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Alkaline Cooking Quality of Polyembryonic and Non-Polyembryonic Maize Populations

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Abstract: Polyembryony is the formation of several embryos in a seed and is present in many plants, included maize. In the present study the chemical, physical and rheological properties of nixtamalized maize flour, masa and tortilla of maize kernel with high polyembryony levels and brachytic population were evaluated and compared to three control populations. The nixtamalized maize flour and tortillas of brachytic population were similar to the control population in most of the tests. The retrogradation in nixtamalized maize flour of brachytic population was lower than the control nixtamalized maize flour showed 191.77 RVU; the protein content of nixtamalized maize flour of brachytic population was greater and content of ash in tortilla was lower than the controls. The flour made from maize brachytic population is an option for the flour and tortilla industry.

Key words: Flour, masa, nixtamalization, polyembryony, rheology, tortilla

INTRODUCTION

Maize (*Zea mays* L.) has been and remains the staple crop of large sectors of urban and rural population of several Latin American countries, mainly Mexico and Central American countries. Maize is mainly processed into tortillas; food offered providing significant amounts of nutrients, 50% protein, 70% of calories, and 49% of the calcium consumed by Mexican population (Bressani, 1990; Flores-Farías *et al*., 2000). In addition, the tortilla, maize is used for production of snack foods, gravies, pinole, and in general for a wide range of products whose uses are associated with the types and characteristics of maize variety and regional adaptations (Mauricio Sánchez *et al*., 2004). Corn has also been used for isolation of starch, which is a raw material in various industries (Ji *et al*., 2003). Most of these products come from the alkaline thermal process called nixtamalization (Gutiérrez-Cortez *et al*., 2009).

A special feature of maize is polyembryony (PE), which refers to the formation of several embryos in a seed (Batygina and Vinogradova, 2007). The PE is extensively documented in various plant species (Webber, 1940) and observed experimentally in maize by Kieselbach (1926) and later by Morgan and Rappleye (1951). Polyembryonic maize has several potential applications, on the one hand, the maize seed that contains two or more embryos is a phenomenon of great importance since the seeds concentrate most oils and protein quality, giving the largest grain nutritional quality, and on the other hand, the possibility of increasing production of dry matter per seed and per unit area (Musito Ramírez *et al*., 2008). Pesev *et al*. (1976) reported the development of maize lines with multiple embryos which had levels of polyembryony between 2.1 and 25.3%. Polyembryonic maize populations have been developed at the Maize Mexican Institute (MMI) of the Universidad Autonoma Agraria Antonio Narro (UAAAN); during the last thirty five years was developed a population of maize with braod-genetic base which had as central feature the plant brachyitic condition (dwarf). Among the segregating progenies from this special population, it was identified a small group of plants (1.5%) showing the twin condition, one seed, two stems. Later, schemes of recurrent selection were applied to increase the polyembryony frequency, achieving levels of 47 % by 1991; after this year the base population was spread in two: One with dwarf plants and other with plants with normal height; during 1996, the two populations had more than 60% of polyembryony. Reproductive

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management of the polyembryonic groups has been through fraternal crosses with mixed pollen, leading to obtain a germination of polyembryonic seeds of 60% in direct sown and about 90% under greenhouses conditions (Espinoza *et al*., 1998). The aim of this study was to evaluate the quality properties of nixtamalized maize flour, masa and tortilla of polyembryonic maize populations.

MATERIALS AND METHODS

Vegetal material: This study was carried out at the Centro de Investigación y de Estudios Avanzados del Instituo Politécnico Nacional at Querétaro, México and Department of Food Research at University Autonomous of Coahuila, Saltillo, México. Four maize populations were provided by the Maize Mexican Institute (MMI) at the Universidad Autonoma Agraria Antonio Narro (UAAAN). One polyembryonic maize population with high polyembryony and brachytic (BAP) and three out of four populations were monoembryonic which were used as control: high oil content (HOC); mixture of commercial hybrids (HIB) and yellow corn maize variety (AMA).

Traditional nixtamalization and milling: Kernels of each sample were used to performed traditional lime cooking process using 2 L of water, 1 kg of maize kernels sample, 1% of lime (w/w) ($Ca(OH)_2$) (El Topo, Monterrey, N.L. México). After cooking, the nixtamal was left to rest for 12 h, then rinsed with 1 L of water and retrieved the rinse water and waste water from cooking (nejayote). Each nixtamal sample was ground in a stone mill to get the masa. The wet masa produced from milled nixtamal was dehydrated in a momemade flash dryer (temperature, 220ºC and 1.8 s, residence timeas), when it was dry was milled to obtain nixtamalized flour.

Distribution of particle size: To determine the average particle size of flour were used procedures described by Fernández-Muñoz *et al*. (2008). It was used 100 g flour sample, this sample was screening using a mesh-INOX MONTI ®, with 30, 40, 60, 100 and 200 screens equivalent to 595, 420, 177, 149, 74 and <74 μm, respectively. In this way was determined the weight of the flour retained on each screen and its corresponding percentage.

Maximum viscosity (RVA): Kernel was milled and sieved through U.S. 60 screen (250 μm) to obtain maize flour (MF). In addition, Nixtamalized Maize Flour (NMF) was also going through the same screen to obtain a homogeneous particle size. The viscosity was measured with a Rapid Visco Analyzer 3C (Newport scientific PTY LTD, Sydney Australia). In this test, 4 g of each flour sample (MF and NMF) were suspended in 24 mL of distilled water. We used the following program times and temperatures: one minute at 50ºC after that a temperature increase of 5.6ºC/min (7.5 min) to 92ºC, temperature was maintained for 5 min and then decreased to 50ºC at the same speed and held this temperature for 1 min. The total test time was 22 min. While developing the test, the computer automatically recorded in relative units of viscosity (RVU), temperature (ºC) of the sample and the time (min) elapsed. It was obtained a curve of viscosity (gelatinization-retrogradation) called viscoamilogram. From these profiles were determined: a) initial temperature of gelatinization, b) initial viscosity, c) high viscosity, d) temperature of maximum viscosity and e) viscosity of retrogression, which is calculated by the difference between minimum and final viscosity (Mauricio Sánchez *et al*., 2004).

Subjective Water Absorption Capacity (SWAC): In this test, 150 g of nixtamalized flour for each sample were mixed with distilled water until masa consistency was right to make tortillas; amount of distilled water utilized in each flour sample was recorded. The amount of water required was taken as the absortion capacity and reported as water/kg of instant flour. The determinations were done in duplicate (Mauricio Sánchez *et al*., 2004).

Water Absorption Index (WAI) and Water Solubility Index (WSI): The WAI and WSI were determined according to the methodology described previously by Anderson *et al*. (1969). Each sample of 2.5 g flour (dry basis) was placed in polypropylene tubes (50 mL) at constant weight and then 40 mL of distilled water at a temperature of 30ºC were added. The tubes were placed in suspension and were kept in agitation and constant temperature for 30 min, the supernatant was removed and the solid residue weight was determined. The supernatant was evaporated in an oven at a temperature of 105ºC to constant weight and then weighed the residue from evaporation. The Water Absorption Index (WAI), was calculated as follow: WAI = (weight of the residue after centrifugation) / (Dry weight of the sample-Evaporation residue weight), while the Water Solubility Index (WSI) was calculated as follow:

WSI = (Evaporation residue weight/Dry weight of the sample) *100.

Preparation of Tortillas: The masa obtained was used to tortillas elaboration with a manual tortilla machine (Casa Gonzalez, México, D.F.). Tortillas were 1.2 mm thick and 12.5 cm in diameter and were cooked on a griddle at a temperature of 270±10ºC for 17 sec one side to form the thin layer, turned around and cooked the other side for 30 sec to produce the thick layer and returned to their original side to continue cooking for 19 sec to achieve the tortilla inflation (Figueroa *et al*., 2001).

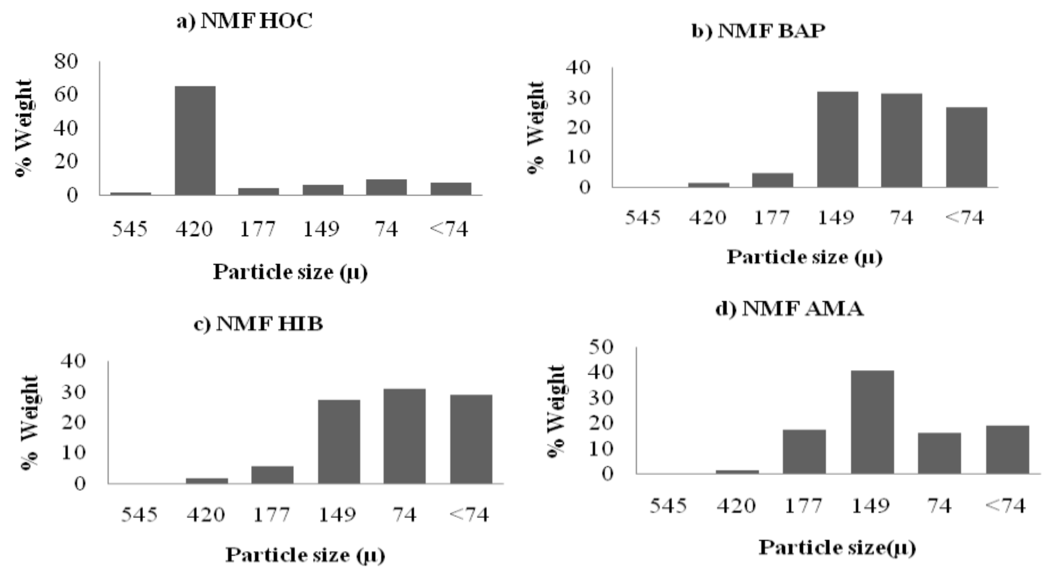

Fig. 1: Particle size distribution in four nixtamalized maize flour: a) Nixtamalized flour from high oil content corn b) Nixtamalized flour from polyembryony brachytic maize, c) Nixtamalized flour from a mixture of maize commercial hybrids and d) Nixtamalized flour from a yellow maize variety

Tortilla evaluations: The tortilla inflation rate was assessed as the proportion of this blister on the tortilla during cooking. Depending on this, it was assigned a rating scale 1 to 3. Where rank 1 = inflation rate between 75-100%, rank 2 = inflation rate between 25-50%, and rank 3 = inflation rate between 0-25 % (Figueroa *et al*., 2001). The tortilla lost weight (WL) after the tortilla reached room temperature, this parameter was calculated with the following formula: % WL = ((Weight of the raw tortilla-weight of the baked tortilla)/weight of the raw tortilla)*100. The dough yield was calculated with the value obtained from SWAC, adding one unit, it was reported as kg mass/kg flour (Mauricio Sanchez *et al*., 2004). The tortilla yield was calculated according to SWAC and the weight lost during tortilla cooking by the following formula:

$$TY = MY\ (1\text{-}WL)$$

where; TY = Tortilla yield, MY = Masa yield and WL = Weight loss.

Rheological analysis: Rheological analysis was carried out on masa and tortilla. For determination of masa cohesion and adhesion, it was molded a masa portion with a plastic ring 7.5 cm in diameter and 1.9 cm high and placed on the aluminum platform TA-XT2 Texture Analyzer (Texture Technologies Corp, Surrey, U.K.). Masa was penetrated with a metallic (1.27 cm in diameter) at a testing speed of 2 mm/s, recording the maximum force (kg-f) required achieving penetration. This force was registered as cohesion and the negative part is referred as adhesion. Tension test simulates the tear strength with hands. Three tortillas were selected randomly from each treatment; the central part of each tortilla was cut using a foiled mold with one I shape and avoiding the tortilla edges. After, the "I" piece of tortilla was clamped with the two tension clamps of the TA-XT2 texture meter (TA-96).

The stress rupture test was carried out at a speed of 2 mm/s and a distance of 10 mm. It was determined the maximum force of the tension (Arámbula *et al*., 2001; Figueroa *et al*., 2001). In addition, it was determined the tortilla cutting force using the Universal Texture Analyzer in order to simulate the cutting action of human molars and breaking by hands. During the test, a flat blade was slided (TA-90). The blade was 3 mm thick and 6.93 cm wide it was slided on the material at a speed of 2 mm/s and a depth of 15 mm, in order to cut the material (Arámbula *et al*., 2001; Figueroa *et al*., 2001).

Proximal chemical analysis of the nixtamalized corn flour and tortilla: Proximal chemical analysis was performed according to the methodology proposed by the AACC (1995) (moisture, ash and protein) and AOAC (1984) (ether extract and crude fiber).

Statistical analysis: The statistical analysis of the data was conducted based on a completely randomized design

Table 1: Gelatinization temperature, maximum viscosity and retrogradation of starches (MF and NMF)

Flour type	ID	Gelatinization temperature ºC	Maximum viscosity cP	Retrogration cP
MF	HIB7	1.71±0.49 a	1581.3±114.6 b	1336.1±103.0 bc
	HOC	72.30±0.13 a	1265.8±144.6 b	1233.0±114.0
	BAP	70.00±0.40 b	2131.3±142.2 a	1716.1±167.1 a
	AMA	71.78±0.37 a	2184.1±89.9 a	1633.6±126.0ab
NMF	HIB7	71.68±0.55	2344.3±25.7 bc	241.11±171.5 a
	HOC	72.58±0.80	2205.5±125.8 c	226.94±197.9 a
	BAP	72.01±0.362	492.2±75.0 b	191.77±14.5 b
	AMA	71.26±0.37	3184.1±85.1 a	250.50±105.8 a

Means with the same letter, in the same column, are not significantly different ($p \leq 0.05$) according to Tukey's test; cP = Centiposies

with 3 replications; the mean comparisons were made with the Tukey test (0.05).The data were analyzed using the software package Simfit (Bardsley, 2010).

RESULTS AND DISCUSSION

Distribution of particle size: Figure 1 shows the NMF's particle size, it was noted that for the NMF's BAP, HIB and AMA, the largest percentage was retained in the 60, 80 and 100 screens (177, 149 and 74 μ, respectively), contrary to the NMF HOC where the highest percentage of flour was trapped in the 40 (420 μm) screen. This can be interpreted from the viewpoint of chemical composition of the NMF HOC. An increase in the soaking time reduces the percentage of big particles and increases the percentage of fine particles (Palacios-Fonseca *et al*., 2009). Rojas-Molina *et al*. (2007) reported that during the lime cooking process there is a continuous diffusion of water and calcium ions producing changes from the outer to inner layers of the endosperm, as a function of time of rest, and during the milling process under the same conditions, promote the generation of fine particles. Other factors that affect the flour particle size are: kernel hardness, lime cooking processing time, amount of alkali used, soaking time, the adjustment of milling speed and flour screening (Flores-Farías *et al*., 2002). The distribution of particle size is the most important criterion to define the specific uses of the flour. For example, flour that is used for making tortillas should have a higher proportion of fine particles that that required for toasted elaboration (Gómez *et al*., 1987). NMF BAP according to its particle size is suitable for tortilla preparation because fine particle size promote greater tortilla flexibility and cohesion, while tortilla toasted or fried chips require big particles which promotes a crunchy texture (Montemayor and Rubio, 1983).

Maximum Viscosity Analysis (RVA): The maximum viscosity of the BAP and AMA MF were significantly different from the HIB and HOC MF (Table 1). Profiles of MF amylographic presented different behaviors according to grain texture. Kernel hardness influences the pasting behavior of flours (Graybosch *et al*., 2003). Narváez-González *et al*. (2006) founded than the pasting properties of corn meal with different degree of compaction in the endosperm has some differences, very compact kernels with a high percentage of hard endosperm required more time to gelatinize and a low-compaction grade corn has the highest peak viscosity and setback.

Gelatinization temperature determined by MF amylographic showed significant differences between the studied flours. BAP MF showed the lowest gelatinization temperature (Table 1). These temperatures are slightly lower than those reported by other authors, suggesting that perhaps maize grinding before analysis slightly damaged the structure of starch granules (Méndez-Montealvo *et al*., 2005).Maize flours with higher gelatinization temperature can be used for instant maize flour production because of the high temperatures used in this process, while maize flours with lower gelatinization temperature would be used in the traditional processing of tortillas (Yuan *et al*., 1993), as is the case of MF BAP which presented a lower gelatinization temperature samples than the HIB mixture used as control. According to the obtained results, the BAP maize would not has advantages over the other tested maize samples on NFM production because the lower gelatinization temperature and may have slight damage at the time of dough formation.

The gelatinization temperature of the four NMF was no significant different, showed an average of 71.88ºC which is within the range reported by other authors (Sefa-Dedeh *et al*., 2004). Gelatinization temperature indicates the maximum viscosity where this phenomenon is strongly affected by diverse chemicals which promote or inhibit the hydrogen bonds formation (Badui-Dergal, 1999). In this case, it was not difference for this trait among the four NMF, this may be attributed that they came from the same botanical specie.

The flour viscosity is influenced by particle size and the dwell time (Fernández-Muñoz *et al*., 2002,Palacios-Fonseca *et al*., 2009), these authors reports that the particle size in nixtamalized maize is an important factor in the rheological properties of tortillas. Maximum viscosity was negatively correlated to particle size, with a maximum peak viscosity presented by the NMF HOC, as this flour presented a particle size lesser than the other three studied NMF.

Retrogradation is the molecular interactions (hydrogen bonds among starch chains) after cooling the gelatinized starch paste (Hoover, 2001). The MF BAP had the highest retrogradation which was significantly different from the other MF, in contrast to the NMF BAP, where retrogradation value was the lowest compared to the other MF. The NMF retain more water compared with the tortilla dough, which produces more hydrogen bonds between starch chains, increasing retrogradation. Also during this phenomenon imperfect crystals develop from

Table 2: Nixtamal quality parameters of maize

ID	SWAC	WL	TP
HIB	1.23±0.01	18.72±2.21	1.81±0.05
HOC	1.18±0.02	18.78±1.93	1.77±0.02
BAP	1.16±0.02	18.36±0.67	1.76±0.01
AMA	1.21±0.06	19.67±0.13	1.77±0.04

SWAC = water absorption L water/ Kg flour; WL = Weight loss %; TP = Tortilla Performance Kg tortilla/kg flour. Mixture of commercial hybrids (HIB); high oil content (HOC); high polyembryony and brachytic (BAP) and yellow corn maize variety (AMA)

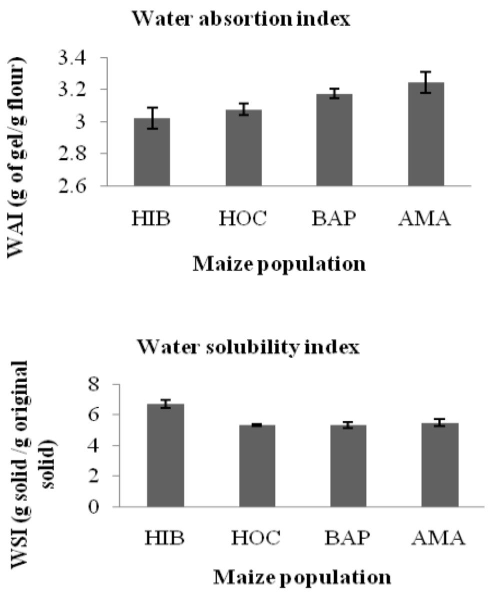

Fig. 2: Water absorption index determined and water solubility index in nixtamalized maize flour. Mixture of commercial hybrids (HIB); high oil content (HOC); high polyembryony and brachytic (BAP) and yellow corn maize variety (AMA)

the reassociation of amylose and amylopectin (Paredes-Lopez *et al*., 1994). The retrogradation sometimes tends to modify the structural, mechanical or organoleptic characteristics of certain products made from starch (Karim *et al*., 2000), so it is important to know the behavior of this phenomenon to determine how the food behavior will be. While the selection of the NMF for a given product is based on the particle size distribution, the behavior of NMF BAP suggests that this flour is better for making tortillas than the other flours, because it presented a lower retrogradation which enhances their shelf life and texture properties.

Subjective water absorption capacity: Among the main physicochemical properties associated with the functionality of the maize flour is the Subjective Water Absorption Capacity (SWAC) (Fernández-Muñoz *et al*., 2008) which is the amount of water absorbed by the flour to obtain a masa with the consistency enough for tortillas preparation (Flores-Farías *et al*., 2002). The values obtained for the 4 NMF showed no significant differences with an average of 1.19 L/kg of flour (Table 2). Tortilla performance showed no significant differences among the 4 different types of tortillas observed an average of 1.77 kg tortilla/kg flour (Table 2).

Water Absorption Index (WAI) and Water Solubility Index (WSI): The NMF AMA and BAP flours showed WAI values higher and different from those observed for HIB and HOC flours (3.02±0.06 and 3.07±0.03 g gel/g solid, respectively) (Fig. 2). The values 3.02 to 3.25 g gel/g solids are within the range reported for this cereal by other authors (Flores-Farias *et al*., 2000). However, Bedolla and Rooney (1984) concluded that acceptable tortillas were made using flour that had a WAI of 4.2 to 4.4 g gel/g solids. A shorter shelf life is associated to flour with high WAI (Bedolla and Rooney, 1984). Drying is a critical factor for producing instant flours with a WAI appropriate, since a long period of drying breaks down the starch chains, which generates short chains, these chains retain a large number of water molecules (Bello-Pérez *et al*., 2002). Campus-Baypoli *et al*. (1999) reported that with excessive heating, starch granules lose their structure and integrity forming a gelatinized paste with a higher WAI which can result in sticky masa, this dough is difficult to handle during tortillas processing. The WAI determined for the NMF BAP flour is acceptable for tortilla production. This parameter is based on changes in the starch granule and its components (Martín-Martínez *et al*., 2003). Bedolla and Rooney (1984) reported that WAI in nixtamalized maize flour depends on: protein content, pH, starch susceptible to enzyme and particle size. NMF HOC flour showed a lower WAI and presented a greater particle size which affects this parameter.

The Water Solubility Index (WSI) determined for HOC NMF (6.715±0.24 g solids / g original solids) was significantly higher than those presented for HIB, BAP and AMA NMF (5.33±0.03, 5.342±0.218, 5.508±0.215 g solid/g original solid respectively) (Fig. 2). These values are within the optimum range for flours and WSI are consistent with those values reported by other researchers (Flores-Farias *et al*., 2000). These authors reported that WSI and WAI are inversely proportional; this is agreed with the results obtained with the NMF studied here. This parameter indicates the amount of solids dissolved by water when a sample of flour is subjected to an excess of this liquid also indicates the degree of cooking of the kernels which was used to flour preparation (González *et al*., 1991).

Tortilla inflation analysis: A formation of a bag in the tortilla is an indicative of good cooking process and tortilla good quality. Tortilla swells when it is heated on the grill, leaving a layer attached to the tortilla ends but not to the center, known as bag. A good quality masa

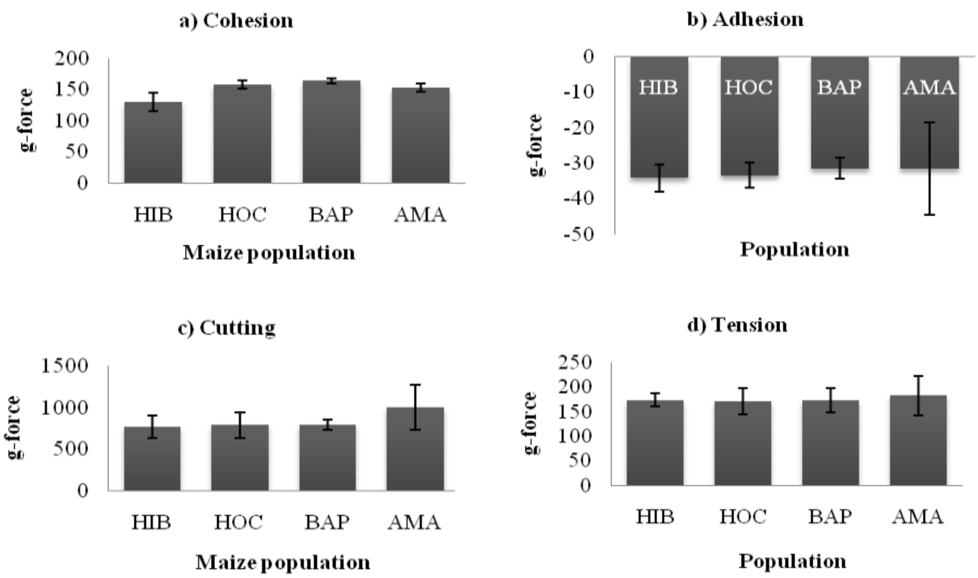

Fig. 3: Rheological analysis of masa a) cohesion and b) adhesion; and tortilla made from nixtamalized maize c) cutting and d) tension in grams-force of four tortillas. Mixture of commercial hybrids (HIB); high oil content (HOC); high polyembryony and brachytic (BAP) and yellow corn maize variety (AMA)

Table 3: Proximal chemical analysis of maize nixtamalized flour and tortilla

	Sample			
Parameter	HIB	HOC	BAP	AMA
Nixtamalized flour				
Moisture	8.93±0.15a	6.89±0.07b	8.73±0.05a	6.31±0.171c
Protein	11.04±1.54a	10.84±0.20a	10.23±0.56b	13.01±0.36 a
Ash	1.48±0.23	1.15±0.13	1.21±0.30	1.19±0.19
Fat	8.57±0.14b	10.61±0.07a	7.24±0.39b	8.23±0.02c
Crude fiber	1.45±0.23	1.15±0.13	1.21±0.03	1.19±0.19
Starch	68.34±1.90	68.80±0.42	70.89±0.97	69.54±0.46
Tortilla				
Moisture	49.31±0.42a	46.61±0.53b	46.50±0.80b	46.13±0.57b
Protein	10.33±0.75b	9.77±0.79b	11.90±1.46ab	13.45±0.18a
Ash	1.71±0.01b	1.78±0.02a	1.73±0.03b	1.72±0.01b
Fat	1.72±0.10b	3.28±0.01a	1.29±0.1d	1.6±0.10c
Crude fiber	1.12±0.08	1.10±0.11	0.70±0.31	0.94±0.08
Starch	35.85±1.35	37.45±1.29	37.85±1.64	36.14± 0.64

Means with the same letter, in the same column, are not significantly different according to Tukey's test ($p \leq 0.05$). Mixture of commercial hybrids (HIB); high oil content (HOC); high polyembryony and brachytic (BAP) and yellow corn maize variety (AMA)

gives a smooth edge, while if it is too dry or it lacks of cooking it will give uneven edges (Billeb de Sinibaldi and Bressani, 2001). The inflation data obtained for BAP tortilla showed 75% as HIB tortilla, while HOC tortilla showed 50% inflation and AMA tortilla inflation was not presented. Greater percentage in inflation is preferred because the tortillas retain more moisture, are smoother and have better texture (Figueroa *et al*., 2001).

Rheological analysis: The masa or dough is a starch product which is considered a complex and unstable system and is submitted to a continuous change in their physical characteristics through the actions of their physical, chemical and biological forces (Rao and Rao, 1993). Masa texture is critical for tortilla processing. When the masa has the adequate texture, it is sticky enough to lightly adhere to the tortilla machine rollers and to properly be separated from the rollers. If maize is over-cooked, the masa is sticky and adheres strongly to the rollers; the sub-cooked maize yields a little tape, inadequate for the formation of tortillas (Ramírez-Wong *et al*., 1993).

Figure 3 shows the adhesion values of the four masa samples where there were no significant differences among them, showing an average adhesion of 32.55 g-force. This trait is influenced by process conditions such as temperature and cooking times and rest, added water and tightening of stones during milling (Gansca-Mancera and Alencáster-Casas, 2007). Ramírez-Wong *et al*. (1993) found that adhesion increases as humidity increases and particle size decreases. These authors reports that highest stickiness was found in the fresh dough of nixtamalized maize while the lowest adhesion was observed in the dough with 30% nixtamalized maize flour. The adhesion values presented by these authors are low compared with the values obtained in this work since they values vary between 8.97 to 25.28 g-force.

Cohesiveness is defined as the strength of internal links that form the product body (Gansca-Mancera and Casas-Alencaster, 2007). Cohesion values (Fig. 3) were significant different among treatments, the HIB masa showed the lowest cohesiveness value (129.68±15.09 g-force) achieving low cohesive strength compared with the HOC, BAP and AMA masas (157.96±7.01, 164.50±4.37 and 153.64±6.59 g-force, respectively). Adequate cohesiveness of maize masa is necessary to form tortillas with acceptable texture. The BAP has a masa cohesiveness adequate for tortilla formation.

The cutting and tension analysis of tortilla simulates the action of molars and breakup with the hands. In addition, tortillas should be soft but at the same time have strength enough to withstand the water that is added when some stew is added for make tacos (Mauricio-Sanchez *et al*., 2004). Besides these parameters evaluate the product plasticity and hardness, if tortilla is softer and milder requires less force for mastication and is considered of better quality (Antuna *et al*., 2008). The average was 837.70 presenting g-force and no significant difference were observed among the 4 type of dough studied (Fig. 3). Figueroa *et al*. (2001) found shear strength values between 919.29 to 1429.15 g-force, showing a good smoothness values in tortillas.

The range of tension values was from 170.93±26.96 g-force (HOC) to 182.50±40.48 g-force (AMA) with a 175.08 average g-force, no significant difference were observed among the different tortillas (Fig. 3). Figueroa *et al*. (2001) reported tension values from 358.81 to 252.80 g-force g-force in tortillas fortified with soybean and vitamins which are slightly above to the results reported in this study.

Proximal chemical analysis of nixtamalized maize flour and tortilla: Moisture percentage determined in the nixtamalized flours was 7.73%. It was observed significant differences among the four flours. The NMF BAP and AMA presented the highest values (Table 3). Low moisture values in flour gives larger shelf life and is also one of the advantages of nixtamalized maize flour compared with corn nixtamalized masa whose has shorter shelf life. Billeb de Sinibaldi and Bressani (2001) reported in flours from eleven varieties of maize a moisture average of 4.88% while Bressani *et al*. (2001) in another paper analyzed maize nixtamalized flour indicating a moisture average of 10.09%. Protein content ranged from 10.23 to 13.01% with an average of 11.29%. It was observed significant differences among the flours, where the NMF BAP showed the lowest percentage of protein content (Table 3). Ayala-Rodriguez *et al*. (2009) reported a percentage of 12.64% in transgenic maize flour while Bressani *et al*. (2001) reported values of protein content of 7.76%, in commercial NMF. The contents of ash and crude fiber were not significantly different among flours (Table 3) where the average was of 1.25 and 1.25%, respectively, these values are similar to those reported by Bressani *et al*., (2001) and Ayala-Rodríguez *et al*. (2009). Fat percentage was significant different among flours where NMF HOC was that presented the highest percentage whereas no differences were observed for starch content (Table 3).

The tortillas moisture average was 47.16%. BAP and HIB tortillas had the highest moisture content and were statistically different from the others (Table 3). Billeb de Sinibaldi and Bressani (2001) reported similar moisture values of maize nixtamalized tortillas with an average rate of 46.86%. In tortillas, moisture content decreases due to the food processing, where some different drying processes are applied, in this study a heat treatment was applied for cooking. Protein content was statistically different among the four tortillas. AMA tortilla had the highest protein content (Table 3). Other works reported protein content values lower than those reported in this study (Figueroa *et al*., 2001). Sample protein content depends on the maize cultivar and food processing (Khan *et al*., 1982). Ash content was significant different among the four tortilla treatments where the HOC tortilla had the highest value (Table 3). The tortilla ash content increased in comparison to the raw grain ash content due to the addition of lime during the processing. Tortilla ash values are similar to those reported by Figueroa *et al*. (2001). Tortillas fat content of was lower than that observed for maize and flour because during the lime cooking process and the nixtamal rest many of the nutrients such as proteins, fats and carbohydrates are dissolved in nejayote (Figueroa *et al*., 2001). This study showed fat significant differences among the 4 types of tortillas where as expected HOC tortillas presented the highest value due to its initial composition. The crude fiber percentages were no significant different among the four tortillas treatments. The crude fiber content average was 0.96% which is lower than that reported in literature (Figueroa *et al*., 2001) this might be due to the washing steps given to the nixtamal in this study. The starch content was no significant different among the four tortillas treatments, the average starch content was 36.82% (Table 3). Starch and moisture are the main components of maize tortilla, starch and moisture proportions depend on cooking conditions (temperature and cooking time), dough moisture which depends directly on the nixtamal moisture and amount of water absorbed during nixtamalization process.

CONCLUSION

Nixtamalization of BAP maize produces NMF with acceptable physical, chemical and functional features in comparison to the control samples (HIB, HOC and AMA). The NMF BAP showed a similarity with the NMF HIB and AMA according to the particle size, WAI and WSI parameters, but had a lower gelatinization temperature. The NMF BAP met with the optimum ranges for foodstuffs production, and has also some advantages or similarities, specifically to the NMF HIB, which is used for production of different maize based foods. BAP tortillas showed a cutting and tension values similar to control treatments (HOC, HIB, AMA).The NMF BAP had lower protein content, but tortilla protein content higher or similar to controls. NMF BAP fat content was intermediate between NMF HOC and AMA treatments. While tortillas fat content was lower than the control treatments, which is an advantage because may extend shelf life. These parameters showed that the tortillas made from polyembryonic maize (BAP) are also an option for tortilla and flour industry with advantages like to need less water for cooking with an adequate particle size distribution.

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