R. – Cappelloni, M. – Di Lullo, G. – Lombardi-Boccia, G.: In vitro calcium availability from *Brassica* vegetables (*Brassica oleracea* L.) and as consumed in composite dishes. Food Chemistry, *64*, 1999, pp 519–523. DOI: 10.1016/S0308-8146(00)00061-3.
18. Al-Okbi, S. Y. – Hussein, A. M. S. – Hamed, I. M. – Mohamed, D. A. – Helal, A. M.: Chemical, rheological, sensorial and functional properties of gelatinized corn-rice bran flour composite corn flakes and tortilla chips. Journal of Food Processing and Preservation, *38*, 2014, pp. 83–89. DOI: 10.1111/j.1745-4549.2012.00747.x.
19. Torres, P. – Guzmán-Ortiz, M. – Ramírez-Wong, B.: Revising the role of pH and thermal treatments in aflatoxin content reduction during the tortilla and deep frying processes. Journal of Agricultural and Food Chemistry, *49*, 2001, pp. 2825–2829. DOI: 10.1021/jf0007030.
20. Rababah, T. M. – Brewer, S. – Yang, W. – Al-Mahasneh, M. – Al-U'datt, M. – Rababa, S. – Ereifej, K.: Physicochemical properties of fortified corn chips with broad bean flour, chickpea flour or isolated soy protein. Journal of Food Quality, *35*, 2012, pp. 200–206. DOI: 10.1111/j.1745-4557.2012.00440.x.
21. Xu, S. – Kerr, W. L.: Comparative study of physical and sensory properties of corn chips made by continuous vacuum drying and deep fat frying. LWT – Food Science and Technology, *48*, 2012, pp. 96–101. DOI: 10.1016/j.lwt.2012.02.019.
22. Stojceska, V. – Ainsworth, P. – Plunkett, A. – İbanoğlu, E. – İbanoğlu, Ş.: Cauliflower by-products as a new source of dietary fibre, antioxidants and proteins in cereal based ready-to-eat expanded snacks. Journal of Food Engineering, *87*, 2008, pp. 554–563. DOI: 10.1016/j.jfoodeng.2008.01.009.
23. Lujan-Acosta, J. – Moreira, R. G.: Effects of different drying processes on oil absorption and microstructure of tortilla chips. Cereal Chemistry, *74*, 1997, pp. 216–223. DOI: 10.1094/CCHEM.1997.74.3.216.
24. Esturk, O. – Kayacier, A. – Singh, R. K.: Reduction of oil uptake in deep fried tortilla chips. Food Science and Technology International, *6*, 2000, pp. 425–431. DOI: 10.1177/108201320000600509.
25. Méndez-Albores, A. – Martínez-Morquecho, R. A. – Moreno-Martínez, E. – Vázquez-Durán, A.: Technological properties of maize tortillas produced by microwave nixtamalization with variable alkalinity. African Journal of Biotechnology, *11*, 2012, pp. 15178-15187. DOI: 10.5897/AJB12.2098.
26. Energy and protein requirements. Report of a Joint FAO/WHO/UNU Expert Consultation. WHO Technical Report Series 724. Geneva: World Health Organization, 1985. 206 pp. ISBN 9241207248.
27. Figueroa-Cárdenas, J. D. – Acero-Godínez, M. G. – Vasco-Méndez, N. L. – Lozano-Guzmán, A. – Flores-Acosta, L. M. – González-Hernández, J.: Fortificación y evaluación de tortillas de nixtamal. Archivos Latinoamericanos de Nutrición, *51,* 2001, pp. 293–302.
28. Maya-Cortés, D. C. – Figueroa-Cárdenas, J. D. – Garnica-Romo, M. G. – Cuevas-Villanueva, R. A. – Cortés-Martínez, R. – Véles-Medina, J. J. – Martínez-Flores, H. E.: Whole-grain corn tortilla prepared using an ecological nixtamalisation process and its impact on the nutritional value. International Journal of Food Science and Technology, *45*, 2010, pp. 23–28. DOI: 10.1111/j.1365-2621.2009.02095.x.
29. Gonzalez, R. – Reguera, E. – Mendoza, L. – Figueroa, J. M. – Sanchez-Sinencio, F.: Physicochemical changes in the hull of corn grains during their alkaline cooking. Journal of Agricultural Food Chemistry, *52*, 2004, pp. 3831–3837. DOI: 10.1021/jf035175h.
30. Rosado, J. L. – Díaz, M. – Rosas, A. – Griffit, I. – García, O. P.: Calcium absorption from corn tortilla is relatively high and is dependent upon calcium content and liming in Mexican women. Journal of Nutrition, *135*, 2005, pp. 2578–2581.

31. Martínez-Flores, H. E. – Figueroa, C. J. D. – Martínez-Bustos, F. – González-Hernández, J. – Rodríguez-García, M. E. – Baños-López, A. M. L. – Garnica-Romo, M. G.: Physical properties and composition of femurs of rat fed with diets based on corn tortillas made from different processes. International Journal of Food Science and Nutrition, *53*, 2002, pp. 155–162. DOI: 10.1080/09637480220132166.
32. Rosado, J. L. – Lopez, P. – Morales, M. – Muñoz, E. – Allen, L. H.: Bioavailability of energy, nitrogen, fat, zinc, iron and calcium from rural and urban Mexican diets. British Journal of Nutrition, *68*, 1992, pp. 45–58. DOI: 10.1079/BJN19920065.
33. Heaney, R. P. – Weaver, C. M. – Hinders, S. M. – Martin, B. – Packard, P. T.: Absorbability of calcium from *Brassica* vegetables: Broccoli, bok choy, and kale. Journal of Food Science, *58,* 1993, pp. 1378–1380. DOI: 10.1111/j.1365-2621.1993.tb06187.x.

Received 11 December 2013; 1st revised 11 February 2014; 2nd revised 7 March 2014; accepted 11 March 2014; published online 24 September 2014.