Cooking Time, Grinding, and Moisture Content Effect on Fresh Corn Masa Texture[1]

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ABSTRACT

Corn was alkaline-cooked for 20, 55, or 80 min, and the nixtamal was ground in a stone grinder into masas with medium or coarse particle size distribution. Each masa was conditioned at three moisture levels. Masa texture was evaluated for adhesiveness and hardness and measured by a compression tension texture test. Samples of each corn masa were freeze-dried and ground for physical and chemical analyses including: water absorption index, particle size index, enzyme susceptible starch, and total amylose. Masas from nixtamal cooked for 20 min, either coarse- or medium-ground, at any moisture content, gave the lowest adhesiveness and the highest hardness and compression tension factor values. Nixtamal cooked for 55 min, ground to medium particle size with a moisture content range of 54.6–56.2%, gave the best masa texture for use in the sheeting and cutting rollers of the tortilla-making process. The cooking time affected the masa moisture, water absorption index, enzyme susceptible starch, and total amylose, whereas grinding affected water absorption index, total amylose, and particle size index. Textural characteristics of fresh corn masa were dependent upon its water retention capacity, which was controlled by the cooking and grinding operations.

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The commercial method for producing corn tortillas and related products is based on the traditional process of nixtamalization. To obtain a good quality table tortilla, it is very important to control all processing conditions. Otherwise, great variations in quality parameters such as liquor solid losses, nixtamal moisture content, tortilla yield, and masa and tortilla texture will occur. One of the most critical aspects of the corn tortilla process is the masa texture. When masa has the appropriate texture, it can be easily molded into flattened round disks. On the other hand, masas with a noncohesive or sticky texture will be inadequate for tortilla formation (Ramírez-Wong et al 1993). Masa texture is determined by factors such as maize variety, endosperm texture and type, drying conditions, and soundness of the corn, as well as the water uptake, and degree of starch gelatinization during processing (Bedolla and Rooney 1982). Among the most important processing conditions to control are cooking time and degree of grinding. During alkali-cooking, chemical and physical changes, such as starch gelatinization, water uptake, and partial removal of the germ and pericarp, occur in the corn kernel. During the formation of masa, grinding disrupts the swollen gelatinized starch granules and distributes the hydrated starch and protein around the ungelatinized portion of the corn endosperm (Rooney and Serna-Saldávar 1987). In addition, grinding gives the final masa particle size and, because of the friction between the stone grinder and nixtamal, causes more damage to the starch.

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Investigations of the corn tortilla production process have not addressed the relationship between masa texture and physical and chemical changes, or between texture and processing conditions. Therefore, the objective of this research was to evaluate the textural characteristics of fresh corn masa under different conditions of nixtamalization by using instrumental methods, as well as to investigate some of the chemical and physical factors affecting corn masa texture.

MATERIALS AND METHODS

Preparation of Fresh Corn Masa

The process used to prepare fresh corn masa is shown in Figure 1. Corn (2 kg; ASGROW 405; chemical composition: moisture, 12.4%; starch, 76.0%; protein, 10.3%; and ash, 1.3%) was cooked with a 1% (w/w) solution of lime [$Ca(OH)_2$], in a steam kettle (model TDC/2-20, Dover Corp., Elk Grove Village, IL), to one of three end points: undercooked, optimum cooked, or overcooked. Cooking times were 20, 55, or 80 min. The cooking temperature was 100°C. The objective was to have a wide range of nixtamalization conditions, from undercooked to overcooked, which were established in preliminary trials. Cooked corn was steeped for 14 hr in an insulated chest at room temperature. The initial cooking liquor temperature was 96 ± 1.3°C; this decreased with the steeping time to 40.0 ± 3.5°C. Then the cooking liquor was collected in a container, and the nixtamal was washed vigorously with tap water. For each cooking time, the washed nixtamal was ground using one of two different gaps between the grinder lava stones (model CG, Casa Herrera Inc., Los Angeles, CA). To avoid excessive heat generation, water was added during grinding. The wide-gap grinder setting yielded coarse corn masas appropriate for tortilla chips, taco shells, and tostadas. The narrow-gap setting yielded medium masa appropriate for table tortillas.

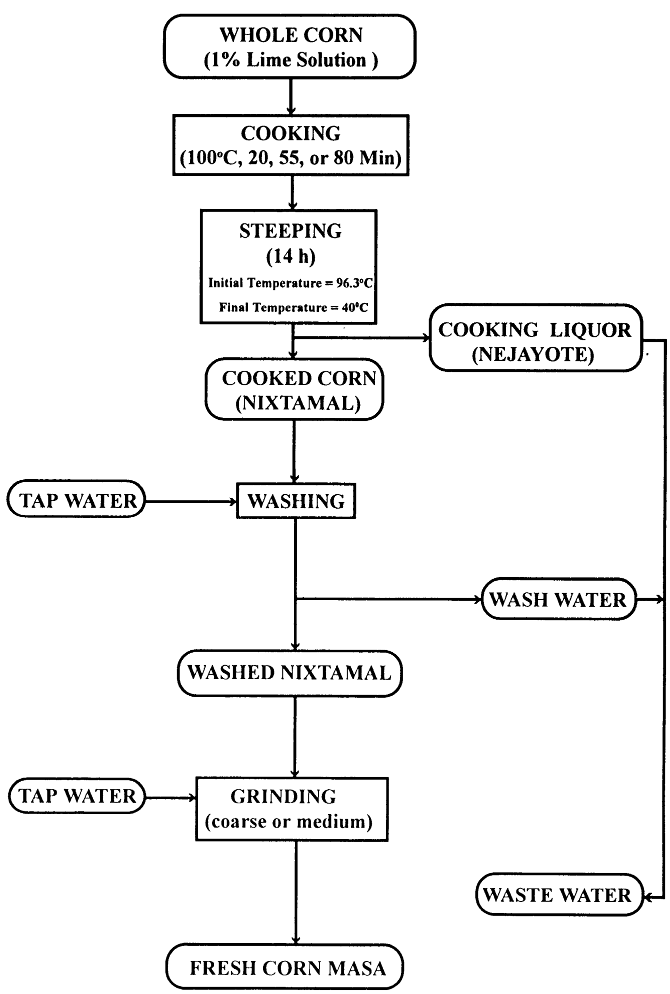

Fig. 1. Flow diagram of the process to make fresh corn masa.

The selection of the gap between the stones was made empirically by experienced operators. According to Clark (1987), in the traditional mill using hand-carved stones of volcanic lava rock, the gap was adjusted within limits when the operator increased the pressure between the stones with a jackscrew located at the front of the mill.

The particle size of masa obtained with the traditional method is extremely difficult to predetermine. Currently, masa particle size measurement is done subjectively. A common method is to squeeze a piece of masa between the fingers. In our experiments, preliminary tests were used to establish grinder gap settings for coarse and medium masas. The masas were dried and ground and passed through a series of sieves to determine their particle size distributions.

Each corn masa was mixed in a 20-L mixer (Hobart, model A 200) for one minute and then divided into three parts. The first part (2.4 kg) was used to evaluate textural characteristics. The second part was used to determine original moisture content. The third part was freeze-dried and used for subsequent physical and chemical determinations.

Corn masa that would be used for texture measurements was further divided into three parts. Individually, samples were put into polyethylene bags and allowed to sit for 30 min. During this time, a rapid method was used to determine masa moisture content (Torres and McDonough 1986). This involved weighing 1.5 g of fresh corn masa and flattening the sample between a small aluminum plate and a sheet of aluminum foil with a tortilla handpress. The foil sheet was removed, and the sample on the aluminum dish was dried in an Ohaus balance (model 6010 with a 375-W infrared lamp). Preset conditions were at setting 2 with 10 min of drying. Water amounts required for stickier masas were calculated with this masa moisture content.

Ramírez-Wong et al (1993) developed methods for corn masa texture evaluation based mainly on adhesiveness or stickiness determinations. These authors reported that moisture content significantly affected the masa texture.

Besides the cooking time and the degree of grinding, the effect of water content on masa texture was also studied. Water content was adjusted in preliminary tests to yield masa with optimum texture, sticky masa, and hard masa. The textural characteristics have been related to moisture content (Ramírez-Wong et al 1993).

Initially, we expected to obtain the same three moisture contents for the corn masas from each cooking time and degree of grinding. This was impossible, because when we increased the cooking time, the nixtamal moisture content also increased. Therefore, we decided to define three levels of moisture for each masa: level 1, moisture content of masa as it exited the grinder (no water added); level 2, moisture content that gave 45–55% adhesiveness, as measured with the mechanical stickiness device (Ramírez-Wong et al 1993); and level 3, moisture content that gave 85–100% adhesiveness, as measured with the same instrument.

Experimentally, at the end of the 30-min holding time, each of the three corn masa samples were placed into the mixing bowl in a random order; then water amounts required for masas with different adhesiveness were calculated. Samples were mixed for 60 sec at speed 1 (the lowest speed) and 15 sec at speed 2. Samples were then put back into a plastic bag to avoid water evaporation.

It is important to distinguish between levels of moisture added and the masa moisture content. Masa moisture content is the resulting moisture content after a specified level of water was added.

One trial was run, per day, for masas with a specific cooking time and grinding level and with the three moisture levels. Before evaluating masa texture, the masa samples were randomized and allowed to reach room temperature (26 ± 0.5°C) (Ramírez-Wong et al 1993).

Masa Texture Evaluation

The Instron compression/tension test (ICTT) developed by

Ramírez-Wong et al (1993), was used to evaluate masa texture. The test was run on an Instron universal testing machine (UTM) (model 1112 Instron, Canton, MA), using a 100-lb compression-tension load cell. The UTM crosshead and chart speeds were 0.5 cm/min and 10 cm/min, respectively. The textural characteristics evaluated were: adhesiveness or stickiness, hardness, and the compression tension factor (CTF), which is defined as the ratio of maximum compressive to tensile forces (Ramírez-Wong et al 1993).

Corn masa texture was evaluated 140 ± 8 min after the original masa was prepared. Four determinations were made for each sample. After each texture evaluation, the final masa disk diameter was recorded. From the curves obtained, the area of the negative curve and the maximum peak heights of both curves were calculated. Adhesiveness was reported as work (N·m); hardness was reported as maximum stress (Pa); and the CTF was dimensionless (ratio of the maximum compressive to maximum tensile force).

To relate the masa texture to the tortilla-making process (masa machinability), trials were run with the masas from the different treatments as described by Ramírez-Wong et al (1993).

Dried Masa Flour Preparation

Frozen masa samples were dried in a freeze-dryer (Freezemobile 12, The Virtis Co., Gardiner, NY). The dried material was ground in a laboratory mill through a 6-mm screen. This screen was used to break down the frozen masa block into its original particle size. The ground, freeze-dried masa was split into two portions. One part was used for particle size index and water absorption index determinations. Because this grinding produced a material too coarse to be used for other physical and chemical analyses, the second part was ground in a cyclone sample mill (model S/N 25084u-3, Udy Co., Fort Collins, CO), using a 60-mesh screen to obtain a fine masa flour.

Water Absorption Index (WAI)

The WAI measures the capacity to retain water. It was measured by using a modification of the method reported by Anderson et al (1969). Freeze-dried masa flour (1 g) from the first grinding and 15 ml of distilled water at room temperature were placed into a 50-ml centrifuge tube. The suspension was agitated in a shaker at the highest speed for 30 min. The supernatant was decanted, then dried in a forced-air oven. The weight of the gel was computed as the precipitate. The WAI was calculated as:

$$\text{WAI} = (\text{g of gel} - \text{g of dry sample}) / \text{g of dry sample}$$

The amount of solids in the supernatant was subtracted from the weight of the dry masa sample. Thus, the amount of dry sample appearing in the equation was corrected for water soluble material. The WAI was expressed as grams of water per grams of dry sample.

Particle Size Index (PSI)

Freeze-dried masa flour (25 g) from the first grinding was placed in a series of U.S. standard testing sieves (No. 20 = 841 μm; 30 = 600 μm; 40 = 420 μm; 60 = 250 μm; 80 = 180 μm; and 100 = 150 μm). Five marbles were put onto each sieve. The sieves were placed on a sieve shaker (Ro-Tap; U.S. Tyler Co.) for 10 min. Material retained on the different sieves and in the pan was weighed and expressed as percent overs. The PSI was computed using the method reported by Bedolla and Rooney (1984). The greater the PSI, the finer the dry masa flour.

Enzyme Susceptible Starch

The enzyme susceptible starch (ESS) analysis gives an index of the degree of masa cooking. Samples (0.2 g) were placed into 75-ml Kjeldahl digestion tubes containing 20 ml of distilled water. The tubes were placed in a water bath at 60°C; 25 ml of 0.1N sodium acetate buffer was added to each tube. Then 1.0 ml of amyloglucosidase solution (Diazyme L100, Miles Laboratory, Elkhart, IN) was added to each tube, and the tubes were incubated. After exactly 30 min of incubation, the enzyme was inactivated by adding 1 ml of 10% sulfuric acid solution to each tube. The tubes were removed from the water bath and allowed to equilibrate to room temperature. Next, the tubes were filled with distilled water and allowed to settle overnight. The next day, the supernatant was poured into autoanalyzer cups, and glucose was measured (autoanalyzer II method SF4-0046FA8, Technicon Instrumental Corp., Tarrytown, NY). The ESS was calculated as milligrams of glucose per gram of starch:

$$\text{Mg of ESS/g of starch} = (\text{ppm} \times 0.075) / \text{sample weight (g)}$$

Total Amylose

A method reported by Williams et al (1970) was used to determine total amylose in dry masa flours. A sample (20 mg) was placed in a 50-ml beaker, and 10 ml of 0.5N KOH solution was added. The sample was transferred to a 100-ml volumetric flask and diluted with distilled water to 100 ml. A 10-ml aliquot was pipetted into a 50-ml volumetric flask and 5 ml of 0.1N HCL was added, followed by 0.5 ml of iodine reagent B, 10 ml of stock solution A, and 90 ml of distilled water. Stock solution A was prepared with 20 g of potassium iodide and 2.0 g of resublimed iodine mixed in a 100-ml beaker, dissolved, and diluted to 100 ml. The volume was diluted with distilled water to 50 ml. After 5 min, the absorbance of the blue color of the solution was measured in a spectrophotometer (model Spectronic 21, Baush and Lomb Co.) at 625 nm. A control sample of pure amylose was also run.

Moisture Determination

The moisture content of fresh corn masa, dry flour masa, and the solids content of liquid samples were determined in a forced-air oven (model 28, Precision Thelco Co.) by measuring the loss of weight after 12 hr of drying at 110°C (AACC 1983). At this time, a constant weight had been obtained.

Statistical Analysis

A split split-plot experimental design was used for texture evaluation. There were three levels of cooking time (20, 55, and 80 min), two levels of degree of grinding (coarse and medium), and three levels of moisture content (1, 2, and 3). This gave 18 different treatments, which were replicated three times. One complete replicate was run on each of three different days (blocks), and they were sequenced in random order. In this experimental design, each block was divided into three parts called whole plots. The cooking times were called the whole plot or main treatment. Each whole plot was divided into two parts called subplots (or split-plot), and one grinding condition was assigned to each one. Each subplot was divided into three parts called sub-subplot (or split split-plot), and one moisture level was assigned to each of them. Moisture level was called the sub-subplot treatment.

The same experimental design was utilized for the physical and chemical determinations (from masas with the original moisture content), but eliminating the sub-subplots, leaving six treatments or subplots.

Analyses of variance were run and levels of significance (P value) was obtained. A test was not statistically significant when its P value ≥ 0.05; the null hypothesis (H_0) was not rejected when P value ≥ 0.05. On the other hand, H_0 was rejected when P value < 0.05; the result was declared significant (*) when $0.01 < P$ value < 0.05, and highly significant (**) when P value < 0.01. Differences among specific treatment effects were tested with Tukey's test. Simple correlation coefficients (r) were computed when necessary. Statistical analyses were performed using Statistical Analytical System software (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Factors Affecting Masa Texture

Adhesiveness. The analysis of variance (ANOVA) showed that adhesiveness of fresh corn masa was affected significantly ($P < 0.05$) by the cooking time, degree of grinding, interaction of cooking time and grinding, moisture level, and interaction of cooking time and moisture level (Table I). Figure 2A presents the effect of the interaction of cooking time and grinding. On coarse masas, adhesiveness increased 96% as the cooking time went from 20 to 55 min; it increased 93% as cooking time went from 20 to 80 min. Adhesiveness was not significantly different between masas cooked 55 and 80 min. For masas with medium particle sizes, adhesiveness increased 153 and 168% when cooking time went from 20 to 55 min and from 20 to 80 min, respectively. When cooking time changed from 55 to 80 min, there was not a significant difference in adhesiveness.

The degree of grinding affected adhesiveness only at cooking times of 55 and 80 min. In masa with medium particle sizes, adhesiveness was 40 and 52% higher than coarse masa at cooking times of 55 and 80 min, respectively.

Figure 3A presents the effects of the interaction of cooking time and moisture level on the masa adhesiveness. At all these levels of moisture, masas made from nixtamal cooked for 55 and 80 min were more adhesive than were masas made with nixtamal cooked for 20 min. However, between those two masas (55 and 80 min of cooking), there were no significant differences ($P > 0.05$). On the other hand, regardless of the cooking time, adhesiveness increased with the level of moisture added.

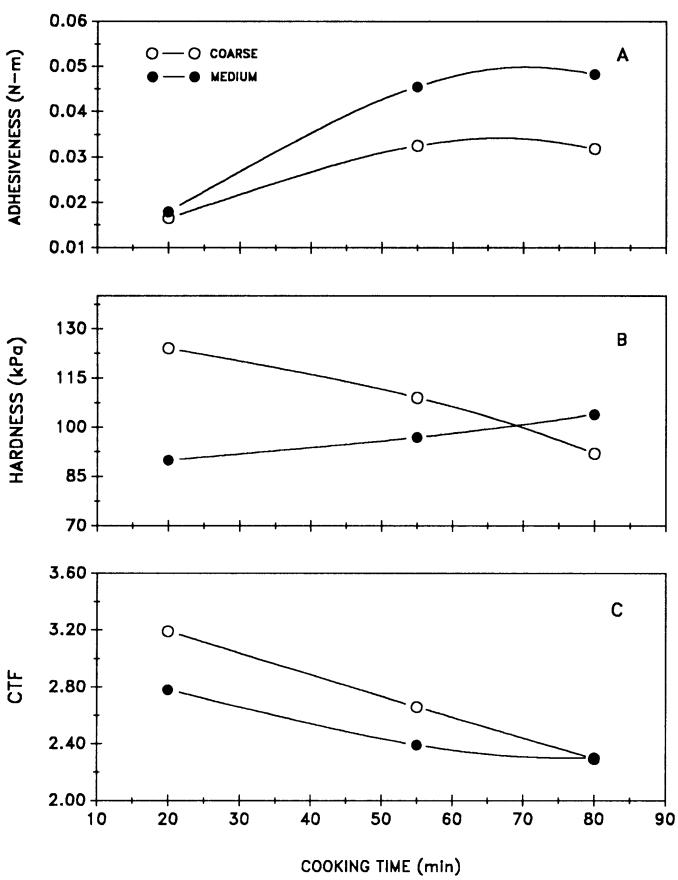

Fig. 2. Effect of cooking time and grinding on the adhesiveness (**A**), hardness (**B**), and compression tension factor (CTF) (**C**) of fresh corn masa.

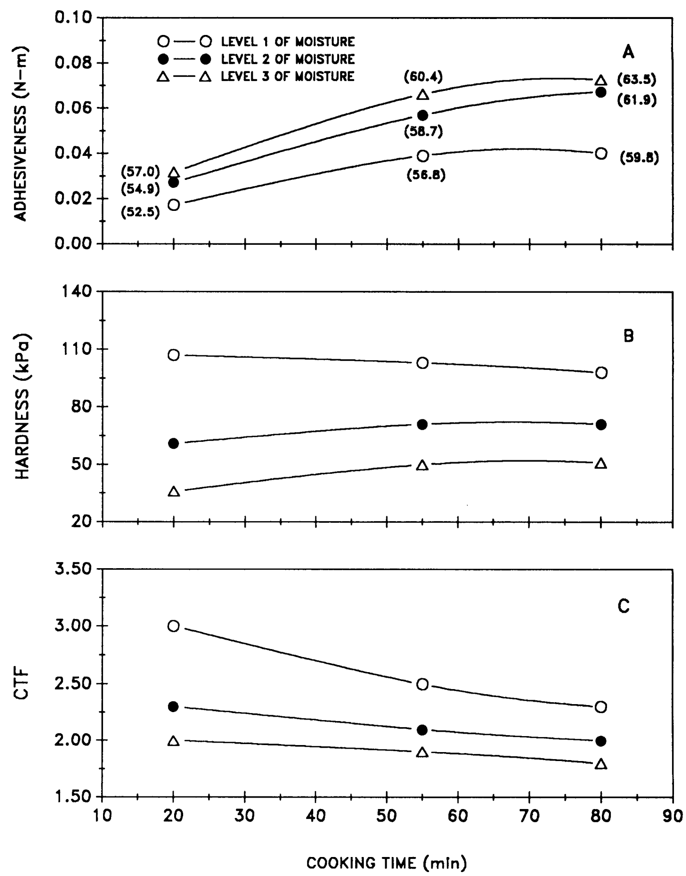

Fig. 3. Effect of cooking time and level of moisture added on the adhesiveness (**A**), hardness (**B**), and compression tension factor (CTF) (**C**) of fresh corn masa. Values in parenthesis indicate percentage of masa moisture content.

TABLE I
Analysis of Variance, Mean Squares of the Textural Characteristics of Fresh Corn Masa

Source of Variation	Degrees of Freedom	Adhesiveness	Hardness	CTF[a]
Cooking time (CT)	2	1.8×10^{-2}**[b]	6.6×10^{8}**	2.4**
Replicates (R)	2	8.0×10^{-5}	3.9×10^{8}	0.2
E (CT × R)[c]	4	1.8×10^{-4}	4.8×10^{7}	0.05
Grinding (G)	1	3.3×10^{-3}*	1.2×10^{5} NS	0.2**
CT × G	2	6.0×10^{-4}*	3.6×10^{9}*	0.3*
E (CT × R × G)[d]	6	1.5×10^{-4}	5.5×10^{8}	0.05
Moisture level (ML)	2	9×10^{-3}*	4.5×10^{9}*	7.4**
CT × ML	4	5×10^{-4}*	8.0×10^{8}*	0.3*
G × ML	2	1.8×10^{-4} NS	1.3×10^{9}*	0.2*
CT × G × ML	4	1.3×10^{-4} NS	2.3×10^{8} NS	0.03 NS
E (CT × R × G × ML)[e]	24	1.3×10^{-4}	1.3×10^{8}	0.03
E(ss)[f]	108	2.7×10^{-5}	8.4×10^{6}	3.0×10^{3}

[a] Compression tension factor.
[b] * = significant at the 0.05 level ($P < 0.05$), ** = significant at the 0.01 level ($P < 0.01$), NS = not significant ($P \geq 0.05$).
[c] Whole plot error.
[d] Subplot error.
[e] Sub-subplot error.
[f] Subsample error.

TABLE II
Analysis of Variance, Mean Squares for Some Physical and Chemical Factors Affecting Fresh Corn Masa Texture[a]

Source of Variation	Degrees of Freedom	WAI	ESS	TA	MM	PSI
Cooking time (CT)	2	8.2**[b]	7.1×10^5*	7.7**	158.2**	28.11 NS
Replicates (R)	2	2.2×10^{-1}	1.6×10^4	4.2×10^{-1}	10.9	15.66
E (CT × R)[c]	4	5.0×10^{-3}	2.2×10^3	3.0×10^3	2.5	19.73
Grinding (G)	1	5.4×10^{-1}**	8.2×10^2 NS	0.8*	0.3 NS	265.96**
CT × G	2	6.0×10^3 NS	7.0×10^2 NS	1.2×10^2 NS	2.4 NS	1.87 NS
E (CT × G)[d]	6	3.0×10^{-3}	1.7×10^3	6.0×10^{-2}	0.9	15.40
E(ss)[e]	18	9.0×10^{-3}	1.5×10^2	2.7×10^{-2}	1.0×10^{-2}	0.147

[a] WAI = water absorption index, ESS = enzyme susceptible starch, TA = total amylose, MM = masa moisture, PSI = particle size index.
[b] * = significant at the 0.05 level ($P < 0.05$), ** = significant at the 0.01 level ($P < 0.01$), NS = not significant ($P \geq 0.05$).
[c] Whole plot error.
[d] Subplot error.
[e] Subsample error.

Hardness. The ANOVA in Table I shows that hardness was affected very significantly ($P < 0.01$) by the cooking time, and it was affected significantly ($P < 0.05$) by the interaction of cooking time and grinding, moisture level, and the interactions of cooking time and moisture level, and grinding and moisture level. Figure 2B illustrates the interaction of cooking time and grinding. Masas with medium particle sizes were not significantly different in hardness at the three cooking times. On the other hand, coarse masa prepared with 20 min of cooking time was harder than were coarse masas made with nixtamal cooked for 55 and 80 min. The latter two masas were not significantly different in hardness. With regard to the degree of grinding: at 20 min of cooking time, coarse masa was 38% harder than masa with medium particle sizes; at 55 and 80 min of cooking, hardness was not significantly affected by level of grinding.

The interaction of cooking time and moisture level is shown in Figure 3B. At all cooking times, the lower the moisture content, the higher the masa hardness. Within a level of moisture, masa hardness was not significantly affected by cooking time.

Figure 4A shows the effects of the interaction of grinding and moisture level. Masa hardness decreased as the level of water increased, regardless of its particle size distribution. When levels of moisture remained constant at level 1, coarse masa was slightly harder than masa with medium particle sizes. However, at levels 2 and 3, medium masas were harder than coarse masas.

CTF. CTF is defined as the ratio of the maximum compression force to the maximum tension force obtained with the ICTT test. With this factor, the corn masa performance in the rollers during processing may be predicted. An optimum CTF predicts a masa with the right degree of hardness and adhesiveness that allows for good machinability in the rollers (Ramírez-Wong et al 1993). The CTF was affected by the cooking time, grinding, moisture level, and the interactions of cooking time and grinding, cooking time and moisture level, and grinding and moisture level (Table I).

The interaction between cooking time and grinding is presented in Figure 2C. The CTF decreased as the cooking time increased for both grinding sizes. At a cooking time of 20 min, coarse masas had a CTF value 14% higher than that of masas with medium particle sizes. At 55 and 80 min, both degrees of grinding gave CTF values that were not significantly different from each other.

The effect of the interaction between cooking time and moisture content on the CTF can be observed in Figure 3C. At level 1 of moisture content, the CTF decreased 30% when cooking time increased from 20 to 80 min. For levels 2 and 3, there were no significant changes in CTF with cooking time. When the CTF was analyzed for changes with levels of moisture content at one cooking time, the CTF value for level 1 was different than that for levels 2 and 3, at any cooking time. However, CTF values for levels 2 and 3 were not significantly different from each other.

Figure 4B shows the interaction of grinding and moisture content on the CTF. For both grinding sizes, as the level of moisture content increased, the CTF value decreased. With regard to grinding, there was a significant difference only at level 1. Coarse masa gave a CTF value 8% higher than that of the masa with medium particle sizes.

TABLE III
Effect of the Cooking Time on Some Physical and Chemical Factors Affecting Fresh Corn Masa Texture[a,b]

Cooking Time, min	WAI	ESS	TA	MM	PSI
20	2.65 c	377 c	27.7 a	52.3 c	57.0 a
55	3.38 b	583 b	22.7 b	56.8 b	58.9 a
80	3.80 a	719 a	19.5 b	59.8 a	58.0 a
Overall means	3.28	560	23.3	56.3	58.0

[a] WAI = water absorption index (expressed as grams of H_2O/grams of dry masa), ESS = enzyme susceptible starch (expressed as mg of glucose/g of starch), TA = total amylose (expressed as %), MM = masa moisture (expressed as %), PSI = particle size index. WAI, ESS, TA, and PSI were determined on freeze-dried corn masa.
[b] Within a column, means with the same letter are not significantly different at the 0.05 level ($P < 0.05$).

Factors Affecting Various Physical and Chemical Characteristics

Table II summarizes the ANOVA for masa moisture content (original masa), PSI, WAI, ESS, and total amylose.

The masa moisture was affected ($P < 0.01$) only by the cooking time. Results indicate that nixtamal with longer cooking time gave masas with higher moisture content (Table III). Table IV presents the moisture for masas with different particle sizes; the means were not significantly different ($P < 0.05$).

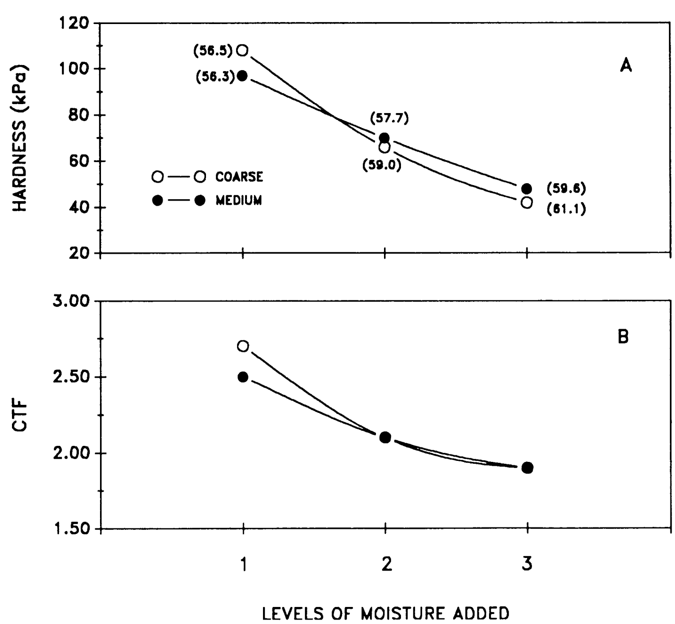

Fig. 4. Effect of grinding and level of moisture added on the hardness (**A**) and compression tension factor (CTF) (**B**) of fresh corn masa. Values in parenthesis indicate percentage of masa moisture content.

The PSI was only affected by the degree of grinding (Tables III and IV). The smaller the gap between the stones, the higher the PSI (Table IV).

WAI predicts the tortilla yield of a certain corn flour. The higher the WAI value, the higher the tortilla yield (Bedolla and Rooney 1984). The WAI was affected by the cooking time ($P < 0.01$) and the degree of grinding ($P < 0.05$). When corn was cooked at 55 and 80 min, the WAI was 27.5 and 43% higher, respectively, than it was when corn was cooked for only 20 min (Table III). When cooking time changed from 55 to 80 min, the WAI increased only 12.4%. This means that between 20 and 55 min there was a higher rate of water uptake by the corn kernel than there was during the latter period of cooking; most of the cooking and gelatinization occurred between 20 and 55 minutes.

With respect to the degree of grinding, dry masa flours with medium particle size had 8.7% higher WAI than did coarse masas (Table IV). Smaller particles resulted from the medium grind as opposed to the coarse grind. With smaller particles comes greater surface area, and more water absorbed per volume of particles due to the greater surface area. In addition to this mechanical action, starch received more damage and absorbed more water when the grinder gap was smaller.

The ESS determination gives an index of starch gelatinization or a measurement of the amount of damaged starch. ESS was affected significantly by cooking time (Tables III and IV). The higher the cooking the time, the higher the ESS (Table III). The higher ESS incremental change occurred when cooking time was changed from 20 to 50 min: 206 mg of glucose per gram of starch.

TABLE IV
Effect of the Degree of Grinding on Some Physical and Chemical Factors Affecting Fresh Corn Masa Texture[a,b]

Degree of Grinding	WAI	ESS	TA	MM	PSI
Coarse	3.20 b	556 a	24.0 a	56.4 a	54.6 b
Medium	3.40 a	563 a	22.5 b	56.1 a	61.3 a
Overall means	3.30	560	23.3	56.3	58.0

[a] WAI = water absorption index (expressed as grams of H_2O/grams of dry masa), ESS = enzyme susceptible starch (expressed as mg of glucose/g of starch), TA = total amylose (expressed as %), MM = masa moisture (expressed as %), PSI = particle size index. WAI, ESS, TA, and PSI were determined on freeze-dried corn masa.
[b] Within a column, means with the same letter are not significantly different at the 0.05 level ($P < 0.05$).

TABLE V
Simple Correlations Between Textural Characteristics and Physical and Chemical Factors of Fresh Corn Masa[a,b]

	ESS	WAI	TA	MM
Adhesiveness	0.764**	0.790**	−0.571**	0.699**
Hardness	−0.306**	−0.378**	0.254	−0.397**
CTF	−0.844**	−0.872**	0.609**	−0.802**

[a] Correlation coefficients are shown if significant at the 0.05 ($P < 0.05$) * or 0.01 ($P < 0.01$) ** level.
[b] ESS = enzyme susceptible starch, WAI = water absorption index, TA = total amylose, MM = masa moisture, CTF = compression tension factor.

TABLE VI
Simple Correlations Among Textural Characteristics and Physical and Chemical Factors of Fresh Corn Masa[a,b]

	ESS	WAI	TA	MM
MM	0.932**	0.873**	−0.891**	1.000
TA	−0.861**	−0.765**	1.000	
WAI	0.943**	1.000		
ESS	1.000			

[a] Correlation coefficients are marked if significant at the 0.05 ($P < 0.05$)* or 0.01 ($P < 0.01$)** level.
[b] ESS = enzyme susceptible starch, WAI = water absorption index, TA = total amylose, MM = masa moisture.

When the cooking time was changed from 50 to 80 min, the increment was only 136 mg of glucose per gram of starch.

Total amylose was affected by the cooking time and the degree of grinding (Tables III and IV). Total amylose decreased as the cooking time increased, and the higher reduction occurred between 20 and 55 min (Table III). In this range, the amylose reduction was 5%, whereas in the range between 55 and 80 min, the reduction was 3.2%. Reduction in total amylose with cooking time may be due to the starch gelatinization. While this process is occurring, soluble amylose is leached from the starch granule and cannot be detected. With regard to the degree of grinding, masas with medium particle size had higher content of total amylose (24%) than did coarse masas (22.5%). Starch damage due to the mechanical action could have separated off some amylopectin fragments that were detected as amylose.

Correlation Between Textural Characteristics and Physical and Chemical Factors

The correlation between masa texture and physical and chemical factors is summarized in Table V. The ESS and WAI correlated negatively with the CTF. Adhesiveness correlated positively, whereas hardness correlated negatively. However, for these two last textural characteristics, the linear relationship was not as strong as it was with the CTF. Total amylose correlated positively with the CTF and negatively with adhesiveness. However, this linear relationship was only moderate. Table V also presents the relationship between masa moisture content and texture parameters.

Table VI shows the relationships among the physical and chemical factors. It can be observed that there are strong correlations among them, $|r| > 0.75$. Higher ESS values were related to higher moisture content of the masa. The correlation between those factors was highly significant (Table VI). It is explained by the higher moisture absorption of the masa when starch is more gelatinized; higher values of ESS indicated more starch gelatinization. The correlation between ESS and total amylose was negative and highly significant (Table VI). Masa moisture and total amylose were also negatively correlated. Amylose leached from the starch granule during the first steps of gelatinization, and this reduced the amylose content of the starch. Advanced gelatinization gave higher ESS, higher moisture content of the masa, and lower total amylose. WAI was highly and significantly correlated to moisture content and negatively and significantly to total amylose (Table VI). WAI of the masa increased with starch gelatinization. Consequently, masa moisture content increased. The negative correlation of WAI with total amylose can be also explained with the leaching of amylose during starch gelatinization.

On the other hand, when comparing Tables V and VI, it is observed that the linear relationships among the masa moisture content and the ESS, WAI, and total amylose were higher than those between masa moisture content and the masa texture characteristics.

Implications

Textural characteristics of fresh corn masa are dependent on the masa water-retention capacity. Tables V and VI show that ESS, WAI, and total amylose gave better correlation with the masa moisture content than with the textural characteristics. These results suggest that the physical and chemical factors do not directly affect the masa texture, but they do affect the way the corn masa can retain water through the cooking and grinding operations.

According to the results obtained, the alkali-cooking and grinding operations are two critical steps in the tortilla-making process. They affect the texture of fresh corn masa in the way that they influence the water-retention capacity of each masa. The effect of grinding was greater than the effect of cooking when corn was cooked for less time (20 min), as evaluated with the ESS determination. On the other hand, the effect of cooking was greater than the effect of grinding when corn was cooked for longer periods of time (55 or 80 min), as evaluated by ESS.

The best masa texture should be that giving good handling or machinability in the sheeting and cutting rollers, producing the higher tortilla yield, and yielding good firmness (stiffness) and rollability in the tortilla. Processing conditions that gave this type of masas were those in which cooking time fell between 20 and 55 min, with either coarse or medium particle size distribution, and with levels 1 or 2 of moisture added.

CONCLUSIONS

Fresh corn masa is an important intermediate material in the preparation of alkaline-cooked products. Its texture is very important in the tortilla-making process and in the quality of the final products. Until now, the texture quality control has been done subjectively, which gives great variation from operator to operator. This type of quality control should be improved in countries where the corn tortilla is a staple food and in the United States where there is a high demand for Mexican foods.

Texture of fresh corn masa was affected by the cooking time, degree of grinding, and amount of water added. Nixtamal cooked for less time, and ground either to medium or coarse particle sizes, produced corn masas that were hard and dry with no adhesiveness. Corn masas made with nixtamal cooked for 80 min, ground either to coarse or medium particle sizes, and at any moisture content, were stickier. These two kinds of masas did not have good machinability during the tortilla-making process. On the other hand, corn masas made with 55 min of cooking time, with medium particle sizes, and with levels 1 or 2 of moisture added, gave the best texture for handling in the sheeting and cutting rollers.

In addition, the cooking time and the degree of grinding also affected some physical and chemical factors such as WAI, ESS, PSI, total amylose, and masa moisture.

Finally, it is important to mention that the instrumental method used to evaluate masa texture was sufficiently precise to detect differences among the experimental treatments performed.

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