Properties of New and Commercial Sorghum Hybrids for Use in Alkaline-Cooked Foods

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ABSTRACT

Twelve sorghums with different grain characteristics were cooked in lime, steeped for 5 hr, washed, and stone-ground into masa. Masa was sheeted, formed, and baked into tortillas. Nixtamal with 49-54% moisture content was acceptable for stone grinding, when water was added during grinding to produce masas with 56-59% moisture. Masas had adequate machinability and produced acceptable table tortillas. Tortillas weighed 25-29 g with 45-49% moisture. All fresh, nonwaxy tortillas had acceptable texture. However, waxy sorghum produced sticky masa and tortillas. The average conversion ratio of grain to tortillas was 1.5 kg of fresh tortillas per kilogram of raw grain. Dorado, Sureno, and Tortillero from Central America and hybrids ATX631 × TX435 and ATX631 × TX8505 from Texas Agricultural Experiment Station, College Station, gave tortillas with the best color and texture. Sorghums with tan plant color like Dorado and Sureno produced white tortillas, whereas ATX631 × TX435 and ATX631 × TX8505 produced yellow tortillas. Soft sorghums (Dorado and Maicillos Criollos) had the shortest optimum cooking times. White sorghums differed in cooking characteristics, but most produced tortillas with acceptable color and texture.

Sorghum is used in Central America and southern Mexico as a total or partial replacement of maize for tortilla production, especially when maize crops fail to produce because of prolonged drought or other unfavorable weather conditions. Factors for preparation of tortillas and tortilla chips have been evaluated for sorghum (Khan et al 1980, Bedolla et al 1983, Choto et al 1985, Serna-Saldivar et al 1988b).

Types of native sorghums called "Maicillos Criollos" are interplanted with maize on the steep hills of Central America. These sorghums are photosensitive and mature under dry conditions, producing white grain with red or purple secondary plant color. The International Sorghum and Millet Collaborative Research Support Program, Central American research agencies, and other international agencies have developed and released several "improved food" sorghums in Central America and Mexico.

The objectives of this research were to evaluate the alkaline cooking properties of 12 white sorghum cultivars with different kernel characteristics for tortilla production using pilot plant equipment and to compare these new sorghums with a typical "Maicillo Criollo."

MATERIALS AND METHODS

Sorghum Samples

The white food-type sorghums evaluated included commercial hybrids from the United States, experimental food hybrids from the Texas Agricultural Experiment Station (TAES), College Station, and the varieties Catracho, Dorado, Sureno, and Tortillero, which have been released in Central America. The grains differed in pericarp thickness, endosperm type, kernel hardness, and plant color (Table I). A composite sample of several Maicillos Criollos types representing white thick-pericarp sorghums from Central America also was used. White maize (Asgrow 405W) and a commercial red-pericarp sorghum (A378 × TX430) were included as positive and negative controls, respectively. All sorghums were grown under irrigation at Halfway, TX, in 1987 except the Maicillos Criollos types, which were grown in Guatemala. The maize was grown at Uvalde, TX.

Determination of Cooking Times

Sorghums were boiled for 0, 5, and 10 min and steeped for 5 hr. Three sets of samples containing duplicates of 100 g of each sorghum were placed in perforated nylon bags. Water (48 L) and lime (80 g) were brought to boil in a 120-L steam kettle (model TDC/2-20, Groen Div., Dover Corp., Elk Grove Village, IL), and a set of samples (10 min of boiling) was added. After 5 min of boiling, another set of samples (5 min of boiling) was added and allowed to boil for 5 min more. After steam was cut off, a third set of samples (0 min of boiling) was added immediately. The temperature of the cooking liquor was kept at about 98°C during boiling. During steeping, the temperature decreased at a rate of 0.15°C/min. The moisture content of nixtamal was determined using the procedure of Serna-Saldivar et al (1988a). The bags were opened, and nixtamal was washed, drained, weighed, and returned to the bags for drying. Grains were dried in a convection oven at 100°C for 72 hr, cooled in a dessicator, and weighed. Moisture contents were calculated from the weight loss of nixtamal during drying. Water uptake (WUT) and dry matter losses (DML) were calculated using the following formulas:

$$WUT = [(\text{nixtamal weight} - \text{nixtamal dry weight})/\text{nixtamal dry weight}] \times 100;$$

$$DML = [(\text{raw grain dry weight} - \text{nixtamal dry weight})/\text{raw grain dry weight}] \times 100.$$

Cooking time required to bring the sorghum nixtamal to 51% moisture content was calculated using second-degree polynomial regression models. This moisture level provided acceptable handling properties during grinding of nixtamal and sheeting and baking of masa.

Tortilla Preparations

Twelve kilograms of grain, including four 3-kg samples of different sorghums or maize, were processed into tortillas using a pilot plant (Fig. 1). Grains were placed into perforated nylon bags and boiled with 48 L of water and 80 g of lime in the steam kettle for the predetermined times. After boiling, steam was cut off, and the grains were steeped for 5 hr. Maize was boiled separately for 40 min with 160 g of lime and steeped for 15 hr. Then cooking liquor was discarded, and the grains were washed in colanders with running tap water (29°C) to remove excess lime and pericarp tissue.

Nixtamal was stone-ground (12-in.-diameter lava stones) using a 20-hp commercial grinder (model CG, Casa Herrera Inc., Los Angeles, CA). Water was added during grinding at the rate of 1 L/min to increase masa moisture content to about 58% and to avoid excessive stone wear. Masa for table tortillas must be ground finer than masa for tortilla chips so that a pliable, always rollable product can be obtained. For all runs, the gap between the stones was adjusted to the same setting, as marked on the adjusting handle, to produce a fine masa suitable for table tortillas. The masa was sheeted continuously and formed with a commercial sheeter/former (model CH4-STM, Superior Food Machinery,

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TABLE I
Kernel Characteristics of the Sorghum Samples

Type	Pericarp		Endosperm		Plant Color
	Color	Thickness	Type	Color	
U.S. commercial hybrids					
A378 × TX430	Red	Thin	Nonwaxy	Heteroyellow	Red
A2557 × OK111	White	Thin	Nonwaxy	Heteroyellow	Purple
Dekalb DK41Y	White	Thin	Nonwaxy	Yellow	Purple
TAES[a] experimental food-type hybrids					
ATX630 × TX435	White	Thin	Heterowaxy	Heteroyellow	Tan
ATX630 × R3338	White	Thin	Waxy	Nonyellow	Purple
ATX631 × TX8505	White	Thin	Nonwaxy	Heteroyellow	Tan
ATX631 × TX435	White	Thin	Nonwaxy	Heteroyellow	Tan
Central America food types					
A155 × SC1207-2	White	Thick	Nonwaxy	Nonyellow	Purple
ATX623 × Tortillero (Catracho from Guatemala)	White	Medium thick	Nonwaxy	Nonyellow	Red
Dorado (El Salvador)	White	Thick	Nonwaxy	Nonyellow	Tan
Sureno (Honduras)	White	Thin	Nonwaxy	Nonyellow	Tan
Tortillero (Honduras)	White	Thin	Nonwaxy	Nonyellow	Tan
Maicillos Criollos[b] (Guatemala)	White	Thick	Nonwaxy	Nonyellow	Purple

[a] Texas Agricultural Experiment Station, College Station.
[b] A composite of several types of Maicillos Criollos.

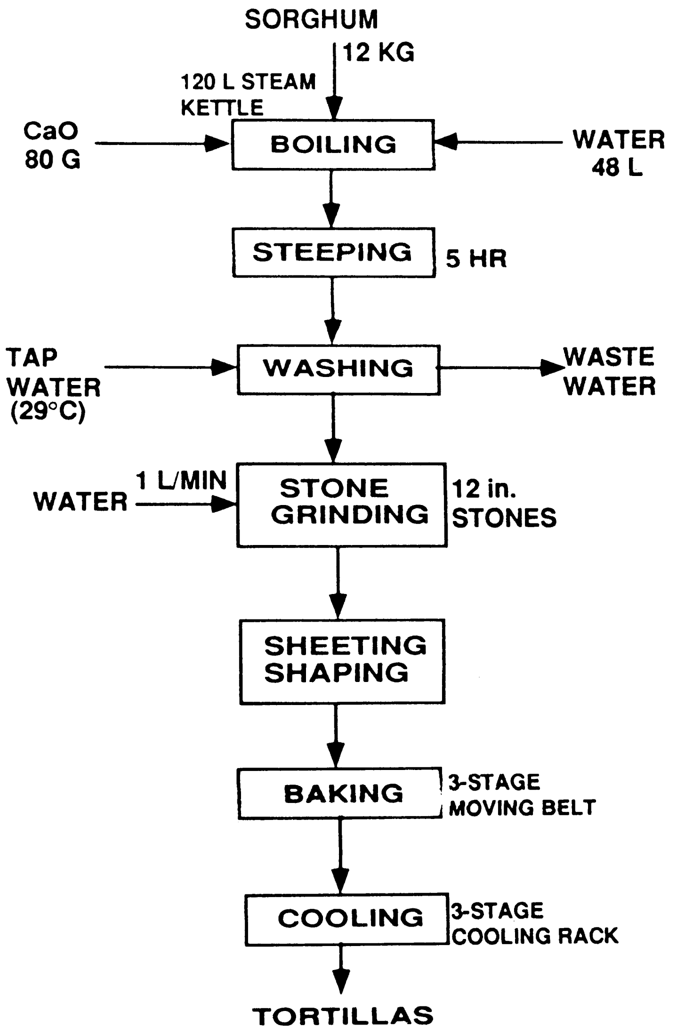

Fig. 1. Procedure used for pilot plant production of sorghum tortillas.

Inc., Pico Rivera, CA) into tortilla disks. Tortilla thickness was indirectly controlled by producing 35 ± 1 g of raw tortilla pieces. Once the thickness was regulated, the masa disks were continuously baked into tortillas in a gas-fired oven with a three-stage moving belt (model C0440, Superior Food Machinery). Masa with 56–59% moisture was the most suitable for making tortillas by machine sheeting and forming and yielded fresh tortillas with good rollability. Tortillas were baked for 39 sec with average temperatures of 343, 222, and 220°C for the first, second, and third tiers, respectively. Then tortillas were conveyed onto a three-stage cooling rack (model 3106-INF, Superior Food Machinery) with an average residence time of 60 sec. Tortillas were equilibrated at room temperature for about 10 min, weighed, and packed in low-density polyethylene bags.

Yields of nixtamal, masa, and tortillas, dry matter losses (grams of dry matter lost per 100 g of initial dry grain) during cooking, and water uptake (grams of water per 100 g of dry nixtamal) of masa were determined.

Analyses

The grain density of 80 g of sorghum was determined using a nitrogen comparison multipycnometer (model MUP-1 S/N 232, Quantachrome Corp., Syosset, NY) with a large cell. Grain hardness (grams of matter removed per 100 g of whole grain) was measured by 4-min decortication of 20-g samples with a Tangential Abrasive Dehulling Device equipped with an aluminum oxide abrasive disk (38A46-I8VBE) and an 8-hole base (TADD, model 4E-115, Venables Machine Works Ltd., Saskatoon, SK), as described by Oomah et al (1981).

Color of raw, whole, and decorticated grain flour, masa, and tortillas was determined using a Gardner colorimeter (Gardner XL-10 Digital Color Difference Meter, lab scale CG-6533, Bethesda, MD) (standard tiles: $L = +91.77$, $a = -1.07$, and $b = +1.36$). Tortilla texture was determined subjectively by rolling a 1-in.-wide tortilla strip around a 1-in.-diameter dowel and grading on a five-point scale (1 = immediate breakage and 5 = no breakage during rolling).

Masa was fractionated by suspending 5 g of masa in a 20-ml solution of ethanol and water (1:1) and sieving through a set of 20-, 40-, and 100-mesh sieves as decribed by Gomez (1988). Fractions retained on each sieve were dried and weighed.

Moisture content of raw grain, nixtamal, masa, and tortillas was determined from the weight loss of samples dried at 100°C for 48 hr in a forced-air oven. The soluble solids content of masa was determined by suspending 5 g of masa in 20 ml of water, centrifuging at 1,949 × *g* for 20 min, collecting the supernatant, and drying at 100°C for 24 hr in a forced-air oven. Tortilla pH was determined following AACC method 02-52 (AACC 1976). Pericarp removal was evaluated subjectively after staining the lime-cooked kernels with eosine Y and methylene blue and washing with methanol as described by Serna-Saldivar et al (1988a).

Statistical Analysis

Multiple mean comparisons were performed using general linear models, and paired comparisons were performed using Fisher's least significant difference with a completely randomized experimental design. Two replications were done on all experiments, and three or more observations were taken for each determination within a replicate. RSQUARE and RSREG procedures were used for variable selection and variable transformation during multiple regression analysis (Freund and Littell 1986).

RESULTS AND DISCUSSION

Physical Characteristics of Sorghums

Among all raw whole-grain and decorticated-grain flours, red sorghum (A378 × TX430) had the darkest and greenest color (Table II). Decortication of the grains significantly improved color of all sorghum types. The *b* values of decorticated grains were highest for ATX631 × TX435, followed by ATX630 × TX435, ATX631 × TX8505, and DK41Y. These sorghums had hetero-yellow or yellow endosperms.

Sorghums had significantly ($\alpha = 0.05$) different densities, 1,000-kernel weight (TKW), and hardness. Density of sorghums ranged from 1.341 to 1.381 g/cm^3 (Table II). Maicillos Criollos and Tortillero had the lowest density. Kernels of Maicillos Criollos and waxy (ATX630 × R3338) sorghum were the smallest, whereas the red sorghum kernels were the largest. Maicillos Criollos and Sureno had the softest and hardest kernels, respectively.

TABLE II
Physical Properties of the Raw Sorghum Samples[a]

	Color[b]								
	Whole grain			Decorticated Grain			1,000-kernel Weight	Density	
Type	*L*	*a*	*b*	*L*	*a*	*b*	(g)	(g/cm^3)	Hardness[c]
U.S. commercial hybrids									
A378 × TX430	68.9	3.7	10.3	79.8	1.0	13.7	37.0	1.358	22.3
A2557 × OK111	72.9	2.6	13.0	81.8	0.3	13.9	31.0	1.359	19.9
DK41Y	72.2	2.4	13.0	81.7	0.5	14.1	30.3	1.381	19.0
TAES[d] experimental food-type hybrids									
ATX630 × TX435	73.4	1.7	14.5	82.2	−0.5	14.5	36.7	1.368	20.0
ATX630 × R3338	75.3	1.7	11.6	82.3	0.3	10.5	27.3	1.377	16.1
ATX631 × TX8505	76.1	1.3	14.3	83.1	−0.7	14.0	31.3	1.381	20.8
ATX631 × TX435	75.4	1.5	14.7	83.2	−0.7	15.2	34.7	1.366	21.8
Central America food types									
A155 × SC1207-2	76.2	2.0	12.4	83.5	−0.1	11.3	31.7	1.362	19.1
Catracho (Guatemala)	74.9	2.6	12.3	83.2	0.2	11.0	33.3	1.363	17.6
Dorado (El Salvador)	77.7	1.3	13.2	83.3	−0.4	10.9	36.0	1.372	19.7
Sureno (Honduras)	78.3	1.4	13.7	82.4	−0.3	11.8	31.3	1.372	15.4
Tortillero (Honduras)	76.5	1.6	13.2	82.1	−0.1	11.1	32.3	1.347	18.9
Maicillos Criollos[e] (Guatemala)	78.6	1.6	10.3	87.5	−0.1	10.3	25.0	1.341	30.5
Least significant difference (0.05)	0.6	0.2	0.3	0.9	0.3	0.6	1.3	0.005	1.4

[a] Values are means of two to six observations.
[b] Values are from a Gardner colorimeter using standard tiles: *L* (whiteness) = +91.77, *a* (greeness) = −1.07, and *b* (yellowness) = +1.36.
[c] Calculated as grams of tissue removed per 100 g of whole grain using a tangential abrasive dehulling device. The higher the value, the softer the grain.
[d] Texas Agricultural Experiment Station, College Station.
[e] A composite of several types of Maicillos Criollos.

TABLE III
Moisture Content (MC, %), Dry Matter Losses (DML),[a] and Water Uptake (WUT)[b] of Sorghums Boiled for Different Times and Steeped for 5 hr[c]

	Boiling Time								
	0 min			5 min			10 min		
Type	MC	DML	WUT	MC	DML	WUT	MC	DML	WUT
U.S. commercial hybrids									
A378 × TX430	46.7	3.5	87.5	49.8	4.3	99.5	52.7	5.5	111.3
A2557 × OK111	46.9	3.0	88.2	48.6	3.6	94.7	53.2	5.4	113.8
DK41Y	47.4	3.4	90.0	48.6	4.4	94.7	55.6	7.0	125.0
TAES[d] experimental food-type hybrids									
ATX630 × TX435	48.3	4.8	93.3	50.9	6.0	103.8	53.6	7.9	115.4
ATX630 × R3338	50.6	4.8	102.4	52.4	5.5	110.0	55.1	7.8	122.6
ATX631 × TX8505	48.5	4.6	94.0	50.3	5.6	102.4	56.1	9.1	127.6
ATX631 × TX435	49.7	4.4	98.8	50.4	5.7	101.4	54.4	7.3	119.1
Central America food types									
A155 × SC1207-2	50.0	4.4	100.0	52.2	6.5	109.0	55.6	8.4	125.2
Catracho (Guatemala)	48.4	3.1	93.7	49.5	3.9	98.1	54.4	6.6	119.3
Dorado (El Salvador)	51.8	6.7	107.6	54.9	11.0	121.5	59.0	13.1	143.8
Sureno (Honduras)	49.6	4.0	98.4	55.1	6.5	122.5	58.0	9.4	138.3
Tortillero (Honduras)	48.2	3.1	93.2	51.3	4.0	105.5	54.7	5.7	120.8
Maicillos Criollos[e] (Guatemala)	54.1	10.4	117.8	56.1	11.5	128.0	59.1	14.0	144.2
Least significant difference (0.05)	1.4	0.8	5.7	1.3	1.1	5.6	1.7	2.5	8.5

[a] DML = grams of dry matter loss per 100 g of initial dry grain.
[b] WUT = grams of water per 100 g of dry nixtamal.
[c] Values are means of four observations.
[d] Texas Agricultural Experiment Station, College Station.
[e] A composite of several types of Maicillos Criollos.

TABLE IV
Optimum Cooking Time and Physical Properties of Cooked Grains and Masas[a]

Type	Optimum Cooking Time[b] (min)	Pericarp Removal[c]	Particle Size[d]				Color[e]		
			+20 mesh	+40 mesh	+100 mesh	−100	*L*	*a*	*b*
U.S. commercial hybrids									
A378 × TX430	6.92	4.0	17.3	14.6	14.2	53.9	52.5	4.6	11.9
A2557 × OK111	7.95	4.0	9.7	11.1	18.1	61.2	61.7	1.4	12.9
DK41Y	7.22	2.5	9.5	12.2	15.7	62.7	62.7	1.2	13.8
TAES[f] experimental food-type hybrids									
ATX630 × TX435	5.13	2.5	10.7	15.2	18.7	55.5	65.6	1.3	16.5
ATX630 × R3338	1.40	4.5	14.6	25.6	22.9	36.8	63.9	1.7	13.2
ATX631 × TX8505	5.87	4.0	12.0	19.6	14.3	61.0	67.5	1.8	16.8
ATX631 × TX435	6.20	4.0	13.0	14.0	15.7	57.4	66.6	1.8	17.0
Central America food types									
A155 × SC1207-2	2.72	4.0	11.6	14.3	17.0	57.1	66.2	1.6	13.6
Catracho (Guatemala)	7.00	4.5	22.0	14.4	15.7	48.0	64.6	2.9	14.4
Dorado (El Salvador)	−0.50	2.5	9.9	13.5	19.6	57.0	68.6	1.4	14.9
Sureno (Honduras)	1.10	5.0	13.8	11.3	16.0	58.9	70.4	1.6	15.8
Tortillero (Honduras)	4.48	5.0	23.3	11.9	12.3	52.5	66.3	1.9	16.2
Maicillos Criollos[g] (Guatemala)	−2.00	2.0	16.7	13.4	15.2	56.7	65.5	1.4	13.4
Least significant difference (0.05)	...	0.9	11.3	6.5	4.5	15.8	0.82	0.28	0.3
Maize (Asgrow 405W)	50.00	...	...	16.4	14.4	69.2	76.9	0.1	15.4

[a] Values are means of two to six observations.
[b] Calculated time. Negative values indicate the time allowed between cutoff of steam and addition of grains to kettle.
[c] Subjective test rating grains on a five-point scale (1 = pink color, complete pericarp removal, and 5 = blue color, no pericarp removal).
[d] Grams of dry matter retained over sieve per 100 g total recovery. −100 = throughs of the 100-mesh sieve.
[e] Color values from a Gardner colorimeter using standard tiles: *L* (whiteness) = +91.77, *a* (greenness) = −1.07, and *b* (yellowness) = +1.36.
[f] Texas Agricultural Experiment Station, College Station.
[g] A composite of several types of Maicillos Criollos.

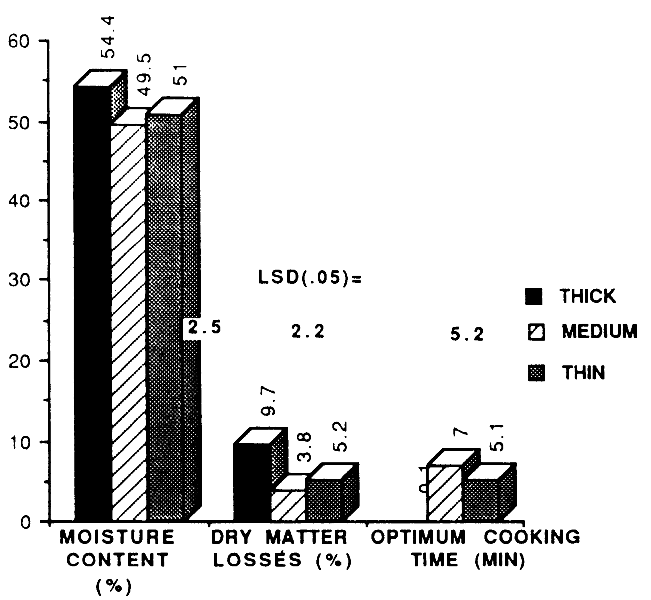

Fig. 2. Effect of pericarp thickness on nixtamal moisture content and dry matter losses during 5-min boiling and optimum cooking time. LSD = least significant difference.

Grain-Cooking Trials

DML and WUT were significantly ($\alpha = 0.01$) different among sorghum cultivars (Table III). Maicillos Criollos had the highest DML and WUT at all three boiling times. Of the Central American sorghums, Dorado, a white sorghum with large kernel, had the highest DML and WUT. The experimental sorghums from TAES had higher DML than the U.S. commercial sorghums at all boiling times.

Soft sorghums with thick pericarp absorbed water more rapidly, lost more dry matter during cooking, and had shorter optimum cooking times than sorghums with thin pericarp and hard endosperm (Fig. 2). The negative correlation ($r = -0.97$) between optimum cooking time and nixtamal moisture content after 5 min of boiling indicated that grains that absorbed water more readily required shorter cooking times. Maicillos Criollos and Dorado, both with soft endosperm and thick pericarp, absorbed water more readily than the other samples. Thus, these two sorghums were cooked without boiling. This meant that the raw grains were added to the steam kettle at a given time after steam was cut off, i.e., 2.0 min for Maicillos Criollos (Table IV). Endosperm hardness has a significant effect on WUT. We believe that a sorghum with soft endosperm and thin pericarp would have high WUT.

Optimum cooking time (OPCOTI) of sorghums was predicted by kernel hardness (HARDNESS) and TKW using multiple regression procedures. The model:

$$\text{OPCOTI} = -51.49 + (0.01 \times \text{TKW}) + (5.25 \times \text{HARDNESS}) - (0.12 \times \text{HARDNESS}^2)$$

accounted for 75.4% of the total variation in optimum cooking time. The model indicated that for a given grain size (TKW) the relationship between OPCOTI and HARDNESS was a second-degree polynomial. TKW was linearly related to OPCOTI; bigger grains had longer cooking times.

Tortilla Productions

Nixtamal with moisture content of 49–54% was acceptable for stone grinding provided that additional water was supplied (about 1 L/min) during grinding. Most of the pericarp was removed from the soft Maicillos Criollos during cooking, whereas the pericarp was mostly intact in the hard Sureno kernels (Table IV). DML and WUT during cooking for the optimum times were not significantly different. Overall means were 4.64% DML and 107% WUT for sorghums and 7.45% DML and 72.2% WUT for maize. Use of proper cooking time for each sorghum is required to avoid excessive loss of dry matter and to produce masa with physical properties acceptable for machine handling and tortillas with adequate texture.

About 23% or less of the masa dry matter was particles retained on the 20-mesh sieve, whereas 50% or more passed through the 100-mesh sieve for most of the samples (Table IV). Finer particles contained more free starch, which imparts elasticity to the masa

TABLE V
Physical Properties of Tortillas[a]

Type	Color[b] L	Color[b] a	Color[b] b	Texture[c] (rollability after three days of storage)	pH	Moisture Content (%)	Tortilla/Grain Ratio
U.S. commercial hybrids							
A378 × TX430	46.9	4.1	10.7	4.5	7.56	48.39	1.47
A2557 × OK111	56.3	1.4	11.9	4.0	7.54	44.81	1.48
DK41Y	56.9	1.3	12.5	4.4	7.61	46.16	1.53
TAES[d] experimental food-type hybrids							
ATX630 × TX435	56.7	1.8	14.9	3.5	7.30	45.70	1.53
ATX630 × R3338	54.6	1.9	12.2	3.2	7.23	46.03	1.51
ATX631 × TX8505	59.6	2.4	16.0	4.3	7.54	48.04	1.54
ATX631 × TX435	58.8	2.3	16.1	4.3	7.55	49.12	1.56
Central America food types							
A155 × SC1207-2	60.1	1.8	12.6	3.8	7.42	45.80	1.53
Catracho (Guatemala)	56.6	3.2	13.4	4.4	7.66	49.31	1.45
Dorado (El Salvador)	62.0	1.3	13.7	4.1	7.13	45.69	1.43
Sureno (Honduras)	63.3	1.8	14.6	3.2	7.27	44.80	1.50
Tortillero (Honduras)	59.5	2.1	14.6	3.4	7.17	45.05	1.48
Maicillos Criollos[e] (Guatemala)	54.5	2.0	12.2	3.3	7.68	44.80	1.49
Least significant difference (0.05)	1.4	0.4	0.4	0.6	0.12	NS	NS
Maize (Asgrow 405W)	72.3	−0.1	14.1	3.8	7.20	44.26	1.53

[a] Values are means of two to six observations. NS = nonsignificant at $\alpha = 0.05$.
[b] Color values from a Gardner colorimeter using standard tile: L (whiteness) = +91.77, a (greenness) = −1.07, and b (yellowness) = +1.36.
[c] Values from a scale of 1 (highly breakable tortillas) to 5 (nonbreakable tortillas) by a subjective evaluation of tortilla rollability.
[d] Texas Agricultural Experiment Station, College Station.
[e] A composite of several types of Maicillos Criollos.

and produces flexible tortillas (Gomez 1988). Sureno and Dorado produced the whitest masa, whereas ATX631 × TX8505 and ATX631 × TX435 (both with heteroyellow endosperm) produced masa with the highest yellow tones.

The baked tortillas weighed 25–29 g with 45–49% moisture content (Table V). The average moisture content of sorghum materials during the whole cooking process was about 2–3 percentage points higher than values generally observed for maize. Average moisture contents of raw sorghum grain, nixtamal, and masa were 12 ± 0.3, 51 ± 2.8, and 58 ± 1.9%, respectively. These values for maize were 9 ± 0.5, 48 ± 1.2, and 56 ± 0.9%, respectively. Approximately 10% moisture was lost during baking, as previously reported by Serna-Saldivar et al (1988b).

All fresh tortillas, except those from waxy sorghum, had acceptable rollability. Waxy sorghum produced very sticky masa and tortillas with rubberlike texture that became rigid after three days of storage. The effect of sorghum type on yield (kg) of tortillas was not significant ($\alpha = 0.05$); however, waxy sorghum produced many irregularly shaped tortillas that caused increased tortilla waste during processing. The cooking and handling properties of waxy sorghum were unacceptable for alkaline cooking and processing. The average conversion ratio of raw grain into tortillas was 1.5 ± 0.04 kg of fresh tortilla per kilogram of raw grain for both sorghum and maize (Table V). Average conversion rates of materials during processing of sorghum were 1.77 ± 0.09 kg of nixtamal per kilogram of raw grain, 1.16 ± 0.03 kg of masa per kilogram of nixtamal, and 0.73 ± 0.03 kg of tortilla per kilogram of masa. For maize, these values were 1.65 ± 0.7, 1.19 ± 0.5, and 0.78 ± 0.04, respectively.

Plant color had a significant ($\alpha = 0.01$) effect on color of raw grains and tortillas (Fig. 3). Kernels with tan plant color produced the whitest and yellowest raw grains and tortillas.

Three sorghums from Central America (Dorado, Sureno, and Tortillero) and two experimental ones from TAES (ATX631 × 435 and ATX631 × TX8505) produced the whitest tortillas (Table V). Dorado and Sureno kernels produced the whitest (highest L value) sorghum tortillas, which were darker and as yellow (similar b value) as tortillas from Asgrow 405W maize. The color values of these five selected cultivars are similar or better than the decorticated white sorghums tested by Bedolla et al (1983) and Choto et al (1985). Considering that undecorticated whole sorghum was used, the five selected cultivars deserve the highest attention for further studies and use for tortilla production. Kernels of ATX631 × TX435 and ATX631 × TX8505 (both with heteroyellow endosperm) produced the most yellow (highest b value) tortillas, which were even more yellow than maize tortillas. None of the white sorghum cultivars produced tortillas with green coloration.

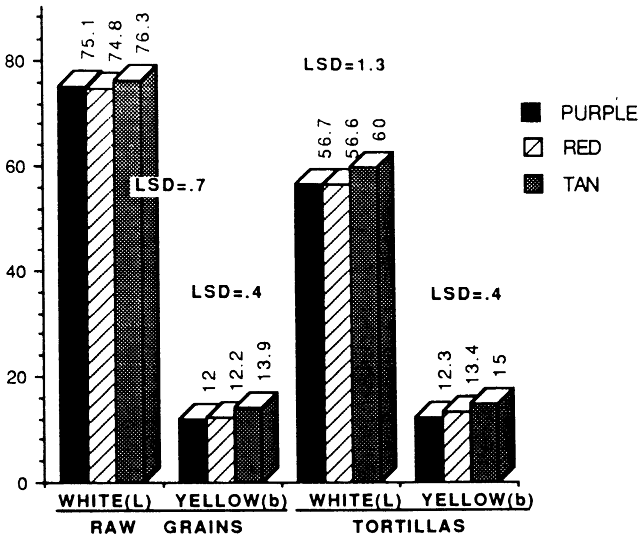

Fig. 3. Effect of plant color on color of raw grain and tortillas. LSD = least significant difference.

Significant ($\alpha = 0.01$) correlations between whiteness (L value) of raw whole-grain flour and tortilla whiteness ($r = 0.74$) and between yellowness (b value) of raw whole-grain flour and tortilla yellowness ($r = 0.86$) were found. Similar correlations were found by Khan et al (1980). The color of raw sorghum kernels can be used to predict the color of tortillas. The following equation predicted about 66% of the total variation in tortilla whiteness (L value) from the grain whiteness:

$$L_{\text{tortilla}} = -886.22 + 24.36 \times L_{\text{grain}} - 0.16 \times L^2_{grain}.$$

The grain yellowness (b value) accounted for 82% of the total variation of the tortilla yellowness according to the following equation:

$$b_{\text{tortilla}} = 36.71 - 4.92 \times b_{\text{grain}} + 0.24 \times b^2_{grain}.$$

Tortillas from ATX631 × TX835 and ATX631 × TX8505 had acceptable rollability even after three days of storage at room temperature in sealed polyethylene bags. Tortillas from Catracho (red plant color) had good rollability after three days of storage but had a light reddish coloration.

Cooking time was correlated with tortilla rollability ($r = 0.67$ at $\alpha = 0.01$) and tortilla whiteness ($r = -0.75$ at $\alpha = 0.01$). Sorghums that had longer optimum cooking times produced tortillas with the best rollability but decreased whiteness. A prolonged cooking time results in more darkening caused by phenolic color development.

CONCLUSIONS

Optimum cooking time varied among the 12 white sorghums. Softer kernels required shorter cooking times. The reduced energy required for cooking sorghum kernels is an advantage for home or commercial operations where reduction of energy costs is desired. Use of proper cooking time for each sorghum cultivar not only helps provide appropriate texture of masa and tortillas but also helps avoid excessive dry matter loss.

A nixtamal moisture content of 51% was adequate for stone grinding, producing a masa suitable for table tortilla production. Masa with 58% moisture content was optimum for sheeting and forming.

All sorghum samples tested, except for the waxy sorghum, produced fresh tortillas with acceptable rollability.

Five sorghum samples (Dorado, Sureno, and Tortillero, from Central America, and ATX631 × TX8505 and ATX631 × TX435, from TAES) produced tortillas with acceptable color and rollability. These cultivars produced tortillas with yellowness that was comparable to but slightly darker than that of white maize tortilla.

Machinability and texture of sorghum masas and tortillas were similar to maize masas and tortillas. Kernels with white thick pericarp, tan plant color, straw glumes, and yellow endosperm have excellent potential for the manufacture of tortillas and other human foods.

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