Effect of Sorghum Flour Addition on the Characteristics of Wheat Flour Tortillas[1]

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ABSTRACT

Wheat flour tortillas were produced from composite flours containing up to 30% decorticated sorghum flour. Sorghum tortillas had a few black specks and were more firm than the control wheat flour tortillas. However, the *L*, *a*, and *b* color values were not affected by substituting decorticated sorghum for wheat flour. Tortillas containing up to 20% fine flour had sensory properties similar to those of the control tortillas. Coarser sorghum flours absorbed less water and produced firmer and less flexible tortillas than did finer flours. The flexibility of fresh tortillas was similar; however, during storage, sorghum tortillas became less rollable, and became so faster, than did wheat flour tortillas. The addition of carboxymethylcellulose to tortillas containing 20% sorghum flour significantly decreased staling. Tortillas stored at 25°C staled more quickly than did frozen (−10°C) or refrigerated (5°C) tortillas. Decorticated sorghum flour can replace up to 20% wheat flour in hot-press wheat flour tortillas. The sorghum should be milled to remove the hilum and be finely ground.

Wheat flour tortillas are popular in Mexico and rapidly expanding in U.S. markets. Technology for the industrial production of flour tortillas in the United States (Serna-Saldivar et al 1988) and the production and nutritive value of wheat flour tortillas fortified with soybean meal and soybean isolates in Mexico (Gonzalez-Agramon and Serna-Saldivar 1988) have been reviewed.

Sorghum (*Sorghum bicolor* Moench) is the second leading cereal crop in Mexico, where wheat is in short supply and more expensive than sorghum. Food-grade sorghums with white pericarp and tan plant color have the potential to be processed into refined flours with light color and bland flavor and the capacity to extend wheat flour for tortilla production.

The objectives of this study were: 1) to determine the optimum conditions and level of sorghum substitution for production of composite wheat flour tortillas, 2) to determine the effect of sorghum flour particle size on the quality of tortillas, and 3) to evaluate the effects of reducing agents, gums, and emulsifiers on tortilla texture during storage at room, refrigeration, and frozen temperatures.

MATERIALS AND METHODS

Sorghum Flour Preparation

Three sorghum flours with different particle size distributions were prepared from decorticated sorghum. Tan-plant, white sorghum (ATx 631 × Tx 8505) was decorticated to remove 10% of the original weight in an abrasive dehuller (IDRC mill; Reichert 1982). A decortication time of 2.7 min was necessary to remove 10% of the grain weight.

Flour A was obtained after hammer milling the decorticated sorghum in a Fitz mill (comminuting machine, model D; Fitzpatrick Co, Elmhurst, IL) equipped with a 1-mm screen. Flour B was produced from flour A by grinding the overs of a U.S. no. 60 sieve with a Udy Cyclone Mill (Udy Corp, Fort Collins, CO; model S/N 25084 U-3). The ground material was reincorporated with the rest of the flour. The finest flour, flour C, was produced by milling decorticated sorghum in an Alpine pin mill (Alpine American Corp., Natick, MA). Particle size distribution was determined by wet sieving. A 2-g sample was dispersed in 20 ml of water and sieved through U.S. no. 40, 60, 80, and 100 sieves and filter paper using water aspiration to expedite sieving (Fig. 1). Flour water absorption indices were determined according to Anderson et al (1969).

Tortilla Preparation

Composite flours containing up to 30% sorghum flour were produced. The different sorghum flours were mixed with commercial enriched, bleached hard wheat flour (GM 44, 10.8% protein; General Mills, Minneapolis, MN). The basic tortilla formula consisted of 12% shortening (Crisco; Procter & Gamble, Cincinnati, OH), 2% salt, 1% baking powder (Clabber Girl Double Action; Hulman & Co., Terre Haute, IN), 0.1% citric acid (Miles Laboratories, Elkhart IN), and 0.4% potassium sorbate (Sorbitat-K; Pfizer, New York).

A trial was designed to study the effect of dough improvers, carboxymethylcellulose (CMC; 9H4F, Hercules Products, Wilmington, DE), sodium stearoyl lactylate (SSL; Breddo, Kansas City, KS), and sodium bisulfite (Fisher Scientific Co., Fair Lawn, NJ) on properties of tortillas containing 20% fine sorghum flour B. The levels of CMC, SSL, and sodium bisulfite, based on flour weight, were 0.3%, 0.5%, and 25 ppm, respectively. The hot-press procedure was used to manufacture tortillas, which were produced in 1-kg flour batches. The flour plus the other ingredients were first mixed for 2 min at speed 1 in a Hobart mixer equipped

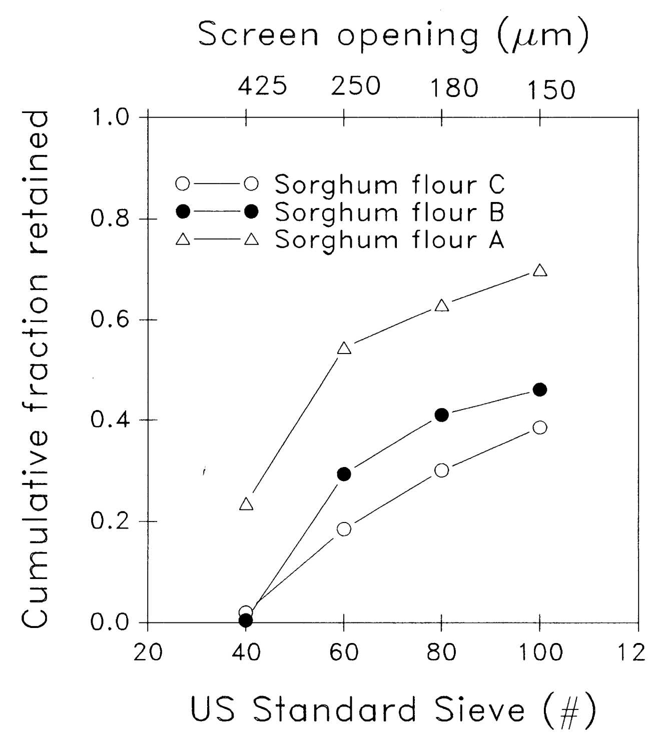

Fig. 1. Particle size distribution of sorghum flours A, B, and C.

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with a hook attachment. Upon water addition, doughs were mixed at speed 2 for 1.2 times the farinograph development time. Optimum water absorption was based on farinograph curves and the subjective evaluation of dough. The resulting dough was relaxed for 5 min in a proof cabinet set at 32°C and 70% rh. Then the dough was manually molded into a circular sheet on a metallic plate for further mechanical pressing, cutting, dividing, and rounding (BESCO, San Antonio, TX; serial no. 16H 3451). The dough was divided into 36 dough balls of approximately 47 g each. The resulting dough balls were rested for 25 min in the proof box and then pressed into disks between a pair of platens (BESCO, no. 66201) set at 210°C. The minimum gap between the platens was 1.8 mm. The resulting tortilla disks were continuously fed into a three-stage gas-fired oven (Superior, Pico Rivera, CA; model CO440). The average operating temperature measured 0.4 mm above the slats of the belts was 200°C. Tortillas were baked for 39 sec. The tortillas exiting the oven were cooled for 90 sec on a three-tier cooling conveyor (Superior, model 3106) and then placed on the counter for 10 min. The tortillas were packaged in polyethylene bags and assigned to room temperature, refrigeration, or frozen storage.

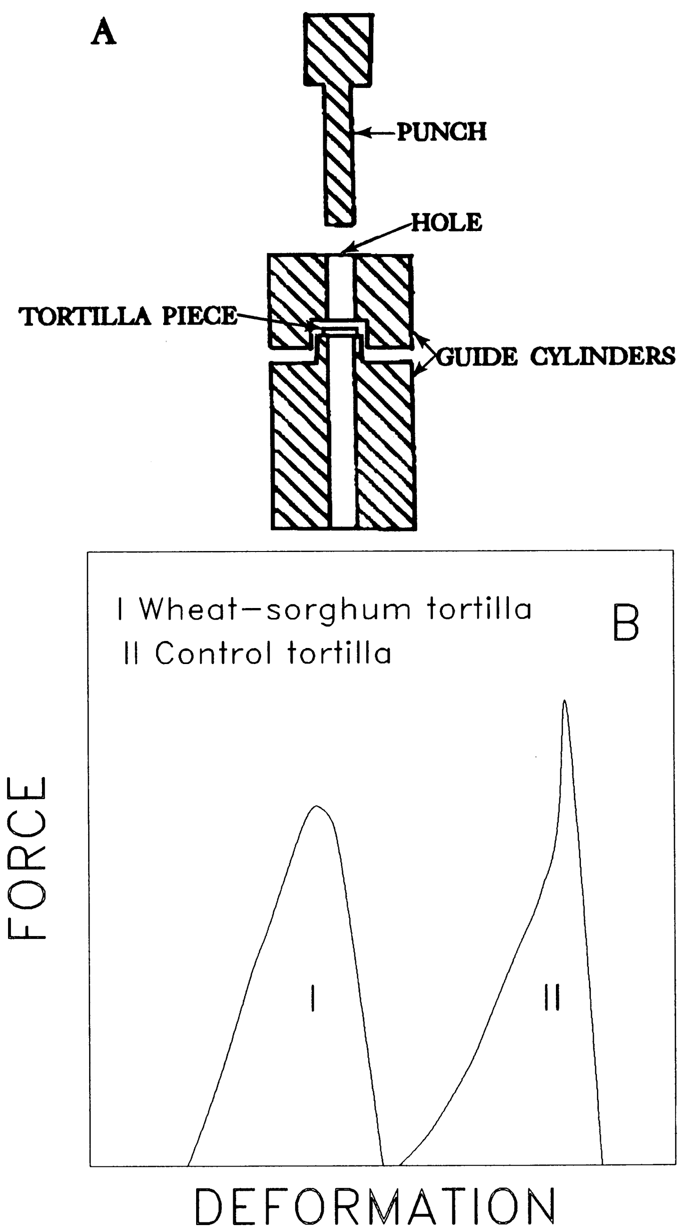

Fig. 2. Punch and die testing to evaluate tortilla firmness. **A,** Apparatus; **B,** force deformation plots of flour tortillas subjected to the puncture test.

Farinograph Procedure

Mixing requirements and water absorption were estimated by a modified farinograph procedure (Bello et al 1991). Fifty grams (14% mb) of flour was mixed with shortening, salt, and baking powder for 2 min at low speed in the farinograph. Then water absorption was estimated by the amount of water required to center the farinograph curve on 750 BU. Upon water addition, the mixing speed was changed to the higher one, and farinograph curves were run for 15 min. The consistency of the properly developed dough was closely related to the consistency of dough used for production of hot-press tortillas.

Tortilla Firmness

Firmness of tortillas was measured with the Instron Universal Testing Machine equipped with a punch and die testing cell (Fig. 2A). The firmness values were expressed in Newton-meters (N-m) and consisted of the force required to puncture a tortilla piece with a 12-mm diameter. The small tortilla disk was clamped between two stainless steel cylinders with a 4-mm diameter hole. A solid stainless steel rod with a flat end penetrated and punctured the tortilla disk. The operational conditions were: a cross head speed of 5 mm/min, a chart speed of 50 mm/min, and a 1,000-lb compression load cell. The firmness value was the area under the time-deformation curve (Fig. 2B), which measured the work required to puncture the tortilla. Three punctures were made per treatment.

Tortilla Rollability

The dowel test was used to score tortilla rollability. Five tortillas were cut into strips 2 cm wide. The randomly chosen five strips (per treatment) were wrapped several times around a dowel with a 7/16-in. diameter. Degree of breakage was subjectively rated as 5 = tortilla did not break; 3 = tortilla partially broke; and 1 = tortilla broke completely.

Color Measurements

Tortilla color scores were measured with a Hunter Lab color meter. The *L, a* and *b* values were obtained after calibrating the instrument with a white tile with standard values of L = 91.77, $a = -1.07$, and $b = 1.36$. Ten measurements were made per treatment.

Sensory Evaluations

The texture, flavor, aroma, and general appearance of the different tortilla systems were evaluated by 12 adult untrained panelists. Three tortillas per treatment were served in closed containers, and panelists were instructed to drink water after each evaluation. The characteristics were graded on a hedonic scale of 1–9, in which 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. In addition, panelists were asked to rank in ascending order a series of five treatments according to their overall acceptability. Sensory evaluations were made in a laboratory open area.

An attempt to correlate sensory and instrumental measurement of firmness was made. A trained panel of three persons evaluated firmness of wheat and wheat-sorghum tortillas. The subjective evaluation of firmness during the first bite was graded on a scale of 1–5. A score of 5 was given to the most firm and 1 to the most tender tortillas. A correlation between sensory evaluation and instrumental measurement of firmness ($r = 0.82$, $n = 25$, $P < 0.05$) was observed.

Chemical Analyses

Nitrogen was assayed by a modified micro-Kjeldahl procedure and quantitated with an autoanalyzer (Technicon 1978; method 334-74A/A). Fat was extracted with petroleum ether with a Goldfish extraction apparatus (AACC 1983; Method 30-20). Crude fiber was determined following AOAC method 7.061 (AOAC 1980). Starch was colorimetrically quantitated in an autoanalyzer (Technicon 1978; method 5FA-0046FA8) after gelatinization and hydrolysis with amyloglucosidase. Ash was determined after incineration of samples at 570°C (AACC 1983; method 08-01).

Moisture was calculated by weight loss after drying at 105°C for 12 hr in a forced-air oven.

Design of Experiments

The objective of a first experiment was to determine the effects of level of sorghum substitution and of temperature and time of storage on the texture of wheat-sorghum tortillas. Treatments were organized as a factorial experiment of three factors with three levels for each one. Sorghum replaced 0, 15, and 30% of the wheat flour; temperatures of storage were −10 (freezing), 5 (refrigeration), and 25°C (room temperature); and times of storage were two, four, and seven days. Sorghum flour C was used for this experiment.

A second experiment was designed to evaluate the effect of particle size of sorghum flour on texture of wheat-sorghum tortillas with 20% sorghum substitution. Flours A and B were used. Treatments were organized in a randomized block design, with the days of evaluation during the storage period as the blocks.

A third experiment was performed to evaluate the effects of 0.3% CMC, 0.5% SSL, and 25 ppm of sodium bisulfite. Treatments were organized in a randomized block design, with the days of evaluation during storage period as the blocks. The response variables for the experiments were rollability (dowel score) and firmness of tortillas.

Measurements of color and sensory properties were independent of the experiments. Flours C and B were used to prepare tortillas and to evaluate their sensory properties and color, respectively.

Analysis of variance and Fisher's least significant differences were used to determine differences among treatments. For rollability and sensory evaluations, the nonparametric Friedman test was performed (Marascuilo and McSweeney 1977). Contrasts were used for pairwise comparisons, and significant differences (95% Scheffe confidence interval) were calculated.

TABLE I
Effect of Sorghum Substitution on Farinograph Properties and Baking Water Absorption of Flour Tortillas[a]

		Farinograph		
Flour	Water Absorption[b] (%)	Development Time (min)	Stability Time (min)	Baking Absorption[c] (%)
Control	44.7	5.5	5.5	44.7
Sorghum A				
15%	39.8	8.0	10.0	42.0
20%	39.9	7.5	10.0	42.9
25%	39.4	6.0	10.0	42.5
30%	36.0	7.5	12.0	40.5
Sorghum B				
15%	42.0	6.5	8.5	44.2
20%	40.5	7.5	9.5	43.5
25%	39.5	7.5	9.5	43.2
30%	39.2	6.5	10.5	43.7
Sorghum C				
15%	44.6	6.0	9.5	44.6
30%	44.6	10.0	11.5	46.0
LSD = 0.85 ($\alpha = 0.05$)				

[a] The water absorption index for sorghum flours A, B, and C were 1.11, 2.38, and 3.48 g of water per gram of dry sample, respectively.
[b] Modified farinograph procedure. Water required to center the curve on the 750-FU line. Duplicated determinations.
[c] Subjectively measured. Water necessary to obtain adequate dough consistency for production of flour tortillas.

TABLE II
Effect of Sorghum Substitution on Flour Tortilla Color Scores[a]

	Color Value[b]			
Tortilla	*L*	*a*	*b*	*E*
Control	65.4 a	−0.1 a	11.1 a	66.3 a
Sorghum flour B				
15%	64.8 a	−0.3 a	11.2 a	65.8 a
20%	64.3 a	−0.3 a	13.1 a	65.6 a
25%	62.2 a	−0.2 a	12.4 a	63.4 a
30%	62.7 a	−0.4 a	12.3 a	63.9 a

[a] Determined with the Hunter Lab color meter. Each value is the mean of 10 observations. Means with the same letter within a column are not significantly different ($P < 0.05$).
[b] L = lightness: 100 = white, 0 = black; a = red (+100), $-a$ = green (−80), b = yellow (+70), $-b$ = blue (−80), $E = (L^2 + a^2 + b^2)^{1/2}$.

RESULTS AND DISCUSSION

Water Absorption

Composite flours containing 15–30% sorghum flours A and B absorbed less water than the control wheat flour (Table I). Composite flours containing up to 30% sorghum flour C had farinograph and baking water absorptions equivalent to those of the control flour, with the exception of the 30% sorghum flour C blend, which had higher baking water absorption. Blends containing the finely ground sample (flour C) had higher water absorptions than those containing coarser flours.

The modified farinograph procedure predicted water absorption requirements effectively when wheat flour was used. However, the farinograph water absorptions for wheat-sorghum blends were slightly lower than the optimum water absorptions determined subjectively during baking (Table I).

Characteristics of Tortillas

After hot-pressing and baking, tortillas had an average diameter of 16 cm (coefficient of variation [CV] = 3%), weight of 40 g (CV = 3.7%), and moisture content of 30% (CV = 2%). Tortilla thickness varied from 1.5 to 2.9 mm. These diameters and moisture contents are comparable with published values for press tortillas (Gonzalez-Agramon and Serna-Saldivar 1988, Serna-Saldivar et al 1988).

TABLE III
Effect of Sorghum Substitution on Sensory Properties of Flour Tortillas[a]

	Preference Test[b]				
Tortilla	Taste	Texture	Aroma	Appearance	Rank Test[c]
Control	8.0 a	7.5 a	7.5 a	8.0 a	1.0 a
Sorghum flour C					
15%	7.0 a	7.0 a	7.0 a	7.5 a	2.0 a
20%	7.0 a	7.0 a	6.0 ab	7.0 a	2.0 a
25%	6.0 b	4.0 b	6.0 ab	4.0 b	4.0 b
30%	5.5 b	4.0 b	5.0 b	4.0 b	5.0 b

[a] Data from 12 untrained panelists, and analyzed with the nonparametric Friedman test.
[b] Medians of subjective evaluation in which 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. Medians with the same letter within a column came from populations not significantly different ($P < 0.05$).
[c] Median of the rankings in which 1 = best tortilla and 5 = worst tortilla.

TABLE IV
Chemical Compositions (%) of Sorghum, Wheat Flour, and Tortillas[a]

Product	Moisture	Protein[b]	Fat	Ash	Starch	Crude Fiber
Sorghum						
Whole	14.1	10.4	3.8	1.7	74.3	1.7
Decorticated	8.1	10.2	2.5	1.5	79.7	0.8
Wheat flour	11.5	10.8	1.3	0.6	77.7	0.1
Tortilla						
Control	29.5	9.7	12.9	2.5	64.9	0.1
Sorghum flour C						
15%	29.6	9.6	13.0	3.0	66.4	0.4
30%	28.0	9.6	13.1	2.9	65.4	0.5

[a] All values are expressed on dry matter basis, except moisture. Values are means of three repetitions.
[b] N × 5.7 and 6.25 for wheat and sorghum products, respectively. For composite tortilla products, the relative amounts of wheat and sorghum ingredients were taken into consideration.

Tortilla Color

The addition of decorticated sorghum flour did not significantly ($P < 0.05$) affect the color of flour tortillas (Table II). However, tortillas containing sorghum flour had undesirable black specks that affected their appearance. The black particles were from the hilum or black layer of the sorghum kernel. More complete milling would eliminate the hilum.

TABLE V
Effect of Percent Sorghum Substitution and of Time and Temperature of Storage on Tortilla Firmness, Analysis of Variance[a]

Source of Variation	Degrees of Freedom	Mean Sum of Squares	*F* Value[b]
Sorghum percent (*S*)	2	1.9537	18.49**
Day (*D*)	2	0.2242	2.12 ns
Temperature (*T*)	2	1.3590	12.86**
$S \times D$	4	0.0561	0.53 ns
$S \times T$	4	0.1364	1.29 ns
$D \times T$	4	0.3483	3.30*
Error	62	0.1056	

[a] Dependent variable: firmness.
[b] * and ** = significant at $P < 0.05$ and $P < 0.01$, respectively; ns = not significant.

Sensory Evaluation

Tortillas prepared from flour C (fine flour) without dough improvers were used for sensory analysis. Less desirable flavor,

TABLE VI
Effect of Particle Size of Sorghum Flour on Tortilla Firmness, Analysis of Variance[a]

Source of Variation	Degrees of Freedom	Mean Sum of Squares	*F* Value[b]
Particle size (*P*)	2	0.5257	5.50*
Day (*D*)	1	3.0253	31.63**
$P \times D$	2	0.7910	8.27**
Error	12	0.0956	

[a] Dependent variable: firmness.
[b] * and ** = significant at $P < 0.05$ and $P < 0.01$, respectively.

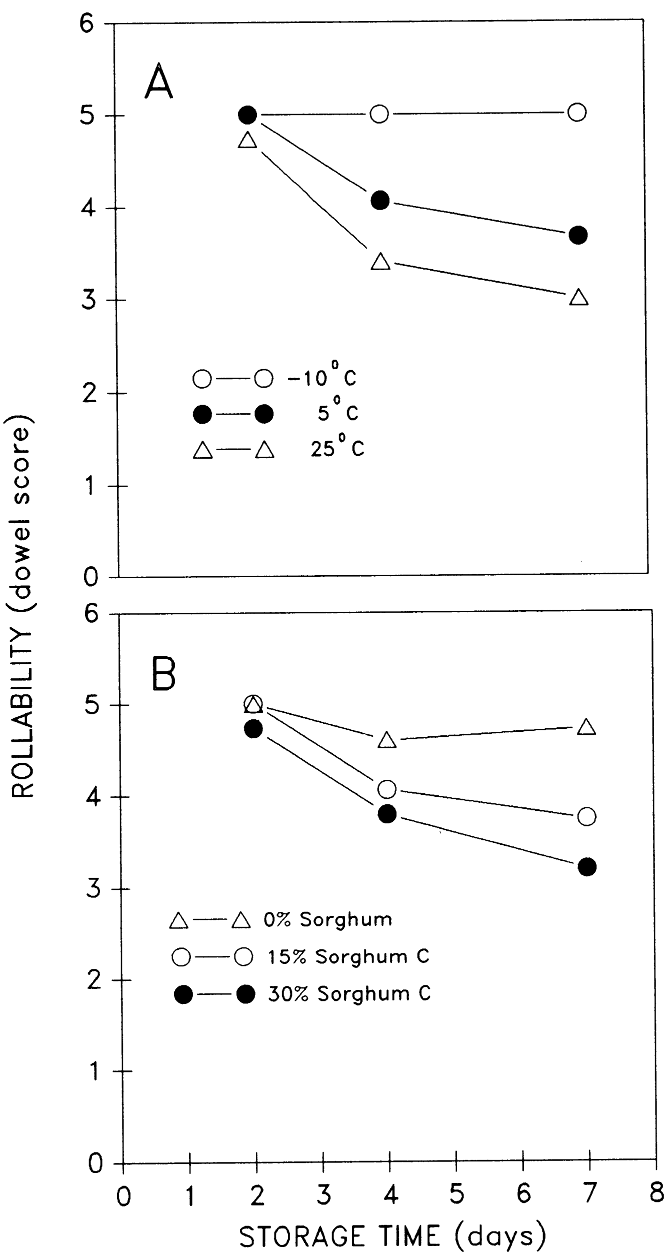

Fig. 3. Effect of storage temperature (**A**) and replacement with sorghum flour C (**B**) on the rollability of flour tortillas.

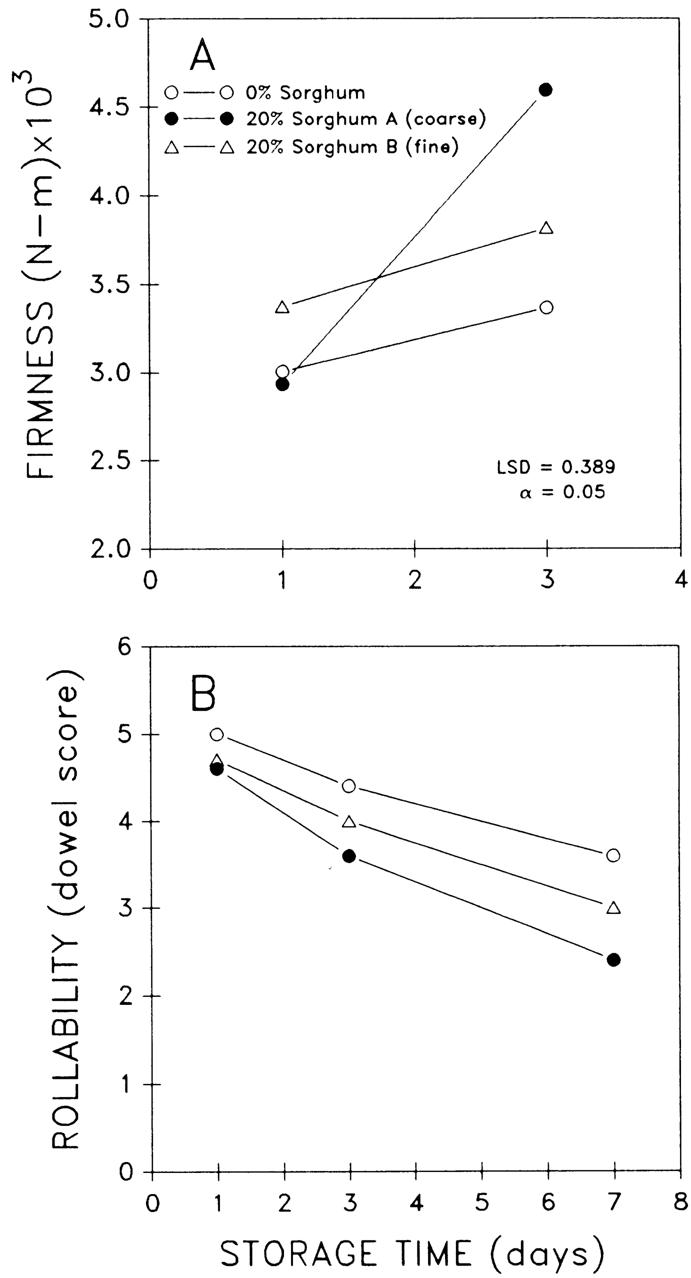

Fig. 4. Effect of sorghum flour particle size on firmness (**A**) and rollability (**B**) of tortillas.

texture, aroma, and decreased overall acceptability were recorded for tortillas containing 25 or 30% sorghum flour (Table III). However, the sensory properties of tortillas containing less than 20% sorghum were not significantly different ($P < 0.05$) from those of the control tortilla. High levels of sorghum lowered appearance scores due to the presence of specks from the hilum and probably influenced the other subjective evaluations.

Chemical Composition

The protein of tortillas varied from 9.6 to 9.7% (Table IV). The fat was similar among tortillas, and the level was high due to the addition of 12% shortening. Ash content was higher in tortillas than in the original flour due to the addition of salt and baking powder. The starch content in the tortillas did not vary and was approximately 65%.

Effect of Sorghum Substitution on Tortilla Texture

Table V shows the analysis of variance in which the effects of percent sorghum substitution and of time and temperature of storage on tortilla firmness were analyzed. The effect of sorghum addition on tortilla firmness could be studied independently because there were no significant interactions between percent sorghum substitution and the factors time and temperature of storage. On the other hand, a significant interaction was observed between the factors time and temperature of storage.

Mean firmness values of tortillas containing 15% sorghum C (2.28 ± 0.31 N-m) were significantly lower than those of the control tortilla (2.67 ± 0.39) and tortillas containing 30% sorghum (2.80 ± 0.46).

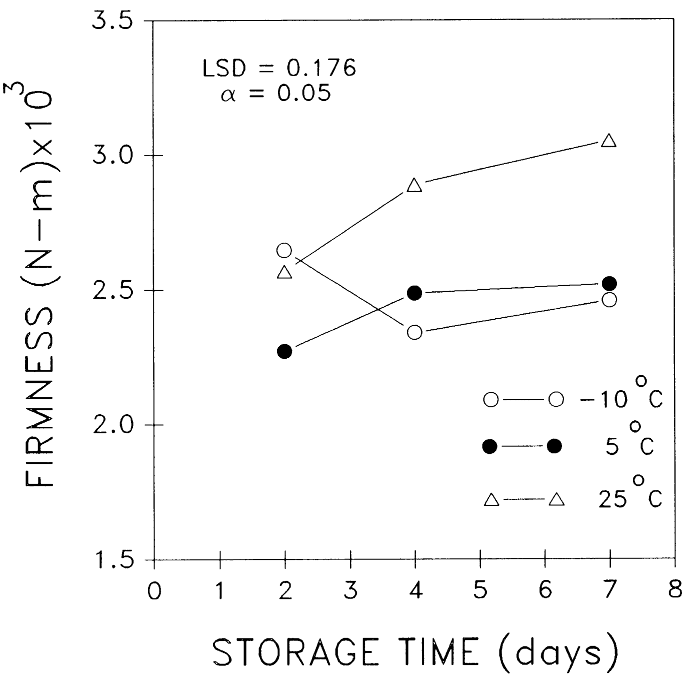

Fig. 5. Effect of storage temperature on firmness values of flour tortillas. Each value is the average of tortillas containing 0, 15, and 30% sorghum flour C.

TABLE VII
Effect of Improvers on 20% Tortilla Firmness, Analysis of Variance[a]

Source of Variation	Degrees of Freedom	Mean Sum of Squares	*F* Value[b]
Improvers (*I*)	5	1.3303	9.24**
Day (*D*)	2	9.2382	64.19**
$D \times I$	10	0.3601	2.50*
Error	88	0.1439	

[a] Dependent variable: firmness.
[b] * and ** = significant at $P < 0.05$ and $P < 0.01$, respectively.

Dowel score values of control tortillas were significantly better ($P < 0.05$) than values of tortillas containing 15 or 30% sorghum. Wheat flour tortillas retained good texture longer than tortillas containing either 15 or 30% sorghum (Fig. 3B). The control flour tortillas were consistently more flexible throughout storage than composite wheat-sorghum tortillas.

Table VI shows the analysis of variance in which the effect of sorghum particle size on tortilla firmness was analyzed. Tortillas prepared with the fine sorghum flour B were more flexible than counterparts prepared with coarse sorghum flour after three days of storage at room temperature (Fig. 4B). Dough prepared with coarse sorghum flour absorbed less water, which may explain the faster firming rate (Fig. 4A) and reduced rollability of tortillas over time (Fig. 4B). Low water absorption has been related to faster staling in bread (Pomeranz 1983).

Effect of Storage Temperature on Tortilla Texture

Firmness values of tortillas stored at room temperature were significantly higher ($P < 0.05$) than those of refrigerated or frozen tortillas equilibrated to room temperature (Fig. 5). Firmness val-

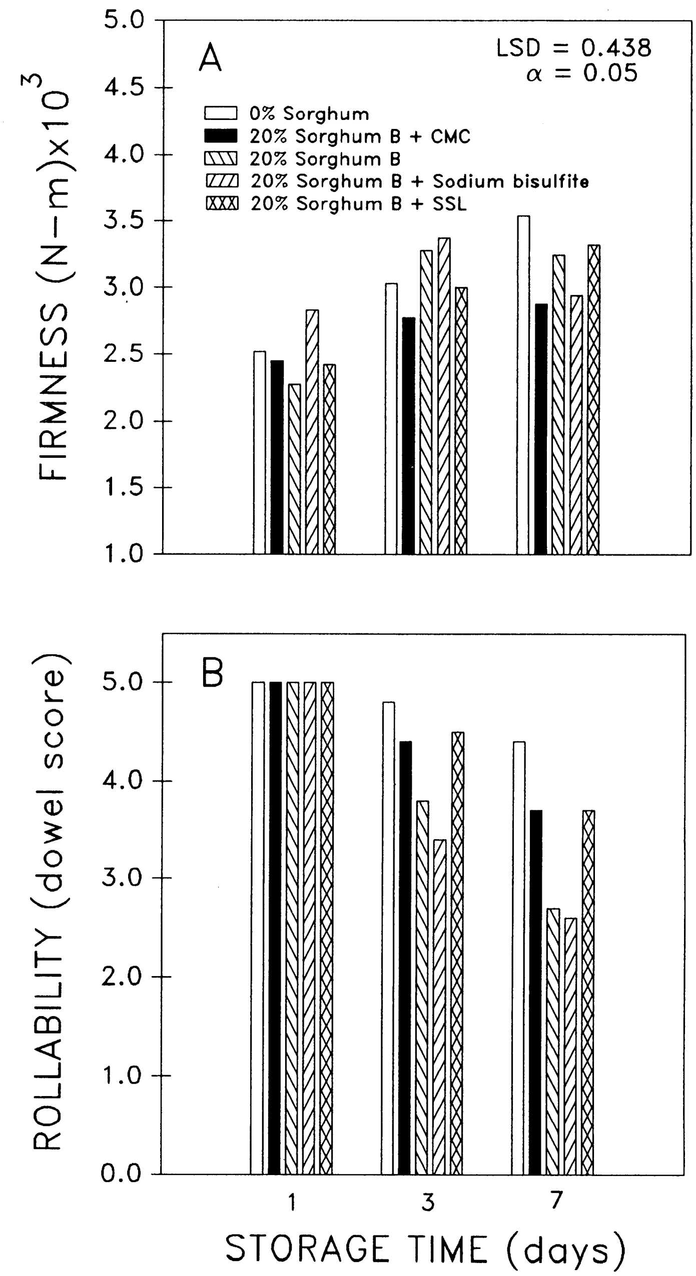

Fig. 6. Effect of carboxymethylcellulose (CMC), sodium stearoyl lactylate (SSL), and sodium bisulfite on firmness (**A**) and on rollability (**B**) of tortillas stored for seven days at 25°C.

ues of frozen and refrigerated tortillas were not significantly different after seven days of storage.

Storage temperature affected tortilla rollability. Upon thawing and equilibration to room temperature, tortillas stored in a freezer were more flexible than tortillas stored in a refrigerator (Fig. 3A). A reduction in tortilla flexibility occurred throughout storage at room and refrigeration temperatures. Tortillas staled faster when stored at room temperature. The mechanism of staling in tortillas may be more consistent with a diffusion phenomenon and less consistent with the crystallization process observed in table bread (Conford et al 1964). Both starch crystallization and moisture diffusion from gluten to starch have been recognized as responsible for bread staling (Pomeranz 1983). In bread, starch crystallization occurs faster during storage at refrigeration temperature than at room temperature. The staling mechanism in tortillas might be different because the system contains less moisture and significantly higher levels of shortening.

Effect of Dough Improvers on Tortilla Texture

Table VII shows the analysis of variance in which the effects of improvers on tortilla firmness were analyzed. CMC significantly ($P < 0.05$) decreased firmness of tortillas containing 20% sorghum flour after seven days of storage at room temperature (Fig. 6A). Addition of SSL and sodium bisulfite also decreased firmness, but the effect was not significant ($P < 0.05$). Control tortillas and tortillas containing CMC, SSL, and sodium bisulfite were very flexible the first day. A decrease in tortilla rollability throughout storage was observed for all treatments (Fig. 6B). After seven days of storage, composite tortillas were less flexible than control tortillas. The addition of CMC and SSL to wheat-sorghum (20%) tortillas significantly improved the dowel scores after seven days of storage.

CONCLUSIONS

Dough with up to 20% sorghum could be successfully used to manufacture flour tortillas without significantly affecting the sensory properties. Higher levels of flour replacement resulted in tortillas with lower sensory scores. The incorporation of decorticated sorghum flour into the tortilla system produced less flexible products with the presence of black specks. The use of decorticated, food grade, white sorghum produced a flour that did not significantly affect color values. During storage, wheat-sorghum tortillas lost flexibility at a faster rate than did control tortillas. Interestingly, tortillas with 15% sorghum had lower firmness values than did control tortillas. Tortillas prepared with coarse sorghum flours became firmer and lost flexibility at a faster rate than their counterparts prepared with fine flours. Wheat sorghum tortillas containing CMC or SSL had better textural characteristics than similar tortillas without the additives. Tortillas kept at room temperature lost flexibility faster than their counterparts stored under refrigeration or frozen conditions. Stale wheat flour tortillas had decreased rollability, increased firmness, loss of aroma, and loss of a typical fresh tortilla flavor.

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