Tortilla Bending Technique: An Objective Method for Corn Tortilla Texture Measurement

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ABSTRACT

An objective bending technique was developed to measure corn tortilla texture. During the test, tortilla strips were bent to a 40° angle. The bending technique detected differences in uniformity, thickness, and puffing. Thick tortillas required more force to bend and had greater moduli of deformation values than thin tortillas. The bending technique detected changes in tortilla texture during storage and textural differences among commercial corn tortillas purchased at supermarkets. Experimental error of the method was low for both commercial and laboratory-prepared tortillas. Parameters measured by the bending technique were significantly correlated with subjective rollability and flexibility test scores. The bending technique was sensitive to sample characteristics, fast, simple, repeatable, and provided information regarding the relationship between force (stress) and distance, which could be used to determine the linear region of viscoelastic materials.

Use of tortillas as wraps in the food industry is increasing dramatically; as a result, the ability of tortillas to roll without breaking is becoming one of the most important attributes of tortillas, in addition to flavor and color. Fresh tortillas are more flexible and rollable than firm, unrollable, staled tortillas and are preferred by consumers.

Subjective rollability is a test often used to evaluate tortilla texture. The major disadvantage of the subjective rollability test is that it is not sensitive enough to monitor changes in tortilla texture within 24 hr of baking (Yau et al 1994, Suhendro 1997). For this reason, an objective measurement of tortilla rollability has been developed to measure the force and work required to roll a tortilla around a dowel. The parameters measured by this method correlated well with subjective rollability scores (Suhendro et al 1998).

Rao et al (1986) used a pliability test to evaluate the pliability or bendability of wheat chapaties—a flat, unleavened baked product. A chapati strip (20 × 70 mm) was allowed to bend under its own weight. Chapaties that bent to a greater extent were softer and more pliable.

To subjectively evaluate rollability, a tortilla is subjected to bending at a certain angle. The extent of bending during the test depends on the diameter of the dowel: the thinner the dowel, the greater the angle of bending. The objectives of the current study were to develop and evaluate an objective bending method to imitate and isolate the bending action of a tortilla during rolling that is not provided by other measurements, such as rollability, puncture, or tensile techniques.

MATERIALS AND METHODS

Corn tortillas were produced in the Cereal Quality Laboratory (CQL) Pilot Plant, Texas A&M University, College Station. Commercial corn tortillas from 12 companies were obtained from selected supermarkets in Bryan-College Station, TX; the age of the tortillas was unknown. Tortilla texture was evaluated using subjective flexibility and rollability methods and an objective bending technique.

Tortilla Preparation

Corn tortillas were produced with nixtamalized corn flour (Tortilla 4, Valley Grain Products, Muleshoe, TX) in the CQL Pilot Plant using the method described by Suhendro et al (1997). Stacks of 30 tortillas were stored inside low-density polyethylene bags at 25°C for up to 240 hr. The texture of the commercial and laboratory tortillas was evaluated at 0.5, 3, 24, 120, and 240 hr of storage using subjective and objective texture measurements.

Subjective Tortilla Texture Measurements

In the rollability technique, a tortilla was rolled around a 1-cm diameter wooden dowel. Rollability was recorded by a trained evaluator using a five-point scale: 1 = unrollable (worst), 5 = no cracking (best).

In the flexibility technique, a tortilla was squeezed by hand and subjectively evaluated for overall flexibility (i.e., firmness, and breakability) by a trained evaluator. The overall firmness score was rated on a scale of 1 to 5: 1 = extremely firm, rigid, and inflexible (worst); 2 = firm, rigid, and inflexible; 3 = slightly firm and rigid; 4 = soft and flexible; and 5 = extremely soft and flexible (best).

Objective Tortilla Texture Measurement

The bending technique used in this study was conducted with a texture analyzer (model TA.XT2, Texture Technologies Corp., Scarsdale, NY). The bending technique used two clamps: one clamp attached to the texture analyzer to hold an aluminum guillotine (1.7 mm thick) vertical (Fig. 1), and the other clamp attached to the texture analyzer platform to hold the tortilla strip horizontal. The probe was calibrated to a distance of 50 mm from platform to guillotine. Horizontal separation between sample clamp and guillotine was kept constant at 6.45 mm with a wooden template. A tortilla strip was cut from the center of the tortilla between two baking lines, using a 30 × 35-mm template. The tortilla strip, double-baked side down, was clamped in a horizontal position. The area of the sample (30 mm wide) in contact with the aluminum guillotine (1.7 mm thick) was 51 mm^2. Tortilla strips used for the bending technique had a uniform size to ensure the same contact area size was analyzed. The bending test was run with a "return to start" option, with compression mode and trigger force of 0.05 N. The probe traveled a distance of 5 mm at a test speed of 1 mm/sec, until the guillotine bent a tortilla strip to a controlled 40° angle. From preliminary tests, a test speed of 1 mm/sec yielded repeatable measurements. The bending modulus of deformation (determined as the slope (N/m) of the deformation curve at the ascending section) in the linear region, with force at 1-mm distance, peak force/apparent force (N), and bending work (apparent work, determined as area under the curve [Nm]) were recorded.

Statistical Analysis

The coefficient of variation (CV) was evaluated for each treatment. The effects of storage time and tortilla thickness on texture were evaluated using one-way analysis of variance (ANOVA) with a

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completely randomized experimental design. Treatment means were averaged for five observations and compared using Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$. SAS statistical software package (version 6.04, SAS Institute, Cary, NC) was used for statistical analyses.

RESULTS

In general, the apparent force necessary to bend tortilla strips increased during deformation (Fig. 2). Fresh tortillas required less force to bend and yielded a flat bending curve. Staled tortillas required more force to bend and yielded a distinctive peak. Staled tortillas were hard, firm, and brittle or rigid, similar to results reported by Yau et al (1994).

Commercial Tortillas

Commercial corn tortillas obtained from supermarkets varied in diameter, weight, thickness, moisture, and age (Table I). Sample variability was due to variability in processing conditions, formulations, and storage time (Table I). Tortillas were numbered based on thickness and weight: generally, thickness and weight increased as the number increased. Commercial tortillas varied significantly in texture characteristics (Fig. 3A–B). Subjective rollability scores of commercial tortillas from different bags of the same brand were significantly different (Fig. 3A), indicating there was a significant difference among tortillas produced by a company. Thicker, heavier tortillas were generally less rollable than thinner, lighter tortillas (Fig. 3A).

The bending technique detected differences in texture among commercial tortillas. Commercial tortillas with sample numbers 1 to 3 were among the tortillas with the lowest force necessary to bend (data not presented) and moduli of deformation (Fig. 3B). In contrast, sample numbers 10º and 12 had the highest force necessary to bend and moduli of deformation, indicating they were firm and rigid. The bending parameters of commercial tortillas of the same brand from different bags (nos. 2, 8, and 10) were significantly different. Commercial tortillas were homogenous within the same bag but differed significantly between bags (i.e., production line, workshift, and company).

The bending technique had excellent precision and low variance. The average CV of the bending technique parameters was 7.8% for modulus of deformation, 4.3% for apparent bending force, and 3.9% for apparent work required to bend. The low CV suggest the bending technique could repeatably differentiate among changes during processing and storage.

TABLE I
Physical and Texture Properties of Commercial Tortillas from Supermarkets in Bryan-College Station, TX[a]

Sample No.[b]	Diameter (cm)	Weight (g)	Thickness (cm)	Moisture (%)	pH
1	14.0	15.9	1.24	38.2	10.6
2*	13.5	20.3	1.56	48.3	5.2
2**	13.5	18.6	1.67	44.5	5.5
3	13.4	19.2	1.64	45.8	5.0
4	14.4	24.3	1.76	48.6	5.6
5	13.9	21.8	1.78	43.1	10.9
6	13.5	24.9	1.79	46.6	9.5
7	14.4	27.4	1.87	44.6	5.5
8#	14.4	27.4	1.87	47.5	5.0
8##	13.3	25.5	1.89	48.6	4.9
9	14.6	29.5	1.92	46.8	4.6
10º	14.5	30.0	1.97	46.5	4.7
10ºº	14.5	29.4	2.04	45.3	5.0
11	13.9	24.9	1.98	45.7	5.5
12	13.7	28.7	2.15	47.4	5.6
CV[c] (%)	3.4	18.0	12.20	3.1	1.8
LSD[d]	0.5	0.9	0.08	1.4	0.1

[a] Values are means of two observations.
[b] Tortilla samples with the same number and different symbols are from different bags of the same brand purchased on the same day.
[c] Coefficient of variation.
[d] Fisher's protected least significant difference test ($\alpha = 0.05$), using one-way analysis of variance. Values are significant at $P \leq 0.05$.

TABLE II
Effect of Storage on Texture of Laboratory-Prepared Corn Tortillas[a]

Storage Time (hr)	Subjective Rollability[b]	Subjective Flexibility[b]	Bending Technique[c]: Modulus of Deformation (N/m)	Force at 1 mm (N)	Peak Force (N)	Work (Nm × 10^{-4})
0.5	5.0	5.0	24.6	0.08	0.10	6.1
3	5.0	4.5	51.9	0.11	0.19	5.2
24	4.7	3.0	280.7	0.29	0.38	9.8
120	3.2	3.0	367.2	0.49	0.61	14.7
240	2.2	2.8	562.1	0.64	0.72	18.0
CV (%)[d]	6.0	9.0	15.9	6.07	10.50	16.1
LSD[e]	0.6	0.7	101.8	0.09	0.09	2.9

[a] Values are means of five observations.
[b] Rated on five-point scales: 1, worst; 5, best.
[c] Slope (N/m) of deformation curve at ascending section in linear region; force at 1-mm distance; apparent force (maximum force of bending curve); apparent work (area under the bending curve), respectively.
[d] Coefficient of variation.
[e] Fisher's protected least significant difference test ($\alpha = 0.05$), using one-way analysis of variance. Values are significant at $P \leq 0.05$.

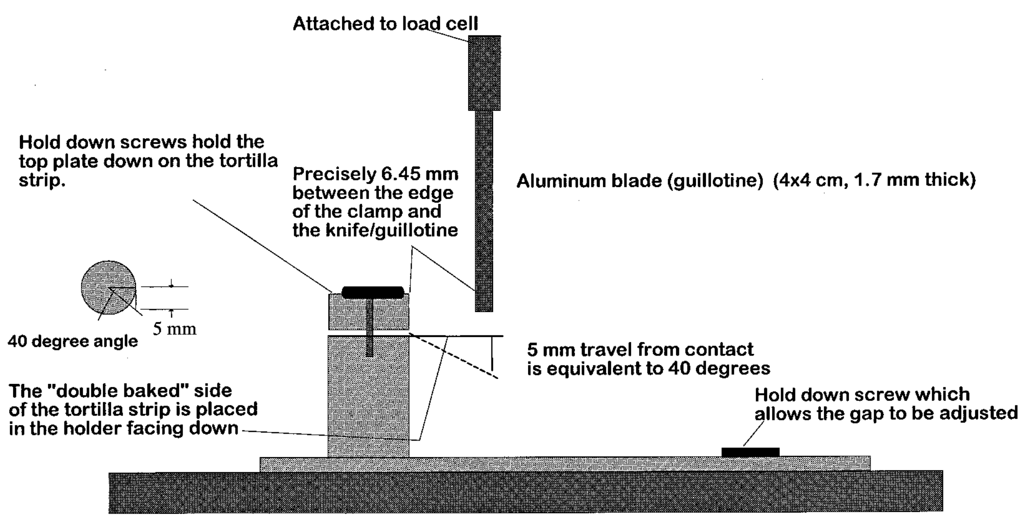

Fig. 1. Apparatus used to objectively measure bending properties of corn tortillas. Tortilla strip cutter was 30 mm wide and 35 mm long.

Laboratory-Prepared Tortillas

Effect of storage time. Fresh corn tortillas began to harden immediately after baking (Table II). Modulus of deformation, force at 1-mm distance, apparent force, and work required to bend tortillas increased during storage, especially during the first 24 hr. The bending technique detected significant changes in tortilla texture during and after the first 24 hr of storage, whereas the subjective rollability technique was not sensitive to changes during the first 24 hr.

The effect of storage was evaluated on uncontrolled laboratory tortilla samples (i.e., tortillas were sampled randomly; as a result, thickness and degree of puffing of samples varied). Sample variability could arise during sheeting or baking, which would yield abnormal, under- or over-baked tortillas (Suhendro et al 1997). CV for laboratory tortillas (10.5–16.1%) was higher than for commercial corn tortillas (3.9–14.7%).

Effect of thickness. Tortillas with different thicknesses were prepared from control masa and evaluated during storage to confirm observations for commercial tortillas. The extent of puffing and thickness of laboratory samples were controlled by selecting samples that represented the bulk of the tortilla batch, so the samples evaluated were more homogenous. CV for the bending method parameters for these samples (7.8–10.6%) was lower than for the uncontrolled laboratory samples (10.5–16.1%).

Thin tortillas required less force, work, and modulus of deformation compared with thick tortillas at each storage stage (Table III). These data were consistent with both subjective and objective rollability data. Thicker tortillas were less rollable (Table III) and required more work to roll, based on an objective texture method (Suhendro et al 1998).

Effect of puffing. Puffed tortilla strips had lower moduli of deformation, force at 1-mm distance, apparent force, and work required to bend than nonpuffed strips (Fig. 4). Puffed tortillas have two separate layers due to expansion during baking. Each layer was thin, tender, pliable, and easily bent. Puffed tortillas were more flexible and rollable than unpuffed tortillas. The commercial tortillas tested were unpuffed; therefore, the effect of puffing was not evaluated on commercial tortillas.

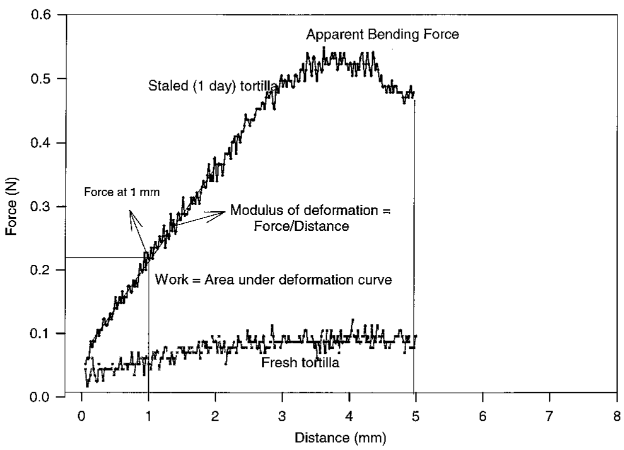

Fig. 2. Typical bending curves of fresh and staled tortillas.

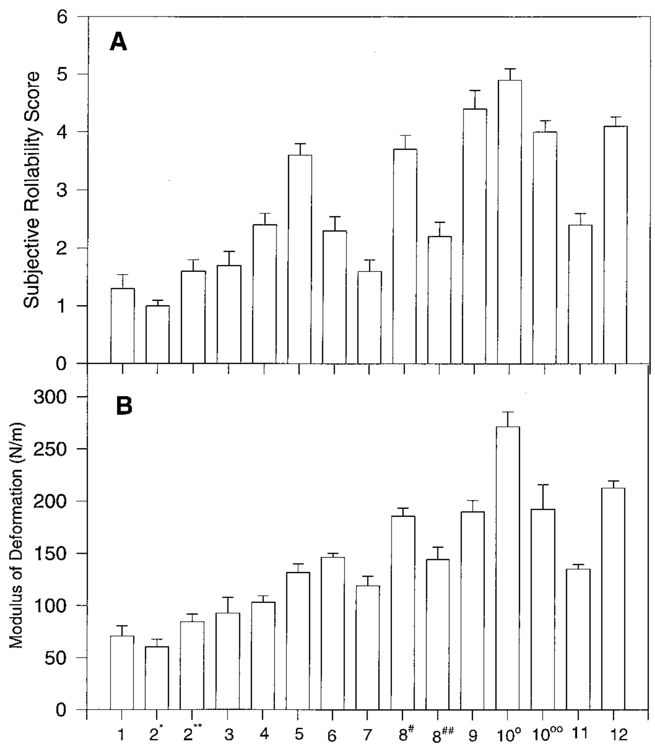

Fig. 3. Subjective rollability score parameters for the bending technique used on commercial corn tortillas from supermarkets.

Correlation Among Bending and Texture Values

Subjective rollability and flexibility values of tortillas were significantly correlated with parameters measured using the bending technique. Tortillas that were firmer and less rollable had greater moduli of deformation and required more force and work to bend (Tables IV and V). Tortilla thickness, diameter, and weight were positively correlated to subjective texture measurements and bending parameters.

DISCUSSION

A 40° angle was used in the bending test because it allowed the probe to travel a distance of up to 5 mm, at which point all tortillas reached their maximum force. Applying an increasing strain from 0 to 5 mm allowed a tortilla to be deformed at its linear and nonlinear region in the force-distance curve; therefore, the linear region of tortillas at a certain age or condition could be determined. A linear region in the force-distance curve, up to a distance of 3 mm, was observed for most tortillas, except for fresh tortillas (Figs. 2 and 4). This suggests the tortilla behaved as a linear viscoelastic material over this region, a simple behavior that can be valuable in the characterization of products. At the linear region, a

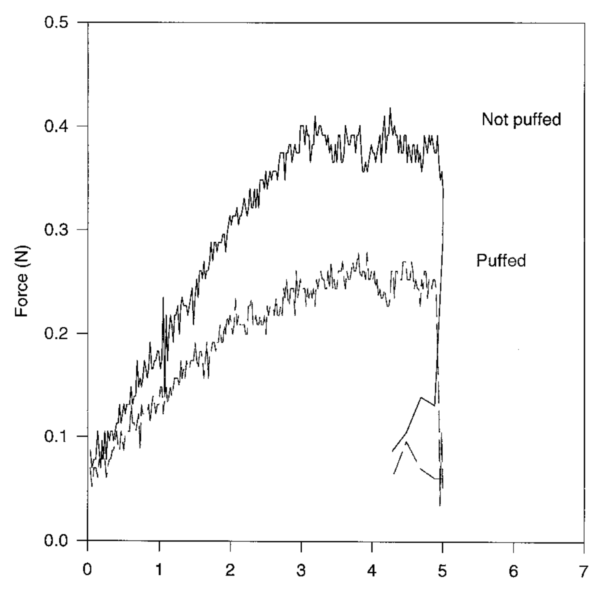

Fig. 4. Effect of puffing during baking on bending characteristics of a 1.7-mm-thick, one-day-old tortilla.

viscoelastic material has properties in which the ratio of stress to strain is a function of time alone and not of stress magnitude. Rheological methods used to determine linear viscoelastic materials include dynamic methods, involving application of oscillatory shear stress, and static methods, involving creep or stress relaxation (Peleg 1980, Steffe 1992). The tortilla bending method could be used as an alternative, simple method to predict the linear region of viscoelastic material, as suggested by the data shown in Figs. 2 and 4. The relationship between stress and distance can be obtained directly from bending deformation curves, which could avoid the need for longer and more complicated procedures. The force required to deform a tortilla at a certain strain level at its linear region (i.e., at 1-mm distance) could be determined using the bending method (Table II). The force at 1-mm distance was significantly correlated to subjective measurements and other bending parameters.

TABLE III
Effect of Thickness on Tortilla Texture Properties[a]

Tortilla Thickness	Storage Time (day)	Bending Technique (modulus of deformation, N/m)[b]	Subjective Rollability[c]
Thin (1.7 mm)	0	15.1	5.0
	1	143.7	4.7
	3	155.8	4.0
	7	170.0	3.1
Thick (2.2 mm)	0	34.3	5.0
	1	169.4	4.0
	3	177.4	2.6
	7	207.4	2.1
CV (%)[d]		10.6	9.5
LSD[e]		13.2	0.4

[a] Values are means of five observations.
[b] Slope (N/m) of deformation curve at ascending section in linear region.
[c] Rated on five-point scale: 1, worst; 5, best.
[d] Coefficient of variation.
[e] Fisher's protected least significant difference test ($\alpha = 0.05$), using one-way analysis of variance. Values are significant at $P \leq 0.05$.

The tortilla bending technique had a constant contact area throughout the test; the force required to bend was directly proportional to the stress required to bend. Stress is defined as force per unit area and usually is expressed in Pascals (N/m^2) (Steffe 1992).

Only the 0.5- and 3-hr-old tortillas bent by gravity alone. The tortillas were soft (subjective evaluation) and required low stresses that peaked and plateaued earlier than in more rigid samples. Tortilla strips were low in mass and wide and short in dimension. Most tortilla strips did not bend by gravity alone. The effect of gravity on bending data was not important, because the rheology of fresh (tortillas that bent) and aged tortillas (tortillas did not bend) was substantially and significantly different.

Testing samples that have different dimensions result in misleading data, because bending force is affected by contact area (width of tortilla strip × thickness of metal guillotine) and tortilla thickness. Wider tortilla strips required more force to bend than narrow strips (data not presented). Thicker tortillas required more force to bend than thinner tortillas. Other sources of variability in bending data include tortilla surface properties and horizontal distance between guillotine and sample clamp. Flat, smooth surfaces resulted in data that were less variable than did blistered or puffed surfaces. The shorter the distance between guillotine and sample clamp, the more force required to bend the strip (data not presented). To minimize these sources of variability, it is recommended that tested samples have similar dimensions (i.e., use a tortilla strip cutter [template] to cut the strip, select tortillas that resemble the bulk of the tortilla batch, avoid abnormal under- or over-baked tortilla pieces, and keep the distance between guillotine and sample clamp constant).

CONCLUSIONS

The tortilla bending technique is a simple, fast, repeatable technique. Excluding time required to set up the bending probes and save files, it takes 50–60 sec to run a bending test. Force versus

TABLE IV
Pearson Correlation Coefficients Among Subjective and Objective Texture Measurements of Commercial Tortillas from Supermarkets in Bryan-College Station, TX[a]

	Bending Technique[b]							
	Peak Force	Bending Work	Modulus of Deformation	Subjective Rollability	Subjective Flexibility	Moisture	Thickness	Weight
Work	0.99							
Modulus of deformation	0.97	0.97						
Rollability	–0.89	–0.89	–0.75					
Flexibility	–0.75	–0.76	–0.97	0.82				
Moisture	ns	ns	ns		ns	ns		
Thickness	0.73	0.72	0.70	0.64	–0.42	0.67		
Weight	0.86	0.87	0.85	0.78	–0.42	0.55	0.83	
Diameter	0.46	0.51	0.49	0.58	–0.57	ns	ns	0.56

[a] Correlations significant at $P \leq 0.05$, $n = 5$. ns = not significant.
[b] Apparent force (maximum force of bending curve); apparent work (area under the bending curve); slope (N/m) of deformation curve at ascending section in linear region.

TABLE V
Pearson Correlation Coefficients Among Subjective and Objective Texture Measurements of Laboratory-Prepared Tortillas[a]

	Bending Technique				
	Force at 1-mm Distance	Peak Force	Bending Work	Modulus of Deformation	Subjective Rollability
Peak force[b]	0.99				
Bending work[c]	0.99	0.98			
Modulus of deformation[d]	0.98	0.97	0.98		
Rollability	–0.97	–0.95	–0.97	–0.93	
Flexibility	–0.94	–0.95	–0.91	–0.97	0.83

[a] Correlations significant at $P \leq 0.05$, $n = 5$.
[b] Apparent force (maximum force of bending curve).
[c] Apparent work (area under the bending curve).
[d] Slope (N/m) of deformation curve at ascending section in linear region.

distance curves generated by the bending method could be used as a simple method to determine the linear region of viscoelastic materials. The technique was correlated to subjective rollability (r = 0.75–0.89) and flexibility (r = 0.75–0.97). The objective bending technique was more sensitive than the subjective rollability test (i.e., the technique detected changes in corn tortilla texture during and after 24 hr of storage, whereas subjective rollability was not sensitive to changes within 24 hr of baking).

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