NUTRITION AND TEXTURE EVALUATION OF MAIZE-WHITE COMMON BEAN NIXTAMALIZED TORTILLAS

Dolores Cuevas-Martínez, Carolina Moreno-Ramos, Enrique Martínez-Manrique, Ernesto Moreno-Martínez and Abraham Méndez-Albores

SUMMARY

The effect of white common bean addition on certain nutritional, physicochemical and textural properties of tortillas was determined. The maize-bean blends used were 100:0, 95:5, 90:10, 85:15, 80:20, and 75:25. The blends were processed using the traditional nixtamalization process. As the bean quantity increased in tortillas, higher protein, lysine, and tryptophan contents were registered. At 25% of bean addition, lysine and tryptophan content in tortillas increased from 56 and 36% of FAO profile to 95 and 84%, respectively. It was concluded that tortillas produced with these blends not only improve protein quality but also had similar physicochemical and textural properties of tortillas prepared with maize.

EVALUACIÓN NUTRICIONAL Y TEXTURAL DE TORTILLAS DE MAÍZ-FRIJOL BLANCO NIXTAMALIZADAS

Dolores Cuevas-Martínez, Carolina Moreno-Ramos, Enrique Martínez-Manrique, Ernesto Moreno-Martínez y Abraham Méndez-Albores

RESUMEN

Se determinó el efecto de la adición de frijol blanco sobre ciertas propiedades nutricionales, fisicoquímicas y texturales de tortillas. Las mezclas de maíz-frijol blanco utilizadas fueron 100:0, 95:5, 90:10, 85:15, 80:20, y 75:25. Las mezclas fueron procesadas utilizando el proceso tradicional de nixtamalización. Al aumentar la cantidad de frijol en las tortillas se registraron contenidos mayores de proteína, lisina y triptófano. Con la adición de 25% de frijol, los contenidos de lisina y triptófano aumentaron en 56 y 36% el valor del perfil FAO, hasta 95 y 84%, respectivamente. Se concluye que las tortillas hechas con las mezclas indicadas no solo mejoran su calidad proteica, sino que presentan propiedades fisicoquímicas y texturales similares a las de las tortillas preparadas con maíz.

Introduction

Tortillas and beans are the most important protein sources for the Mexican population, providing 70% of the calories and 90% of total protein intake (Pérez *et al.*, 2002; Rosado *et al.*, 2005). Tortillas are traditionally made using the alkaline process called nixtamalization, which consists of cooking grain in abundant water and lime (2-3 l of water per kg of maize processed, with 1-3% $Ca(OH)_2$) at temperatures near boiling, for 35-70min, with a steeping period of 8-16h. After steeping, the lime cooking solution is decanted, and the grain is thoroughly washed to leave it ready for milling in order to obtain the *masa* (maize dough) for making the tortillas (Serna-Saldívar *et al.*, 1990).

The nixtamalization process enhances the nutritional value of maize by improving protein quality, increasing the calcium and niacin availability and reducing phytic acid levels. Unfortunately, nixtamalization also leads to losses of protein, carbohydrates and vitamins (Figueroa-Cárdenas *et al.*, 2001). Due to this fact, the tortilla industry suffers from a compromise in quality with low protein levels, as well as deficiencies of lysine and tryptophan in the product. Therefore, several studies have been conducted regarding nutrient improvement in tortillas. The amount of protein has been increased by adding soybean (Franze, 1975; Bressani *et al.*, 1979), defatted soybean flour (González-Agramón and Serna-Saldívar, 1988), sorghum (Serna-Saldívar *et al.*, 1988a), cottonseed flour (McPherson and Ou, 1976), germinated corn (Wang and Fields, 1978), spent soymilk residue, and direct lysine and tryptophan (Waliszewski *et al.*, 2000, 2002), among others. However, such strategies have proven to be expensive or impractical, due to the change in physico-

Dolores Cuevas-Martínez. B.Sc. in Food Engineering and Graduate Student, Facultad de Estudios Superiores Cuautitlán (FESC), Universidad Nacional Autónoma de México (UNAM), Mexico.

Carolina Moreno-Ramos. Doctor in Animal Production and Health Sciences, FESC-UNAM, Mexico. Professor, FESC-UNAM, Mexico.

Enrique Martínez-Manrique. M.Sc. in Food Science and Technology, UNAM, Mexico. Professor, FESC-UNAM, Mexico.

Ernesto Moreno-Martínez. Ph.D. in Phytopatholgy, University of Minnesota, USA. Professor, FESC-UNAM, Mexico.

Abraham Méndez-Albores. Doctor in Materials Sciences, CINVESTAV-IPN, Mexico. Professor, FESC-UNAM, Mexico. Address: Facultad de Estudios Superiores Cuautitlán, UNAM. Km 2.5 Carretera Cuautitlan-Teoloyucan. Cuautitlan Izcalli, Estado de México. CP. 54714. e-mail: albores@unam.mx

AVALIAÇÃO NUTRITIVA E DE TEXTURA DE PANQUECAS DE MILHO E FEIJÃO BRANCO NIXTAMALIZADAS

Dolores Cuevas-Martínez, Carolina Moreno-Ramos, Enrique Martínez-Manrique, Ernesto Moreno-Martínez e Abraham Méndez-Albores

RESUMO

Determinou-se o efeito de la adición de feijão branco sobre algumas propriedades nutricionais, fisicoquímicas e de textura das panquecas. As misturas milho-feijão utilizadas foram 100:0, 95:5, 90:10, 85:15, 80:20, e 75:25. As misturas foram processadas utilizando o método tradicional de nixtamalização. Ao aumentar a quantidade de feijão nas panquecas se registraram incrementos nos conteúdos de proteínas, lisina e triptofano. Com a adição de 25% de feijão os conteúdos de lisina e triptofano nas panquecas aumentaram desde 56 e 36% no perfil FAO até 95 e 84%, respectivamente. Conclui-se que as panquecas produzidas com essas misturas não somente melhoram sua qualidade proteica mas que também têm propriedades fisicoquímicas e de textura semelhantes a aquelas preparadas com milho. Em países onde o feijão branco está disponível, sua utilização até em 25% no processo de nixtamalização é recomendado para o enriquecimiento das panquecas.

chemical, textural and sensorial properties in the enriched tortilla.

In Mexico, the daily consumption of tortilla per person is >250g and tortillas are commonly consumed accompanied with other foods, including common bean, another important food legume which is consumed in large quantities of up to 60g per person per day (López-Mejía *et al.*, 1997). Considering that the consumption of proteins with insufficient essential amino acids is a serious problem in some poverty areas of Mexico, principally where maize is the basic staple food, it is of interest to evaluate the effect of the nixtamalization of maize-white bean blends on the physicochemical and textural characteristics of tortillas, in an attempt to develop practical and economical processes for tortilla production with improved nutritional characteristics.

Materials and Methods

Raw materials

Maize grain (*Zea mays* L.) of the commercial hybrid AS-900, and white 157 common bean (*Phaseolus vulgaris* L.) were used, with initial moisture contents of 9.1 and 11.2%, respectively. Moisture content (MC) was determined by drying replicate portions of 5-10g each of whole grain at 103°C for 72h, and percentages calculated on a wet-weight basis.

Tortilla-making process

The traditional nixtamalization process was used. Each experimental unit consisted of 1000g of maize-bean blend (100:0, 95:5, 90:10, 85:15, 80:20, 75:25) mixed with 3 l distilled water and 15g of lime (99% calcium hydroxide). The blends were cooked in a covered aluminum pan for 55min and steeped 16h at room temperature (22 ±1°C). The steep liquor was removed, and the cooked maize was washed with 4 l of tap water to remove excess lime and pericarp tissue. The nixtamal (cooked grain) was stone-ground to provide a *masa* with a MC of ~59%. The *masa* was flattened into thin disks of 12.5cm diameter and 1.2mm thickness using a commercial tortilla roll machine (Casa González. Monterrey, NL, Mexico). Tortillas were baked on a griddle at 270 ±5°C for 17s on one side, 55s on the other side, and again 17s on the first side. The temperature was measured with a non-contact portable infrared thermometer Fluke-572 (Fluke, Melrose, MA, USA). Tortilla puffing was evaluated subjectively by using scores of 1-3, where 1= little or no puffing (0–25%), 2= medium puffing (25–75%), and 3= complete puffing (75–100%). Rollability was evaluated by rolling a tortilla over a 1cm diameter tube, quantifying the extent of breaking using a scale of 1 to 3, where 1= tortillas with no breaking; 2= a partial breaking at the center and edges of the tortilla; and 3= completely flattened tortillas.

Physicochemical analysis

The pH was determined according to the 02-52 AACC method (AACC, 2000). Tortillas were subjected to surface-color analysis with a MiniScan XE model 45/0-L colorimeter (Hunter Associates Laboratory, Reston, VA, USA). The colorimeter was calibrated with a white porcelain plaque (L= 97.02, a= 0.13, b= 1.77). Readings were made in triplicate at four positions at 90° with respect to each other. Three derived functions (ΔE, chroma, and hue value) were computed from the L, a, and b readings, as:

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

$$Chroma= (a^2 + b^2)^{1/2}$$

$$Hue\ angle= \arctan (b/a)$$

Tortilla texture

The texture of the tortilla (tensile strength and cutting force) was evaluated using the Texture Analyzer TA-XT2 (Texture Technologies Corp., Scarsdale, NY, USA). Texture was evaluated immediately after preparation. To avoid loss of water and temperature, tortillas were kept at 40°C inside polyethylene bags. For tensile strength evaluation, a piece of tortilla in the form of a test strip (8.7×3.75cm at each end, and 1.5cm wide at the thinnest part) of the central part of the tortilla was cut and placed in retention clamps TA-96. The test was carried out at 2mm·s⁻¹, and pincers were opened 15mm until the tortilla piece was broken. To measure the cutting force, a piece of tortilla with the same form was cut using the blade TA-90 at 2mm·s⁻¹ and a cutting depth of 10mm.

Protein, lysine and tryptophan content

The 960.52 micro-Kjeldhal official method of the AOAC (2000) was used to determine the protein content in tortilla flours (N×6.25). Amino acid analysis was performed by reversed phase-high performance liquid chromatography (RP-HPLC, Model 510, Waters Associates, Milford, MA, USA). Samples (100mg) were hydrolyzed under nitrogen at 110°C with 2ml of 6N HCl for 24h. The acid was removed by rotary evaporation. For tryptophan analysis, samples were hydrolyzed at 140°C with 3ml of 4N Ba(OH)₂ for 8h, then neutralized with 12N HCl to a pH of 7. After filtration, 25μl were used for derivatization with phenylisothiocyanate and derivatized samples were analyzed in a Waters Nova-pak C18 column

Treatments	Moisture (%)	pH	Color (ΔE)	L	Chroma	Hue	Puffing	Rollabilty	Tensile strength	Cutting force
100- 0	47.56 ±0.14a	8.95 ±0.006a	34.88 ±0.93a	71.19 ±1.53a	25.22 ±0.76a	87.33 ±0.27a	3	1	1.11 ±0.05a	7.90 ±0.12a
95- 5	48.16 ±0.76a	8.97 ±0.005a	34.72 ±0.77a	71.71 ±1.23a	25.54 ±0.87a	87.04 ±0.12a	3	1	1.11 ±0.07a	7.89 ±0.10a
90-10	47.56 ±0.40a	8.91 ±0.003a	36.33 ±0.25a	70.93 ±0.97a	25.41 ±0.46a	87.62 ±0.69a	3	1	1.13 ±0.04a	7.92 ±0.11a
85-15	47.49 ±0.24a	8.92 ±0.003a	34.55 ±0.12a	71.21 ±0.41a	25.19 ±0.16a	87.17 ±0.47a	3	1	1.13 ±0.08a	7.91 ±0.13a
80-20	47.11 ±0.34a	8.91 ±0.005a	34.38 ±0.27a	70.34 ±0.85a	25.16 ±0.43a	87.21 ±0.97a	3	1	1.10 ±0.03a	7.86 ±0.09a
75-25	47.50 ±0.25a	8.90 ±0.005a	34.63 ±0.38a	71.04 ±1.43a	24.91 ±1.62a	87.18 ±0.19a	3	1	1.16 ±0.05a	7.92 ±0.11a

Mean of three replicates ±standard error. Mean values with same letter in the same column are not significantly different (Dunnet>0.05)
Tortilla puffing: 1= little or no puffing (0-25%), 2= medium puffing (25-75%), and 3= complete puffing (75-100%).
Tortilla rollability: 1= tortillas with no breaking; 2= a partial breaking at the center and edges of the tortilla, and 3= completely flattened tortillas.
Tensile strength and cutting force in Newtons (N).

(5μm, 3.9×150mm). Amino acid analysis was conducted in triplicate for each sample.

Trypsin inhibitor, phytic acid and tannins

Trypsin inhibitor activity was determined using the method of Kadake *et al.* (1974), from the decrease in the rate in which trypsin hydrolyzes BApNA (N-alpha-benzoyl-DL-arginine p-nitroanilide). Briefly, the ground (60 mesh) and defatted samples were stirred in 0.01N NaOH for 1h, and aliquots were used for the analysis. Trypsin inhibitor activity was expressed as trypsin units inhibited, one trypsin unit being arbitrarily defined as an increase of 0.01 absorbance unit at 410nm·ml^{-1} of the reaction mixture under the described conditions. Phytic acid was extracted in 0.5M nitric acid by shaking at room temperature for 3h and determined spectrophotometrically at 512nm, as described by Davies and Reid (1979). Tannin content was also estimated with a spectrophotometer (Beckman Coulter, DU-530) at 760nm, using the Folin-Denis reagent after extraction with 1% hydrochloric acid in methanol (method 952.03; AOAC, 2000).

Statistical analysis

The experiment was conducted as a completely randomized design. The experimental conditions were carried out with three repli-cates. Data was assessed by analysis of variance (ANO-VA), and comparisons of means were performed according to the Dunnet test using SAS (1998). A significance of α= 0.05 was used to distinguish significant differences between treatments.

Results and Discussion

Table I shows some physicochemical and textural properties of tortillas obtained through the traditional nixtamalization process. No statistical differences were observed in those properties in tortillas prepared with the maize-bean blends. Moisture content (MC) ranged from 47.11 to 48.16%, and the pH values from 8.90 to 8.97. These values are similar to those reported by other researchers (Saldana and Brown, 1984; Serna-Saldívar *et al.*, 1988b; Méndez-Albores *et al.*, 2004a, b). In nixtamalized products, the lime concentration represents an important factor in color, odor, flavor, shelf life and texture characteristics; when the lime content is not sufficient to give the characteristic alkaline flavor, the tortillas are rejected by consumers. Likewise, if this compound is in excess, tortillas become astringent and are also rejected. However, with some maize genotypes, a high concentration of lime could be used (3% wt/wt), which leads to a yellowish end-product and also extends the shelf-life of the tortillas.

The tortilla color was not affected by the addition of bean to the maize (Table I). All treatments had the same lime concentration of 1.5% (wt/wt), and consequently the tortillas presented a yellowish color, as shown by the ΔE values near 35. Moreover, the inclusion of different ratios of white bean did not significantly affect the L, chroma and hue in tortillas as shown in Table I. Changes in the color of tortillas were directly attributed to the amount of lime retained during the cooking and washing of the nixtamal. Lime content affects the tortilla color even when tortillas are produced from white maize grains, and the color intensity is closely related to carotenoid pigments, flavonoids, and pH. However, the development of color during the alkaline cooking is more complex, considering that the calcium hydroxide reacts with the different pigments found in the maize grain and interferes with browning reactions such as caramelization and Maillard reactions (Gómez *et al.*, 1987).

Table I also shows some quality and textural properties of tortillas. Tortilla puffing was not significantly affected. All tortillas evaluated presented a value of 3, which indicates complete puffing (75-100%). A good puffing is obtained when two layers are formed in the tortilla; these layers, produced during the cooking process, are impermeable, retaining the steam that gives rise to the puffing during heating. Moreover, all tortillas evaluated presented a good rollability, with a value close to 1, defined as no breaking; therefore, tortillas were also considered within the acceptable margins of quality, presenting a soft texture and rolled without breaking.

As to the texture, tortillas made with maize presented tensile strength values (measured in Newtons) of 1.11N; and no significant differences were observed between control tortillas and tortillas prepared with the maize-bean blends. Also, regarding the cutting force, no significant differences were observed, the average values were 7.9N for tortillas made with the blends as well as for tortillas made with maize alone. These texture values are similar to those reported in tortillas produced with high moisture content in stored maize grain (Méndez-Albores *et al.*, 2003). In general, tortillas prepared from maize alone or from blends were stretchable, elastic, and resistant to tearing and cracking. However, a shelf-life study is needed to determine if storage time causes changes in tortilla texture (tensile strength or cutting force).

Protein content was reduced after the nixtamalization process. Protein content in raw maize was 94.80g·kg^{-1} db (dry basis), and when nixtamalized, protein was reduced to 91.53g·kg^{-1} db (Table II). This reduction of 3.5% is consistent

TABLE II
PROTEIN CONTENT AND QUALITY OF RAW GRAINS AND TORTILLAS MADE WITH MAIZE-BEAN BLENDS

Component	FAO requirement	Raw grains		Maize-bean ratios					
		Maize	Bean	100-0	95-5	90-10	85-15	80-20	75-25
Protein		94.80 ±1.17	210.40 ±6.64	91.53 ±0.29a	97.13 ±1.33b	100.53 ±0.46c	105.60 ±2.08d	110.27 ±0.92e	114.8 ±1.38f
Lysine	54.4	33.89 ±0.57	67.91 ±1.16	30.63 ±1.62a	36.98 ±0.25b	39.93 ±1.21c	43.33 ±0.65d	46.87 ±1.01e	51.84 ±0.46f
Tryptophan	9.6	7.28 ±0.11	32.90 ±1.89	3.45 ±0.27a	4.26 ±0.09b	4.3 ±10.18b	5.67 ±0.07c	6.90 ±0.06d	8.04 ±0.01e

Mean of three replicates + standard error. Mean values with same letter in the same row are not significantly different (Dunnet>0.05).
Protein content in g·kg^{-1} (dry basis). Amino acids are expressed in g/kg of protein.

TABLE III
ANTI-NUTRITIONAL FACTORS IN TORTILLAS MADE WITH MAIZE-BEAN BLENDS

Treatments	Trypsin inhibitor*	Phytic acid (%)	Tannins (%)
Maize	1.0 ±0.39	2.1 ±0.08	0.20 ±0.02
Bean	13.6 ±1.14	2.4 ±0.02	0.25 ±0.01
100- 0	N.D.	0.8 ±0.02a	0.07 ±0.01a
95- 5	N.D.	0.9 ±0.04a	0.07 ±0.01a
90-10	N.D.	0.9 ±0.06a	0.08 ±0.02a
85-15	N.D.	1.0 ±0.05a	0.08 ±0.01a
80-20	0.6 ±0.13a	1.1 ±0.07a	0.08 ±0.01a
75-25	1.4 ±0.19b	1.1 ±0.07a	0.09 ±0.01a

Mean of three replicates ±standard error. Mean values with same letter in the same column are not significantly different(Dunnet>0.05).
*Trypsin inhibitor unit/mg sample.
N.D.: Not detectable (below detection limit).

with previous reports, which indicate that protein is lost during tortilla elaboration (Bressani, 1990; Milan-Carrillo et al., 2004). Regarding the amino acid content, lysine and tryptophan were also reduced in maize tortillas in 9.62 and 52.61%, respectively (Table II). Mora-Avilés et al. (2007) reported that lysine and tryptophan content in quality protein maize (QPM) were reduced in 8% after lime treatment, while in regular maize they were reduced 25 and 15%, respectively. Rojas-Molina et al. (2008) reported reductions of 36 and 32% in the total lysine and reactive lysine, as well as 38.7% for tryptophan content during traditional nixtamalization of QPM (H-368C). These differences in amino acid reductions are attributable to the conditions used during the nixtamalization process, such as lime concentration, temperature, cooking and steeping time (Bressani, 1990; Serna-Saldívar et al., 1990). Also, the protein solubility distribution and the essential amino acids location could partially explain the protein quality changes observed during nixtamalization (Rojas-Molina et al., 2008). On the contrary, the quantity and quality of the protein in tortillas prepared with maize-bean blends evidently increase (Table II).

Tryptophan, an amino acid highly sensitive to the thermal-alkaline treatment, can be considered the first limiting amino acid of maize nixtamalized tortillas (3.45g·kg^{-1} protein), the second limiting amino acid being lysine (30.63g·kg^{-1} protein), covering 36 and 56% of the FAO/WHO requirements (FAO/WHO/UNU, 1985). However, as a result of the inclusion of the bean, there were significant increases in tryptophan and lysine content in maize-bean tortillas. As expected, as the bean content increased, higher levels of those amino acids were registered, without affecting the physicochemical or textural properties of tortillas (Table II). Tortillas produced with the blend 75:25 presented 51.84 and 8.04g·kg^{-1} protein of lysine and tryptophan, respectively; which represents 95 and 84% of FAO profile.

Table III summarizes the anti-nutritional factors found in raw maize, raw bean, and tortillas elaborated with the maize-bean blends. As expected, raw bean had the highest trypsin inhibitor activity, presenting a value of 13.6 units/mg sample, as well as phytic acid (2.4%) and tannin content (0.25%). Reductions on these anti-nutritionals were observed, to various extents,

depending on the maize-bean ratio processed. About 90-96% trypsin inhibitor, 46-54% phytic acid, and 16-20% tannin content were reduced upon nixtamalization. These results are consistent with the findings of other studies that reported a reduction in tannins and other antinutrients upon cooking legumes (Sharma and Sehgal, 1992; Singh, 1993; Rehman and Shah, 2005; Siddhuraju and Becker, 2005). In general, the decrease in the levels of these antinutrients, particularly of trypsin inhibitor, might also be due to thermal degradation and denaturation, as well as to the formation of insoluble complexes (Kataria et al., 1989; Siddhuraju and Becker, 2001).

A major challenge for many Latin American countries is to ensure that sectors of society that consume tortillas as a principal energy and protein source improve their diet quality. Consequently, in countries where white common bean is available, its use is recommended during the nixtamalization process for up to 25% for tortilla enrichment.

Conclusion

After processing maize-bean blends with the traditional nixtamalization process, an important improvement in protein, lysine and tryptophan contents in tortillas were observed. Up to 25% bean incorporation did not affect the physicochemical and textural properties of the tortillas. Consequently, as an alternative to solving the problem of low protein quantity/quality of cereal-based foods caused by the high starch content of cereals, white bean fortification is suggested, without modifications in the processing condition or equipment during tortilla elaboration.

REFERENCES

AACC (2000) Approved Methods. 10th ed. American Association of Cereal Chemists. St. Paul, MN, USA.

AOAC (2000) Official Methods of Analysis. 16th ed. Association of Official Analytical Chemists. Gaithersburg, MD, USA.

Bressani R (1990) Chemistry, technology and nutritive value of maize tortillas. Food Rev. Int. 6: 225-264.

Bressani R, Braham JE, Elías LG, Rubio M (1979) Further studies on the enrichment of lime treated corn with whole soybean. J. Food Sci. 44: 1707-1710.

Davies NT, Reid H (1979) An evaluation of the phytate, zinc, cop-

per, iron and manganese content of, and Zn availability from, soya-based textured- vegetable-protein meat-substitute or meat-extenders. *Br. J. Nutr. 41*: 579-589.

FAO/WHO/UNU (1985) *Energy and Protein Requirements. Report of a Joint FAO/WHO/UNU Expert Consultation.* WHO Technical Report Series N° 724. Geneva, Switzerland. 206 pp.

Figueroa-Cárdenas JD, Acero-Godínez MG, Vasco-Méndez NL, Lozano-Guzmán A, Flores-Acosta LM, González-Hernández J (2001) Fortification and evaluation of the nixtamal tortillas. *Arch. Latinoam. Nutr. 51*: 293-302.

Franze K (1975) Tortillas fortified with whole soybeans prepared by different methods. *J. Food Sci. 40*: 1275-1277.

Gómez MH, Rooney LW, Waniska RD, Pflugfelder RL (1987) Dry maize masa flours for tortilla and snack production. *Cereal Foods World 32*: 372.

González-Agramón MM, Serna-Saldívar SO (1988) Effect of defatted soybean meal and soybean isolate on the nutritional, physical, chemical and organoleptic properties of wheat flour tortillas. *J. Food Sci. 53*: 793-797.

Kadake ML, Rackis JJ, McGhee JE, Puski G (1974) Determination of trypsin inhibitor activity of soy product: A collaborative analysis of an improved procedure. *Cereal Chem. 51*: 376-381.

Kataria A, Chauhan BM, Punia D (1989) Antinutrients and protein digestibility (*in vitro*) of mung bean as affected by domestic processing and cooking. *Food Chem 32*: 9-17.

López-Mejía OA, Hernández-Becerra JA, Cárdenas-Cagal A, Beri-

stain-Guevara CI, García-Galindo HS (1997) Sensory evaluation of maize tortillas supplemented with lysine and tryptophan. *Food Sci. Tech. Int. 3*: 175-179.

Mc Pherson CM, Ou SL (1976) Evaluation of corn tortillas supplemented with cottonseed flour. *J. Food Sc. 41*: 1301-1303.

Méndez-Albores JA, Arámbula VG, Vázquez BME, Mendoza EM, Preciado ORE, Moreno-Martínez E (2003) Effect of high moisture maize storage on tortilla quality. *J. Food Sci. 68*: 1878-1881.

Méndez-Albores JA, Villa GA, Del Río-García JC, Martínez EM (2004a) Aflatoxin-detoxification achieved with Mexican Traditional Nixtamalization Process (MTNP) is reversible. *J. Sci. Food Agric. 84*: 1611-1614.

Méndez-Albores JA, Arámbula-Villa G, Loarca-Piña MG, González-Hernández J, Castaño-Tostado E, Moreno-Martínez E (2004b) Aflatoxin's fate during the nixtamalization of contaminated maize by two tortilla-making processes. *J. Stor. Prod. Res. 40*: 87-94.

Milán-Carrillo J, Gutiérrez-Dorado R, Cuevas-Rodríguez EO, Garzón-Tiznado JA, Reyes-Moreno C (2004) Nixtamalized flour from quality protein maize (*Zea mays* L.) optimization of alkaline processing. *Plant Foods Hum. Nutr. 59*: 35-44.

Mora-Avilés A, Lemus-Flores B, Miranda-López R, Hernández-López D, Pons-Hernández JL, Acosta-Gallegos JA, Guzmán-Maldonado SH (2007) Effects of common bean enrichment on nutritional quality of tortillas produced from nixtamalized regular and quality protein maize flours. *J. Sci. Food Agric. 87*: 880-886.

Pérez P, Esquivel G, Rosales R, Acosta-Gallegos J (2002) Caracterización física, culinaria y nutricional del frijol del altiplano subhúmedo de México. *Arch. Latinoam. Nutr. 52*: 172-180.

Rehman Z, Shah WH (2005) Thermal heat processing effects on antinutrients, protein and starch digestibility of food legumes. *Food Chem. 91*: 327-331.

Rojas-Molina I, Gutiérrez E, Cortés-Acevedo ME, Falcón A, Bressani R, Rojas A, Ibarra C, Pons-Hernández JL, Guzmán-Maldonado SH, Cornejo-Villegas A, Rodríguez ME (2008) Analysis of quality protein changes in nixtamalized QPM flours as a function of the steeping time. *Cereal Chem. 85*:409-416.

Rosado JL, Díaz M, Rosas A, Griffit I, García O (2005) Calcium absorption from corn tortilla is relatively high and is dependent upon calcium content and liming in Mexican women. *J. Nutr. 135*: 2578-2581.

Saldana G, Brown EH (1984) Nutritional composition of corn and flour tortillas. *J. Food Sci. 9*: 1202-1224.

SAS (1998) *Statistical Analysis System. Introductory Guide for Personal Computers.* Ver 6.12 ed. SAS Institute. Cary, NC, USA.

Serna-Saldívar S, Téllez-Girón A, Rooney LW (1988a) Production of tortilla chips from sorghum and maize. *J. Cereal Sci. 8*: 275-284.

Serna-Saldívar SO, Knabe DA, Rooney LW, Tanksley TD, Sproule A (1988b) Nutritional value of sorghum and maize tortillas. *J. Cereal Sci. 7*: 83-94.

Serna-Saldívar SO, Gómez MH, Rooney LW (1990) Technology, chemistry and nutritional

value of alkaline cooked corn products. In Pomeranz Y (Ed.) *Advances in Cereal Science and Technology.* Vol. X. American Association of Cereal Chemists. St. Paul, MN, USA. pp. 243-307.

Sharma A, Sehgal S (1992) Effect of domestic processing, cooking and germination on the trypsin inhibitor and tannin content of faba bean (*Vicia faba*). *Plant Foods Hum. Nutr. 42*: 127-133.

Siddhuraju P, Becker K (2001) Preliminary nutritional evaluation of Mucuna seed meal (*Mucuna pruriens* var. *utilis*) in common carp (*Cyprinus carpio* L.): an assessment by growth performance and feed utilization. *Aquaculture 196*: 105-123.

Siddhuraju P, Becker K (2005) Nutritional and antinutritional composition, in vitro amino acid availability, starch digestibility and predicted glycemic index of differentially processed mucuna beans (*Mucuna pruriens* var. *utilis*): an underutilised legume. *Food Chem. 91*: 275-286.

Singh U (1993) Protein quality of pigeon pea as influenced by seed polyphenols and cooking process. *Plant Foods Hum. Nutr. 43*: 171-179.

Waliszewski KN, Estrada Y, Pardio VT (2000) Lysine and tryptophan fortification of nixtamalized corn flour. *Int. J. Food Sci. Tech. 35*: 523-527.

Waliszewski KN, Pardio VT, Carreón E (2002) Physicochemical and sensory properties of corn tortillas made from nixtamalized corn flour fortified with spent soymilk residue (okara). *J. Food Sci. 67*: 3194-3197.

Wang YYD, Fields ML (1978) Enrichment of home-prepared tortillas made from germinated corn. *J. Food Sci. 43*: 1630-1631.