Development of Two Instrumental Methods for Corn Masa Texture Evaluation[1]

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ABSTRACT

To evaluate corn masa texture, two instrumental methods were developed. The mechanical stickiness device (MSD) method used two rectangular bars (with movable upper bar) fastened at one end in a parallel arrangement with a 12-mm gap between them. A block of masa was formed between the bars and partially split with a special cutter, then one end of the movable bar was raised until the masa detached from it. The degree of adhesion of masa to the upper bar gave an adhesiveness index. The Instron compression-tension texture (ICTT) method compressed a masa disk between two flat plates to a thickness of 2 mm, then put the same sample under tension. The textural characteristics evaluated were: adhesiveness, hardness, and the compression-tension factor (CTF). Both methods tested masa made from nixtamal cooked for 55 min and conditioned at three moisture levels (56.8, 58.8, and 60.4%). Results were quite reproducible as evaluated by the coefficient of variation (range: 3.7–35.2%). Optimum masa had an MSD adhesiveness of 10–35%, an ICTT adhesiveness between 8.7×10^4 and 1×10^5 Pa, and a CTF of 2.4–2.7. Masa moisture content increased adhesiveness and decreased hardness and CTF. The MSD adhesiveness had a high correlation with ICTT hardness ($r = -0.90$).

Corn tortilla is a staple food in Mexico and Central America. In the United States, masa-based Mexican foods have increased steadily in popularity. In 1986, the total sales reached $4 billion (Spencer 1986). Tortillas are made from corn masa prepared through the nixtamalization process. Corn is cooked in a boiling lime solution for 5–50 min and steeped overnight. Then the cooked corn (nixtamal) is ground with a stone grinder into masa (Rooney and Serna-Saldivar 1987).

Masa texture is critical for the tortilla-making process. When masa has the appropriate texture, it is adhesive enough to lightly adhere to the sheeting rollers and to separate properly. Otherwise, two common textural problems occur: 1) overcooked corn produces sticky masa that strongly adheres to the rollers, or 2) undercooked corn produces noncohesive masa inadequate for tortilla formation.

Adhesiveness, or stickiness, is usually evaluated instrumentally as the maximum tensile force developed during adhesion or as cohesive rupture between two flat, circular metal plates and the food sample (Sherman 1979). It is also measured by the negative curve of the force versus distance obtained experimentally as the plate separation increases. According to de Man (1976), stickiness is proportional to the work needed to overcome the adhesive forces.

The objective of this research was to develop two instrumental methods to evaluate textural characteristics of corn masa. The effect of masa moisture was also evaluated.

MATERIALS AND METHODS

Preparation of Fresh Corn Masa

Corn (3 kg with chemical composition of 12.4% moisture, 76.0% starch, 10.3% protein, and 1.3% ash [data supplied by M. H. Gomez, Cereal Quality Laboratory, Soil and Crop Science Dept., Texas A&M University]) 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) for 55 min at 100°C. The cooked corn was steeped for 14 hr in an insulated chest at room temperature. Then the cooking liquor was collected in a container, and the nixtamal was washed with tap water. Washed nixtamal was ground with a lava-stone grinder (model CG, Casa Herrera Inc., Los Angeles, CA). To avoid excessive heat generation, water (250–450 ml) was added during grinding. The amount was determined by preliminary tests. The corn masa was mixed at low speed in a 20-L mixer (model A 200, Hobart, Troy, OH) for 1 min and divided into three parts. Each part was put in a polyethylene bag and allowed to set for 30 min. During this time, a rapid method to determine masa moisture content, as reported by Torres and McDonough (1986), was used. Water amounts required for masas with a wide range of stickiness were calculated. At the end of the 30-min holding time, each of the three corn masa samples was placed into the mixer bowl, and the appropriate amount of water was added. Samples were mixed for 1 min at speed 1 (lowest) and 15 sec at speed 2; then, to avoid moisture loss, they were put back into plastic bags. The moisture content for the three samples was 56.8 ± 0.5, 58.8 ± 0.5, and 60.4 ± 0.5%, respectively.

The moisture content of fresh corn masa was determined in a forced-air oven (model 28, Precision Thelco) by measuring the weight loss after 12 hr of drying at 110°C (AACC 1983).

Before masa texture evaluation, the three samples with different moisture content were randomized. Masa samples were allowed to reach room temperature (26 ± 0.5°C). When masa exited the stone grinder, its average temperature was 40°C. Because of the high temperature, the exact extent of the effect of temperature on masa texture is not known. Therefore, the measurements were taken at room temperature within a certain time interval after masa preparation.

Preparation of Corn Table Tortillas

To relate the masa texture to the tortilla-making process, trials were run with masa at different moisture levels. Each dough was formed into tortillas using a pair of rollers (model CH4-STM, Superior, Pico Rivera, CA) that pressed the masa into a thin (2 mm) masa sheet that was cut into circular dough pieces for tortillas. Dough pieces were then conveyed to the oven. Tortillas were baked on a three-tier gas-fired oven (model C0440, Superior). Temperatures in the oven were 198°C for the first tier, 114°C for the second tier, and 106°C for the third tier. The residence time for tortillas in the oven was 41 sec. Tortillas were cooled in a three-tier cooling conveyer (model 13106-INF, Superior) and packaged in polyethylene bags after 30 min holding.

The relationship between the masa texture and the process was determined in the sheeting and cutting operation (rollers). In this step, the dough machinability was subjectively evaluated by observing: 1) whether the dough adhered to the rollers (masa that was too dry and hard was not adhesive); 2) whether the masa was sticky enough to adhere to the rollers but nonsticky enough to separate from the rollers after cutting (masa had optimum texture); and 3) whether the dough stuck very tightly to the rollers (masa was too sticky).

Mechanical Stickiness Device Test

Description of the apparatus. The mechanical stickiness device (MSD) operated on the same principle as the equipment used

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by Grupo Maseca, S.A. (GRUMA), the leading producer of dry corn flour in Mexico (Anonymous 1985). The two devices this test required were constructed in the Agricultural Engineering Department shop at Texas A&M University. The MSD consisted of two smooth, flat-surfaced rectangular bars made of aluminum, both 25- × 1.6- × 1.6-cm in length, width, and height, respectively (Fig. 1). A screw in the stationary bar allowed one end of the upper bar to move upwards. When parallel (starting position), the bars had a 1.2-cm gap between them.

The second device cut the corn masa after it was placed in the MSD. Figure 2 shows a diagram of this masa cutter device.

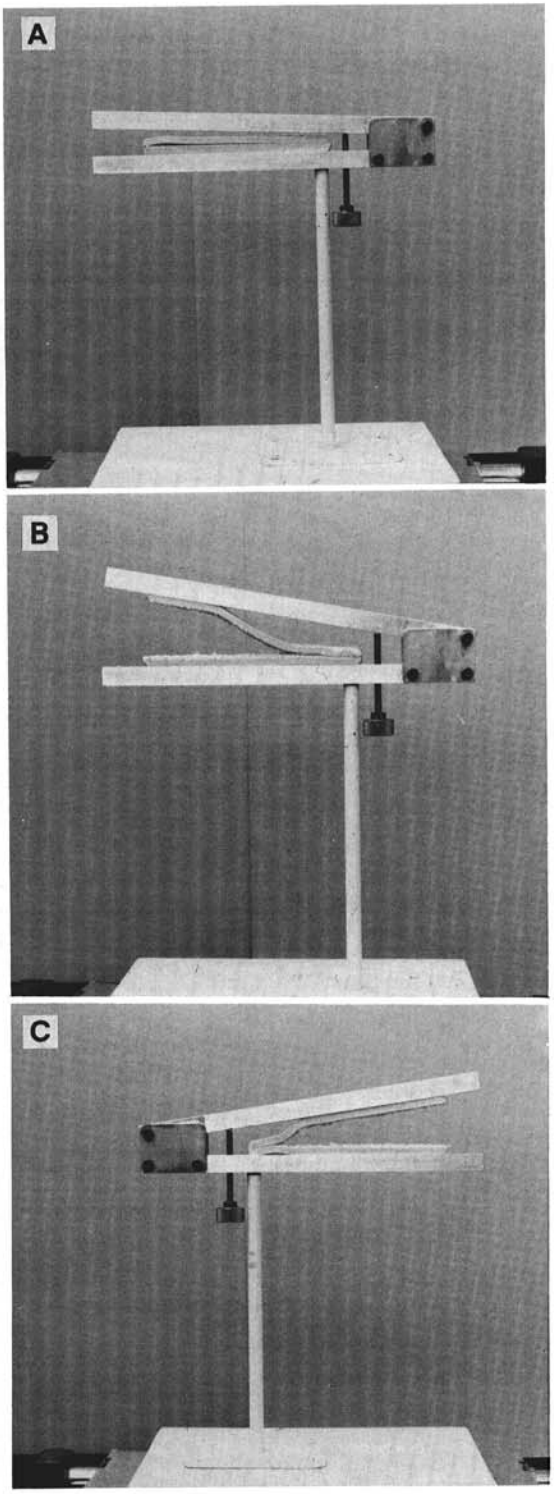

Fig. 1. Textural characteristics of corn masas evaluated with the mechanical stickiness device. **A**, fresh, hard (not sticky). **B**, optimum. **C**, sticky.

It has a rectangular frame with no bottom and one end made of 3-mm (1/8-in.) plexiglass. The dimensions were 30- × 1.6- × 1.6-cm in length, width, and height, respectively. Two guitar strings (dia. 013, no. 4, Malin Music Wire) were attached to the center of the end piece. The other ends of the wires were attached to the side walls at the other end of the device so that both wires were horizontal. This V-shaped masa cutter worked in the following manner. A block of masa was placed in position between the bars, and the masa cutter was moved over the bars from one end to the other so that it made a partial V-shaped cut in the masa block, as shown in Figure 3.

The final specifications of both devices were selected after several preliminary prototypes were constructed in different sizes. The mechanical device with dimensions described here gave the best results of masa stickiness. Other specifications of length, width, height, or the gap between the bars produced either too much or not enough adhesiveness between the masa and the metallic surfaces.

The cutter dimensions were the same as those of the MSD, but 5-cm longer. Because the cutter was longer than the MSD, it allowed more flexibility to make the V-shape cut in the middle

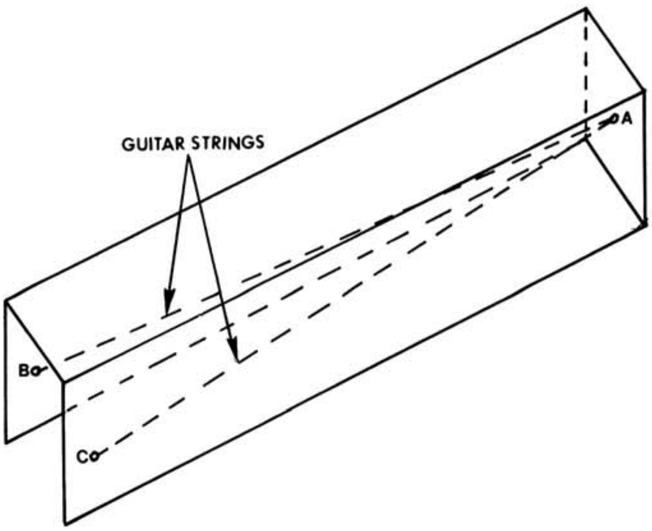

Fig. 2. Sketch of masa cutter. Two guitar strings attached to the center of the end piece (**A**). The other ends of the wires attached to the side walls at the other end of the device (**B** and **C**), so that both wires were horizontal.

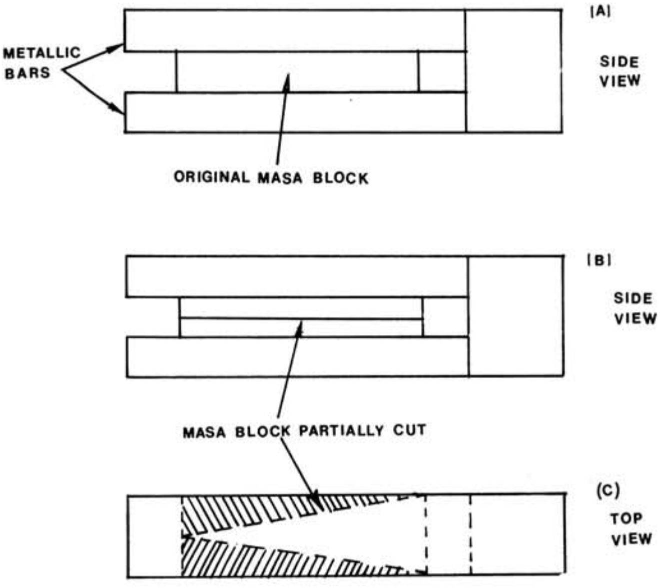

Fig. 3. Views of the masa block before cutting (**A**) and after cutting (**B** and **C**).

of the masa block, which could be made from different lengths. The cutter and the MSD were of equal width so that the cutter could run tight along the longitudinal side of both bars. Both devices were the same height so the parallel guitar strings of the cutter could split the masa block partially through the middle.

Development of test procedure. Before measuring masa texture with the MSD, the interior surfaces of both bars were cleaned and dried. Then, using the screw, both bars were placed in parallel position. Masa weighing 175 ± 0.1 g was rolled by hand on a surface covered with a plastic sheet. It was shaped cylindrically, 15 cm in length and 3 cm in diameter. Next, the upper bar was raised to allow the cylinder of masa to be placed on the stationary lower bar, and the masa was compressed between the two bars. Using a fine thread, masa flowing outside the bars was cut even with the edges of the bars, giving a masa block of 42 ± 2 g between the bars. Masa was partially split along the longitudinal section with the masa cutter as shown in Figure 3. The upper bar was slowly raised, and some of the masa detached from the bar as shown in Figure 1. The length of masa adhering to the upper bar gave an index of masa texture evaluated as adhesiveness. Masa with no adhesiveness did not cling to the upper bar; sticky masa adhered to the entire length of the bar. Masa with optimum texture adhered partially to the bar. Figure 1 shows fresh corn hard (nonsticky), optimum, and sticky masas. To compute the degree of adhesiveness, the following formula was used:

% adhesiveness = (cm of masa adhering to the upper bar/15 cm) × 100

This formula gives a 0–100% scale of masa adhesiveness. The range limits for each kind of masa were considered: hard 0–12%, optimum 10–35%, and sticky 73–100%.

As the test procedure was standardized, some other factors affected the masa adhesiveness: sample size, the use of items other than a fine thread (such as a knife) to cut masa flowing outside the bars, the speed at which the upper bar was raised, and moisture lost by masa block when in contact with air for a long period of time. These factors should be taken into account to reduce or avoid errors.

Texture evaluation. Masa adhesiveness was measured with the MSD test 75 ± 3 min after the original masa was obtained. Four determinations were performed for each of the three samples.

Instron Compression-Tension Test (ICTT)

Description of the apparatus. The ICTT test followed the General Food Instrumental texture profile scheme (Brennan and Mohamed 1984). Two smooth, flat, stainless steel plates, 6.9 cm in diameter, were constructed and used in the Instron Universal Testing Machine (model 1112, Instron Co., Canton, MA). The top plate was stationary and attached to a 1,000-lb compression-tension load cell. The bottom plate was attached to the crosshead

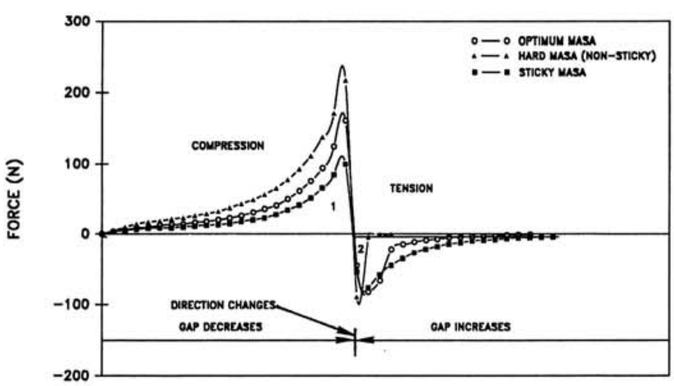

Fig. 4. Typical force-distance curves obtained with the Instron compression-tension texture test for fresh, hard (not sticky), optimum, and sticky corn masas.

that moved up or down at constant speed of 0.5 cm/min. The test first compressed the masa sample between the two plates and then moved the lower plate apart to apply tension loading to the sample. The compressive and tensile forces were recorded with a chart speed of 10 cm/min. Figure 4 shows typical force-distance curves for fresh hard (nonsticky), optimum, and sticky corn masa. Each curve provided three textural parameters. Hardness was defined as the maximum compression force or the compressive work (area 1). Adhesiveness, or stickiness, was defined as the maximum tensile force or the tensile work (area 2). The ratio of maximum compressive-to-tensile force and the ratio of compressive-to-tensile work were also used as indices of masa texture.

Development of test procedure. In the ICTT method, before the test started, the texturometer was calibrated with the recorder zeroed at the center of the chart. Masa texture was determined by shaping a lump of corn masa (5 ± 0.05 g) into a sphere that was flattened into a cylindrical plastic container 31 mm in diameter and 6 mm in height. This masa disk was placed between the two stainless steel plates and centered. The compression-tension loading was performed as previously described. As the compression load increased, the recorder pen moved in a positive direction. The compression loading proceeded until the plates were 2-mm apart (tortilla thickness). Then the crosshead movement stopped and automatically started moving in the opposite direction. As the tensile force increased, the recording pen moved in the negative direction.

From each graphic, the masa textural parameters computed were: adhesiveness as work ($N{\cdot}m$, area under the negative curve); maximum stress (Pa) selected for hardness; and the compression-tension factor, defined as the ratio of the maximum compressive-to-tensile force. Adhesiveness and hardness are reported in these units in the literature (De Padua and Padua-Maroun 1984).

Preliminary tests showed that factors affecting the procedure were sample size, sample shape, texturometer crosshead speed, plate separation, plate cleanliness, and loss of masa moisture content. Conditions that gave the curves with the best resolution were selected for the standard test procedure.

Texture evaluation. Using the ICTT test, corn masa texture was determined 140 ± 8 min after the original masa was prepared. Four determinations were made on each of the three samples. After the test, the final masa disk diameter was recorded. The area of the negative curve and the maximum peak heights of both curves were calculated.

Statistical Analysis

Six batches of corn were alkaline-cooked for 55 min and ground to obtain corn masa (original masa). The original masa was divided into three parts, each conditioned at a different moisture content. One complete replicate was run per day. Each masa sample with a determined moisture content was used to measure texture with the MSD and ICTT tests. Four texture determinations were made for each sample. Twenty-four texture determinations were made for each moisture level per test. A complete randomized block design was used. The factor used was the masa moisture content with three levels (56.8 ± 0.5 [original masa], 58.8 ± 0.5, and 60.4 ± 0.5%). Analysis of variance was run to see the effect of masa moisture content on masa texture as evaluated with the ICTT and MSD tests. Where analysis showed significant differences ($P < 0.05$), means were compared using Tukey's test. Simple linear correlation coefficients were computed when necessary. Statistical analyses were performed using Statistical Analytical System software (SAS Institute, Raleigh, NC).

RESULTS AND DISCUSSION

Methods Rationale

Stickiness is a textural characteristic that contributes to the sensory evaluation of some foods. In some foods, stickiness is considered a good characteristic (i.e., honey), but, in others, it is an undesired characteristic (i.e., corn dough, cooked rice, or cooked spaghetti). Other textural attributes have been described successfully using instrumental methods (i.e., firmness and resilience), but stickiness in foods has received less attention because it is more difficult to quantify.

Studying the instrumental evaluation of stickiness involves two categories of forces: 1) the adhesive forces between the instrument surface and the sample surface, and 2) the cohesive forces within the sample's microstructure. Depending upon the relative magnitude of these forces, two things can occur: 1) when the adhesion forces are larger than the cohesion forces, the sample is drawn upward with the plate as it moves away from the sample surface and eventually rupture occurs (cohesive rupture); or 2) when cohesion exceeds adhesion, rupture involves a clean break between plate and sample (adhesion rupture) (Boyd et al 1974).

In the MSD test, adhesion and cohesion forces were developed by compressing the masa between the bars. During the preliminary trials, it was observed that cohesive forces were larger than adhesive forces; masas with all levels of stickiness did not cling to the upper bar. This prompted the decision to make a partial V-shaped cut in the middle of the masa block. Once a balance of adhesive and cohesive forces was achieved, the upper bar was slowly raised. When cohesive forces were much larger than adhesive forces, masa did not cling to the upper bar (nonsticky). But when adhesive forces were much larger than cohesive forces, masa adhered to the entire length of the bar (sticky). In optimum masa, these two types of forces were balanced and masa adhered partially to the upper bar.

For the ICTT test, masa was compressed between the two plates. The objectives were to develop adhesive and cohesive forces between the masa and the plate surfaces. After compression, the lower plate was pulled away from the top plate to measure the tension forces required to separate the masa from the upper plate. Masas that were too dry had the highest values of hardness; the upper plate and the sample had a clean break (cohesive forces were larger than adhesive forces). Sticky masas had the lowest values of hardness; the sample adhered to the lower plate as it moved away until rupture occurred (adhesive forces were larger than cohesive forces). Optimum masas had intermediate values of hardness and adhesiveness.

Reproducibility and Variability of the Texture Methods

Adhesiveness, hardness, and the ratio of compressive-to-tensile forces (CTF) were measured on masa prepared at one cooking time (55 min) with three moisture contents. The same samples were used for both the MSD and ICTT tests. Table I shows ranges, means, and coefficients of variation for each of the textural parameters evaluated. The MSD and ICTT adhesiveness showed the highest variability in samples with the lowest moisture content. However, at the next two levels of moisture, both values were quite reproducible. Hardness and CTF showed less variability than adhesiveness, regardless of the masa moisture content. CTF was the best texture parameter to evaluate masa because it showed the lowest coefficient of variation.

Physical Meaning of the Texture Parameters

When the dough machinability was subjectively evaluated in the tortilla-making process, corn masa with optimum textural characteristics showed an MDS adhesiveness of 10–35%, or an ICTT adhesiveness of 0.01–0.03 *N-m*, an ICTT hardness between 8.5×10^4 and 1×10^5 Pa, and a CTF of 2.4–2.7. Optimum textural characteristics meant that the masa had sufficient cohesiveness to stick together and form a tortilla without being so sticky that it stuck to the forming rollers. Masa with adhesiveness below the optimum range had high hardness values. This type of masa can be molded well in the roller, but it does not adhere to the roller surface. On the other hand, corn masa with higher than optimum textural parameter values is sticky and soft.

TABLE I
Comparison of Methods to Evaluate Masa Texture

Test	Characteristic Evaluated	Range	Mean	Coefficient of Variation (%)
Masa moisture, %, 56.8 ± 0.5[a] (*n*-24)				
MSD[b]	Adhesiveness, %	0–12	8.1	35.2
ICTT[c]	Adhesiveness, N-m	0.023–0.043	0.038	23.7
	Hardness, Pa	85,900–120,000	102,825	9.7
	CTF[d]	2.34–2.93	2.52	8.4
Masa moisture, %; 58.8 ± 0.5 (*n*-24)				
MSD	Adhesiveness, %	45.7–62.7	52.4	17.1
ICTT	Adhesiveness, N-m	0.047–0.065	0.059	16.4
	Hardness, Pa	55,400–81,200	71,426	16.3
	CTF	1.89–2.21	2.07	4.9
Masa moisture, %; 60.4 ± 0.5 (*n*-24)				
MSD	Adhesiveness, %	72.7–98	84.4	14.9
ICTT	Adhesiveness, N-m	0.072–0.087	0.078	13.8
	Hardness, Pa	36,300–50,200	49,900	17.4
	CTF	1.54–1.80	1.76	3.7

[a] Standard deviation.
[b] Mechanical stickiness device.
[c] Instron compression/tension texture.
[d] Compression tension factor.

TABLE II
Analysis of Variance Mean Squares of Adhesiveness, Hardness, and CTF of Fresh Corn Masa (Prepared at Three Moisture Contents)

Source of Variation	Degrees of Freedom	Variable: MSD[a] Adhesiveness	Variable: ICTT[b] Adhesiveness	Variable: ICTT[b] Hardness	Variable: CTF[c]
Moisture	2	35240.7**[d]	5.9×10^{-3}**	1.7×10^{10}**	2.7**
Blocks	5	598.4	3.6×10^{-4}	5.8×10^{8}	6.0×10^{-2}
Error	64	62.7	6.8×10^{-5}	6.6×10^{7}	1.7×10^{-3}

[a] Mechanical stickiness device.
[b] Instron compression/tension texture.
[c] Compression tension factor.
[d] ** = Significant at 0.01 level of probability.

Both problems make it impossible to produce tortillas with optimum sensory attributes.

The analogy made between CTF and dough machinability was as follows. The compression force of the CTF represented the force required to compress the masa between the rollers. Tensile forces represented the force required to separate the masa from the rollers after molding and cutting. CTF can predict the corn masa performance in the rollers during processing. An optimum CTF value means the masa has the appropriate degree of hardness and adhesiveness to allow good handling in the rollers. The optimum CTF range requires a compressive force 2.4–2.7 times the tension force.

Texture Tests on Masas with Different Stickiness Levels

The texture of the three masas in Table I generally represent the entire range of masa stickiness. Masa at 56.8% moisture is too hard (not sticky enough); MSD adhesiveness was 0–12%, which is mostly below the optimum range of 10–35% described in the previous section. Masa at 60.4% moisture is too sticky; MSD adhesiveness was 73–100%. Masa at 58.8% moisture was also too sticky; MSD adhesiveness was 46–63%. Based on these data, one would expect 57–58% masa moisture content to yield optimum stickiness, for the masa used in this study.

Figure 4 illustrates the sensitivity of the ICTT test in measuring stickiness. The compression phase of the test provided good separation of hard (not sticky enough), optimum (desirable stickiness), and sticky (too sticky) masa, whereas the tension phase of the test was much less effective in differentiating the three stickiness levels.

Correlation Between Texture Measurement Methods

The two methods had excellent correlations for evaluating fresh corn masa texture. The MSD adhesiveness correlated negatively with hardness ($r = -0.90$) and with the CTF ($r = -0.88$), and positively with the ICTT adhesiveness ($r = 0.76$). The ICTT adhesiveness correlated negatively with hardness ($r = -0.75$) and with the CTF ($r = -0.85$). The CTF correlated positively with hardness ($r = 0.94$).*

MSD Test vs. the ICTT Test

Both methods can be useful for textural evaluation of masa. The MSD test is an inexpensive method that requires 175 g of sample and approximately 12 min per test. The apparatus can be easily constructed and could be used near a processing line to obtain an index of masa texture. It is sensitive to the masa moisture content.

The ICTT test measures three textural characteristics: adhesiveness, hardness, and CTF. This test requires 5 g of sample, and five measurements can be made per hour. However, the high cost of the Instron testing machine makes it difficult to evaluate masa texture in the production plant. One solution to this problem could be to construct tables for masa with different textures that correlate the adhesiveness measured with the MSD test and the adhesiveness, hardness, and CTF measured with the ICTT test.

Effect of Moisture Content on Masa Textural Properties

Data for corn masas with a range of moisture levels were used to analyze the effect of moisture content on the masa textural properties. The analysis of variance in Table II shows that the MSD adhesiveness, the ICTT adhesiveness, the ICTT hardness, and the ICTT CTF were affected very significantly ($P < 0.01$) by the masa moisture content. Moisture content increased adhesiveness and decreased hardness and CTF (Table I).

CONCLUSIONS

The MSD test measured masa adhesiveness as a percentage of adhesion to the upper bar of the apparatus. The ICTT test measured three textural characteristics. All of these properties were quite reproducible as evaluated by the coefficient of variation, except for adhesiveness evaluated by both tests at the lowest moisture content.

The MSD and the ICTT tests can be useful in evaluating masa texture instrumentally. These methods can be applied in either production or research. In production, the instrumental texture measurements allow a better control of the conditions of the tortilla-making process required to obtain an optimum masa texture for a specific product. This information could also be helpful in designing and constructing better process equipment. In research, both methods could be useful in determining the effect of processing conditions on masa texture. In addition, both tests could be applied to masas made of corn flour. This could be of value in corn masa quality research, because it could replace subjective evaluation as the reference test.

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