Steam Flaking Characteristics of Sorghum Hybrids and Lines with Differing Endosperm Characteristics

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ABSTRACT

Commercial and food-type sorghum hybrids with differing kernel and endosperm characteristics were grown under comparable conditions and steam flaked in each of three years. The raw-grain kernel characteristics and proximate analyses were homogenous over the three-year period. The waxy hybrid produced large, translucent, durable flakes that had significantly higher enzyme-susceptible starch values for all years compared to the other varieties. Flakes with lower amylose contents (waxy endosperm) were positively correlated with percent whole flakes (r^2 = 0.509), flake diameter (r^2 = 0.846), and enzyme-susceptible starches (r^2 = 0.564) and negatively correlated with higher flake fragility (r^2 = –0.647), test weight (r^2 = –0.626), and flake breakage (r^2 = –0.560). The heterowaxy flakes had a good appearance and were generally comparable in quality to the nonwaxy commercial and experimental hybrids. Heterowaxy sorghum hybrids with good grain yields can provide improved quality grain and flakes without sacrificing agronomic performance and yields. No difference in flaking performance was detectable among the kernels with different pericarp colors; flakes from the white food-type sorghums had excellent appearance. Nontempered control samples were inferior in quality to all conditioned treatments.

Steam flaking is a method designed to increase starch availability to the enzymes and bacteria of the rumen, thus creating a concentrated feed ration that maximizes weight gain. The popularity and efficacy of steam flaking are well documented (Schuh et al 1970, Wagner et al 1974, Rahnema et al 1987, Xiong et al 1991, Chen et al 1995, Oliveira et al 1995). Kernel size, shape, endosperm type, and germ placement inside the kernel are known to affect the processing properties of sorghum (Rooney and Miller 1982). Streeter et al (1990) reported that the site and extent of nutrient digestion of steam-flaked material in cattle was affected by sorghum variety.

The development and improvement of sorghum varieties with modified amylose contents (waxy, heterowaxy, nonwaxy) combined with optimized processing practices may further increase sorghum utilization in steam flaking. Grains with low amylose contents (1–2%) are termed "waxy", and are associated with homogenous recessive genes (*wxwxwx*). Nonwaxy grains are those with normal levels of amylose (23–28%). Heterowaxy grains have lower amylose contents than normal (20%) but display many of the physical attributes of nonwaxy grains. New foodtype sorghum hybrids with thin, white pericarp, tan plant color, and without pigmented testa have been developed and show promise for use in steam flaking (Rooney et al 1992). These hybrids have waxy, heterowaxy, and nonwaxy endosperm characteristics.

Waxy sorghum hybrids in general have reduced grain yields compared to nonwaxy hybrids. Waxy hybrids often have poor seedling vigor, and the grain is slightly less dense. A heterowaxy hybrid has a normal nonwaxy female crossed to a waxy pollinator. These hybrids have competitive grain yield, good seedling vigor, and significantly reduced levels of amylose; the grain sold by the farmer has ≈25% waxy kernels, based on appearance. Genetically, the kernels are a 1:1:1:1 ratio of *WxWxWx*, *WxWxwx*, *Wxwxwx*, and *wxwxwx* (Lichtenwalner et al 1978).

Red, cream, and true yellow endosperm sorghums are the most common hybrids grown today. Sometimes, premiums are paid by feedyards for cream or yellow sorghums. The relative rates of water uptake, kernel plumpness, and other physicochemical characteristics affect flaking, and the attractive appearance of the light-colored flakes gives a positive impression.

Waxy sorghums process differently than nonwaxy ones. Rusnak et al (1980) reported that micronized waxy sorghums were more gelatinized, expanded more, and had lower flake densities than similarly processed nonwaxy sorghums. Extrudates of sorghums with reduced amylose had higher expansion rates, enzyme-susceptible starch (ESS), and water solubility indices than nonwaxy sorghums (Gomez et al 1988). Waxy sorghum hybrids have been used in breakfast cereal production with good results (Rusnak et al 1980, Gomez 1987, Cruz y Celis et al 1996).

Waxy hybrid flakes had higher digestion rates than nonwaxy hybrids (Rooney and Pflugfelder 1986). Streeter et al (1990) reported that in vitro dry matter disappearance rates and starch availability of steam-flaked, waxy sorghums were higher than those of similarly treated, nonwaxy sorghums. Increasing the waxy gene dose in sorghum increased in vitro starch and dry matter digestion values (Lichtenwalner et al 1978). Although several studies have dealt with the performance of grains with different endosperm characteristics, none of them have documented the quality of flakes from sorghum hybrids grown under different environmental conditions. Therefore, the objective of this study was to evaluate differences in steamed flakes of commercial and new sorghum hybrids with nonwaxy, heterowaxy, and waxy endosperm characteristics grown under comparable conditions in each of three years.

MATERIALS AND METHODS

Raw Materials

Hybrids chosen represented the significant types of grain grown commercially along with new experimental food sorghums developed in the Texas Agricultural Experiment Station Sorghum Improvement Program. Commercial and experimental food-type sorghums were grown under irrigation in 1992 (Experiment I), 1993 (Experiment II), and 1994 (Experiment III) at the Texas Agricultural Experiment Station at Halfway, near Lubbock, TX (Table I). Grain was grown, harvested, cleaned, and stored in sacks until used; trash and broken kernels were removed before processing. A commercial, red, nonwaxy hybrid (ATx399 × Tx430) was used as the control for all years. All grain samples met the standards for U.S. no. 1 sorghum (i.e., white sorghum with clean, bright, plump kernels).

Steam Flaking

All grain samples were steam flaked using a pilot steam-flaker (model 18x12 HYD, Ferrel-Ross, Oklahoma City, OK) located at the Burnett Feedlot Research Center, Texas Tech University, Lubbock, TX. The flaking rolls were warmed up initially with a standard grain sample that was used to adjust the flaker to produce flakes with 24 lb/bu bulk density, which is often used in commercial

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flaking operations (McDonough et al 1997). All samples were flaked using fixed conditions once a 24-lb/bu flake was obtained.

Tempering

In Experiment I, triplicate 50-lb samples were tempered to 20% internal moisture for 24 hr with water and a commercial conditioner (EZ Flake, Loveland Industries, Loveland, CO, 6 oz/ton application) at 25°C, and then steam cooked for 30 min at 212°F (100°C) (McDonough et al 1997). For Experiments II and III, the grain was tempered to 18.5% and processed as described. A randomized complete block design was used with three replicates and three duplicates in Experiments I and II and four replicates in Experiment III. The replicates were based on steam flaking, while the duplicates were on the flakes obtained within each replicate.

Characterization of Uncooked Grain

Raw grains were evaluated for test weight using a quart cup bushel meter (no. 204, Seedburo Equipment Co., International Division, Chicago, IL). Thousand-kernel weight was determined by weighing 40 kernels and multiplying the result by 25. Raw grains were evaluated for true density (80-g samples) using the manufacturer's recommendations on a nitrogen-displacement multipycnometer (model MVP 1, Quantachrome Co., Powder Instrumentation, Syosset, NY). Kernel hardness was evaluated using a tangential abrasive decortication device (TADD, model 4E-115, International Development Research Center, Ottawa, Canada) (Reichert et al 1982). Samples in Experiments II and III were also tested for hardness with a single-kernel characterization system (SKCS, model 4100, Perten Instruments, Reno, NV) (Pedersen et al 1996). Physical tests were run in triplicate for each processing replicate.

Steam-Flaked Sorghum Characterization

Flake appearance and quality were subjectively evaluated by the authors and several feedlot managers based on many years of experience with steam-flaked grain.

Flake diameter and thickness were determined on 20 flakes per replicate using stainless steel calipers (no. 2272A21, Vernier, Rome, Italy). Steamed flakes were evaluated for test weight with a bushel meter using a quart cup (no. 204, Seedburo).

Whole, broken, and fine flakes were analyzed using 600 g of flakes sieved over U.S. standard sieves (no. 4, 5, 8, 10; E. H. Sargent & Co., Chicago, IL) on a Ro-Tap sifter (Combustion Engineering, Inc., Mentor, OH) for 10 min. The fractions were weighed and reported as the percentage of whole flakes, broken flakes, and fines.

The difference in percentage of whole flakes before and after agitation in a single-speed pellet durability machine (Seedburo), divided by the weight of whole flakes before agitation, was recorded as the flake breakage value, expressed in percent. Samples with the highest portions of whole flakes were considered stronger and of higher quality.

Flake fragility was measured in triplicate by taking the test weight of flaked samples before and after agitating for 10 min in the pellet durability machine. Fragility was then calculated as the difference in the test weight before and after agitation, divided by the test weight before agitation, expressed as a percent. Flakes with lower percentages were more durable.

Flake tenderness was determined using a texture analyzer (TA.XT2, Texture Technologies Corp., Scarsdale, NY). The force to break a flake was determined on 15 individual flakes supported on a 0.5-cm die using a rounded 3-mm diameter plunger. The analyzer was set at three cycles per 20 sec (Anderson 1994).

Chemical Analyses

All samples were ground with a cyclone sample mill equipped with a 1-mm screen (Udy Corporation, Fort Collins, CO). All chemical tests were run in triplicate. Moistures of raw grain, steamed grain, and flaked samples were determined by Approved Method 44-16 (AACC 1995). Apparent amylose was determined by the iodine method on decorticated grains, according to the procedure developed at the USDA Rice Quality Laboratory, Texas Agricultural Experiment Station, Beaumont, TX.

Total starch and ESS were determined after digestion of samples with glucoamylase (Diazyme L-200, Solvay Enzymes, Elkhart, IN) at 60°C for 30 min and quantified using a Technicon II Autoanalyzer and starch method SF4-0046FA8 (Technicon Instrument Co., Tarrytown, NY).

Water solubility index (WSI) was determined by extracting 1 g of sample with 15 mL of water for 30 min. The samples were centrifuged (5,000 × *g* for 20 min) and water-soluble solids in the supernatant were determined by drying.

Statistical Analysis

Analysis of variance was conducted using a randomized block design. The grains were flaked on each of three or four days. Each day, the standard grain sample was used to adjust the conditions to achieve 24-lb/bu flakes. All experimental samples were randomized within each replicate. Treatment means were compared with least significant difference (protected Fisher LSD) and simple correlation (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Uncooked Grain Characteristics

The physicochemical characteristics of all grains are presented in Table II. The grains were relatively homogenous throughout the experiment, although protein levels were lower in 1994 grains and the kernels were somewhat softer than in the other two years. Test weights for 1992 were slightly lower overall, but over three years' time, they were consistent. The waxy grains had lower test weights than the nonwaxy hybrids, which, in two of the three years, were similar to those of the heterowaxy hybrids. The waxy hybrids were also softer than the other varieties, based on the percent-removal hardness values.

TABLE I
Physical Characteristics of New Improved Food and Commercial Sorghum Hybrids and Lines Grown at Halfway, TX[a]

Hybrid	Appearance	Pericarp Color	Plant Color	Endosperm Type	Endosperm Color[b]	Grain Class[c]
ATxArg1 × Tx2907	White	White	Tan	Waxy		White
ATxArg1 × Tx436	White	White	Tan	Heterowaxy		White
ATx631 × Tx436	White	White	Tan	Nonwaxy		White
ATx399 × ATx430	Red	Red	Purple	Nonwaxy	hy	Red (bronze)
AOK11 × Tx2737	White	White	Purple	Nonwaxy	hy	White (cream)
NC+363y	White	White	Purple	Nonwaxy	hy	White (cream)
CA 837	Red	Red	Purple	Nonwaxy	hy	Red (bronze)
DK41Y	Yellow	White	Purple	Nonwaxy	y	Yellow

[a] Sorghums were grown under irrigation at the Texas A&M Agricultural Experiment Station, Halfway, TX.
[b] hy = a heteroyellow variety, y = a yellow variety.
[c] Class refers to FGIS market class. Parentheses contain terms used by the sorghum industry.

Subjective Evaluation of Steamed Flakes

The flakes prepared from the grains in this study were evaluated subjectively by the authors and experienced feedlot personnel on site at the time of flaking. Grain from the hybrids behaved in significantly different manners when flaked. In all three years, the waxy flakes were large and attractive, with a golden appearance; they smelled and tasted sweeter than the other varieties. Waxy flakes were deemed exceptionally good by the local feedlot personnel; the flakes were large in diameter but strong enough to tolerate normal feed conveyance systems. Heterowaxy flake quality was judged to be equal to or better than the nonwaxy flakes, and in Experiment III, the flakes were as good as the waxy flakes. In some cases, waxy grain became tacky during cooking and affected the flaking rolls by forming a mat on the surface, so the improper cooking of waxy grain could result in difficulty during flaking. The heterowaxy grain passed through the rollers faster than the other varieties across all years; however, no numbers were recorded. The food-type red nonwaxy and cream nonwaxy sorghums produced excellent flakes that were comparable in condition to those from the commercial controls.

Hybrid Flake Properties and Characteristics

Flake quality characteristics are presented in Figs. 1–4. Flakes with good quality are typically those with large diameters, low fragility, low breakage, and a high percentage of whole flakes that are well gelatinized. The waxy flakes were more translucent than typical heterowaxy and nonwaxy samples. McDonough et al (1997) reported in a tempering study that translucent flakes were more digestible than the opaque flakes because of higher degrees of starch gelatinization; they were stronger and better able to withstand the stresses of mixing and feed delivery into the feed bunks, producing a minimum of fines.

Flakes with lower amylose contents (waxy endosperm) were positively correlated with percent whole flakes ($r^2 = 0.509$), flake diameter ($r^2 = 0.846$), and ESS ($r^2 = 0.564$) and negatively correlated with higher flake fragility ($r^2 = –0.647$), test weight ($r^2 = –0.626$), and flake breakage ($r^2 = –0.560$). The waxy flakes had larger diameters over all years than the other varieties (Fig. 1), which indicates that the grain was more plasticized when it passed through the rollers and was able to expand more easily.

The waxy flakes were less fragile, had lower breakage rates, and retained a larger percentage of whole flakes after processing than the other varieties (Figs. 1 and 2). These flakes were the most gelatinized samples, indicated by ESS levels and the WSI (Fig. 3). Hibberd et al (1982) and Streeter et al (1990) reported similar digestibility results and decided that further research was needed to prove that waxy sorghums were statistically more digestible than nonwaxy hybrids. High WSI values for waxy grains are supported by data from Gomez et al (1988). Waxy sorghum was more digestible than nonwaxy sorghum in previous in vitro and in situ digestibility studies (Lichtenwalner 1978, Wester et al 1992).

The waxy flakes required less force to break than did the others when tested with a texture analyzer (Fig. 4). These results appear to be in direct contradiction to the flake fragility and breakage tests, as well as the subjective evaluation of the flakes. Cruz y Celis et al (1996) also reported that in granola prepared from micronized flakes, the waxy flakes were more tender than nonwaxy flakes when measured with a TA.XT2 texture analyzer. Although the three tests were assumed to be measuring the same phenomenon, they actually measure flake properties as affected by different impinging forces. The waxy flakes were clearly more durable than the heterowaxy and nonwaxy flakes when judged subjectively by feedlot personnel.

The heterowaxy flakes were not equal to or superior in quality to the waxy flakes but were similar in all tests to the nonwaxy flakes. No significant differences were found between the heterowaxy and nonwaxy flakes in percent whole flakes, flake diameter, flake breakage, and flake fragility. However, WSI values were slightly higher for heterowaxy than for nonwaxy flakes in all years. ESS tended to be as high or higher in most cases, making the flakes more translucent than the nonwaxy grains; however the differences were not significant. When properly tempered, the heterowaxy grain can produce a flake that is similar to a nonwaxy flake but with higher digestibility, making it a viable choice for feedlot rations.

TABLE II
Physical and Chemical Properties of Sorghum Grain from Hybrids Grown in Halfway, TX

Hybrid	Moisture (%)	Protein (%)	Crude Fat (%)	Amylose (%)	Test Weight kg/hL (lb/bu)	1,000 Kernel Wt (g)	Hardness[a] (% removal)	Hardness[b] Index	Density (g/mL)
1992									
ATxArg-1 × Tx2907	8.1f[c]	11.1c	3.1d	2.0d	77.2b (59.9)	31.9cd	17.3cd	···	1.37c
ATxArg-1 × Tx436	9.0d	10.6d	3.3cd	21.0c	77.2b (59.9)	31.9cd	17.3cd	···	1.37c
ATx631 × Tx436	9.3c	9.1e	2.7e	25.6a	77.2a (61.9)	33.7bc	17.5c	···	1.36e
ATx399 × ATx430	10.2b	10.5d	2.8e	26.0a	79.1a (61.4)	39.3a	16.3de	···	1.37d
AOK11 × Tx2737	8.6e	11.1c	3.3cd	24.0b	80.3a (62.4)	32.1cd	13.0f	···	1.37c
DK41Y[d]									
LSD (*P* = 0.05)	0.15	0.33	0.27	1.2	1.0	2.4	1.2	···	0.004
1993									
ATxArg1 × Tx2907	11.0b	11.3ab	3.6a	2.4e	76.8f (59.7)	30.7d	16.3a	89.5a	1.360e
ATxArg1 × Tx436	10.9b	11.0b	2.9b	22.6d	78.7c (61.1)	27.6f	13.1d	88.2a	1.379a
ATx631 × Tx436	10.9b	11.4a	2.7b	28.0ab	79.7b (62.0)	33.4b	16.3a	76.1c	1.371b
ATx399 × Tx430	11.0b	11.2ab	3.0b	27.7c	77.7e (60.4)	40.0a	14.3bc	75.0c	1.367d
AOK11 × Tx2737	11.0b	9.4d	2.7b	28.1a	78.3cd (60.8)	29.9de	14.9b	75.0c	1.368cd
DK41Y	11.8a	8.9f	2.9ab	27.8bc	78.2d (60.8)	31.3c	14.0b	79.2b	1.37b
LSD (*P* = 0.05)	0.63	0.40	0.41	0.28	0.43	1.22	0.70	1.52	0.002
1994									
ATxArg1 × Tx2907	10.5d	10.8a	3.6ab	2.40c	78.5cd (61.1)	26.4c	22.0c	99.7a	1.362d
ATxArg1 × Tx436	11.9ab	10.0b	3.4a–c	23.0b	78.6b–d (61.1)	25.7d	16.2e	99.6a	1.385a
ATx631 × Tx436	11.3bc	9.8b	3.3bc	26.9a	80.6a (62.6)	27.3b	17.5d	76.0e	1.377b
ATx399 × Tx430	11.1cd	9.8b	3.2bc	27.0a	79.1bc (61.3)	31.0a	24.0ab	93.1c	1.367c
AOK11 × Tx2737	12.2a	8.5c	3.9a	27.4a	77.6d (60.4)	25.8d	17.1de	89.5d	1.368c
DK41Y	11.3a–c	9.6bc	3.3a	27.5ab	80.8a (62.8)	25.1e	16.7d	97.4b	1.38a
LSD (*P* = 0.05)	0.71	0.54	0.59	1.01	1.30	0.53	1.00	0.62	0.004

[a] Determined with a TADD mill, the higher the percentage, the softer the grain. Done on clean unbroken kernels retained over U.S. no. 7 sieve.
[b] Determined with a single kernel wheat characterization instrument. Relative hardness scale based on soft wheat = 50, hard wheat = 100. Determined on clean unbroken kernels retained over U.S. no. 7 sieve.
[c] Means in columns with the same letter and within the same year are not significantly different at *P* = 0.05. Calculated on dry weight basis.
[d] Grown only in 1993 and 1994.

The nontempered control samples were inferior in quality in all instances when compared to the tempered treatments, primarily because of the lack of proper water uptake. Preflake and flake moisture levels are important for flake quality (McDonough et al 1997), and a relationship between raw grain moisture and water uptake during steaming has been suggested (Hsu 1984). In this study, preflake (tempered steamed grain) and flake moistures were positively correlated with ESS (r^2 = 0.764 and 0.506, respectively) and negatively correlated with flake fragility (r^2 = –0.429 and –0.509, respectively) and percent whole flakes (r^2 = –0.500 and –0.816, respectively). These results imply that if moisture in the grains is at optimum levels by the time the grains reach the flaking rollers, a more durable, better quality flake results.

Commercial waxy sorghum hybrids have agronomic yields inferior to those of normal, nonwaxy sorghum hybrids because relatively little effort to select waxy sorghums occurs. The reduced yield potential, decreased seedling vigor, and enhanced susceptibility of waxy endosperm to molds and weathering seriously inhibits their widespread adoption unless significant premiums can be paid. Therefore, heterowaxy sorghum hybrids, which do have good grain yields, could provide improved quality grain for flaking.

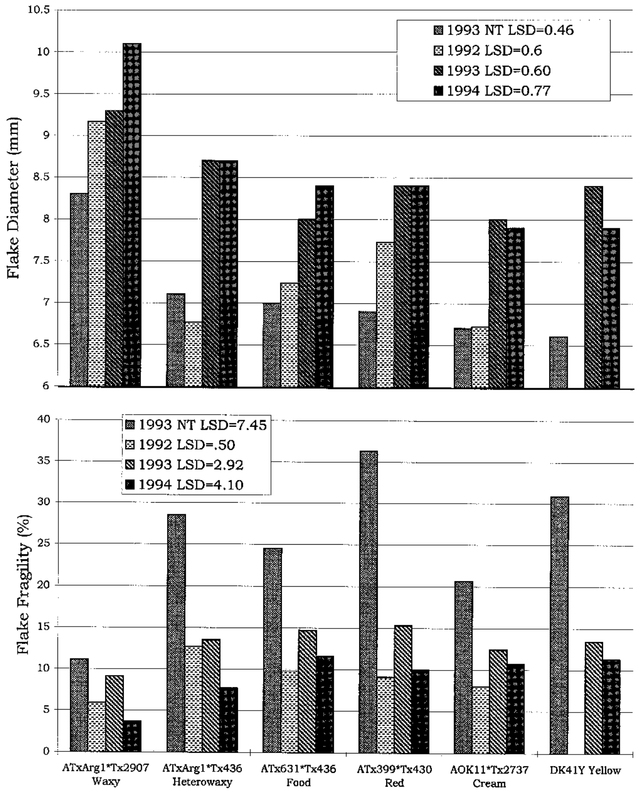

Fig. 1. Diameter and fragility of steamed flakes from six sorghum hybrids processed over a period of three years.

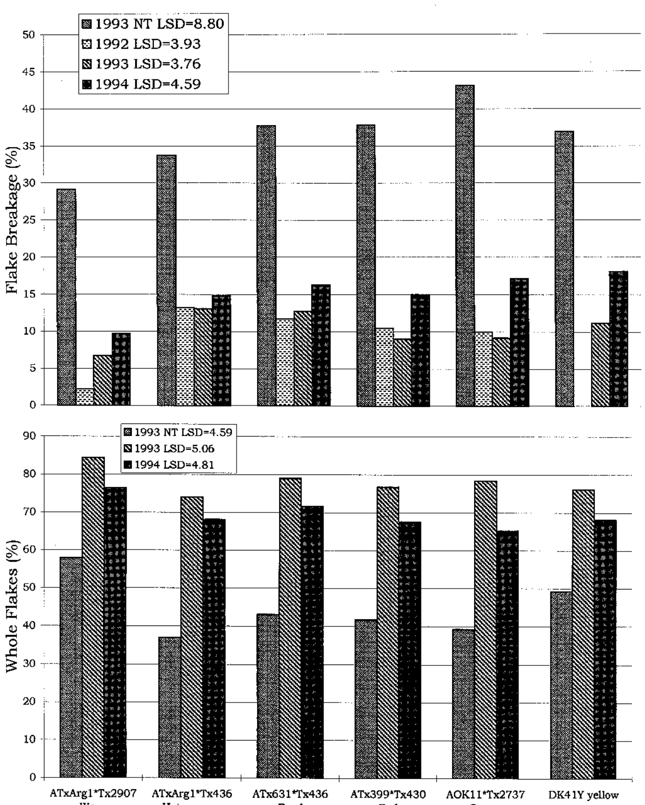

Fig. 2. Breakage and percent whole flakes of steamed flakes from six sorghum hybrids processed over a period of three years.

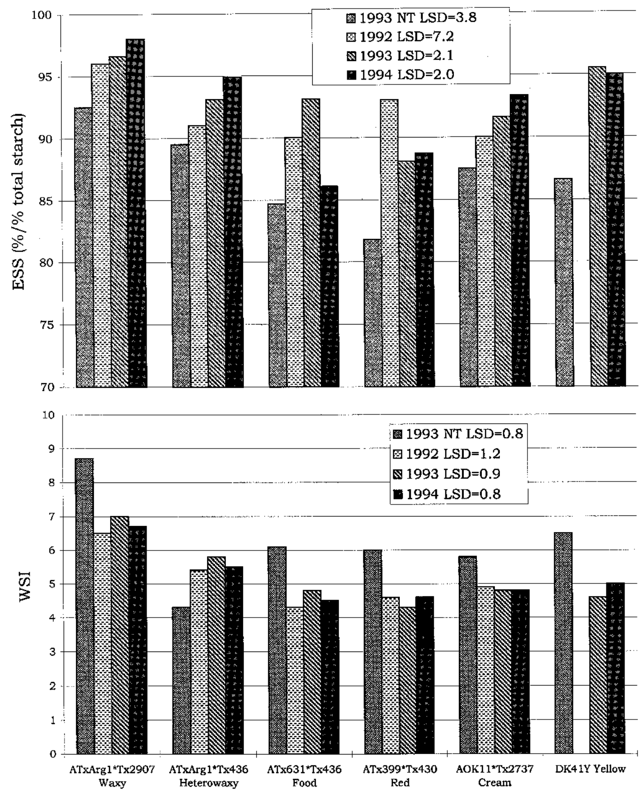

Fig. 3. Enzyme-susceptible starches (ESS, %) and water-solubility index (WSI) of steamed flakes from six sorghum hybrids processed over a period of three years.

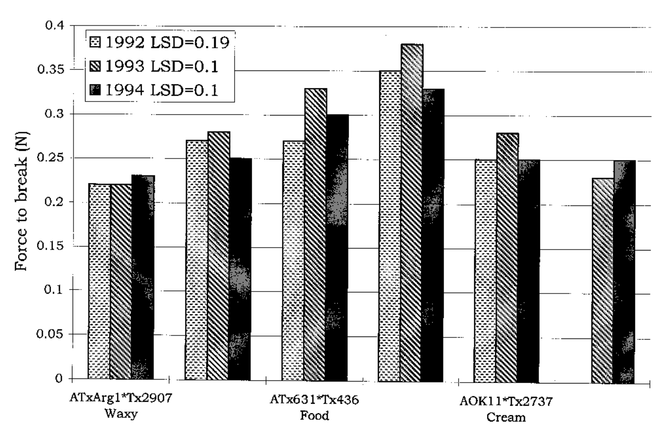

Fig. 4. Flake texture of steamed flakes from six sorghum hybrids processed over a period of three years.

Flakes from the white food sorghum had excellent appearance, but their properties were not significantly different from those of the yellow, cream, or red sorghum flakes. The red sorghum flakes had the worst appearance.

CONCLUSIONS

This study showed a clear difference in the flake quality of waxy varieties compared to that of heterowaxy and nonwaxy varieties. The waxy flakes were also subjectively judged to produce flakes superior to the others. The heterowaxy grain produced a flake that was as good as or better than a nonwaxy flake, when judged both objectively and subjectively. The white food sorghums produced very light-colored, attractive flakes; however, the experiments failed to document any clear-cut differences in flake quality among the red, yellow, white, and cream sorghums other than appearance.

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Erratum

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Steam Flaking Characteristics of Sorghum Hybrids and Lines with Differing Endosperm Characteristics

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On page 637, Figure 4 has been corrected as shown below.

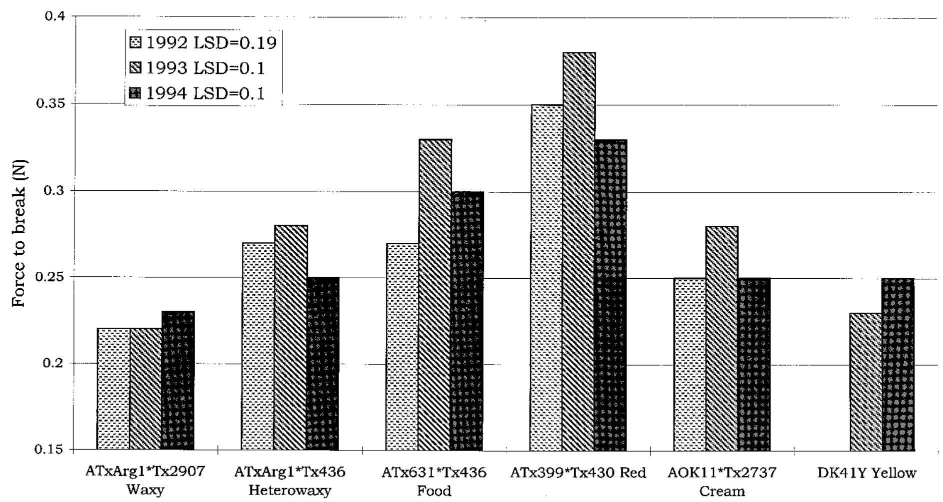

Fig. 4. Flake texture of steamed flakes from six sorghum hybrids processed over a period of three years.