Scarification and Degermination of Sorghum for Grits Production: Effects of Hybrid and Conditioning[1]

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ABSTRACT

Three sorghum hybrids were tempered and decorticated with an abrasive-type mill (scarifier) to produce low-ash and low-fat grits. The effects of tempering time and temperature were investigated, and the optimum tempering conditions for obtaining low-ash and low-fat grits were found for each sorghum hybrid. The conditions were 3 min at 30°C for bronze sorghum with heteroyellow endosperm, 40 min at 40°C for white sorghum with white endosperm, and 10 min at 20°C for red sorghum with white endosperm. The grits yields were low using the scarifier, hence, another abrasive-type mill was investigated for improving grits yields. A modified experimental corn decorticator-degerminator was used to dry-mill the three sorghum hybrids tempered to the optimum conditions found with the scarifier. The yields were 45.3% grits with 0.23% ash and 0.18% fat for the bronze/heteroyellow hybrid, 49.1% grits with 0.22% ash and 0.36% fat for white/white hybrid, and 44.2% grits with 0.20% ash and 0.22% fat for red/white hybrid. This study showed that grits yields were higher and ash and fat contents were lower when sorghum was processed with the decorticator-degerminator than with the scarifier under the same optimum conditioning.

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Sorghum is grown widely for food in Asia and Africa and as feed grain in the United States and other developed countries. As recently as 1994–95, only 1 million bushels of domestic sorghum went into food, alcohol, and industrial use, and >90% is used for animal feeding (Sosland 1998). About 86% of the annual sorghum crop in the United States is grown in four states: Kansas, Texas, Nebraska, and Missouri. Kansas is the number one producer with >50% of the total production (USDA 1999). The revitalized interest in sorghum for food and industrial outlets (FAO 1995) has prompted an investigation of the possibility of producing sorghum grits with good yield and low fat content (≤1%) and ash (<0.5%).

One of the major problems that hinders the development of sorghum utilization in food products is the effectiveness in decorticating the grain. Reichert and Youngs (1976) tested attrition and abrasive type mills for decorticating and concluded that the abrasive type mill was better because of efficiencies in terms of color removal, kernel cracking, and throughput number, as well as other considerations such as maintenance requirements and simplicity.

A scarifier is one example of an abrasive-type decorticator that employs carborundum or other abrasive surfaces (sandpaper) mounted on a horizontal drum to progressively abrade the outer layers of the grain. It offers low maintenance, simplicity, convenience, long use, and ease of operation. A scarifier will abrade the outer layers of the grain, and depending on the hardness of the grains and other factors such as processing and tempering time, some grains will be broken up into grits and flour fractions.

Weinecke and Montgomery (1965) designed an experimental unit based on a dry degermination procedure as a method to separate the components of sorghum kernel, endosperm, germ, and bran, into fractions of the highest practical purity to permit use by industry. The brush-type degerminator with 7/64″ (2.778 mm) diameter holes in the perforated screen was identified as suitable for scale-up to a production level for the manufacturing of high-yield, bran-free, low-fat sorghum grits from both soft and hard grain cultivars. The throughput ranged from 0.50 lb/min (0.23 kg/min) for the hard cultivar to 1.46 lb/min (0.66 kg/min) for the soft cultivar at 18-19% moisture. The highest +25 grits yield of 76.9% of the total throughput and the lowest oil and crude fiber contents of 0.37 and 0.29%, respectively, were obtained from the hard cultivar.

The primary objective of this study was to set up procedures for production of sorghum grits (intermediate form of grain sorghum), in which they will have more potential to be used for human consumption because of less color contamination resulting from bran removal as shown by low ash content, and for industrial purposes such as in starch wet-milling where the procedures might shorten the steeping time and reduce the amount of steeping water. Thus, the purposes of this study were 1) to test a dry-milling laboratory-scale procedure using an abrasive-type decorticator (scarifier) for obtaining endosperm fractions (grits) with low ash content and low crude fat content from newly developed hybrids of sorghum; 2) to investigate the effects of tempering conditions (time and temperature) on each of the sorghum hybrids; 3) to obtain the optimum tempering conditions for producing low-ash and low-crude fat grits from each of the sorghum hybrids; and 4) to investigate the use of a modified laboratory horizontal-drum decorticator-degerminator to produce grits from three sorghum hybrids tempered at optimum conditioning for producing low-ash and low-fat product.

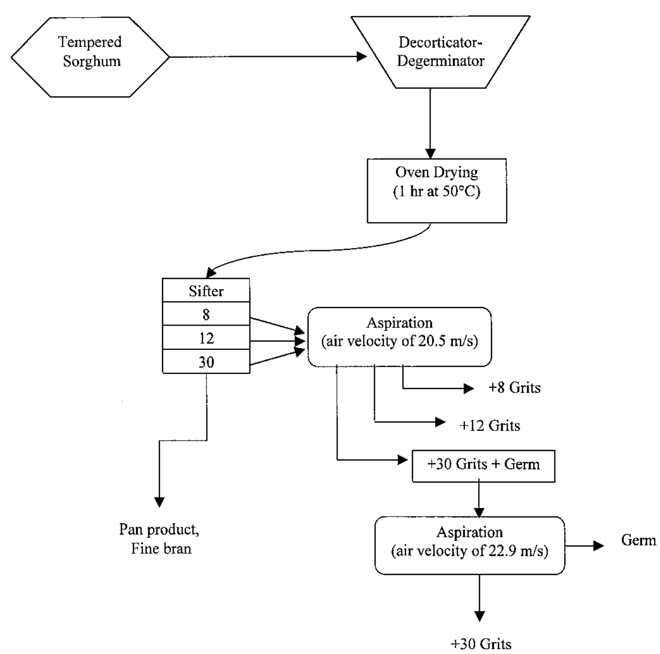

Fig. 1. Milling sorghum with a dehuller-degerminator.

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MATERIALS AND METHODS

Bronze sorghum with heteroyellow endosperm (hybrid DK35), white sorghum with white endosperm (hybrid TR445), and red sorghum with white endosperm (hybrid Pioneer 8500) grown and harvested in Manhattan, KS, in 1997 were cleaned on a laboratory separator-cleaner (model N S L, C36-B, Tripette & Renaud Villeneuve La Garenne, France). The cleaned sorghum samples were characterized for physical and chemical compositions before experimental study (Table I).

A laboratory scarifier (Forsberg's Inc., Thief River Falls, MN) with a processing drum lined with carborundum (40-grit sandpaper, Abrasive Leaders & Innovators, Fairborn, OH) and equipped with a rotating steel propeller for thorough and efficient impact scarification of grains was used to abrade the kernels into different fractions. These fractions were separated on a Ro-Tap shaker (W. S. Tyler, Mentor, OH) following the ASAE method S319.1 (ASAE 1989).

The equipment used in this study was an experimental decorticator-degerminator similar to the one used by Yuan and Flores (1996) on white corn and constructed at Kansas State University. It consisted of stainless-steel wire brush, 6 in. diameter (15.24 cm), and 10 in. long (25.40 cm) rotating within a 7 in. diameter (17.78 cm) perforated cylinder. The wire brush was constructed by packing 12 medium-face crimped wire wheel brushes of 0.0104 in. (0.0264 cm) wire thickness and ground to a 6 in. (15.24 cm) round diameter (medium face wheel brushes, crimped wire, Weiler Corp., Cresco, PA). It rotated on a shaft mounted on horizontal bearings. For this study, two perforated metal screens were used: 1) a 3/32″ (2.38 mm) hole diameter screen made from a 18-gauge stainless steel with 33% open area and staggered holes at 5/32″ (3.97 mm) spaced from center to center; and 2) a 1/8″ (3.175 mm) hole diameter screen made from a 16-gauge stainless steel with 40% open area and staggered holes at 3/16″ (4.76 mm) spaced from center to center. These screens will be referred to as small and large screen,

TABLE I
Physical, Chemical, and Single Kernel[a] Characteristics of Sorghum

Hybrid	Test Wt (lb/bu)	1,000 Kernel Wt (g)	True Density (g/cm^3)	Geometric Mean Diam (μm)	Moisture (% as is)	Ash (% db)	Crude Fat (% db)	Protein (% db)	SK-WT (mg)	SK-DIA (mm)	SK-HI
DK35 (bronze-heteroyellow)	60.3	28.70	1.478	3,259	12.1	1.5	3.0	12.0	28.26 (5.90)	2.26 (0.37)	71.89 (17.77)
TR445 (white-white)	60.0	26.55	1.479	3,149	11.0	1.5	3.1	11.5	26.76 (7.17)	2.09 (0.45)	66.95 (17.82)
Pioneer8500 (red-white)	60.8	26.10	1.488	3,036	10.5	1.4	3.5	11.2	26.3 0(5.54)	2.17 (0.38)	84.62 (15.08)

[a] SK-WT, single kernel weight; SK-DIA, single kernel diameter; SK-HI, single kernel hardness index.Mean and standard deviation (in parentheses) calculated by average of three replicates for each hybrid.

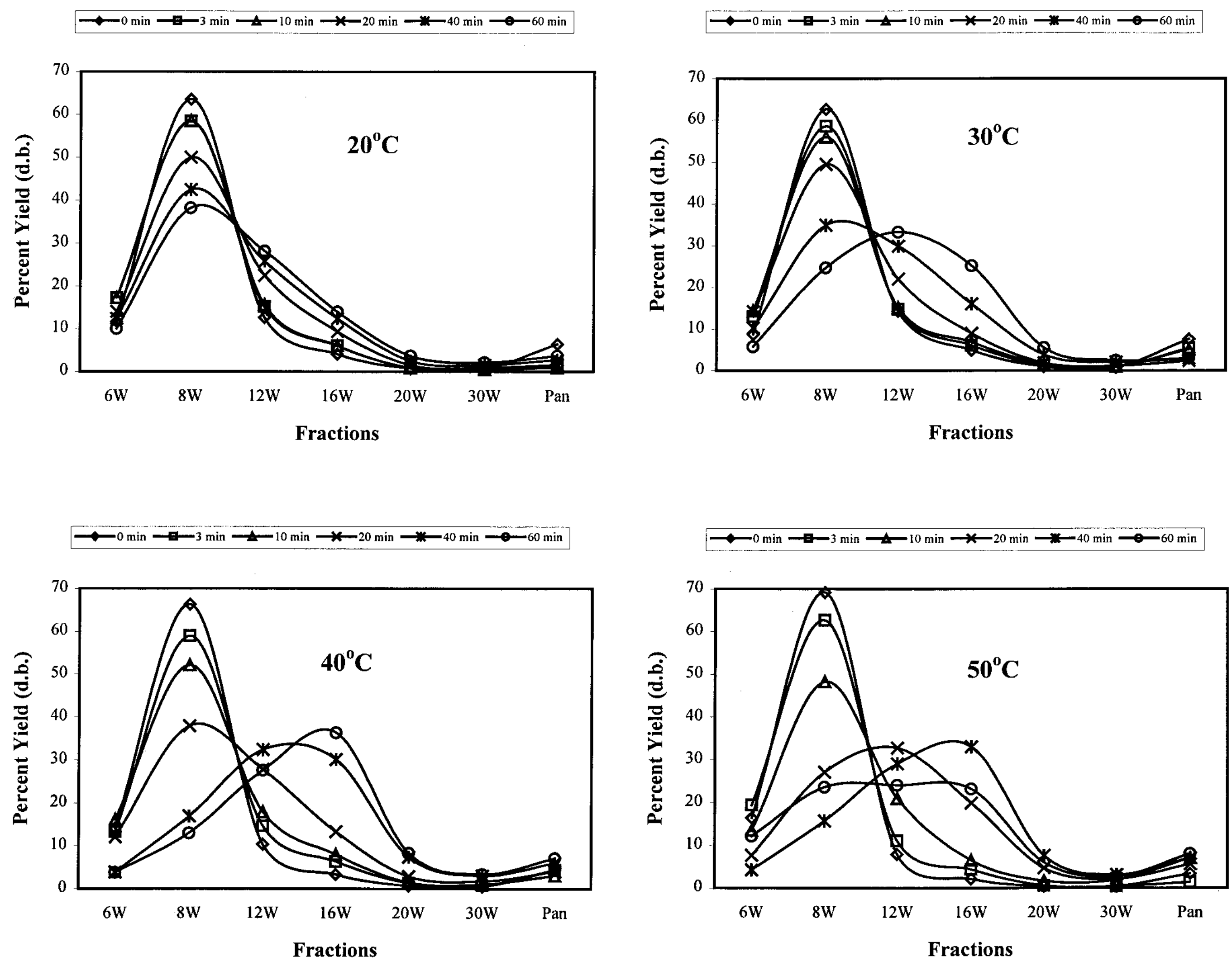

Fig. 2. Yield distribution of bronze grain with heteroyellow endosperm sorghum (DK35) tempered at various temperatures and times and then scarified.

respectively. The degerminator was driven by a 1 HP electric motor (120V, 60 Hz, 2,500 rpm) (PM3428P type industrial motor, Baldor Electric Co., Fort Smith, AR) with a speed control (model BC-140, Baldor Electric) to keep the brush rotor speed close to 1,800 rpm.

The chemical properties evaluated were moisture, ash, crude fat, and protein contents. Moisture was determined by oven drying according to ASAE S352.2 (ASAE 1989), and ash and crude fat contents were determined by Approved Methods 08-03 and 30-25, respectively (AACC 2000). Protein content (N × 6.25) was assayed by a protein/nitrogen analyzer (FP 2000 model, LECO Corporation, St. Joseph, MI).

Sorghum single kernel characteristics and standard deviations were measured with the single kernel characterization system (SKCS) (Table I) developed by Martin et al (1993) at the USDA, Agricultural Research Service, Grain Marketing and Production Research Center, Manhattan, KS, and currently being marketed by Perten Instruments (SKCS 4100, Perten Instruments AB, Huddinge, Sweden). The SKCS, developed for wheat classification, was successful on sorghum seed application (Pedersen et al 1996). The SKCS was used to measure the mean values of single kernel weight (SK-WT), single kernel diameter (SK-DM), and single kernel hardness index (SK-HI) of sorghum, and to calculate the standard deviation (SD) of each parameter using data obtained from 300 kernels. It measures hardness based on the force required for crushing single kernels. True density of the kernels was obtained using a gas pycnometer with helium (model SPY2, Quantachrome Corp., Syosset, NY) following the manufacturer's instructions.

Scarifying

To study the effects of different tempering conditions on the behavior of the sorghum hybrids during scarifying, four holding temperatures (20°C [closest to room temperature], 30, 40, and 50°C) and six holding times (0, 3, 10, 20, 40, and 60 min) were combined to form 24 sets of tempering conditions. Each sorghum sample was blended well with water in a beaker to reach a moisture level of 20% (wb) and the beaker was placed in a water bath at each holding temperature. Then 250-g samples were removed at the specified holding times and scarified for 30 sec. After scarifying, samples were dried for 1 hr at 50°C in a laboratory oven (Thelco, Precision Scientific, Inc., Chicago, IL) to get rid of surface moisture before they were sieved into different fractions. The percentages of the fractions from each sample treatment were determined.

Seven fractions were obtained from each scarifier treatment. The fractions were defined as the overs on the U.S. screens 6, 8, 12, 16, 20, and 30, and throughs of the 30 (pan, fine bran). Products of interest that have grits-like characteristics were defined as the fractions over the 6-, 8-, and 12-mesh screens. These fractions were analyzed for moisture, crude fat, and ash contents according to Approved Methods 30-25 and 08-03, respectively (AACC 2000). All analyses are reported on a dry basis. Henceforth, fractions will be referred by the screen number, on which they were overs: +6, +8, and +12.

Degerminating

For each experimental run, a 750-g sample of cleaned sorghum was placed into a plastic bag and tempered at optimum conditions:

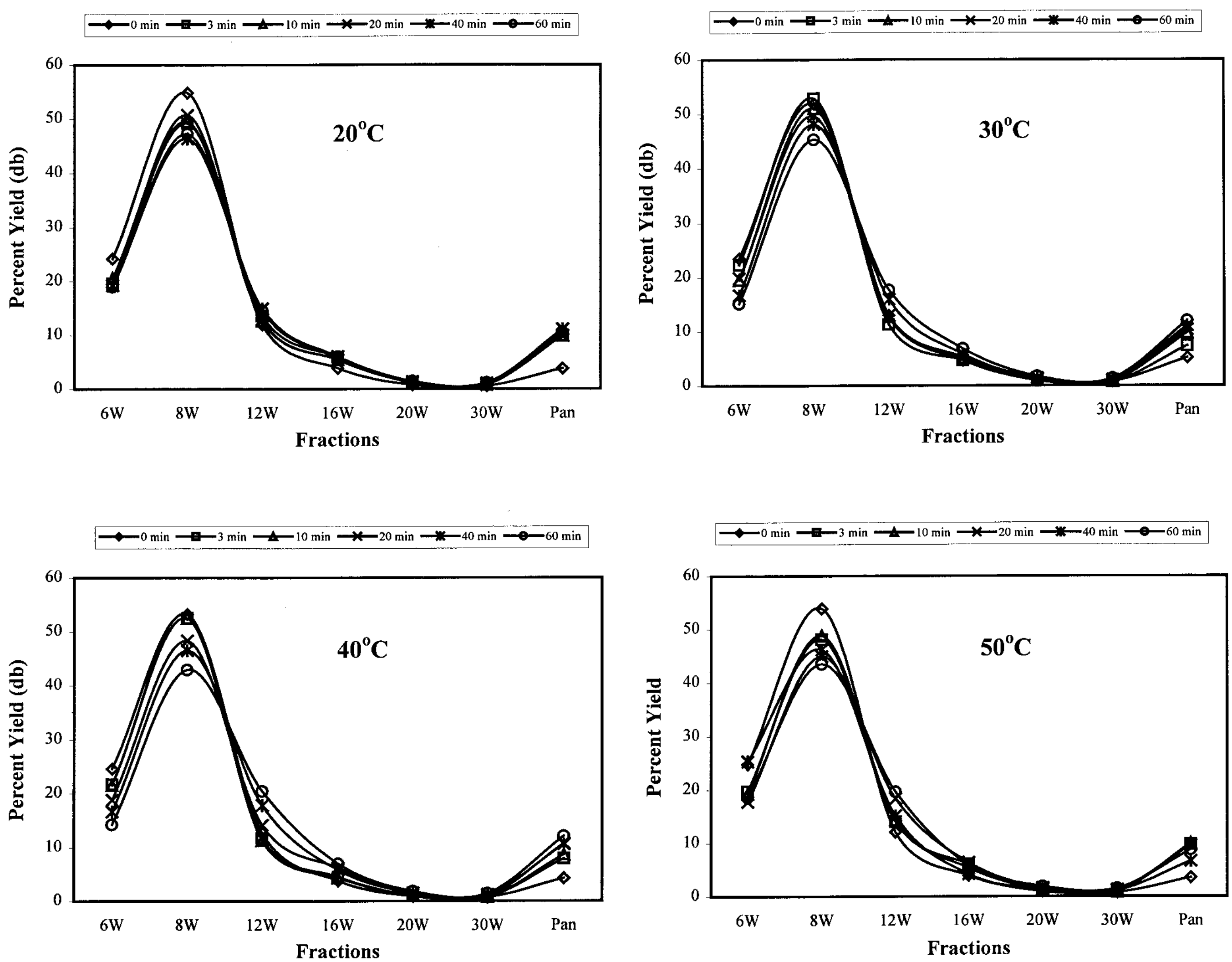

Fig. 3. Yield distribution of white grain with white endosperm sorghum (TR445) tempered at various temperatures and times and then scarified.

30°C for 3 min for DK35, 40°C for 40 min for TR445, and 20°C for 10 min for Pioneer 8500. After tempering, the grain was degerminated immediately. Figure 1 shows the process diagram of sorghum milling with the modified experimental decorticator-degerminator.

The tempered sorghum was fed at a constant rate of 0.4 kg/min using a vibratory feeder (HI-VI Vibratory Equipment, Eriez Manufacturing Co., Erie, PA) to the laboratory horizontal drum decorticator-degerminator through a metered opening in the screen into the area between the rotating brush and perforated screen.

All samples of the degerminated products were fractionated according to laboratory procedure. The samples were dried for 1 hr at 50°C in an oven (Thelco), then separated by using a screen shaker (Ro-Tap) with three screens (8, 12, and 30 mesh) for 10 min. The fractions were defined as the overs on screens 8, 12, and 30, and throughs of the 30 (pan, fine bran). These will be referred to by the screen size (+8, +12, and +30).

The overs on the three screens were aspirated to remove the coarse bran (fraction 5) with a laboratory aspirator (South Dakota Aspirator, Seedburo Equipment Co., Chicago, IL) with a valve cap setting at 1 cm (air velocity of 20.5 m/sec). The germ (fraction 6) obtained from the 30-mesh screen was separated from the grits using the same laboratory aspirator with a valve cap setting at 3.5 cm (air velocity of 22.9 m/sec). The valve cap settings for separating coarse bran and germ were obtained through experimentation until the best separation was achieved. The same settings were used throughout the study. All samples then were analyzed for ash and crude fat according to Approved Method 08-03 (AACC 2000) and a general acid hydrolysis and solvent extraction procedure using Soxtec System HT (model 1043, Tecator AB, Hoganas, Sweden).

Experimental Design and Statistical Analysis

A split-split plot design was used in the scarifier study. The main plot treatment was the sorghum hybrids in a completely randomized design. The subplot treatment (first split) was tempering temperature, and the sub-subplot treatment (second split) was tempering time.

All 24 combinations of tempering temperatures and holding times were tested for each of the three sorghum hybrids. In each treatment, the sample was milled with the same equipment setting. The percentages of total products in the fractions from each sample were determined. The +6, +8, and +12 fractions were analyzed for moisture, crude fat, and ash with two, one, and two repetitions, respectively. The whole experiment was replicated three times. The statistical analyses were performed only on the fractions of +6, +8, and +12 because the objective was to evaluate the quality of grits. The effect of each introduced variable (time of tempering, temperature of tempering, sorghum hybrid) on the grits produced was analyzed individually for each fraction because of large differences across fractions and, thus, was treated as a separate response. Analyses of variance were performed using the Statistical Analysis System software package (SAS Cary, NC). Simple correlations of SKCS values; physical and chemical characterization values; and the yield and ash and crude fat contents of the grits from different treatments were determined using PROC CORR.

A completely randomized design was used in the degermination investigation. The effects of two different size perforation holes

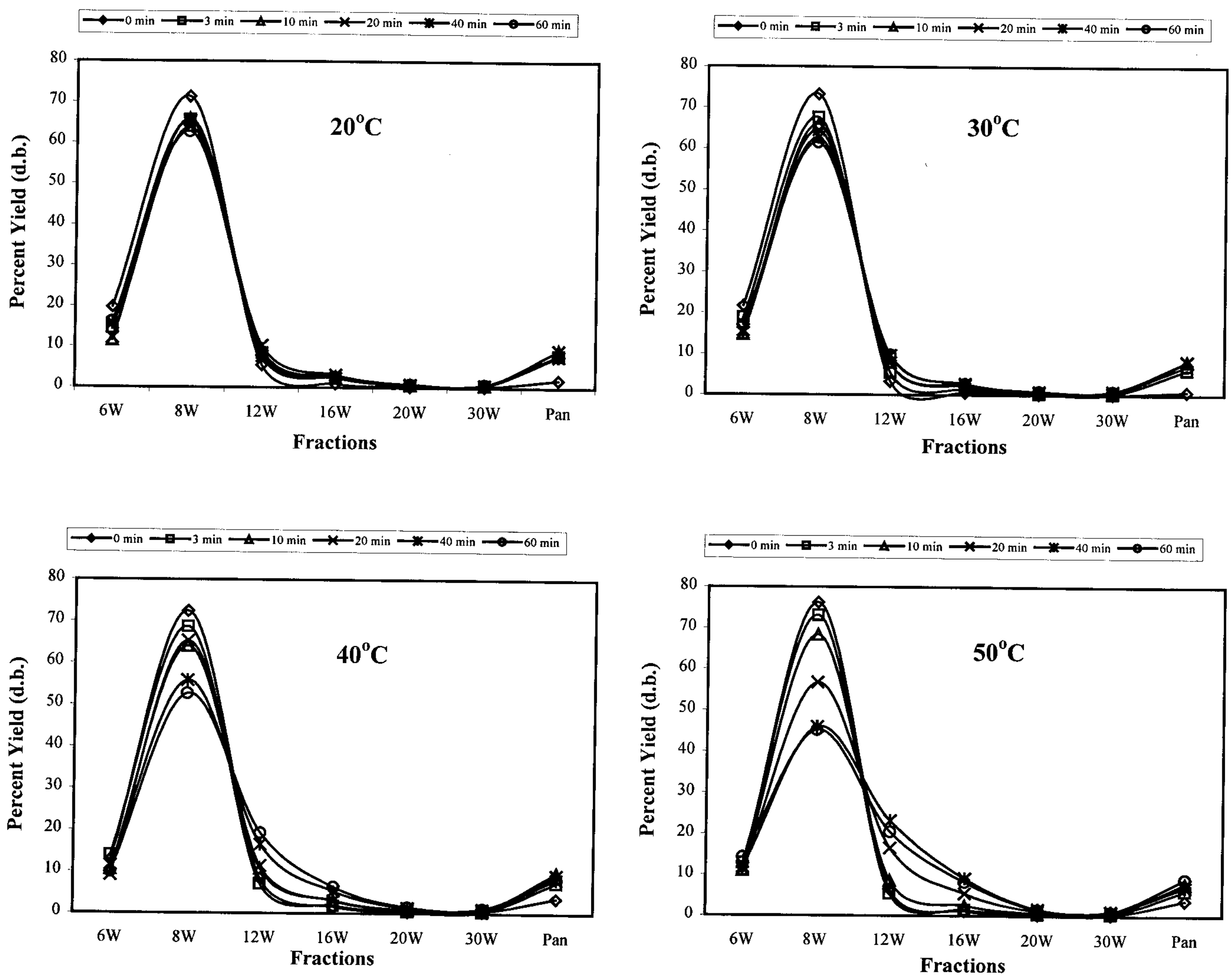

Fig. 4. Yield distribution of red grain with white endosperm sorghum (Pioneer 8500) tempered at various temperatures and times and then scarified.

and three sorghum hybrids on the ash and crude fat contents and yield of sorghum grits were studied in 2 × 3 factorial experimental design. Each treatment combination was repeated three times, and duplicate values were obtained for the ash and crude fat contents. The effects of perforation size and hybrids were statistically analyzed separately for each fraction because of large differences across the fractions. Analyses of variance were performed on the data collected. The statistical analysis was performed using the SAS software package. Simple correlations of SKCS values, physical and chemical characterization values of sorghum, and the yield and ash and crude fat contents of the grits obtained from the treatments with the large screen were determined using PROC CORR. The analysis was performed only on large screen treatments which gave higher grits yield than the small screen treatments.

RESULTS AND DISCUSSION

Scarifier

The yields of the dry-milled fractions are summarized in Figs. 2–4 and are reported as the percentage of the milled fraction retained on a sieve of a specific mesh size from the original sorghum sample weight. The grits products were flaking grits (+6), coarse grits (+8), and fine grits (+12). All the dry-milling results are dry basis.

All yields across fractions showed similar curves, a normal bell distribution with a tendency for skewing to the left toward the larger screens to give grits products, except for sorghum DK35 tempered at 30, 40, and 50°C before milling. Fig. 2 of 30, 40, and 50°C tempering temperatures show that the yield redistributed into a normal bell curve, without a noticeable skewing effect from increased tempering temperature, probably because this hybrid had the softer grain. The SKCS hardness index for DK35 was 72, whereas for Pioneer 8500 and TR445 hardness index was 85 and 67, respectively. DK35 also had higher protein content than the other hybrids (Table I).

+6 Grits

Sorghum hybrids and tempering time affected the yield of +6 grits ($P < 0.05$) (Table II). As the tempering time increased, the yield decreased, probably because the friability of the corneous endosperm increased so it was more easily reduced to smaller grits size. The 3-min tempering time produced the highest yield for all hybrids. At all tempering times, the white hybrid (TR445) produced the highest yield, followed by the red (Pioneer 8500) and bronze (DK35) ($P < 0.05$) hybrids, indicating that TR445 might have a higher ratio of corneous endosperm.

The ash content of +6 grits was affected by cultivar and the interaction of hybrid and tempering time ($P < 0.05$) (Table III). The 3-min tempering time produced grits with ash contents that were not significantly different among all hybrids ($P < 0.05$) and had a range of 1.23–1.33%. At longer tempering times, ash contents were significantly different among the hybrids ($P < 0.05$). The lowest ash contents were obtained for DK35 (1.22%) with 20 min of tempering, Pioneer 8500 (1.15%) with 10 min, and TR445 (1.14%) with 60 min.

The crude fat content of +6 grits was affected by sorghum hybrid, tempering temperature, and the interaction of these two factors, the interaction of hybrid and tempering time and the interaction of tempering temperature and time ($P < 0.05$) (Table III). At tempering temperatures of 20 and 50°C, crude fat contents of grits did not differ significantly among hybrids ($P < 0.05$) and were almost always higher than contents at other temperatures, except for TR445. The crude fat contents were lowest for DK35 at 30°C and for both Pioneer 8500 and TR445 at 40°C. As tempering time increased, the crude fat content increased for grits of DK35 but almost always tended to decrease for grits of Pioneer 8500 and TR445.

+8 Grits

The yield was affected by main effects due to hybrid and temperature; cultivar and time and their interaction; the interaction of temperature and time; and the three-way interaction of cultivar, tempering time, and temperature ($P < 0.05$). Yield was highest for the red hybrid (Pioneer 8500), followed by the white (TR445), and bronze (DK35) hybrids, in that order, with means of 64, 49, and 45%, respectively ($P < 0.05$). This supported the hypothesis that DK35 was a soft hybrid that would break up into small grits (+12 grits) under milling and thus would have low yield for large grits (+8 grits). The yield decreased with increasing tempering temperature, which illustrates the effect of conditioning in endosperm friability. In general, the yields of all hybrids decreased with increasing tempering time, presumably because friability of the endosperm increased. As the time increased, the yield of Pioneer 8500 was always higher than yields of TR445 and DK35 ($P < 0.05$), probably because it has an intermediate proportion of corneous endosperm, characterized by the highest hardness index number and lowest protein content. The yield decreased for all tempering temperatures as tempering time increased. At ≥20 min, the higher tempering temperature produced lower yield because the combination of

TABLE II
Ash Content (% db) of Scarified Grits from Three Sorghum Hybrids

Tempering	DK35				TR445				Pioneer8500			
Time (min)	20°C	30°C	40°C	50°C	20°C	30°C	40°C	50°C	20°C	30°C	40°C	50°C
+6 Grits												
0	1.22	1.15	1.25	1.32	1.26	1.24	1.28	1.26	1.30	1.41	1.20	1.24
3	1.33	1.26	1.25	1.31	1.23	1.28	1.27	1.24	1.23	1.31	1.27	1.27
10	1.32	1.29	1.29	1.31	1.20	1.18	1.24	1.23	1.28	1.15	1.23	1.22
20	1.23	1.27	1.30	1.32	1.14	1.17	1.21	1.21	1.28	1.30	1.27	1.29
40	1.24	1.35	1.37	1.32	1.15	1.23	1.22	1.28	1.34	1.24	1.19	1.29
60	1.30	1.38	1.09	1.38	1.15	1.14	1.20	1.19	1.27	1.28	1.29	1.34
+8 Grits												
0	1.02	1.04	1.12	1.17	1.16	1.08	1.13	1.19	1.22	1.29	1.11	1.10
3	1.09	1.04	1.05	1.15	1.00	1.10	1.04	0.96	1.09	1.19	1.15	1.18
10	1.08	1.07	1.15	1.01	0.98	0.97	1.02	1.04	1.04	1.09	1.05	1.14
20	0.99	1.01	0.96	1.02	0.99	0.96	0.92	0.79	1.02	1.14	1.01	1.13
40	0.86	0.89	0.88	1.09	0.86	0.91	0.86	0.96	1.11	1.03	1.00	1.12
60	0.83	0.90	0.99	1.09	0.81	0.63	0.64	0.77	1.05	0.96	0.95	1.09
+12 Grits												
0	0.52	0.42	0.47	0.44	0.49	0.46	0.51	0.67	0.41	0.44	0.44	0.43
3	0.47	0.27	0.33	0.39	0.30	0.42	0.59	0.37	0.35	0.42	0.43	0.44
10	0.47	0.27	0.34	0.30	0.28	0.43	0.55	0.34	0.33	0.35	0.38	0.40
20	0.46	0.41	0.41	0.35	0.40	0.43	0.31	0.42	0.37	0.43	0.40	0.48
40	0.46	0.57	0.47	0.47	0.45	0.37	0.43	0.71	0.48	0.50	0.46	0.52
60	0.48	0.67	0.58	0.52	0.50	0.41	0.40	0.67	0.54	0.56	0.42	0.45

elevated temperature and longer time increased the moisture absorption rate and caused the endosperm to be even more friable. The highest yields of +8 grits were produced at 3 min and 50°C for DK35 (≈63%), 3 min and 50°C for Pioneer 8500 (≈73%), and 3 min and 30°C for TR445 (≈53%). At any combination of tempering time and temperature, the yield of Pioneer 8500 was always higher than yields of DK35 and TR445 ($P < 0.05$). At higher temperatures and longer time periods, the yield of DK35 sharply decreased, probably because of a higher proportion of soft endosperm.

The ash content of +8 grits was affected by hybrid and tempering time and the interaction effects ($P < 0.05$) (Table II). The 60-min tempering time produced the lowest ash content for all hybrids at 0.77–1.09%. In general, as tempering time increased, the ash content of all hybrids decreased. TR445 produced the lowest ash content, followed by DK35 and Pioneer 8500, with mean contents of 0.95, 1.02, and 1.09% ($P < 0.05$), respectively, for +8 grits.

The crude fat content of +8 grits was affected by hybrid, tempering temperature and the interaction as well as cultivar and tempering time with interactions ($P < 0.05$) (Table III). At the highest tempering temperature, the crude fat content in grits was lowest for TR445 (1.85%) and highest for DK35 (2.68%) and Pioneer 8500 (2.70%). Longer tempering times almost always yielded grits with the lowest crude fat content for all hybrids. The 40-min tempering time produced the lowest crude fat content for DK35 (2.27%), whereas 60 min produced the lowest crude fat contents for Pioneer 8500 and TR445 (2.22 and 1.33%, respectively).

+12 Grits

Yield was affected by main effects due to hybrid, temperature, and time, as well as the interactions of hybrid and time, temperature and time, and the three-way interaction ($P < 0.05$). The yield of DK35 was highest, followed by TR445 and Pioneer 8500, with means of 21, 14, and 10%, respectively ($P < 0.05$). Yields of all hybrids increased as the tempering temperature and time increased. At any given tempering time, the yield of DK35 was highest, followed by TR445 and Pioneer 8500 in that order ($P < 0.05$), showing that DK35 had a softer endosperm. With tempering times >10 min, the yield was higher at highest temperature because the water absorption rate was greater. The highest yields for +12 grits were produced by tempering for 60 min at 30°C for DK35, 40 min at 50°C for Pioneer 8500, and 60 min at 40°C for TR445.

The ash content of +12 grits was affected by time and the interaction of cultivar and temperature ($P < 0.05$) (Table III). As tempering time increased from 3 to 60 min, the ash content increased from 0.40 to 0.52%. The 3- and 10-min tempering times almost always produced grits with the lowest ash content for all hybrids among the different temperatures, except for DK35 at 50°C, TR445 at 40°C, and Pioneer 8500 at 30°C. The lowest ash contents were produced at 30°C for DK35, and at 20°C for both Pioneer 8500 and TR445. The lowest ash contents were produced with 3- or 10-min tempering at 30°C for DK35 (≈0.27%) and at 20°C with 3 or 10 min for both Pioneer 8500 (≈0.35%) and TR445 (≈0.30%).

The crude fat content of +12 grits was affected by hybrid, tempering time, and the interaction of these two factors; interaction of temperature and time; and the three-way interaction of cultivar, tempering time, and temperature ($P < 0.05$) (Table III). As the tempering time increased, the crude fat content almost always increased. This may be due to moisture penetrating into the cementing layer between endosperm and germ, thus easing the release of the germ contributing to high crude fat content. Crude fat contents were not significantly different among samples at tempering times of ≤10 min ($P < 0.05$). With tempering times >10 min, the crude fat content of TR445 was significantly lower than that of DK35, but not significantly lower than that of Pioneer 8500 ($P < 0.05$). The 3-min tempering time at 30 and 40°C produced the lowest crude fat contents of DK35. The 20°C tempering temperature for both 10 and 20 min produced the lowest crude fat content of Pioneer 8500. The 40°C tempering temperature for 40- and 60-min produced the lowest crude fat content of TR445.

Degermination

A combination of compressing, shearing, packing, splitting, and brushing took place on the grain between the brush and screen. These actions removed the hull and germ and reduced the endosperm to a size that permitted it to pass through the perforated holes along with the hull and germ. Table IV indicates that the rate of degerminator throughput was related proportionally to the size of hole of the perforation screen. Throughput ranged from 0.02 kg/min for the small screen to 0.045 kg/min for the large screen on a dry basis with an 0.4 kg/min input rate.

The yield of products was defined as the percentage of the milled fraction retained on a sieve of specific mesh size. The total grits yield (combined grits of +8, +12, and +30) freed of germ and hull by the degerminator (Table IV) was higher for the large screen (average of 77.5% of the original sample weight) and lower for the small screen (65.5%).

TABLE III
Crude Fat Content (%, db) of Scarified Grits from Three Sorghum Hybrids

Tempering	DK35				TR445				Pioneer8500			
Time (min)	20°C	30°C	40°C	50°C	20°C	30°C	40°C	50°C	20°C	30°C	40°C	50°C
+6 Grits												
0	2.74	2.68	2.82	2.84	3.59	3.12	2.42	2.84	3.14	3.10	2.70	3.10
3	3.28	2.53	2.75	2.91	3.30	3.06	2.48	2.58	3.04	3.49	3.04	3.12
10	3.03	2.89	2.90	2.86	2.96	3.47	2.42	2.84	3.11	3.26	2.85	2.91
20	2.91	2.85	3.18	3.09	2.99	3.09	2.29	2.67	2.90	2.87	2.98	3.11
40	3.13	3.03	2.79	3.88	2.83	2.89	1.89	2.46	2.87	2.87	2.89	3.21
60	3.00	2.69	3.57	3.60	2.86	2.98	1.93	2.35	2.61	2.79	2.75	3.15
+8 Grits												
0	2.39	2.28	2.49	2.75	3.43	2.45	1.98	2.33	3.04	3.17	2.68	2.80
3	2.72	2.71	3.11	3.00	2.88	3.14	2.01	2.11	2.63	3.24	2.84	3.01
10	2.60	2.06	2.79	2.43	2.55	2.81	1.99	2.04	2.71	3.02	2.55	2.81
20	2.39	2.39	2.30	2.51	2.46	2.46	1.79	1.81	2.45	2.64	2.61	2.70
40	2.25	2.19	1.93	2.73	2.00	1.98	1.20	1.57	2.45	2.21	2.49	2.38
60	2.49	1.93	2.57	2.65	1.72	1.55	0.80	1.25	2.01	2.12	2.22	2.54
+12 Grits												
0	1.22	0.92	0.92	1.04	1.43	0.92	0.36	0.90	0.71	0.83	0.76	0.93
3	0.92	0.42	0.43	0.82	0.84	0.55	0.74	0.51	0.61	0.92	0.72	0.87
10	0.96	0.65	0.63	0.57	0.57	0.73	1.50	0.56	0.59	0.87	0.61	0.81
20	0.95	1.02	0.88	0.77	0.79	0.91	0.39	0.72	0.58	0.77	0.92	0.93
40	1.02	1.34	1.17	1.58	0.74	0.72	0.35	1.19	0.69	0.69	0.94	1.02
60	0.76	1.64	1.78	1.16	0.69	0.82	0.38	1.11	0.76	1.08	0.86	0.97

Of the six fractions obtained from this laboratory separation, the +12 grits was defined as the fraction of interest because it had the highest yield (21–49% for small and large screens, respectively) with the lowest ash content (0.14–0.23%) and lowest crude fat content (0.07–0.36%).

Pioneer 8500 produced the lowest germ fraction (3.3%) with a high crude fat content (20.37%) when the large screen was used, indicating that the separated germ in this hybrid was freed of attached endosperm. However, more germ fine particles were produced, as evidenced by the high crude fat content of the throughs 30 mesh (pan) fraction (10.92%).

The size of the perforation holes significantly affected the ash and crude fat contents, and yield of +8 grits ($P < 0.05$). When a small perforation screen was used, the values for ash, crude fat, and yield were 0.57, 0.98, and 6.6%, respectively. The small screen needed a longer time (32 min) to process the whole kernel into the size permitted by the perforation holes. Thus, most of the pericarp was abraded and the germ was freed from the endosperm but, at the same time, yield decreased considerably. Analysis showed a highly negative correlation ($r = -0.99$) between the yield of +8 grits and ash content. When the kernels were milled to produce more +8 grits, more bran was removed resulting in lower ash content.

The size of the perforation holes significantly affected ($P < 0.05$) the crude fat content and the yield of +12 grits, with the small screen producing a low yield of grits but with lower crude fat. Hybrids also significantly affected ($P < 0.05$) the yield; TR445 produced the highest yield (≈43%) followed by Pioneer 8500 (≈36%) and DK35 (≈33%). This was very consistent throughout this study, showing the TR445 hybrid belongs to corneous sorghum.

Ash, crude fat contents, and yield of +30 grits were affected significantly ($P < 0.05$) by the size hole of the perforation screen and sorghum hybrids. The small screen produced low ash and crude fat contents but high yield. This was consistent with the findings that the small perforation holes retained the sorghum kernels longer inside the drum where the abrading and splitting action reduced the grits size until they passed through the holes. Pioneer 8500 produced a lower yield of grits compared with DK35; however, the grits had lower ash and crude fat contents. The yield of +30 grits was correlated positively with the crude fat content ($r = 1.00$) (Table IV). The germ had the same size as the +30 grits (0.6 mm), thus, the germ also would be collected in this fraction, thereby increasing the fat content.

The sizes of the hole of the perforated screen and sorghum hybrids also affected ($P < 0.05$) the ash and crude fat contents and yield of fine bran. Smaller holes produced a higher yield of fine bran because of its size (0.0925 in.). TR445 produced the lowest yield of fine bran and lower ash value, indicating that this hybrid had more vitreous/flinty endosperm, whereas the other hybrids had softer endosperm indicated by higher yields of fine bran. Moreover, the optimum tempering conditions required indicated that the white endosperms of the white and red grains were harder, whereas the heteroyellow endosperm of the bronze grain (DK35) was softer. However, the single kernel characterization analysis showed that red grain was the hardest, followed by bronze and white grains. These results were not conclusive because the SKCS was developed originally for wheat, and very little work has been done to justify its application to grain sorghum (Pedersen et al 1996).

Sorghum hybrids and the size of the perforation hole affected ($P < 0.05$) the yield of coarse bran. Large holes produced more coarse bran. Pioneer 8500 produced more coarse bran than the other hybrids, indicating that the tempering conditions provided sufficient moisture and time to permit peeling of the pericarp from the endosperm.

Sorghum hybrids affected the yield of germ, with TR445 producing the highest yield (7.9%). Pioneer 8500 produced the lowest germ yield but the highest crude fat content, and its grits had the lowest crude fat content, indicating that the separation of germ and endosperm was quite complete.

Comparison of +12 Grits from Scarifier and Degerminator Dry Milling

The modified decorticator-degerminator dry-milling system with a large screen generally provided statistically ($P < 0.05$) higher yields of +12 sorghum grits with lowest ash and lowest crude fat

TABLE IV
Yield , Ash Content, and Crude Fat Content of Degerminated Fractions[a] from Three Sorghum Hybrids[b]

	DK35		TR445		Pioneer 8500	
Product	Large Screen	Small Screen	Large Screen	Small Screen	Large Screen	Small Screen
Throughput rate, kg/min	0.043	0.020	0.045	0.022	0.035	0.022
Yield (% db)						
Total grits	77.1	62.9	78.8	67.5	76.5	66.0
+8 grits	25.7b	5.8a	20.6b	3.0a	28.1b	11.0a
+12 grits	45.3d	21.0a	49.1d	35.4c	44.2d	28.4b
+30 grits	6.1a	36.1c	9.1a	29.1b	4.2a	26.6b
–30 (pan) bran fines	15.6b	27.2e	12.0a	21.0c	16.5b	25.6d
Coarse bran (hull)	3.1c	2.5b	2.6b	2.4a	3.8d	3.2c
Germ	4.3b	7.4c	6.6c	9.2d	3.3a	5.2b
Ash (% db)						
Average total grits	0.45	0.40	0.49	0.29	0.38	0.25
+8 grits	0.71c	0.75c	0.79c	0.36a	0.68b	0.42ac
+12 grits	0.22b	0.23b	0.23b	0.15a	0.20b	0.14a
+30 grits	0.43de	0.23ab	0.46e	0.35cd	0.26bc	0.18a
–30 (pan) bran fines	4.04d	2.85a	3.84c	2.71a	4.08d	3.16b
Coarse bran (hull)	4.37ab	4.24ab	5.41b	4.43b	4.27ab	3.90a
Germ	8.32d	5.36a	7.50c	6.20b	7.92cd	5.78ab
Crude fat (% db)						
Average total grits	0.83	0.63	1.1	0.49	0.81	0.38
+8 grits	1.51b	1.47a	1.90b	0.65a	1.58b	0.83a
+12 grits	0.18b	0.19a	0.36b	0.13a	0.22b	0.07a
+30 grits	0.79b	0.24a	1.04b	0.69b	0.63a	0.23a
–30 (pan) bran fines	9.41bc	7.28a	10.31cd	7.31a	10.92d	8.53ab
Coarse bran (hull)	7.16ab	6.96a	6.14a	6.91a	9.21b	8.64b
Germ	19.47c	11.98a	19.54c	15.45b	20.37c	14.40b

[a] Large screen = 1/8″ (3.175 mm) hole diameter; small screen = 3/32″ (2.38 mm) hole diameter.
[b] Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

contents compared with those produced by scarifier dry milling. The only exceptions were ash content of DK35 and crude fat content of TR445. The comparison was based on equal variance analysis of *t*-test for each sorghum hybrid tempered to optimum temperature and processed in the scarifier and the modified decorticator-degerminator to obtain +12 sorghum grits.

SUMMARY

Decorticating of sorghum with a scarifier, an abrasive-type mill, resulted in grits with the lowest ash and lowest crude fat contents collected in fraction +12; however yield was unsatisfactory (<10%). The general trend was an increase in grits yield with increased tempering time, but not always with increased tempering temperature. Ash and crude fat contents of +12 grits were affected significantly by tempering time and temperature and interactions with sorghum hybrids. Thus, optimum tempering conditions to obtain low ash and low fat sorghum grits were different for each hybrid. The size of the hole of the perforated screen inside the modified decorticator-degerminator affected the yield, ash, and crude fat contents of sorghum grits. The large screen (1/8" hole) gave higher yields of grits with higher contents of ash and higher crude fat than the small screen for all hybrids. After each sorghum hybrid was tempered at optimum conditions, dry milling with a modified decorticator-degerminator gave better results than the scarifier: a higher yield of +12 grits (four times the scarifier) with low contents of ash (<0.25%) and crude fat (<0.5%). These characteristics of +12 grits (fine) would find potential uses in food applications while the +6 grits (flaking) and +8 grits (coarse) with slightly high ash and crude fat content could find applications as brewer's grits and other industrial applications.

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