African Journal of Biotechnology Vol. 10(71), pp. 16028-16036, 14 November, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.1820
ISSN 1684–5315 © 2011 Academic Journals

Full Length Research Paper

Physicochemical properties of masa and corn tortilla made by ohmic heating

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Accepted 28 September, 2011

Instant corn flour obtained by ohmic heating (OHICF) was used to prepare masa and tortillas. In this study, the effect of average particle size, moisture, and the final temperature on the physicochemical properties of masa and tortillas elaborated from OHICF was evaluated and were compared with flour obtained by the traditional process instant corn flours (TPICF). The results show that the final temperature and the moisture were the variables that affected the viscosity of OHICF. When comparing the quality of the tortillas obtained from the OHICF and TPICF; OHICF gave soft tortillas with higher yield than the TPICF. This was because the pericarp of the corn grain is not lost during processing which acts as natural gums. The ohmic heating has a great potential to be used in the industry of the flours snap shots of maize, with the advantage of being a friendly technology with the environment.

Key words: Ohmic heating, instant corn flour, nixtamalization, masa, tortilla.

INTRODUCTION

In Mexico and several countries of Central America, corn is consumed mainly as tortillas. The basic principles of tortilla production have remained unchanged since ancient times. The most important change that has been done is the use of instant flours of corn (ICF). The industrial production of ICF is based on traditional nixtamalization process that consists of alkaline cooking of maize with calcium hydroxide (1 or 2%) which has been scaled for industrial production. Small variations in the process significantly affect the quality of end products (Almeida-Domínguez et al., 1996). Nixtamalization has several disadvantages such as: Produce large amounts of water discarded during cooking and washing of corn grains; environmental difficulties because nejayote is an organically rich waste water stream that contains a high concentration of solid materials; cost and space involved in boiling; and some nutrients are lost (Gutiérrez-Uribe et al., 2010; Maya-Cortes et al., 2010). Therefore, new technologies with many potential advantages compared to the traditional method have been explored. Fernández-Muñoz et al. (2011) indicated that regardless of the technology used to obtain ICF, associated quality parameters are the distribution and the index of the particle size; the absorption of water, pH and color and relative viscosity..

Ohmic heating (OH) is considered one of the most promising emerging technologies in the food industry for its high efficiency and simplicity. OH is used to heat food internally by passing a electrical current through it (Sastry and Salengke, 1998); the applied voltage and the electrical current are associated with the amount of heat generated (Sastry and Li, 1996). There are several commercial processing plants based on OH in various countries such as the United Kingdom, Italy and Mexico producing liquid and semi-solid food products such as:

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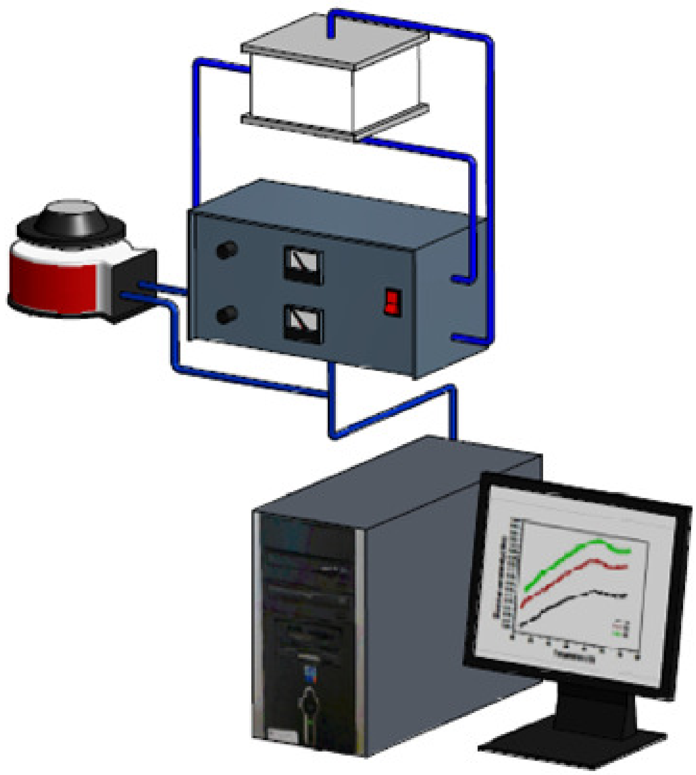

Figure 1. Schematic diagram of the ohmic heating used for processing flour**.**

Fruit and/or vegetables in sauces, liquid eggs, pasteurized orange, and meat emulsions. Also, other applications using OH for processing food solids, such as sausage and surimi, have been reported (Zell et al., 2009).

The aim of the present work was to use the OH as a method of processing for obtaining instant corn flours (OHICF), as well as assess the physicochemical characteristics and texture of the masa and tortillas obtained from the flours.

MATERIALS AND METHODS

Commercial white dent corn (Cargill 633) was purchased from a local market in the city of Querétaro, Qro, México. Food grade calcium hydroxide (El topo, Monterrey, N.L, México) and distilled water were used in all experiments.

Production of ohmic heating instant corn flour

The raw corn was milled using a Pulvex mill (Model 200, Pulvex, S.A. de C.V., México, D.F.), equipped with a hammer head and screens of different mesh sizes: 0.5, 0.8 and 1.3 mm to obtain raw whole corn. In order to measure the particle size distribution, 100 g of each sample was placed in a stack of 6 US standard sieves, 20, 40, 60, 80, and 120 meshes, and placed in a Ro-Tap Shaker (Lab Depot Dawsonville, GA, USA) for 30 min. The particles retained on each mesh were weighed and then the particle size index was determined using the following equation:

$$PSI = \left(W_1D_1 + W_2D_2 + W_3D_3 + W_4D_4 + W_5D_5 + W_6D_6\right) / TS \quad (1)$$

Where, *PSI* is particle size index; $W_{1\text{-}6}$ is the weight of the particles retained on each sieve; $D_{1\text{-}6}$ is the mesh size of each sieve, and *TS* is the weight of the total sample. The raw corn obtained had particle size index of 270, 320 and 390 µm, respectively.

200 g of raw corn sample was then mixed with 0.25 g of calcium hydroxide per 100 g of corn (Ca $(OH)_2$, El Topo, Monterrey, N.L, México) (Rodríguez et al., 1995; Fernández-Muñoz et al., 2002); and adjusted to a moisture content of 45, 52.5 or 60% (w/w) respectively according to the experimental design. Figure 1 shows the batch type ohmic heating cooker used to process OHICF, which has a capacity of 200 g (mixture of solid and liquid) and two stainless steel electrodes (Morales-Sánchez, 2007). The temperature was measured with a Watlow programmable ramp-model 981 with a single T-type thermocouple (Watlow Electric Manufacturing Co., St Louis, MO). A computer program based in LabView (National Instruments, 2008) was developed to record the voltage, current, and temperature during the processing of the samples.Each blended sample was placed in the cooking cell to apply the ohmic heating. Voltage was applied to each sample, beginning with a power of 1 W/g, according to Equation 2, considering the electrical properties of each mixture corn-lime-water. The heating rate of 1 W/g was adequate to achieve the desired temperatures and avoid electroporation (voltage too high), according to preliminary results.

$$P = V^2 / R \quad (2)$$

Where, P is the power (W); V is the voltage applied across the electrodes and R is the electrical resistance (Ω).

The corn masa was dehydrated using a flash type dryer (Cinvestav-AV, M2000, Querétaro). The dryer conditions were adjusted to have 250 ±10°C inlet air temperature and 90±5°C to the exhaust air to avoid burning the material. Then, the material was remilled using a hammer mill (PULVEX 200, México DF, México) equipped with a 0.5 mm screen. The remaining sample was stored in plastic bags at 4°C.

Production of traditional process instant corn flour

The traditional corn instant flour was prepared. In the initial cooking step of the nixtamalization process; the sample was prepared by cooking 2 kg of corn in a solution of 6 L of distilled water and 20 g of calcium hydroxide (1%, w/w) ($Ca(OH)_2$, El Topo, Monterrey, N.L, México). The sample was cooked at 92°C for 25 min. After cooking, the corn was steeped for 7 h. The cooking liquor (nejayote) was drained off and the nixtamalized corn was washed twice in water with a 2:1 (v/w) ratio. The nixtamalized corn was then ground in a stone mill (FUMASA, mod. US-25) for corn masa. The corn masa was dehydrated using a flash type dryer (Cinvestav-AV, M2000, Querétaro). The dryer conditions were adjusted to have 250 ±10°C inlet air temperature and 90±5°C to the exhaust air to avoid burning the material. Then, the material was re-milled using a hammer mill (PULVEX 200, México DF, México) equipped with a 0.5 mm screen. The remaining sample was stored in plastic bags at 4°C.

Characterization of instant corn flour

Particle size distribution

Particle size distribution was measured for ohmic heating instant corn flours (OHICF) and traditional process instant corn flours (TPICF), using a Ro-TAP equipment (Ro-Tap Modelo Rx-29 de Tyler Incorporated, Cleveland, Ohio, USA) with a set of meshes, US standard no. 30 (590 µm), 40 (420 µm), 60 (250 µm), 80 (177 µm), 100 (149 µm) and pan.

The sieve size determined the particle size categories. The sieving procedure was done according to ASAE Standards (1995) for 100 g of flour 10 min sieving. The fractions retained in each of the different meshes were separated and weighed. The fractionation process was performed in triplicate. Means with standard deviations were reported.

Pasting properties

The pasting properties behavior of OHIFC and TPICF was determined using a Rapid Visco-Analyzer (RVA Super 4, Newport Scientific PTY Ltd; Sydney, Australia). Four grams of flour with 14% moisture and particle size of <259 mm was stirred slowly in 24 ml of distilled water. The analyzer required 1 min to reach 50°C, after which the sample was heated to 92°C at 5.6°C/min (7.5 min) and held constant at 92°C for 5 min. The sample was then cooled down to 50°C (5.6°C/min). Viscogram profile/pasting curves show a relationship between time, viscosity and temperature during the cooking processes. Viscosity (cP) was recorded from the pasting curve.

Masa and tortilla preparation from OHICF and TPICF

Instant corn flours (300 g) were rehydrated with water at 27°C to obtain masa with proper consistency to make tortillas. The masa was rounded and shaped in the form of at discs using a manual form (Casa González, México, D.F.). The masa discs were baked on a hot griddle at 270±10°C for 17 s on one side, followed by 30 s on the opposite side, and were then turned onto the first baked side until puffing during the final time on the griddle. The tortilla dimensions were 1.19±0.1 mm thickness, 12.8±0.2 cm diameter. Tortillas from each treatment (n = 20) were evaluated after cooling for 30 min at room temperature.

Physicochemical properties of masa and tortilla

Moisture content

The moisture of the masa and tortillas was measured using the method 44-15 of the American Association of Cereal Chemists International (AACC, 2000).

Masa yield

The masa yield was calculated with the value obtained from the water absorption capacity test, and it was reported as masa kg/kg flour according to the methodology proposed by Arámbula et al. (2001).

Tortilla yield

Tortilla yield was evaluated by the ratio between the weight of the tortilla after and before cooking.

Texture analysis of masa and tortillas

The masa texture (adhesiveness and hardness force) and tortilla texture (cutting force and tensile strength) were evaluated using the Universal Texture Analyzer TA-TX2 (Texture Technologies Corp., Scarsdale, N.Y., U.S.A./Stable Micro System, Godalming, Surrey, UK). All measurements were done with 4 replicates, and the results were expressed as force in Newton (N).

The masa adhesiveness and hardness were measured by penetrating a TA-18 1.27 cm stainless steel ball probe into the masa at a speed of 2 mm/s to a distance of 4 mm.

For tensile strength and cutting force tests, a piece of tortilla sample was cut into a strip-shaped specimen ("I"). The strip dimensions were 3.5 × 2 cm and 1.8 cm in the thin part of the strip. The trials of tensile strength and cutting force were performed according to the method reported by Arámbula et al. (2004).

Experimental design and statistical analysis

A factorial arrangement (3 × 2 × 2) was used to select the best quality OHICF to tortilla, as Table 1 shows. The independent variables were particle size index (270, 320 and 390 µm), final temperature (80 and 90°C), and moisture (52.5 and 60%). Each treatment was replicated twice; these experiments were completed in random order. All data were analyzed and the standard deviations and Tukey's means comparison ($p < 0.05$) were obtained by the used of Statistical Analysis System program (SAS Institute, Cary, NC, USA, 2008). The control sample consisted of instance corn flour prepared by traditional process.

Table 1. Factors and levels utilized for obtaining instant corn flour by ohmic heating.

Factor	Level
Particle size index (µm)	270 320 390
Moisture (%)	52.5 60
Final temperature (℃)	80 90

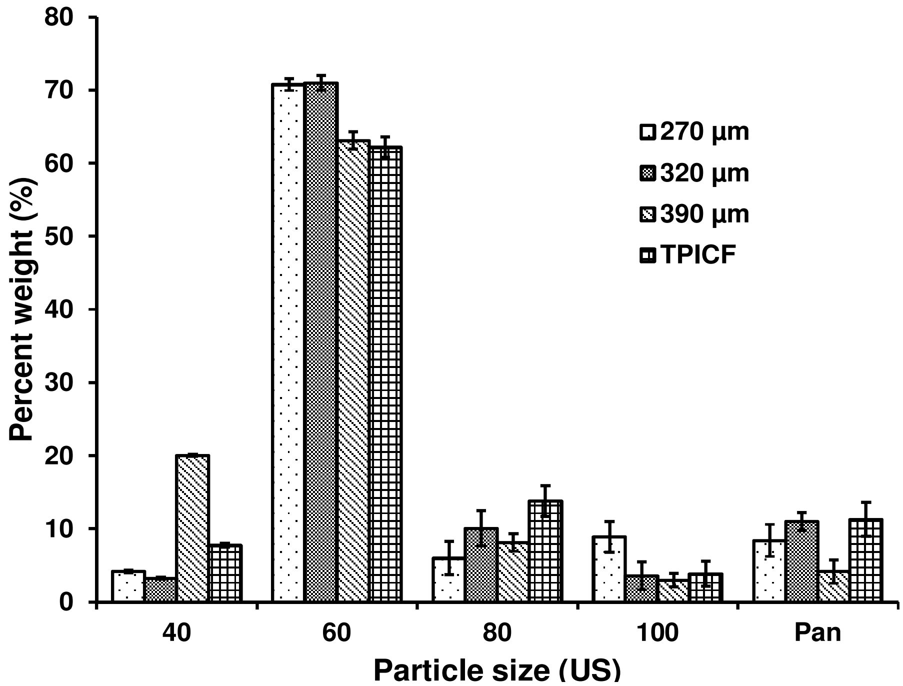

Figure 2. Particle size distribution of OHICF (270, 320 and 390 µm) and TPICF.

RESULTS AND DISCUSSION

The percentage of particle size distribution (PSD) for OHICF and TPICF is shown in Figure 2. The 75% of OHICF with 270 and 320 µm was retained in the 60 and 80 US mesh sieves and a small amount of flour was retained in 100 US mesh sieves and the pan; the TPICF PSD had no significant differences ($p < 0.05$) compared to OHICF. However, variance analysis indicated that the PSD of the OHICF with 390 µm were significantly different ($p < 0.05$) among 270 and 320 µm. This difference in the PSD can be attributed to processing conditions. This combination of particles is required for the production of tortillas in order to satisfy the official norm for flours in Mexico (US No. 60 or 250 µm). Tortillas require a fine particle size flour to develop flexibility and cohesiveness, whereas corn chips and tortilla chips require a coarse particle size formulation to promote crispiness in chips after frying (Montemayor and Rubio, 1983). It is generally believed that smaller particles are responsible for most of the water uptake, cohesiveness, plasticity, and smoothness of masa (Gómez et al., 1987). However, the processing conditions are to be considered (temperature-time, concentration the lime, etc.) in order to obtain a masa with the characteristics appropriate to the end uses.

Pasting properties

The first turning point is where the curve changes slope is referred to as pasting temperature (transition). Pasting temperature must be distinguished from the initial temperature of gelatinization, due to a high swelling that must take place before it develops the viscosity enough to be detected by the Viscogram profile. The pasting temperature was significantly affected by the final temperature ($p < 0.001$). Pasting temperature of the OHICF presented significant differences with regard to the TPICF ($p < 0.05$). The OHICF presented higher pasting temperature with respect to the TPICF. An and King (2006) reported a similar behavior in the processing

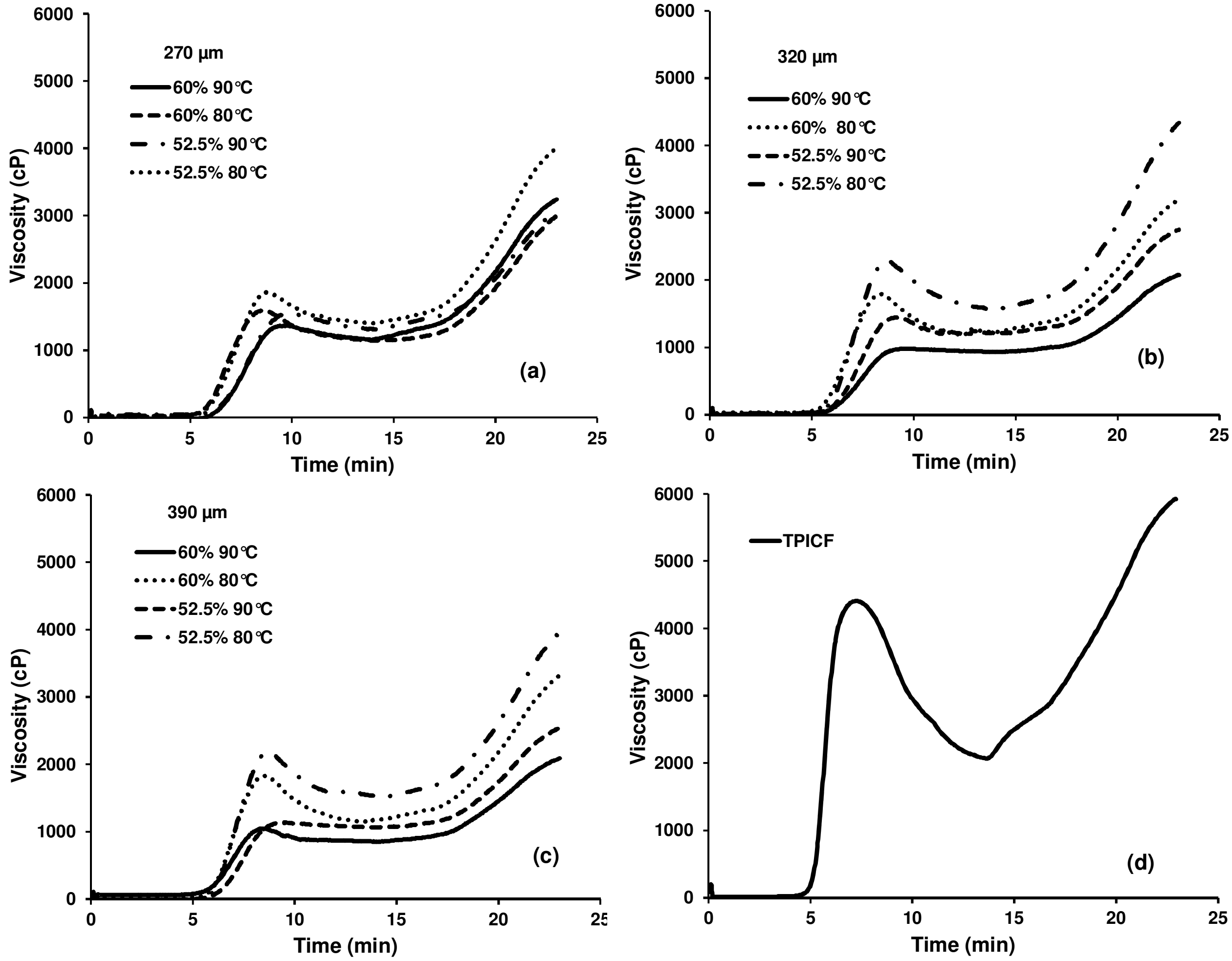

Figure 3. Pasting profile of instant corn flour obtained by: ohmic heating (a), (b), (c) and traditional process (d).

of brown rice by OH at a temperature of 100°C. The increase in pasting temperature was directly proportional to the time of processing, which is consistent with our results since the OHICF processed with temperatures of 90°C presented a pasting temperature higher than the OHICF processed with temperatures of 80°C, while the TPICF presented a pasting temperature of 70.7°C (Figure 3).

Maximum viscosity (MV) is considered a balance between the capacity of the granules to swell and the leaching of polymers that form the starch; this process is affected by the processing conditions. The MV of the OHICF was significantly affected ($p < 0.001$) by the final temperature and moisture. The MV showed significant differences ($p < 0.05$) between the OHICF and TPICF, due to the heating mechanisms used to get the flour (Figure 3). In the OH, the mixture of corn-water is heated simultaneously, generating internally the heat by the electric power applied (Sastry and Palaniappan, 1992), which causes structural changes in the starch, resulting in a decrease in viscosity (Jimenez et al., 2007; Chaunier et al., 2007). It is important to note that despite the fact that the OHICF showed lower values of viscosity in comparison with the TPICF, the reductions was directly proportional to the increase in temperature and moisture, which indicates that in OH it is possible to have a control of the degree of starch gelatinization (Figure 3). In both cases, TPICF developed the greater MV, since during nixtamalization, baking takes place with the grain of the whole corn, so it is less damaged by the thermal process. However, the grinding nixtamal changes occur in the structure and properties of starch by friction (Gómez et al., 1992; Campus-Baypoli et al., 1999).

The viscosity increases during cooling (FV); this trend indicates that the elements present in the flour are associated during the retrogradation step and are related to the flour quality during storage (Quintanar-Guzmán et al., 2009; Férnandez-Muñoz et al., 2004). The OHICF and TPICF showed significant differences in the FV (Figure 3). The OHICF showed lower values of FV, which indicates a greater stability of the starch to the cooking and cooling hence fewer tendencies to retrogradation,

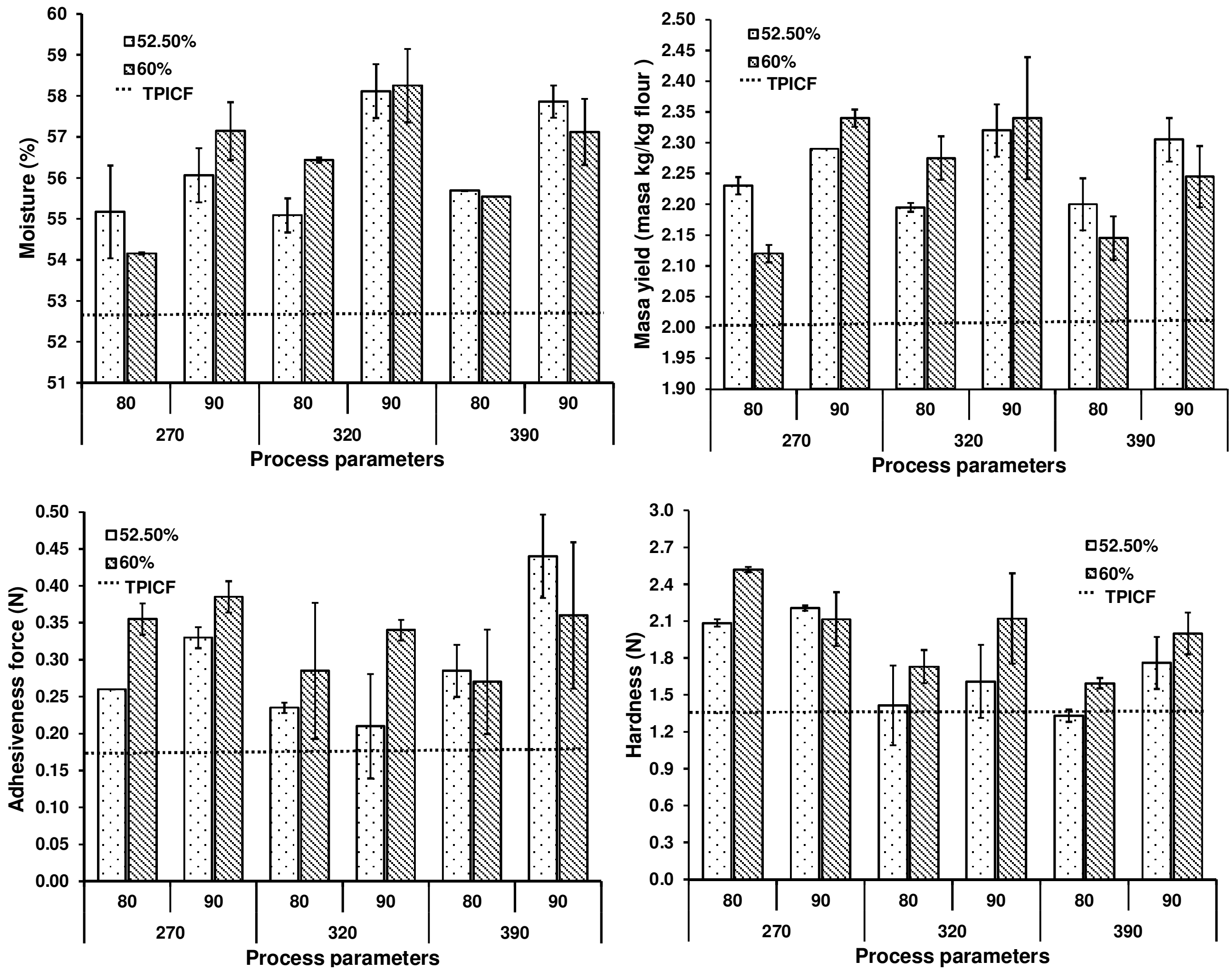

Figure 4. Physicochemical properties of masa elaborated from OHICF and TPICF.

which would provide tortillas softer for re-heating, in comparison with the TPICF. This indicates that the OH would obtain tortillas with greater stability during its shelf life, which represents an advantage over the traditional process, where significant losses are usually observed by tortilla hardening during shelf life.

Evaluation of masa

Moisture, particle size, and final temperature parameters affected physicochemical properties of the masa made from OHICF. There was a significant influence of the final temperature ($p < 0.001$) on masa yield. The masa yield was higher in corn flours processed with PSI of 270 and 320 µm, compared to OHICF with a PSI of 390 µm (Figure 4). This is consistent with the data reported by Fernández-Muñoz et al. (2008) who indicate that higher particle size significantly decreases both the water absorption capacity and the yield. The parameters that significantly influenced the moisture content in masa were the final temperature ($p < 0.001$) and PSI ($p < 0.001$). The moisture content of the masa obtained by OHICF and TPICF are shown in Figure 4. The masa of OHICF had moisture content significantly ($p < 0.05$) higher (58.25 a 54.16%) than the masa of TPICF (52.67%). The moisture content is related to the water absorption capacity of ICF and masa yield. These values are within the range described in the literature that was in the range of 56.3 to 52.9% (Figueroa et al., 2001). Martínez-Flores et al. (1998) reported a wider range in masas obtained by extrusion technology (58 to 49%).

The textural characteristics of masa (hardness and adhesiveness force) are related to water content. In the masa system, small particles act as glue to maintain together the big particles and other components that form the structure of masa, while the water acts as a plasticizer that controls the rheology of the masa. The texture of the masa is affected by the water absorption and the degree of gelatinization during processing

(Bedolla and Rooney, 1982); these facts agree with the results obtained with OHICF, because the texture of the masa was significantly affected by the OH process parameters evaluated.

Hardness is a parameter that is measured by the force required to deform the masa, at optimal conditions of moisture, without causing its disintegration. The results found for the hardness of masa (Figure 4) had significant differences ($p < 0.05$); the values were 2.52 to 1.33 N and the TPICF 1.38 N. The literature values for masa hardness ranged from a minimum of 0.074 kg-F (0.7 N) to a maximum value of 0.2 kg-F (2 N) (Figueroa et al., 2001).

When the masa presents good texture, it has enough adhesive force to allow been rolled and also to be separated in sheets in an appropriate manner; which is critical in the manufacturing process of the tortilla (Bello-Pérez et al., 2002). The adhesiveness was in the range of 0.44 to 0.21 N and the TPICF had less adhesive force (0.17 N). The OHICF processed with moisture of 60% and FT of 90°C and PSI of 270 and 320 µm showed the highest values of adhesiveness (Figure 4). Figueroa et al. (2001) reported adhesiveness values of 0.035 to 0.030 kg-F (0.35 to 0.30 N) in commercial flours, while Martínez-Flores et al. (1998) reports adhesiveness values ranging from 0.051 to 0.008 kg-F (0.5 to 0.08 N) in masa extruded at different conditions.

During the traditional nixtamalization process, small quantities of starch granules are gelatinized, mostly due to friction during the milling, which partially disperses the swollen granules within the matrix, acting as glue that keeps the particles of the masa together (Bello-Pérez et al., 2002). However, during the OHICF, milling with a stone mill is omitted, suggesting that OH is responsible for the formation of masa with the appropriate characteristics of moisture, yield and texture similar to masas obtained by the traditional process, controlling the processing parameters of OH. Colonna et al. (1987) reported that in pre-gelatinized starches, when no cutting force is applied to the swollen granules, a process similar to that carried out during the OH, where partial leaching of amylose occurs, and the components of the starch degrade slightly, and probably continue to be connected within a continuous matrix.

This situation produces greater absorption of water being reflected in masa with higher moisture content in the OHICF, without affecting negatively the texture of the masa and quality of the tortilla.

Quality properties of tortilla obtained with OHICF and TPICF

In Mexico and several countries of Central America, corn is consumed mainly as tortillas. The processing conditions produce starch which undergoes functional and structural changes; this has great implication in the rheological and textural properties of masa and tortilla.

According to the results, the final temperature ($p < 0.0001$) and the PSI ($p < 0.001$) presented a significant effect on the moisture content of the tortilla. The moisture content of the tortilla showed significant differences ($p < 0.05$) between the OHICF and TPICF. The range found for the moisture of the tortillas obtained OHICF were 47.59 to 41.88% and for TPICF, 40.87% (Figure 5). These data are in agreement with Arámbula et al. (2001) who indicated that higher water uptake was correlated with good tortilla textural characteristics.

The tortilla yield is an important parameter that is directly related to the weight loss during the tortilla cooking, a condition that is reflected in overall performance. The PSI ($p < 0.01$) and final temperature ($p < 0.0001$) had a significant effect on tortilla yield, tortilla moisture and tortilla texture.

Tortilla yield, tortilla moisture and tortilla textural characteristics such as tensile force and shear strength or cutting force are shown in Figure 5. The tortilla yield range found was 1.86 to 1.74 kg of tortillas/kg of flour higher than that obtained in the TPICF (1.63 kg of tortillas/kg of flour).

Figure 5 shows the values of tensile and cutting force for tortilla elaborated with OHICF and TPICF. The tensile strength in tortillas showed significant differences between OHICF (1.96 to 0.76 N) and TPICF (1.56 N). The literature reports values for tensile strength of 1.76 to 1.24 N for tortillas with different gums (Arámbula et al., 1999) and 4.69 to 4.62 N for tortillas made with the traditional method of nixtamalization (Figueroa et al., 2001). The tensile strength is related to the attributes of elasticity and hardness in the tortilla evaluated subjecttively by the consumer, because these represent the strength necessary to tear a tortilla to stretch, simulating the torn with your hands (Reyes-Vega et al., 1998). The tortillas obtained by the OHICF are softer than the tortillas nixtamal, and therefore are easy for tearing.

The tortilla cutting force in the OHICF (9.84 to 5.55 N) showed significant differences ($p < 0.05$) with values within TPICF (8.67 N). The average values reported for traditional corn nixtamal tortillas range from 22.69 to 8.93 N (Figueroa et al., 2001). The cutting force parameter shows a numeric value of the sensory perception of hardness of the tortilla to the biting, or cutting with the teeth (Reyes-Vega et al., 1998), by which, the low values of resistance to the cutting force show a soft tortilla, easy-to-biting, as is the case of the tortillas produced by OHICF. Therefore, the tortillas made using OH in this study had excellent quality related to the tortilla texture. It can be observed that tortilla yield and tortilla moisture are interrelated. The OHICF produces tortillas with good textural characteristics; these characteristics are explained in part by the starch gelatinization as well as the presence of the more pericarp in the corn, which is not removed during the processing of flour using OH. Martínez et al. (2001) report that the pericarp, on contact with lime, results in the rupture of the hemicelullose structure (a component of the pericarp), incorporating

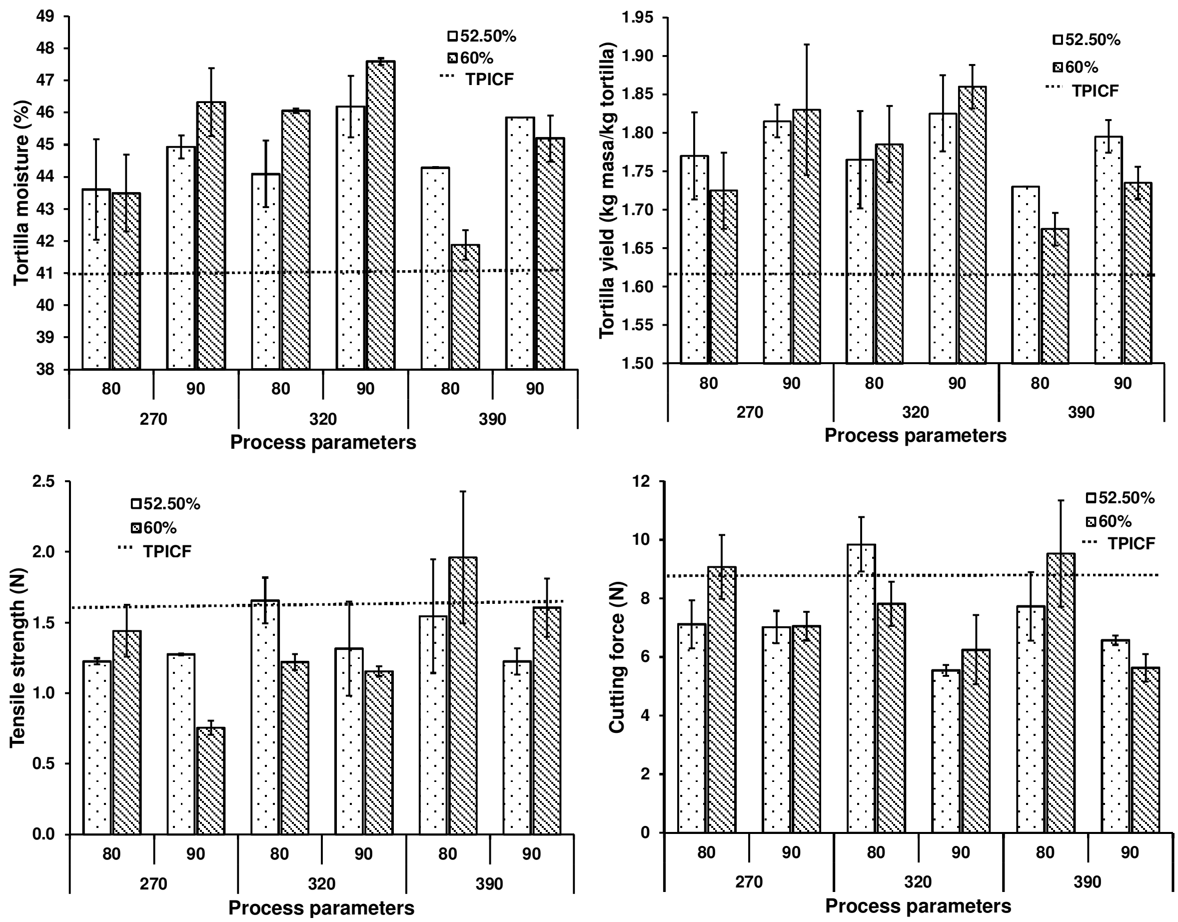

Figure 5. Quality properties of tortilla obtained with OHICF and TPICF.

itself in the flour in the form of natural gums that promote a higher water retention and improve the textural properties of the tortilla. These alkali-soluble hemicelluloses show interesting functional properties as adhesives, thickeners, stabilizers and developer of a good texture in the tortilla.

Conclusions

The results show that ohmic heating is a simple and clean technology with potential applications to obtaining corn tortillas with good textural properties. The most important parameter in OH to control the physicochemical properties of the end-product was the final temperature.The tortillas elaborated from OHICF were softer than those obtained from TPICF, because the OH allows processing a whole corn into flour without losing the pericarp (natural soluble gums) with benefits that promote higher water retention and improve the textural properties of the tortilla, and in the process, avoiding polluting waste products, primarily pericarp, which are generated in the cooking liquid or nejayote in the traditional process.

ACKNOWLEDGEMENTS

We thank M.C. José Juan Véles Medina and Ing. Carlos Alberto Ávila Herrera for technical support.

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