

Sensory Characteristics of Grain Sorghum Hybrids with Potential for Use in Human Food¹

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ABSTRACT

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Descriptive sensory characteristics were measured for porridges made from flour samples collected from the 1996 Kansas feed grain sorghum performance tests and from commercial food grain sorghum samples. Totals of eight and 11 sensory attributes characterized the feed grain and food grain samples, respectively. Two screenings provided descriptive sensory data for univariate and multivariate analyses. Four feed grain samples from the performance tests and seven food grain samples were

identified as low in astringency and bitterness; six of these were used in 100% sorghum flour muffins to determine consumer acceptability. Flavor acceptability of muffins was perceived as equal, and appearance was an important factor for acceptance. Optimization of all sensory attributes for each specific product is needed to increase acceptability of grain sorghum in consumer products.

Grain sorghum contains phenolic compounds other than tannin that affect the sensory characteristics and the nutritional quality of the grain and its subsequent products (Hahn et al 1984). These compounds, alone or in combination with other components, give rise to sensory characteristics that impart astringency and bitter and sour tastes (Maga and Lorenz 1973), which affect overall acceptability of a given product. Some phenolic acids act as antioxidants and anticarcinogens (Ho 1992) and normally are located in the pericarp. Decortication removes the pericarp and can alter the beneficial health effects and the flavor of grain sorghum for use in foods.

Data sets with several variables (large number of samples, chemical components, and sensory characteristics) can produce ambiguous findings. Univariate and multivariate procedures have been used to separate and interpret such data sets. Univariate analysis often uses a weighting factor for each variable in screening studies. Falconer (1964) used an index to sort through the multivariate factors involved in genetic selection. Milliken et al (1990) computed a score that reflected the weighted linear combination of predetermined attributes of samples in determining an optimum formula for a healthful muffin. The scores were analyzed using a response model. Yang et al (1994) assigned weights to sensory ratings of individual panelists based on perception and performance. Analysis of variance (ANOVA) and multivariate procedures indicated that the weighted method is useful in accentuating sample differences.

Multivariate statistical procedures have been used in the sensory field for applications such as evaluation of panelist performance (Powers 1984), sensory characterization of beer flavor (Mawatari et al 1991), relating consumer liking to sensory profile description of mozzarella cheese (Pagharini et al 1997), and establishing relationships between sensory and chemical parameters in white cabbage (Martens 1985). Cluster analysis (CA), principal component analysis (PCA), and multivariate analysis of variance (MANOVA) are three commonly used multivariate analysis procedures.

The objectives of this study were to 1) characterize the flavor properties of feed grain and food grain, whole and decorticated sorghum samples grown in different geographical regions in Kansas and Texas; 2) screen samples for potential human use, based on descriptive sensory data, using univariate and multivariate statistical methods; and 3) validate the screening results with consumer testing.

MATERIALS AND METHODS

Grain Sorghum Samples

This study used two groups of grain sorghum samples (Table I). Kernel and plant characteristics of samples are shown in Table II. The first group included 19 samples that represented commonly grown commercial feed grain hybrids from the Kansas grain sorghum performance tests for the 1996 crop year, plus two Cargill parental lines. These samples were cultivated under a wide range of conditions in several Kansas locales: northwest (Thomas County [TH]), southwest (Finney County [FI]), southeast (Labette County [LAB]), and northeast (Brown County [BRO]). Suppliers included Pioneer (P), Crosbyton (OKTX), Cargill (C), and Dekalb (D). Growing conditions in Thomas and Finney counties are indicated as "I" for irrigated and "F" for fallow.

The second group included 22 food grain sorghum samples from the 1996 crop year obtained from commercial seed companies in Texas and Kansas (Tables I, II) plus a subset of feed grains selected from screening I. Jowar whole grain (JWG) and Jowar decorticated grain (JDG) samples obtained from two different sources were used as a check on variability within a sample type. Darker (d) and lighter (l) sample versions of NC+ XFG665 were supplied by NC+ Hybrids.

Flour Preparation

Whole grain sorghums were cleaned to remove impurities and then ground without decortication, except for the Jowar commercial samples that were obtained from suppliers in decorticated form. Grinding involved one pass each on commercial grinders set for the finest particle size (Kitchen Mill, K-Tec, Orem, UT; Grain Master Whisper Mill, Creative Technologies, Salt Lake City, UT). The resulting flours had an average particle size of 22 μm (subsieve sizer, Fisher Scientific Co., Fairlawn, NJ). Prepared flours were packed in one-gallon Ziploc plastic freezer bags (DowBrands, Indianapolis, IN) and stored frozen until used.

Instrumental Color Analysis

Color of whole grains and flours was measured using a spectrophotometer (UltraScan, HunterLab, Reston, VA) to obtain L , a , b values. Hue angle was calculated as $\tan^{-1}(b/a)$.

Descriptive Sensory Methodology

In screening I, 1:4 (w/w) mixtures of grain sorghum flour and water porridges were heated to 70°C. In screening II, a 1:6 ratio of grain sorghum flour and water was heated to 83.0 \pm 2.0°C to assure complete starch gelatinization at 71–80°C (Sweat et al 1984). Six professional panelists, all women, with >200 hr of training were chosen from a pool at the Sensory Analysis Center of the Department of Foods and Nutrition, Kansas State University, Manhattan, KS.

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TABLE I
Grain Sorghum Samples from Crop Year 1996 Obtained from Kansas and Texas Suppliers Evaluated During Screenings I and II

Screening I: Feed Grains ^{a-c} (by growing locale)	Screening II: Food Grains ^d (by supplier)
Northeast	Jowar Foods Inc., TX
P8212y BRO	Whole grain (JWG)
P8505 BRO	Decorticated grain (JDG)
OKTX BRO	NC+ Hybrids, KS
C737 BRO	NC+ XFG665 (darker)
DK-45 BRO	NC+ XFG665 (lighter)
Southeast	NC+ X-40934
P8212y LAB	Cargill Hybrid Seeds, TX
P8500 LAB	R13034
OKTX LAB	R16013
C737 LAB	R19033
DK-45 LAB	HP162
DK-40y LAB	Dorado
Northwest	A15043
P8505 THI	A39006
OKTX THF	A11034
OKTX THI	Commercial (Comm) 611y
C737 THI	X23333
Southwest	X12010
OKTX FIF	X13116
OKTX FII	Asgrow Seed Co., TX
	JWG and JDG
	J96V1845
	J96V1851
	J96V1848

^a All grains from Kansas crop performance tests, except C737 parental lines also included in this study.

^b Suppliers: Pioneer Hi-Bred, Intl., Amarillo, TX (P); Crosbyton Seed Co., Crosbyton, TX (OKTX); NC+ Hybrids, Colwich, KS (NC+); Cargill Hybrid Seeds, Lockney, TX (C); Dekalb Genetics, Mt. Hope, KS (DK).

^c Kansas counties: Labette (LAB); Brown (BRO); Thomas irrigated (THI); Thomas fallow (THF); Finney irrigated (FII); Finney fallow (FIF).

^d Obtained directly from each supplier. In addition, some grain sorghum samples from screening I were included in screening II.

Orientation included 4 hr over a three-day period to familiarize the panelists with the samples, modify descriptive terms from a previous study (Chang 1997), and establish testing procedures. Eight attributes were evaluated: dusty aroma, bitter taste, astringency, dusty flavor, nutty flavor, green flavor, and sweet and sour tastes. Nutty flavor and sweet taste were considered positive attributes. The definitions and references used are given in Table III.

Before tasting each sample, panelists cleared their palates using a cracker and a deionized water rinse. Porridge portions (20 g) were served to each panelist at ambient temperature in plastic cups (90 mL, Solo Cup Co., Urbana, IL) covered with a watch glass (6.5-cm diameter). Panelists were asked to use 5 g (1/4 tsp) of sample for each evaluation. An interstimulus rinse consisting of 0.5% carboxymethylcellulose (CMC-7H3 SF, Aqualon, Wilmington, DE) in deionized water was used after evaluating bitterness, astringency, and sweetness (Brannan et al 2001). Deionized water was used as the interstimulus rinse for evaluations of the other sensory characteristics. Each attribute was rated on a 150-mm line scale, where a higher score corresponded to a stronger intensity.

In screening II, seven panelists, six women and one man, were recruited from the Manhattan, KS, area and received 25 hr of general training in descriptive sensory analysis. An additional 4-hr orientation familiarized the panelists with the grain sorghum samples, modified terminologies from screening I, and established testing procedures. Three attributes (woody aroma, green aroma, and doughy flavor) plus the original eight attributes (Table III) were evaluated.

Acceptability testing based on a 9-point hedonic scale was used to determine whether screenings I and II were successful in predicting which sorghums would be acceptable in a typical, bland bakery product.

Consumer Acceptance Testing

Consumer test I used a plain muffin formula supplied by Jowar, Inc. (Hereford, TX) with slight modification (Table IV). Six samples were used: C Comm 611y, OKTX THI, JDG (purchased), C737

TABLE II
Kernel and Plant Characteristics of Grain Sorghum Samples^a

Sample	Pericarp		Appearance		Endosperm		
	Color	Thickness	Plant	Glume	Color	Type	Texture
Feed grains							
DK-45	White/colorless	Medium	Purple	Dark tan	Hetero-yellow	Normal	Intermediate
DK-40y	White/colorless	Thin	Purple	Light tan	Yellow	Normal	Corneous
P8505	Red	Thin	Purple	Mahogany	White	Normal	Intermediate
P8500	Red	Thin	Purple	Mahogany	White	Normal	Intermediate
P8212y	White/colorless	Thin	Purple	Mahogany	Yellow	Normal	Intermediate
OKTX	White/colorless	Medium	Purple	Dark	Yellow	Normal	Intermediate
C737	Red	Unknown	Purple	Purple	White	Unknown	Unknown
C737 parental lines							
C737 female	Red	Unknown	Purple	Red-purple	White	Unknown	Unknown
C737 male	White/colorless	Unknown	Purple	Tan	White	Unknown	Unknown
Food grains							
JWG or JDG	White/colorless	Thin	Tan	Light straw	White	Normal	Intermediate to corneous
NC+ X-40934	White/colorless	Unknown	Tan	Blonde	White	Hetero-waxy	Intermediate
J96V1851	White/colorless	Thin	Tan	Straw or light red	White	Normal	Corneous
NC+ XFG665	White/colorless	Unknown	Tan	Tan	Hetero-yellow	Hetero-waxy	Intermediate
C Dorado	White/colorless	Unknown	Tan	Light brown	White	Unknown	Unknown
C A15043	White/colorless	Unknown	Tan	Straw	Yellow	Unknown	Unknown
C R19033	White/colorless	Unknown	Tan	Tan	Yellow	Unknown	Unknown
C R13034	White/colorless	Unknown	Tan	Straw	Yellow	Unknown	Unknown
C HP162	White/colorless	Unknown	Tan	Tan	Yellow	Unknown	Unknown
C R16013	White/colorless	Unknown	Tan	Tan	Yellow	Unknown	Unknown
C A39006	White/colorless	Unknown	Tan	Tan	Yellow	Unknown	Unknown
C A11034	White/colorless	Unknown	Tan	Red-tan	Yellow	Unknown	Unknown
C Comm 611y	White/colorless	Unknown	Tan	Light brown	Yellow	Unknown	Unknown
C X12010	White/colorless	Unknown	Tan	Tan	Yellow	Unknown	Unknown
C X13116	White/colorless	Unknown	Tan	Brown	Yellow	Unknown	Unknown
C X2333	White/colorless	Unknown	Tan	Tan	Yellow	Unknown	Unknown
J96V1848	White/colorless	Thin	Tan	Straw	White	Normal	Intermediate to corneous
J96V1845	White/colorless	Thin	Tan	Straw	White	Normal	Intermediate to corneous

^a Suppliers: Jowar Foods, Hereford, TX (J); Cargill Hybrid Seeds, Lockney, TX (C); NC+ Hybrids, Colwich, KS (NC+); Pioneer Hi-Bred, Intl., Amarillo, TX (P); Crosbyton Seed Co., Crosbyton, TX (OKTX); Dekalb Genetics, Mt. Hope, KS (DK). Testa were absent in all samples.

male, C737 female, and NC+ XFG665 (d). Three samples chosen from the 11 identified in the screening II had relatively low levels of the negative flavor attributes for bitterness, astringency, green aroma, and dusty flavor. Availability of samples was determined, and PCA was used to identify three other samples with high levels of the negative attributes.

A total of 53 consumers, who were cereal product users, were recruited from the Manhattan, KS, area and paid to participate in consumer test I. The group included 30 males and 23 females within the ages of 18–64. Consumers rinsed with water and a cracker at the start of the 0.5-hr session. In addition, 15 mL of a 2:1 tapioca pudding and 3% CMC gum solution was used between evaluations. (This was based on preliminary studies that indicated it effectively alleviated drying or astringent sensations.) Each panelist was served one-half muffin in a resealable Ziploc snack-size bag with randomized three-digit codes. Whole samples were available for appearance evaluations. The hedonic scale (1 = dislike extremely; 9 = like extremely) was used for evaluations of overall appearance, aroma, flavor, and texture acceptability.

Consumer test II attempted to determine the roles of color and flavor for consumer acceptability. Two samples were chosen from the remaining available samples of the two groups based on flavor characteristics. Appearance attributes used for selection included the highest and lowest *L* and *b* values for muffins and *L* values for flour.

Prescreened cereal product consumers (10 males and 34 females) within the ages of 18–63 were recruited from the Manhattan, KS area. The procedure outlined in consumer test I was followed, and color was evaluated in addition to the other five factors evaluated.

Experimental Design

A completely randomized design with each sorghum sample as the experimental unit and three replicates was used in both screening stages. In screening I, test sessions were conducted over a five-

TABLE IV
Muffin Formula and Baking Procedure^a

Ingredients	Original	Modified
Dry (g)		
Grain sorghum flour	220	110
Cornstarch	20	10
Sugar, granulated	32	13
Baking powder	12	8
Xanthan gum	0	0.13
Liquid (mL)		
Whole egg and egg white mixture	77	40
Nonfat dry milk (1/3 c powder diluted to 1 c)	180	100
Shortening	88	45
Water	0	25
Procedure		
Mix dry ingredients together and set aside. Mix liquid ingredients together and pour over dry ingredients. Stir 20 strokes to moisten dry ingredients.		
Pour into greased muffin pans until 2/3 full		
Bake at 204°C	22 min	12 min
Yield	12 muffins	6 muffins

^a Formula from Jowar Foods, Hereford, TX; cornstarch from F&A's Concord, Concordia, KS; sugar from Food Club, Topco Associates, Skokie, IL; Clabber Girl baking powder from Hulman and Co., Terre Haute, IN; Keltrol xanthan gum from Kelco, San Diego, CA; Carnation nonfat dry milk from Nestle Foods, Glendale, CA; Crisco shortening from Procter & Gamble, Cincinnati, OH.

TABLE III
Lexicon and References for Evaluating Grain Sorghum in Screenings I and II

Attribute	Definition ^a	References ^b	Score		
Aroma					
Dusty	Light dusty, musty, earthy aroma associated with grain	NC 174# 9 porridge	6.0		
Woody	Aroma associated with damp, cured (kiln-dried) wood	Toothpicks soaked in water placed in a glass snifter	9.0		
Green	Aroma associated with a bag of feed, wet dog, or laundry	Asgrow A436# 1 porridge	6.0		
Flavor and taste					
Bitter	Fundamental taste of which caffeine solution is typical	Caffeine solution (%)			
		I	II	I	II
		0.01	0.01	2.0	2.0
		0.02	0.02	3.5	5.0
		0.035	0.035	5.0	12.0
0.05		6.0			
Astringent	Chemical sensation associated with puckering of tongue surface caused by substances such as tannins or alum	Alum solution (%)			
		I	II	I	II
		0.05	0.05	2.5	2.5
		0.07	0.06	3.5	8.0
		0.10	0.07	5.0	12.0
Dusty	Light dusty, musty aromatics associated with grain	NC 174# 9 porridge	7.5		
Doughy	Flavor associated with wet white flour or dough	NC 174# 9 porridge	7.5		
Nutty	Light brown, slightly musty aromatic associated with nuts, wheat germ, and certain whole grains	Gold Medal whole wheat flour			
		I	4.5		
		II	3.5		
Green	Flavor associated with green, unripe grain	Asgrow A436#1 porridge	7.5		
		Sucrose solutions (%)			
Sweet	Fundamental taste sensation of which sucrose is typical	I	II	I	II
		2.0	1.0	2.0	2.0
			2.0		7.0
Sour	Fundamental taste sensation of which citric, malic, phosphoric, and other acids are typical	Citric acid solutions (%)			
		I	II	I	II
		0.025	0.025	2.5	3.5
		0.05	0.05	3.5	9.0
		0.08	0.08	9.0	12.0

^a Aroma attributes woody and green and flavor attribute doughy were used only in screening II.

^b NC 174#9 and Asgrow A436#1 are grain sorghum samples supplied by the National Grain Sorghum Producers, Abernathy, TX. Both were grown on irrigated plots near Lubbock, TX.

TABLE V
Descriptive Sensory Attributes and Scores from Screening I of Kansas Feed Grain Sorghums^a

Samples by Locale ^{b,d}	Dusty	Green	Astringent	Dusty	Nutty	Bitter	Sour	Sweet
Northwest								
P8505 THI	44.4	28.3	31.9	43.1	31.4	29.7	17.8	9.7
OKTX THI	44.2	30.6	33.1	43.1	26.9	29.4	18.1	10.3
OKTX THF	41.4	35.0	34.7	45.6	26.4	27.2	18.6	8.6
C737 THI	36.1	37.8	33.1	44.4	26.9	32.2	18.1	8.1
Southwest								
OKTX FII	44.2	32.2	33.6	45.3	27.2	30.3	17.2	8.6
OKTX FIF	40.8	27.8	32.2	43.3	29.4	30.0	17.8	9.4
Southeast								
DK-45 LAB	37.8	33.6	33.3	45.8	25.8	29.4	18.6	8.3
DK-40y LAB	39.4	38.1	33.9	49.4	26.4	31.1	19.7	8.9
P8500 LAB	42.2	28.6	32.2	45.6	28.6	30.0	17.8	8.9
P8212y LAB	42.5	35.3	31.1	48.3	29.4	33.3	19.2	8.1
OKTX LAB	42.5	36.4	33.6	47.8	24.4	34.7	20.0	8.3
C737 LAB	36.9	33.1	31.9	45.3	30.6	31.1	19.4	8.3
Northeast								
DK-45 BRO	39.4	27.8	33.6	44.4	26.7	27.5	17.2	9.2
P8505 BRO	42.5	33.3	33.1	45.0	31.4	32.8	17.8	8.9
P8212y BRO	43.9	34.2	34.2	45.0	27.8	28.9	18.9	9.2
OKTX BRO	42.8	31.7	32.2	44.2	24.4	32.2	18.3	8.1
C737 BRO	44.4	30.8	33.3	45.6	26.7	34.2	17.2	8.6
Parental lines for C737								
C737 female	44.4	38.6	31.9	44.7	30.3	34.2	20.0	9.7
C737 male	40.3	39.2	32.2	43.9	27.5	35.8	18.9	8.9

^a Score based on a 150-mm scale where 0 corresponded to none and 150 to strong. Three replicates; $n = 6$; $df = 18$.

^b All grains from Kansas crop performance tests (except parental lines for C737).

^c Suppliers: Pioneer Hi-Bred, Intl., Amarillo, TX (P); Crosbyton Seed Co., Crosbyton, TX (OKTX); Cargill Hybrid Seeds, Lockney, TX (C); Dekalb Genetics, Mt. Hope, KS (DK).

^d Kansas counties: Labette (LAB); Brown (BRO); Thomas irrigated (THI); Thomas fallow (THF); Finney irrigated (FII); Finney fallow (FIF).

TABLE VI
Cluster Distribution and Similar Attribute Groupings from Screening I of Kansas Feed Grain Sorghums

Cluster Number	Sample ^{a,c}	Similar Attributes ^d
1	P8505 THI	- bitterness
	OKTX FIF	- green flavor
	P8500 LAB	+sweetness
	DK-45 BRO	
	OKTX THI	
2	P8212y BRO	- nutty flavor
	OKTX THF	- green flavor
	DK-45 LAB	+ dusty aroma
	OKTX FII	
	OKTX BRO	
	C737BRO	
3	P8505 BRO	- astringency
	C737 LAB	- nutty flavor
	C737 female	+ green flavor
	C737 male	- dusty aroma
	C737 THI	+ dusty flavor
	P8212y LAB	
4	DK-40y LAB	+ bitterness
	OKTX LAB	+ green flavor

^a All grains from Kansas crop performance tests (except parental lines for C737).

^b Suppliers: Pioneer Hi-Bred, Intl., Amarillo, TX (P); Crosbyton Seed Co., Crosbyton, TX (OKTX); Cargill Hybrid Seeds, Lockney, TX (C); Dekalb Genetics, Mt. Hope, KS (DK). C737 parental lines also included in this study.

^c Kansas counties: Labette (LAB); Brown (BRO); Thomas irrigated (THI); Thomas fallow (THF); Finney irrigated (FII); Finney fallow (FIF).

^d Low (-) and high (+) occurrence of an attribute in a cluster.

day period. Panelists received 10 samples on day 1; 8 samples on day 2; and 13 samples each on days 3, 4, and 5. Sessions were 1.5 hr long, except for 1 hr on day 2. In screening II, test sessions were conducted over a 12-day period with 8 samples at 1-hr sessions each day. Consumer tests I and II used a randomized complete block design (panelists were used as the blocking factor).

TABLE VII
Weighted Mean Scores^a from Screening I of Kansas Feed Grain Sorghums

Samples by Locale ^{b,c}	Weighted Mean Scores
Northwest	
P8505 THI	-5.1
OKTX THI	-5.4
OKTX THF	-5.7
C737 THI	-5.9
Southwest	
OKTX FII	-5.6
OKTX FIF	-5.2
Southeast	
DK-45 LAB	-5.6
DK-40y LAB	-6.0
P8500 LAB	-5.3
P8212y LAB	-5.8
OKTX LAB	-6.3
C737 LAB	-5.5
Northeast	
DK-45 BRO	-5.2
P8505 BRO	-5.6
P8212y BRO	-5.7
OKTX BRO	-5.8
C737 BRO	-5.8
C737 female	-5.9
C737 male	-6.1

^a Obtained by adding the weighted scores of all attributes per sample and dividing by the number of attributes. Values in bold type are the least negative and not significantly different from each other ($P > 0.05$).

^b Suppliers: Pioneer Hi-Bred, Intl., Amarillo, TX (P); Crosbyton Seed Co., Crosbyton, TX (OKTX); Cargill Hybrid Seeds, Lockney, TX (C); Dekalb Genetics, Mt. Hope, KS (DK). C737 parental lines also included in this study.

^c Kansas counties: Labette (LAB); Brown (BRO); Thomas irrigated (THI); Thomas fallow (THF); Finney irrigated (FII); Finney fallow (FIF).

Data Analysis

The Statistical Analysis System was used in analyzing all data (v. 6.12, SAS Institute, Cary, NC). For the three replicates of the instrumental appearance data, a general linear model was used with sample and replicate as main effects. Descriptive data were analyzed using univariate analysis on total weighted scores.

TABLE VIII
Descriptive Sensory Attributes^a and Scores^b from Screening II of 28 Grain Sorghum Samples

Sample ^c	DYF	BIT	AST	DF	NF	GF	SO	SW	WA	GA	DA
Food grains											
JWG ^d	22.9	15.4	27.3	21.8	17.3	28.6	8.0	8.3	24.6	30.7	22.0
NC+ X-40934	29.9	25.3	21.7	18.5	24.1	30.4	8.4	9.2	37.0	19.0	16.8
J96V1851	17.3	14.8	29.2	35.6	13.9	26.8	10.6	6.6	23.4	22.8	32.8
JDG ^e	22.7	16.9	25.0	24.6	12.6	34.2	9.4	6.6	22.5	34.5	22.6
NC+ XFG665 (d) ^f	18.3	33.9	34.2	40.5	15.1	37.7	12.7	7.0	37.9	30.5	29.7
NC+ XFG665 (l) ^f	26.6	22.9	18.3	27.9	21.3	25.8	9.4	10.7	32.7	20.4	20.7
C Dorado	17.1	20.6	25.8	26.2	14.2	40.0	11.3	7.9	20.7	44.2	21.5
C A15043	26.6	10.9	29.0	19.8	22.9	22.6	6.6	14.2	29.3	24.2	25.3
C R19033	17.5	12.7	26.3	26.2	17.7	30.4	8.1	7.1	30.7	33.7	22.4
C R13034	22.5	15.6	19.8	28.7	20.8	32.2	11.2	7.5	35.0	31.9	27.6
C HP162	18.1	26.6	33.9	32.5	20.7	29.8	11.3	8.8	29.1	31.0	23.6
C R16013	19.0	15.6	26.2	29.7	15.9	30.0	7.8	7.0	26.3	31.5	25.3
C A39006	35.0	11.3	32.7	19.0	25.2	25.2	7.0	16.3	34.1	24.5	20.3
C A11034	23.5	13.2	27.2	26.5	18.0	29.6	7.6	6.8	24.1	34.9	26.3
C Comm 611y	25.2	10.9	24.1	19.8	22.8	26.9	7.5	11.3	27.4	23.1	18.8
C X12010	10.0	17.8	41.0	24.0	10.9	46.3	10.0	4.1	29.0	35.4	20.0
JDG ^d	22.0	9.6	25.8	16.0	11.7	28.7	6.8	8.6	23.7	33.6	15.9
C X13116	11.4	23.1	37.4	35.0	12.2	45.2	11.0	7.1	31.3	35.2	24.1
C X2333	13.4	20.7	31.8	34.3	11.2	44.2	9.9	6.5	33.7	35.0	26.3
JWG ^e	13.2	14.6	27.4	36.7	9.2	48.7	10.9	11.2	26.8	57.9	29.4
J96V1848	22.6	13.5	29.0	24.3	17.7	26.5	7.7	7.7	29.3	29.3	18.1
J96V1845	19.6	14.0	29.0	26.0	19.3	31.4	7.2	6.2	28.0	29.7	23.5
Feed grains											
DK-45 BRO	20.6	17.9	29.2	26.0	14.6	23.3	7.4	7.2	30.0	18.2	24.6
P8505 THI	24.6	10.2	24.6	29.7	16.8	25.9	7.1	7.9	29.5	20.4	27.1
OKTX THI	39.5	15.7	20.4	24.2	23.0	19.4	7.8	11.2	27.6	17.0	24.1
P8500 LAB	18.6	11.4	28.2	39.5	15.5	22.7	8.6	7.7	25.8	15.8	21.3
C737 LAB	25.3	16.0	29.9	36.0	14.5	21.6	8.4	7.4	23.9	23.0	28.8
OKTX FIF	23.1	15.6	35.5	31.4	17.5	25.6	8.1	7.0	24.4	27.6	30.6

^a Doughy flavor (DYF), bitter (BIT), astringent (AST), dusty flavor (DF), nutty flavor (NF), green flavor (GF), sour (SO), sweet (SW), woody aroma (WA), green aroma (GA), dusty aroma (DA).

^b Score based on a 150-mm scale where 0 corresponded to none and 150 to strong. Three replicates; $n = 7$; $df = 27$.

^c Suppliers: Jowar Foods, Hereford, TX (J); Cargill Hybrid Seeds, Lockney, TX (C); NC+ Hybrids, Colwich, KS (NC+); Pioneer Hi-Bred, Intl., Amarillo, TX (P); Crosbyton Seed Co., Crosbyton, TX (OKTX); Dekalb Genetics, Mt. Hope, KS (DK).

^d Whole grain (JWG) and decorticated grain (JDG) supplied by Jowar Foods Inc., TX.

^e JWG, JDG, J96V1851, J96V1848, and J96V1845 all supplied by Asgrow Seed Co., TX.

^f Darker (d) and lighter (l) of the samples.

The importance of attributes based on previous observations of researchers and experience was weighted (1 = least important and 5 = most important). A positive sign (+) indicated a generally perceived desirable attribute, whereas a negative sign (-) indicated a generally perceived undesirable attribute. In screening I, the attributes derived by the panelists with the investigators' corresponding weightings were sour (-3), green flavor (-3), bitter (-5), astringent (-5), dusty flavor (-1), nutty flavor (+3), sweet (+3), and dusty aroma (-1). In screening II, woody and green aromas were assigned scores of (-3), and doughy flavor was assigned a score of (-1). The raw score for each attribute was multiplied by the assigned weight to obtain a weighted score. The weighted score for each attribute was added for each sample to obtain the total weighted score.

ANOVA and least squares means were performed on total weighted scores. Samples with the highest positive scores were identified based on the assumption that more positive attributes resulted in a more positive score. MANOVA and CA also were performed on the raw scores. ANOVA and least squares means were also performed on consumer test I data. Linear contrasts were used to compare the samples that were selected with those that were rejected based on the weighted flavor scores or multivariate analysis. Spearman correlation coefficients of consumer data with descriptive data and color values for muffin, flour, and seed were determined. Test data from consumer test I were analyzed using a paired *t*-test. PCA was performed on factors affecting consumer acceptability of muffins.

RESULTS AND DISCUSSION

Color Analysis

Whole grain sorghum samples from the Kansas performance tests and commercial suppliers had color value ranges of *L* (40–66),

a (2–8), *b* (7–17), and hue (52–92). Flour from the same samples had color value ranges of *L* (68–85), *a* (-0.04 to 4.0), *b* (9–14), and hue (74–100). There were significant differences ($P < 0.05$) for whole grain and flour *L*, *a*, *b* and hue values between the two groups.

The commercial food grain samples generally had higher *L* values than the performance test feed grain samples, indicating a lighter color. Both commercial and performance test samples had +*a* values for the whole grain, indicating redness in the samples. On the other hand, some food grain samples had a -*a* value for flour, indicating some greenness. This supports the finding that appearance is affected largely by the pericarp color. But other factors such as pericarp thickness; presence, thickness, and color of pigmented testa; and endosperm color also play an important role in color perception of the resulting flour or subsequent products (Rooney and Miller 1982). A +*b* value in all samples indicated yellowness of the samples. Hue angles indicated sorghums varied from slightly greenish yellow to a reddish yellow.

Screening I Descriptive Analysis

Eight attributes characterized the feed grain samples from the performance test samples. The intensities of the flavor attributes in screening I were at the lower end of the 150-mm line scale (Table V). However, the intensity of negative attributes (bitter, astringent) was higher than the positive attributes (sweet and nutty flavors). This has been considered one of the major deterrents in using grain sorghum for human food.

MANOVA indicated that 95.4% of the flavor variation among the samples was explained by five factors: 1, characterized by green flavor (accounting for 36.6% of the variation); 2, characterized by dusty aroma (26.0%); 3–5, characterized by nutty flavor, bitterness, and dusty flavor (14.3, 12.3, and 6.2%, respectively).

The remaining 5% of the variance was accounted for by sourness, sweetness, and astringency.

CA grouped the samples from screening I into four categories (clusters) based on similarities of several factors (Table VI). A negative value indicated a low occurrence of an attribute in a cluster, and a positive value indicated a high occurrence. Values for samples in cluster 1 were negative for bitterness and green flavor and positive for sweetness. Values for samples in cluster 2 were negative for nutty and green flavor and positive for dusty aroma. Values for samples in cluster 3 were negative for astringency, nutty flavor and dusty aroma and positive for green and dusty flavors. Values for samples in cluster 4 were positive for bitterness and green flavor.

The least square means for total weighted scores following ANOVA for screening I are shown in Table VII. Six samples were considered worthy of further testing based on flavor scores. Five samples with the least negative total weighted scores and not significantly different from one another ($P > 0.05$) were in cluster 1. The C737 LAB sample appeared to have the highest negative scores among the six samples, except for astringency, which is probably why it was in cluster 3. The slight discrepancy in the selection between the two methods was due to differences in the weighting of the attributes.

Screening II Descriptive Analysis

This screening included a subset from screening I of the commercial feed grain sorghums and additional commercial food grain

sorghums. As observed in screening I, the intensities for the descriptors in screening II were at the low end of the 150-mm line scale (Table VIII). The low intensity for the negative descriptors was expected for commercial samples developed for possible food usage, but it was not necessarily expected for the feed grain sorghums.

MANOVA for screening II indicated that 78.9% of the variation among samples was explained by four factors: 1, characterized by green aroma (accounted for 39.0% of the variation); 2, characterized by dusty flavor (19.5%); 3, characterized by bitterness (12.2%); 4, characterized by sweetness and astringency (8.2%). The rest of the variance was accounted for by sweetness, nutty flavor, dusty aroma, doughy, woody flavor, and sourness. As in screening I, commercial food grain samples did not differ in astringency or bitterness. Greenness and dustiness were again the main differentiating attributes. Interestingly, the JDG sample had no less astringency and bitterness than the JWG samples.

CA grouped the samples from screening II into four categories (clusters) based on similarities of attributes (Table IX). Cluster 4 was composed of six of the 11 samples identified by the univariate method with low negative flavor attributes. It had low green aroma and dusty flavor, which were the two main differentiating attributes. Two other samples, J 96V1848 and JDG, were in cluster 1. The remaining three samples (feed grains C737 LAB, P8505 THI, and P8500 LAB) were in cluster 3. Interestingly, five out of the six feed grains were in cluster 3.

TABLE IX
Cluster Distribution and Similar Attribute Groupings
from Screening II of 28 Grain Sorghum Samples

Cluster	Sample ^{a,c}	Similar Attributes ^d
1	C R19033	-bitterness
	J96V1845 ^f	-sweetness
	C R16013	*green aroma
	JWG ^e	*dusty flavor
	J96V1848 ^f	*astringency
	C A11034	
	JDG ^f	
	C Dorado	
	C R13034	
	JDG ^e	
2	C X13116	-sweetness
	C X2333	*green aroma
	C X12010	*bitterness
	NC+ XFG665 (d) ^g	+dusty flavor
	C HP162	+astringency
JWG ^f		
3	C737 LAB	-green aroma
	OKTX FIF	-bitterness,
	DK-45 BRO	-sweetness
	P8505 THI	*astringency
	J96V1851 ^f	+dusty flavor
	P8500 LAB	
4	C A15043	-green aroma
	C Comm 611y	-dusty flavor
	NC+ X-40934	*bitterness
	NC+ XFG665 (l) ^g	*astringency
	C A39006	+sweetness
	OKTX THI	

^a Feed grain hybrids are in bold type. All others are considered food grain hybrids.

^b Suppliers: Jowar Foods, Hereford, TX (J); Pioneer Hi-Bred, Intl., Amarillo, TX (P); Crosbyton Seed Co., Crosbyton, TX (OKTX); Cargill Hybrid Seeds, Lockney, TX (C); Dekalb Genetics, Mt. Hope, KS (DK).

^c Kansas counties: Labette (LAB); Brown (BRO); Thomas irrigated (THI); Thomas fallow (THF); Finney irrigated (FII); Finney fallow (FIF).

^d Low (-), medium (*), high (+) occurrence of an attribute in a cluster.

^e Whole grain (JWG) and decorticated grain (JDG) supplied by Jowar Foods Inc., TX.

^f JWG, JDG, J96V1851, J96V1848, and J96V1845 all supplied by Asgrow Seed Co., TX.

^g Darker (d) and lighter (l) of the two NC+ XFG665 samples.

TABLE X
Weighted Mean Scores^a from Screening II
of 28 Grain Sorghum Samples

Samples by Locale ^{b,c}	Weighted Mean Scores
Food grains	
JWG ^d	-4.5
NC+ X-40934	-4.2
J96V1851 ^e	-4.5
JDG ^e	-4.8
NC+ XFG665 (d) ^f	-6.5
NC+ XFG665 (l)^f	-4.1
C Dorado	-5.3
C A15043	-3.7
C R19033	-4.5
C R13034	-4.6
C HP162	-5.3
C R16013	-4.6
C A39006	-4.0
C A11034	-4.5
C Comm 611y	-3.6
C X12010	-6.1
JDG^d	-4.0
C X13116	-6.2
C X23333	-6.0
JWG ^e	-6.0
J96V1848^e	-4.3
J96V1845 ^e	-4.6
Feed grains	
DK-45 BRO	-4.5
P8505 THI	-3.9
OKTX THI	-3.5
P8500 LAB	-3.8
C737 LAB	-4.4
OKTX FIF	-4.7

^a Obtained by adding the weighted scores of all attributes per sample and dividing by the number of attributes. Values in bold type are the least negative and not significantly different from each other.

^b Suppliers: Jowar Foods, Hereford, TX (J); Pioneer Hi-Bred, Intl., Amarillo, TX (P); Crosbyton Seed Co., Crosbyton, TX (OKTX); Cargill Hybrid Seeds, Lockney, TX (C); Dekalb Genetics, Mt. Hope, KS (DK).

^c Kansas counties: Labette (LAB); Brown (BRO); Thomas irrigated (THI); Thomas fallow (THF); Finney irrigated (FII); Finney fallow (FIF).

^d Whole grain (JWG) and decorticated grain (JDG) supplied by Jowar Foods Inc., TX.

^e JWG, JDG, J96V1851, J96V1848, and J96V1845 all supplied by Asgrow Seed Co., TX.

^f Darker (d) and lighter (l) of the two NC+ XFG665 samples.

The least square means are shown in Table X. Eleven samples were selected for testing by consumers. These samples included both food and feed grains and had the least negative total weighted scores and were not significantly different from one another ($P > 0.05$).

Contrary to what was expected, astringency and bitterness were similar among samples with or without decortication and were relatively low in intensity. This implies that the phenolic levels were not changed by decortication. Food and feed grain sorghums were in the same clusters based on aroma and flavor. Furthermore, the same hybrids (e.g., OKTX) grown in different environmental conditions (Table VII), or JWG obtained from different suppliers (Table X), were in different clusters based on flavor. Based on these findings, environmental conditions apparently influence the flavor as much as decortication, and the color of endosperm or pericarp does not necessarily imply positive or negative phenolic component flavors.

Consumer Acceptability

Significant differences among samples were based on acceptability of appearance ($P = 0.0001$) or aroma ($P = 0.04$) of the muffins. Contrasts between means also resulted in a significant difference ($P = 0.02$) between the selected and rejected sample groups. Scores were 5.2 and 4.8 for appearance acceptability and 3.8 and 4.1 for aroma acceptability for accepted and rejected sample groups, respectively. In consumer test I ($n = 53$), overall muffin and flavor acceptability were similar for all samples; mean scores were between 4 (dislike slightly) and 5 (neither like nor dislike) for overall acceptability and between 3 (dislike moderately) and 4 (dislike slightly) for flavor acceptability. The screening procedures, based on increased intensities of negative flavor attributes, were not predictive of differences in overall, texture, or flavor acceptability. However, appearance acceptability scores differed ($P = 0.05$) for the samples. To understand the relationship of the consumer data to the descriptive data, appearance was investigated further as a driver of overall acceptability. Overall acceptability related moderately positively (+0.77) to muffin color L and b values, and appearance acceptability related moderately (+0.75) to flour L value. All other correlation coefficients were <0.6 and not significant ($P = 0.10$). PCA indicated that consumer overall, flavor, texture, and appearance acceptability were related to color parameters identified in the correlation procedure.

Consumer test II ($n = 44$) investigated how the muffin and flour L and b hues affected acceptance of the grain sorghum muffins. Samples were selected from the remaining available samples of the two groups of grain sorghums 1) C R19033, a food grain sample with the highest color values for muffin ($L = 59$ and $b = 18$) and flour ($L = 80$); and 2) P8505 BRO, a feed grain sample with the lowest color values for muffin ($L = 42$ and $b = 7.5$) and flour ($L = 70$). The muffin with the higher L value, indicating a lighter product, and the lower b value, indicating less greenness, yielded significantly ($P = 0.03$) higher overall (3.9 vs. 3.2), aroma (4.6 vs. 4.0), texture (4.4 vs. 3.8), and flavor (3.8 vs. 3.1) acceptability. However, neither the color (4.9 vs. 4.7) nor appearance (5.2 vs. 4.8) acceptability scores differed significantly for the two samples.

The appearance and color acceptability results of consumer tests I and II appear somewhat contradictory and confusing. When screening was based on flavor (consumer test I), appearance acceptability differed significantly but flavor acceptability did not. When screening was based on the instrumental color values of the samples (consumer test II), appearance and color acceptability were not significantly different. A closer inspection of the visual characteristics of the samples and consumer comments indicated that in consumer test I, two selected samples (OKTX THI and JDG) and two rejected samples (C737 male and NC+ XFG665) had a greenish color. Three of these samples had lower overall and appearance acceptability scores, but JDG was equal to another sample with the highest scores (Table XI). JDG produced muffins with a lighter greenish yellow color compared with the other greenish yellow

muffins, which was confirmed by the instrumental data. Seemingly, consumers identified the darker muffin with slightly green hues unacceptable.

Two samples (P8505 BRO and C R19033) used for muffins in consumer test II were light or dark brown and within a hue spectrum acceptable to consumers. The lighter-colored muffin looked like a plain or corn muffin, and the darker one looked like a chocolate or perhaps pumpernickel or dark bran muffin. Thus, overall acceptability seemed to be related to the products that met consumer expectations based on appearance.

Color variation among samples offers a wide range of choices for different applications. Although a light-colored grain sorghum is usable in more products, some products such as pumpkin muffins and brownies are not so color-dependent. The resulting color of products made with grain sorghum cannot be predicted based on the color of the seed or whole grain. Previous studies noted that the color of grain sorghum products depends on the pericarp and endosperm colors, pigmented or nonpigmented testa, degree of milling, and pH of the food system (Rooney 1996). In acidic media, anthocyanins are converted readily to anthocyanidin. Alkali conditions (as in tortilla production) can result in an off-color, particularly in colored grains.

Processing would be more economical if decortication were not necessary. In this study, decortication did not result in higher flavor or overall acceptability compared with using the whole sorghum grains. Avoiding decortication also would retain the phenolic compounds in the pericarp and possibly increase nutritional benefits. Decortication removes 12–30% of the grain, which results in decreased amounts of fiber, ash, and fat. Although decorticated grain sorghum has better nutrient digestibility than the whole grain, nitrogen retention and protein efficiency ratios are lower because of the partial germ loss. Efforts are being made to correct this. In fact, recent development of white sorghum with a thick pericarp resulted in milled products with a pleasing light color and more nutritional value and increased milling yields (Rooney 1996).

SUMMARY AND CONCLUSIONS

Descriptive testing of porridge flavors was used to screen samples collected from 1996 Kansas feed grain sorghum performance tests. Univariate and multivariate analyses indicated six samples with potentially acceptable flavor characteristics. These samples were included in a second flavor screening of 28 samples including 22 food grain samples from the 1996 crop. Four of the six samples from the feed grain performance tests again were identified with potentially acceptable flavor qualities, along

TABLE XI
Consumer Overall and Appearance Acceptability Scores
and Muffin Color Values

Samples ^{a,b}	Acceptability Score		Color Values ^c			Hue Angle ^d
	Overall	Appearance	L	a	b	
Selected						
C Comm 611y	4.5	5.6	55.2	1.2	13.3	94.4
OKTX THI	4.0	4.5	45.1	2.2	8.2	83.2
JDG	4.5	5.6	58.4	0.5	19.6	98.5
Rejected						
C737 male	4.1	4.6	49.8	1.7	11.9	90.9
C737 female	4.4	5.6	45.7	3.9	10.5	77.5
NC+ XFG665 (d)	4.0	4.3	46.0	1.8	11.1	89.9

^a Bold face type indicates feed grains. All others are food grains.

^b Suppliers: Cargill Hybrid Seeds, Lockney, TX (C); Crosbyton Seed Co., Crosbyton, TX (OKTX); grown irrigated in Thomas County, KS (THI); decorticated grain (JDG) from Jowar Foods Inc., TX; NC+ Hybrids, Colwich, KS (NC+). C737 parental lines were also included in this study. Darker (d) of the two NC+ XFG665 samples.

^c Tristimulus color scale: L is degree of lightness, a and b indicate red-green, and yellow-blue axes, respectively.

^d Hue angle: $\tan^{-1}(b/a)$.

with seven of the commercial food grain samples, based on low levels of astringency and bitterness. To verify the effectiveness of the flavor screening, three samples selected by the second screening and three that were eliminated during the first and second screenings were baked into muffins for consumer acceptance testing. The relationship of color parameters to consumer acceptability indicated that increased flour and muffin lightness, and more yellowness or brownness rather than dark and yellow-green muffin values, yielded higher overall, aroma, texture, and flavor acceptability scores.

Flavor acceptability of all grain sorghum muffins in this study, whether using whole or decorticated grains or food or feed grains, was perceived by consumers as equal. Flavor was not the only factor related to muffin acceptability in this study. The relatively low overall acceptability scores for muffins (4–6 on a 9-point scale) indicate a need for further improvement of all sensory characteristics. Similar flavor attributes probably caused the consumer to focus on other sensory characteristics that differentiate the products, such as appearance and texture. Consumers rated muffins that were either light or dark as acceptable, but a greenish-yellow hue was perceived to be an unacceptable color, especially if it was dark.

The muffin formula used in this test was based on 100% grain sorghum flour and minimal quantities of other ingredients to focus on the inherent sensory attributes of sorghum. It was not optimal as such, and the addition of corn, wheat, or other grains could improve acceptability. Successful products made from grain sorghum alone or in mixtures with other grains such as tortilla chips and tortillas have been reported, but the flavor or texture characteristics and acceptability were not quantified (Iruegas et al 1981; Rooney 1996). Recent efforts (Carson et al 2000) indicated high acceptability (6.9 on a 9-point scale) for an optimized grain sorghum composite bread using 50% grain sorghum flour. The relatively low overall acceptability scores for the 100% sorghum flour muffins reinforce the need for using such composite flour blends and optimizing appearance, flavor, and texture.

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