A Ready-to-Eat Breakfast Cereal from Food-Grade Sorghum

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ABSTRACT

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Two food-grade sorghum hybrids, ATx631*Tx436 (nonwaxy) and B.BON 34 (waxy), were micronized and evaluated for their potential use in ready-to-eat breakfast cereals (RTE-BC). Whole and decorticated grains were exposed to infrared burners and flaked between corrugated rollers. Whole B.BON 34 flakes had the lowest density, best flavor and texture, and the most starch gelatinization. Decorticated flakes from both micronized sorghums expanded more and had different texture than their whole grain flakes. Based on flake characteristics (texture, expansion, and flavor), whole B.BON 34 and decorticated ATx631*Tx436 flakes were selected for granola preparation. Granolas were prepared by mixing, baking, and cooling sorghum flakes, wheat bran, sesame and sunflower seeds, raisins, sorghum molasses, oil, fructose and water. A control granola was prepared with rolled oats instead of sorghum flakes. Texture and flavor were the most important attributes of granolas. All granolas were crispy, sweet, and had a nutty flavor. Decorticated ATx631*Tx436 granola had the hardest texture and remained crispy in milk for the longest time. Whole B.BON 34 granola was the most acceptable; it was preferred ($P < 0.05$, $n = 36$) by a sensory panel over the decorticated ATx631*Tx436 and control granolas. The micronized waxy sorghum, B.BON 34, produced whole-grain fiber-rich flakes with a puffed texture that resulted in excellent granola-type RTE-BC and granola bars.

Ready-to-eat breakfast cereals (RTE-BC) are defined as "processed grain formulations suitable for human consumption without further cooking" (Fast 1987). Cereals that are most often used in the formulation of RTE-BC include maize, wheat, oats, rice, and barley. Growth in the RTE-BC market has been estimated at 3% annually in the United States and 10% in Europe. By the year 2000, Europe's overall consumption of RTE-BC is expected to double (Jones 1992).

Granolas, a type of RTE-BC, are mixes of ingredients toasted with natural sweeteners. Typically rolled oats and honey have been the main ingredients. Additional ingredients may include other flakes (wheat, rye, triticale, soybean), wheat bran, puffed rice, oilseeds (sunflower, sesame), dried fruits (raisins, dates, coconut), nuts (almonds, pecans, peanuts), flavorings (malt extract, cinnamon, nutmeg, dried milk), oils, and sweeteners (brown sugar, molasses). There are as many formulations as the possible combinations of these ingredients.

Processing granolas involves mixing the dry ingredients followed by the addition of the sweetening solution usually containing honey or molasses and oil. The mix is conveyed through the oven (300–425°F), where it is toasted to the desired point. After toasting, granolas are cooled, crumbled into smaller pieces, and packaged. Today, granola sales have risen tremendously because consumers are looking for products that are lower in fat and richer in healthy and more natural ingredients (Liesse 1993).

The use of flaked sorghums for RTE-BC was suggested by Rusnak et al (1980). Lu (1986) proposed two methodologies for the laboratory-scale production of RTE-BC sorghum flakes. Al-Kahtani (1988) produced a flaked RTE-BC made with a mixture of sorghum and wheat flours. Endosperm characteristics (waxy or nonwaxy) are important in the processing of sorghum. Rusnak et al (1980) and Gomez et al (1988) reported that, after micronizing and extrusion, respectively, waxy sorghums were not only more expanded but also more extensively gelatinized, lighter in density, had more uniform distribution of air cells, and needed less force to break. Waxy sorghums needed less severe processing conditions to achieve the same degree of gelatinization as nonwaxy ones, which could reduce energy costs (Rusnak et al 1980).

Micronizing is a process in which gas-fired infrared burners are used to generate dry heat. Infrared rays penetrate the grain, excite the water molecules, and cause rapid internal heating that raises the water vapor pressure. This causes cooking in the grain from the inside out; it expands almost to the point of eversion. Immediately before eversion, the grain is flaked through corrugated rollers under pressure. Part of the superheated water of the grain is flash-evaporated as flaking takes place (Anonymous 1977). The degree of cooking achieved depends on the composition of the grain.

Micronizing has typically been used to process grain for feed (Rooney and Serna-Saldivar 1990) and for the production of flakes included in breakfast cereal formulations. Desirable attributes of the flakes are low density, expanded size, crisp texture, cooked flavor, breakage resistance, and flake integrity.

Sorghum hybrids with improved processing characteristics have been developed for food uses. Uniform grain size, thin white pericarp without pigmented testa, and specific endosperm types (waxy or nonwaxy) are some of the characteristics recommended for different products (Rooney et al 1992). The use of waxy sorghum hybrids to produce breakfast cereals had been previously suggested (Rusnak et al 1980, Gomez 1987). Therefore, the objective of this study was to evaluate micronized sorghums with different endosperm types for their potential use in a granola-type RTE-BC.

MATERIALS AND METHODS

Raw Materials

Grain of two sorghum hybrids grown in 1991 at the Texas Agricultural Experiment Station, Halfway, TX, were evaluated. Characteristics of the sorghums ATx631*Tx436, a nonwaxy endosperm type, and B.BON 34, a waxy endosperm type, are listed in Table I.

Flake Production

Sorghums were cleaned using sieves and the Kice dockage tester (model 6DT4-1, Kice Industries, Inc., Wichita, KS). Part of the grain was decorticated in 3-kg batches for 3 min in a Prairie regional lab mini-dehuller (Nutana Machine Co., Saskatoon, Canada) and cleaned. Whole and decorticated sorghum were micronized in a Pierce laboratory micronizer as described by Rusnak et al (1980). The micronizer was preheated (15 min) to

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TABLE I
Descriptive Characteristics of Sorghums Used for Ready-to-Eat Breakfast Cereals[a]

Sample	Pericarp			Endosperm		Plant Color[b]	Ratio of Waxy to Nonwaxy Kernels[c]
	Color	Thickness	Pigmented Testa	Type	Color		
ATx631*Tx436	White	Thin	None	Nonwaxy	White	Tan	0:100
B.BON 34	White	Thin	None	Waxy	White	Tan	96:4

[a] Sorghums were grown at Halfway, TX, 1991.
[b] Secondary plant color.
[c] Subjective determination based on examination of decorticated kernels.

allow the burners and skillet to equilibrate. Approximately 20 kg of commercial red sorghum were processed before the experimental samples to warm and adjust the rollers to produce flakes with a test weight of 33.5 kg/hl. The gap between the rollers was ≈1 mm. Experimental samples were then micronized, collected, and cooled overnight at room temperature. Triplicate runs were conducted with each grain. Composite samples were prepared by mixing equal portions of flakes from the three different runs. Micronized flakes were stored at –18°C for product development and analysis.

Product Development

Micronized flakes from whole and decorticated grain were evaluated for their potential use in granolas. The most important attributes for selection of good flakes were texture (crunchy, friable), acceptable cooked flavor, light density, resistance to breakage, and adequate expansion (size of rolled oats ≈9 mm). A method and optimum formulation to produce granola with the best-suited micronized sorghum flakes was developed (Fig. 1, Table II). Micronized sorghum flakes were mixed manually with wheat bran, sesame seed, sunflower seed, and raisins in a stainless steel bowl. A sorghum molasses-oil-fructose-water solution (5:1:0.3:1, w/w) was added to the dry ingredients and mixed until it was homogeneously dispersed. In contrast to honey, which is commonly used in granola production, sorghum molasses is heat-processed and has a very high osmotic pressure. It has a slightly different, lighter flavor than honey. The resulting mix was spread on baking trays covered with wax paper and baked at 205°C for 15 min until toasted uniformly. Granolas were cooled at room temperature, packaged in plastic bags and stored at –18°C and at room temperature. A control granola was prepared as described above, using rolled oats instead of micronized sorghum flakes. All ingredients, except for the sorghum molasses (Lloyd Roe Farms, Pomeroyton, KY), were purchased in a local health food store.

Physical Analyses

All analyses were run in triplicate. Thousand-kernel weight was determined on the raw grains by weighing 100 kernels and multiplying their weight by 10. Test weight (bulk density) of the raw grains and flakes was determined with the Winchester bushel meter (Seedburo Equipment Co., Chicago, IL). Density was determined using a nitrogen-displacement multipycnometer (model MVP-1, Quantachrome Co., Powder Instrumentation, Syosset, NY). Kernel hardness was determined using the tangential abrasive decortication device (model 4E-115, International Development Research Center, Ottawa, Canada) (Reichert et al 1982).

Size and thickness of the flakes were determined on 30 flakes per treatment using calipers (economy vernier stainless steel, 2272A21, Italy). Texture (force to break) was determined on 30 micronized flakes per treatment using a manual penetrometer (Force Dial FDK 80, Wagner Instruments, Greenwich, CT). Texture of the granolas and the flaked cereals was determined on 16 flakes per treatment using the texture analyzer (model TA.XT2, Texture Technologies Corp., Scarsdale, NY) with the small punch

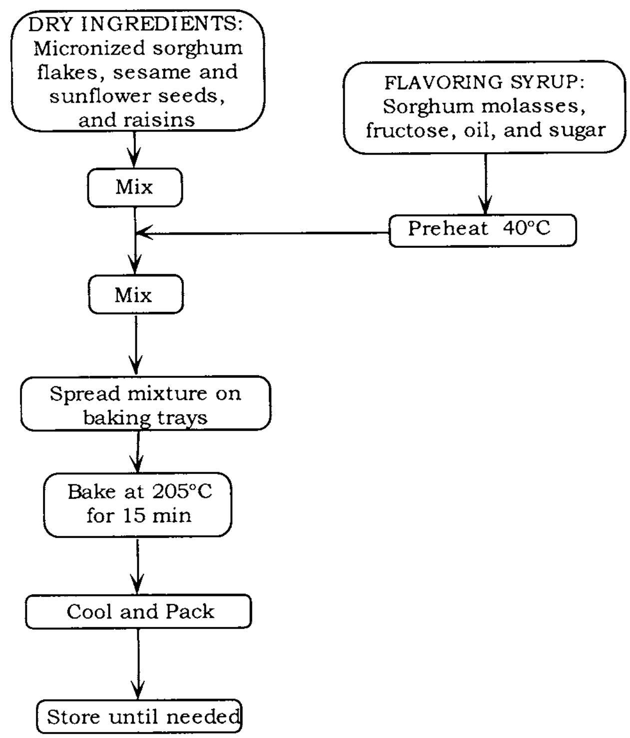

Fig. 1. Procedure for the preparation of granolas.

TABLE II
Granola Formulation

Ingredients	Percent
Micronized sorghum flakes[a]	39.9
Sorghum molasses	30.1
Water	6.3
Vegetable oil	6.3
Sesame seed	4.0
Sunflower seed	4.0
Raisins	4.0
Wheat bran	3.2
Fructose	2.2

[a] In control granola, rolled oats were used instead of micronized sorghum flakes.

probe (TA-52). The parameters were: distance = 9 mm, speed = 5 m/sec, and count = 4.

Sogginess (disappearance of crispiness) was determined subjectively by placing 20 g of sample in cold milk (10°C) and chewing an aliquot at 1-min intervals until crispiness disappeared. The time (min) for crispiness to disappear was recorded as sogginess. The longer the time, the crispier the breakfast cereal.

Chemical Analyses

Samples were ground in the Udy cyclone sample mill for analysis. Moisture, fat (Goldfisch method), and ash were determined in all samples by standard procedures (AACC 1983). Crude protein (N × 6.25) was determined using Kjeldahl digestion (AACC 1983) and a Technicon automated nitrogen assay (Technicon 1976). Dietary fiber was determined by the enzymatic gravimetric procedure of Asp et al (1983).

Total and enzyme susceptible starches (ESS) were determined after digestion of samples with glucoamylase (Diazyme L-200, Solvay Enzymes, Elkhart, IN) at 60°C for 30 min; the glucose released was measured using the autoanalyzer Technicon II (Technicon 1979).

Amylose and amylopectin contents were determined using aqueous high-performance size-exclusion chromatography (HPLC-SEC) as described by Jackson et al (1988). Samples (0.05 g) were extracted (10 ml of degassed-deionized water), autoclaved (120°C for 10 min), sonicated (15 sec, 20 kHz), centrifuged (5,000 × *g*, 20 min), and filtered through a 0.5-μm nylon filter. Filtrates were then injected into the HPLC-SEC. Flaked cereal samples were desalted before injection into the HPLC-SEC using a short column containing 25 ml of Bio-gel P-6DG. Data from the HPLC-SEC system was collected, and peaks were integrated and analyzed using Apple IIe Adalab hardware and Chromatochart software (Interactive Microwares, State College, PA).

Physicochemical Analyses

Pasting properties of starch were evaluated using 28 g of sample (14% solids) in the Rapid Visco Analyzer (RVA) (Newport Scientific Pty, Ltd., Narabeen, Australia) held at 50°C for 2 min, increased to 95°C in 4.5 min, held 95°C for 4 min, decreased to 50°C in 4.5 min, and held at 50°C for 3 min.

Water solubility (WSI) and water absorption indices (WAI) were determined by extracting 1 g of sample with 15 ml of water (30 min), and centrifuging (5,000 × *g*, 20 min). Water soluble solids in the supernatant were determined by drying. Water absorption was determined by weighing the remaining gel (Anderson et al 1969).

Microscopic Analyses

Defatted samples were mounted on aluminum stubs with conductive adhesive, dried overnight in a vacuum oven at 50°C, coated with 200Å gold-palladium, and viewed on a JEOL JSM T330A scanning electron microscope (SEM) at an accelerating voltage of 15 Kv.

Sensory Analysis

Granolas at room temperature were organoleptically evaluated by 36 untrained panelists. The attributes evaluated were: acceptability, color, texture, appearance, and flavor, using a 9- point hedonic scale (1 = dislike, 9 = like).

Statistical Analysis

Statistical analysis was conducted using an SAS software package (version 6.04, SAS Institute, Inc., Cary, NC). Protected Fisher least significant difference (LSD) was used for multiple mean comparison.

RESULTS AND DISCUSSION

Raw Materials

ATx631*Tx436 and B.BON 34 had similar physical characteristics, although ATx631*Tx436 grain was somewhat larger and denser (Table III). Moisture of the grains were equilibrated before processing. The grain of the nonwaxy hybrids was slightly softer than that of the waxy grain.

Decortication of the grains in a PRL rollover mini-dehuller removed 12.0 and 10.5% of the weight of ATx631*Tx436 and B.BON 34, respectively. The yields of decorticated sorghum were 88 and 90.5%, respectively, based on initial grain weight. Decortication caused significant losses of fat, ash, and dietary fiber (Table IV). Pericarp removal during decortication was excellent and nearly complete.

Composition

The proximate compositions of the grains were typical of those of other sorghums (Table IV). The amylose content of the starch

TABLE III
Physical Characteristics and Composition of Sorghums Used for Ready-to-Eat Breakfast Cereals[a,b]

Sorghum Grain	Test Weight (kg/hl)	1,000-Kernel Weight (g)	Bulk Density (g/cm^3)	Hardness (%)[c]	Protein (%)[d]	Fat (%)	Ash (%)
ATx631*Tx436	79.8 a	31.2 a	1.363 a	17.5 a	10.9 b	3.6	1.8
B.BON 34	78.5 b	27.0 b	1.356 b	15.3 b	11.7 a	3.2	2.1
LSD	0.5	1.4	0.007	0.2	0.2	0.2	0.04

[a] Sorghum grown at Halfway, TX, 1991.
[b] Means in the same column with the same letter are not significantly different.
[c] The higher % loss, the softer the kernel.
[d] %N (6.25).

TABLE IV
Proximate Composition (%) of Sorghum Flakes and Oats Used for Ready-to-Eat Breakfast Cereals and Rolled Oats[a–e]

Sample	Moisture	Protein	Fat	Ash	Total Starch	Dietary Fiber
ATx631*Tx436	12.0 b	10.7 cd	3.5 c	1.8 ab	74.4 b	10.1 a
B. BON 34	10.7 c	11.7 b	3.1 b	2.0 ab	73.1 b	10.5 a
Dec. ATx631* Tx436	12.1 b	10.3 d	0.9 d	1.3 c	82.3 a	4.2 c
Dec. B. BON 34	12.7 a	11.0 c	1.5 c	1.7 b	80.9 a	4.8 c
Rolled oats	8.4 d	16.1 a	2.9 a	2.1 a	66.7 c	8.4 b
LSD	0.5	0.5	0.2	0.04	1.9	1.4

[a] All values reported on dry weight basis.
[b] Means in the same column with the same letter are not significantly different.
[c] N × 6.25.
[d] Insoluble dietary fiber fraction.
[e] Dec. = decorticated.

determined by HPLC-SEC was 27.4% in the nonwaxy hybrid, ATx631*Tx436, and <5% in the waxy cultivar, B.BON 34. The sorghums had no condensed tannins nor polyphenols.

Flake Production

Whole ATx631*Tx436 and B.BON 34 responded significantly different to micronizing (Tables V and VI), although, micronizing conditions were held exactly the same for all the grains. Whole waxy grains (B.BON 34) produced flakes that were more gelatinized, similar in density, more expanded, whiter in color, had better texture (friable and crunchy but not hard), and a more cooked flavor than the whole nonwaxy (ATx631*Tx436) flakes. The whole nonwaxy flakes were extremely small, dense, too hard in texture (Fig. 2a), and had an uncooked (raw) flavor. In contrast, the internal structure of whole B.BON 34 flakes consisted of a continuous phase composed of melted starch, protein, lipid, and cell wall materials (Fig. 2b). Air tunnels, formed during the evaporation of the internal water during micronizing, were responsible for the puffed texture, light density, and the expansion of these flakes (Fig. 2d and 2f, arrows). In contrast, there was less disruption of starch organization in whole ATx631*Tx436 flakes. The internal structure had starch granules that retained their individual shapes and did not form a continuous network (Fig. 2e). However, some areas had completely gelatinized starch granules (Fig. 2c, arrows). The internal water evaporated without leaving air tunnels and resulted in a flake with firm texture and very little expansion, which explains why they were so hard. These results agree with those of Rusnak et al (1980), who processed other genetically different waxy and nonwaxy sorghum cultivars.

Differences in the extent of starch changes in the micronized flakes were due to the composition of the starch in the endosperm, the moisture content of the raw grain, and the transfer of heat within the grain. Waxy endosperm types tended to swell and melt more extensively than did nonwaxy ones, because the presence of amylose in nonwaxy endosperm restricts starch swelling (Akingbala and Rooney 1987, Gomez 1987, Tester and Morrison 1990).

Decorticated micronized flakes from both sorghums expanded more and had different texture than their respective whole grain flakes. The pericarp may act as a physical barrier that interferes with the transfer of heat. When the pericarp was eliminated, heat transfer was improved, which caused greater cooking of the starch, greater expansion and much better texture in ATx631*Tx436 decorticated flakes. Decorticated nonwaxy (ATx631*Tx436) flakes were almost as expanded as those from whole B.BON 34, but they were noticeably harder in texture when handled. In contrast, decorticated waxy grains produced flakes that were extremely thin, fragile, and easily broken due to extensive melting and plasticizing of the starchy continuous phase. Impressions from the corrugated rollers were clearly imprinted into the flakes. They had a pleasant sweet flavor and toasted color due to dextrinization of the starch and the Maillard browning reaction. The higher amount of brokens and fines in the decorticated B.BON 34 flaked sample resulted in higher density values as compared to the ATx631*Tx436 flaked sample.

B.BON 34 had lower RVA viscosity profiles than did ATx631*Tx436 in both the raw grain and the micronized flakes (Figs. 3 and 4). Similar pasting viscosities were reported by Akingbala and Rooney (1987) in whole waxy and nonwaxy sorghums. Whole and decorticated nonwaxy grains took more time to reach their maximum viscosities than did the waxy grains. Amylose restricts swelling in nonwaxy grains so longer times are needed to form maximum viscosities. Nonwaxy grains had higher end viscosities than did the waxy ones because amylose chains reorient themselves and increase the viscosity during cooling (setback).

TABLE V
Physical Characteristics of Micronized Flakes and Rolled Oats[a]

Sample	Test Weight (kg/hl)	Density (g/cc)	Size (mm)	Thickness (mm)	Manual Texture (kg)[b]	Texture (kg)[c]
Whole Atx631*Tx436	35.8 b	1.35 a	6.5 d	1.4 a	0.9 a	...[e]
Whole B. BON 34	27.9 c	1.40 a	8.0 c	1.1 b	0.5 b	0.5 a
Dec. ATx631*Tx436[d]	17.6 e	0.76 b	9.5 a	1.1 b	0.4 b	0.4 b
Dec. B. BON 34	22.4 d	1.33 a	9.3 ab	0.8 c	0.2 c	0.1 c
Rolled oats	39.3 a	1.39 a	9.1 b	0.7 c	...[e]	0.1 c
Least significant difference	1.4	0.55	0.3	0.1	0.1	0.08

[a] Means in the same column with the same letter are not significantly different.
[b] Force to break measured with manual Penetrometer.
[c] Force to break measured with Texture Analyzer TA.XT2.
[d] Dec. = decorticated.
[e] Impossible tomeasure, due to limitations of the equipment.

TABLE VI
Physicochemical Characteristics of Sorghums, Micronized Sorghum Flakes, and Rolled Oats[a–c]

Sample	Starch (%)	Enzyme Susceptibility (mg glucose/ g starch)	Water Solubility Index (%)	Water Absorption Index (g/g)
ATx631*Tx436 (raw grain)	74.4 b	415 f	6.2 d	1.9 de
Whole ATx631*Tx436 (flakes)	74.4 b	877 c	5.1 e	3.3 c
Dec.[d] ATx631*Tx436 (raw grain)	82.3 a	375 g	5.2 e	1.8 de
Dec. ATx631*Tx436 (flakes)	82.3 a	916 ab	6.4 cd	3.8 b
B. BON 34 (raw grain)	73.1 b	576 e	9.4 b	2.0 d
Whole B. BON 34 (flakes)	73.1 b	951 a	10.5 a	3.8 b
Dec. B.BON 34 (raw grain)	80.9 a	434 f	9.0 b	1.7 e
Dec. B. BON 34 (flakes)	80.9 a	911 bc	10.5 a	4.4 a
Rolled oats (flakes)	66.7 c	795 d	7.0 c	1.7 d
Least significant difference	1.9	35	0.6	0.3

[a] All values reported on dry weight basis.
[b] Means in the same column with the same letter are not significantly different.
[c] Milligrams of glucose per gram of sample.
[d] Dec. = decorticated.

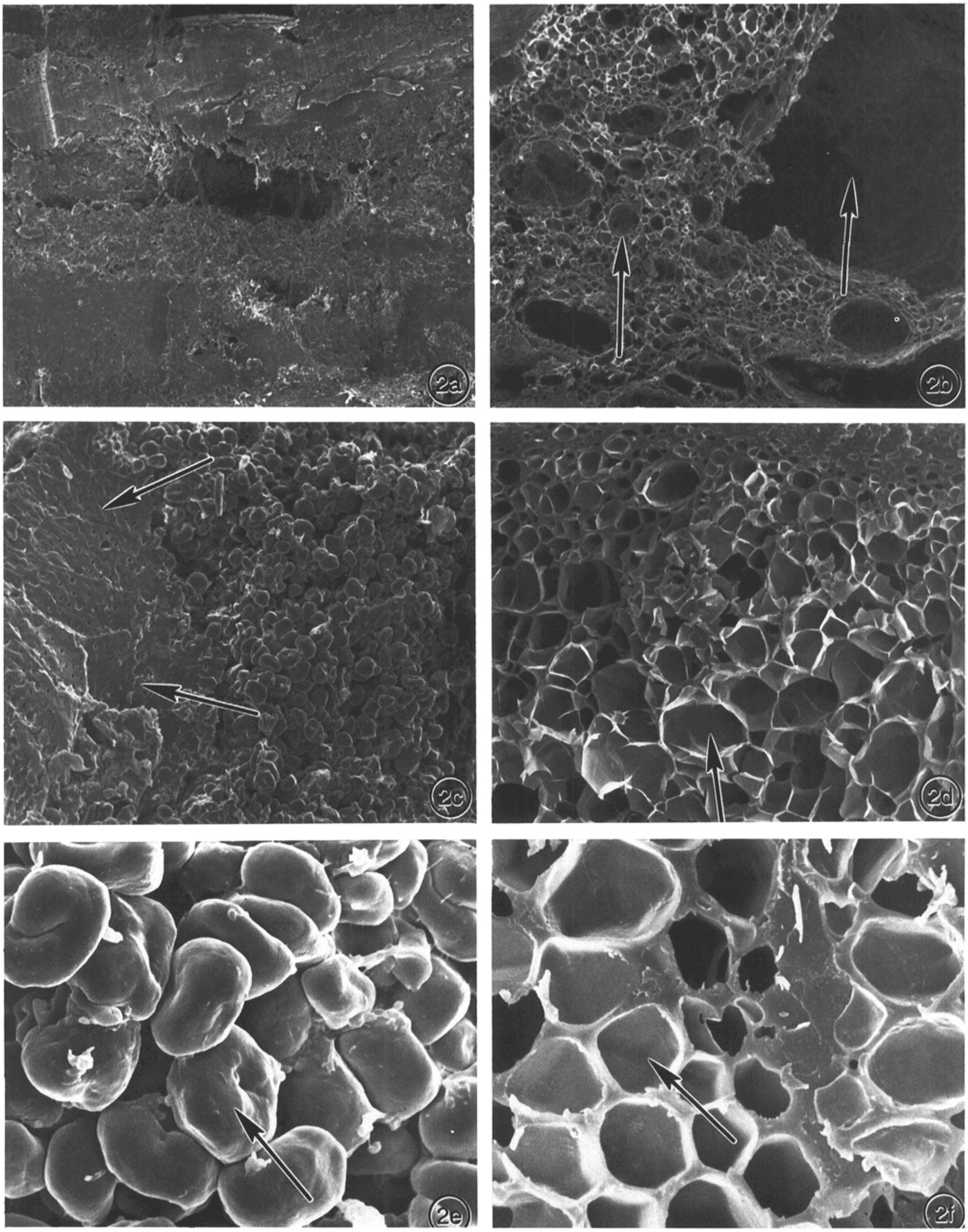

Fig. 2. Scanning electron micrographs showing the differences in nonwaxy (ATx623*Tx436) and waxy (B.BON 34) micronized flakes. **a,** Dense interior of micronized nonwaxy grain; **b,** airy, light interior of the micronized waxy sorghum cultivar; **c,** small area of gelatinized starch granules (arrows) next to an area of less gelatinized starch; **d,** air tunnels and bubbles formed during the vaporization of the internal water in waxy grain; **e,** starch granules in the nonwaxy sorghum are slightly gelatinized but remain whole and intact after processing; **f,** each starch granule has completely melted in the waxy cultivar treated under the same conditions (arrow points to a melted starch granule).

Whole and decorticated micronized waxy flakes reached peak viscosities before the nonwaxy flakes. Nonwaxy flakes (whole and decorticated) had greater end viscosities than did the waxy flakes (data not shown). Compared with the raw flours, micronizing reduced the RVA peak viscosity of both whole and decorticated grains because significant starch gelatinization occurs during micronizing. Decorticated ATx631*Tx436 had the most drastic drop in peak viscosity (≈170 RVA units). Micronized B.BON 34 flakes had the highest initial viscosity (cold viscosity, 50–75 RVA units); this behavior is typical of pregelatinized samples.

Granolas

Formulation. The most acceptable flakes for the production of granolas were from whole B.BON 34 and decorticated ATx631*Tx436, due to their texture, expansion, and flavor. Granolas are identified by the flakes used in their formulation: whole B.BON 34 and dec. (decorticated) ATx631*Tx436 granolas, respectively. Control granola contained rolled oats.

Chemical analysis of granolas. Protein, ether extract, ash, and dietary fiber (Table VII) were highest in the control granola, followed by those of whole B.BON 34 and dec. ATx631*Tx436 granolas, respectively. The latter was expected from the original composition of the flakes.

Physical and physicochemical analysis. Processing of flakes into granolas significantly affected the texture of dec. ATx631*Tx436 because the baked granola was much harder than the others (Table VIII). Whole B.BON 34 and control granolas were similar in texture, although whole B.BON 34 was described as being "more puffy". The hard texture of dec. ATx631*Tx436 granola probably resulted from dehydration of the flakes during baking and the formation of retrograded amylose. Retrograded amylose contributes to the formation of resistant starch (Russell et al 1989). Technically, resistant starch (RS) is the term applied to starch that resists degradation by amylolytic enzymes in vitro and in vivo (Cairns et al 1990). RS can be significantly increased by altering processing parameters such as the amylose and moisture contents, duration and severity of thermal processing conditions, and the number of heating-cooling cycles (Russell et al 1989, Sievert and Pomeranz 1989). Flakes from the dec. ATx631*Tx436 granola were subjected to two heating-cooling cycles (micronizing-freezing storage, and baking-cooling), thus favoring the formation of retrograded amylose and resulting in harder flakes. Amylose has been reported to influence the hardening of processed products like breakfast cereals and extrudates (Gomez et al 1988, Würsch 1989).

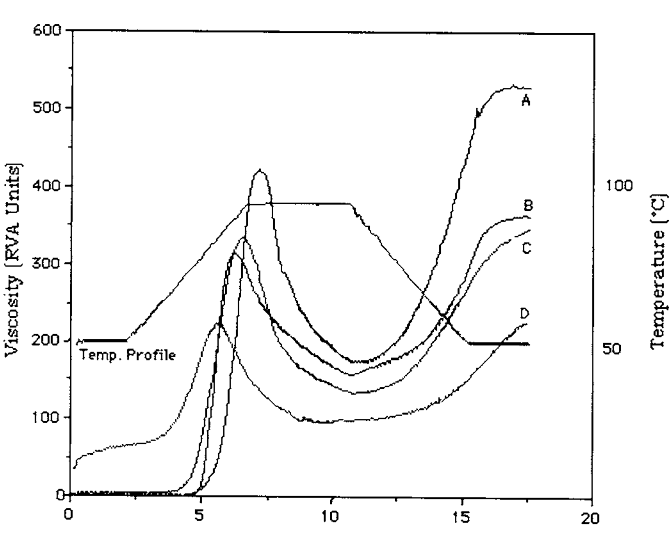

Fig. 3. Pasting properties of whole waxy and nonwaxy grains (A and B) and whole waxy and nonwaxy (C and D) flakes at 14% solids levels.

Whole B. BON 34 granola had the greatest WSI and WAI followed by the dec. ATx631*Tx436 and the control granolas, respectively. The waxy and nonwaxy whole flakes differed significantly in water absorption from the whole and decorticated grain.

The time that a RTE-BC retains crispiness after wetting with milk is critically important. The most crisp granola was that prepared from dec. ATx631*Tx436, followed by whole B.BON 34 and control granolas, respectively. Granola crispiness was directly related to the hardness of the flakes used in their preparation. Dec. ATx631*Tx436 flakes were actually too firm. The rolled oat flakes in the control granola were very thin and disintegrated easily after a short time; disintegration of the flakes may have been

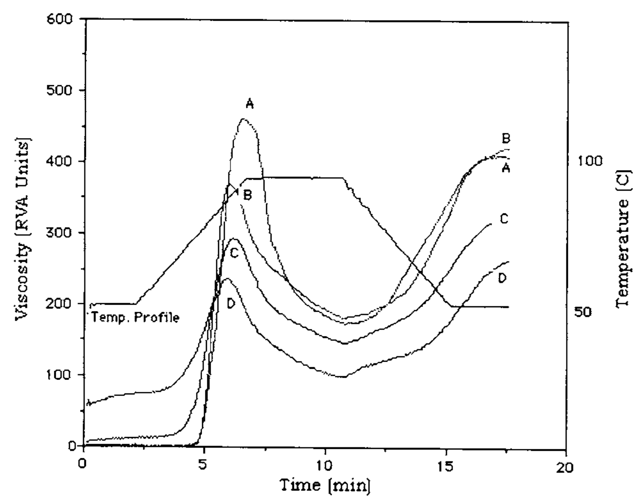

Fig. 4. Pasting properties of decorticated waxy and nonwaxy grains (A and B) and decorticated waxy and nonwaxy flakes (C and D) at 14% solids levels.

TABLE VII
Proximate Composition of Granolas[a,b]

Sample	Protein[c] (%)	Fat (%)	Ash (%)	Dietary Fiber[d] (%)	Moisture (%)
Whole B. BON 34	9.0 b	13.2 b	1.6 b	10.6 b	2.9 a
Dec. ATx631*Tx436	7.9 c	11.6 c	1.4 b	8.3 c	2.9 a
Control (oats)	12.9 a	15.9 a	2.0 a	13.6 a	2.9 a
Least significant difference	0.6	1.3	0.2	1.5	0.2

[a] All values reported on dry weight basis.
[b] Means in the same column with the same letter are not significantly different.
[c] N × 6.25.
[d] Asp et al (1983).

TABLE VIII
Physical and Physicochemical Characteristics of Granolas[a-e]

Granola	Texture (kg)	WSI (%)	WAI (g/g)	Sogginess (min)
Whole B.BON 34	0.6 b	36 ab	4.8 a	6.0 b
Dec.[f] ATx631*Tx436	0.9 a	39 a	3.9 b	> 8.0 a
Control (oats)	0.6 b	30 b	1.9 c	4.0 c
Least significant difference	0.1	6.5	0.7	1.0

[a] Means in the same column with the same letter are not significantly different.
[b] Force to break measured with Texture Analyzer TA.XT2.
[c] WSI = water solubility index. Reported on dry weight basis
[d] WAI = water absorption index. Reported on dry weight basis
[e] Sogginess = Subjective determination of the time for disappearance of crispiness.
[f] Dec. = decorticated.

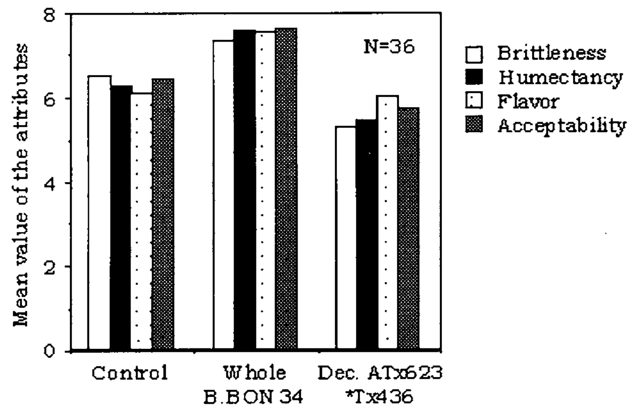

Fig. 5. Sensory evaluation of granolas. Least significant differences (α = 0.05): 0.84 brittleness; 0.86 humectancy; 0.80 flavor; 0.78 acceptability.

due to either their thickness or their high soluble fiber content, which favors disintegration. Usually, longer time to disintegration is preferred, although some consumers prefer soggy RTE-BC.

Sensory analysis. Texture and flavor were the most important attributes of granolas. The sorghum molasses imparted a pleasant, sweet, nutty taste. In the sensory panel (n = 36), all granolas were rated acceptable (average >5.0) for the attributes evaluated (Fig. 5). These attributes were brittleness (referring to the first bite characteristics of the dry granolas), humectancy (the mouthfeel and texture characteristics of granolas soaked in milk), flavor, and overall acceptability. The whole B.BON 34 granola was the most acceptable and was preferred by 64% of the panelists. The control and dec. ATx631*Tx436 granolas had the same acceptability factors of 19 and 17%, respectively.

Granola prepared from B.BON 34 was extremely well liked and accepted by numerous public consumers who tasted it in various oral and poster presentations (i.e., American Association of Cereal Chemists 77th Annual Meeting, September 1992, Minneapolis, MN; Sorghum Utilization Conference, February 1993, Lubbock, TX; Latin American Food Congress, March 1993, Mexico City, Mexico). This grain could serve as a satisfactory ingredient in many granola products currently on the market.

CONCLUSIONS

Grain from a new food-grade waxy sorghum, B.BON 34, with improved characteristics for food processing, produced an excellent RTE granola product without decortication. A nonwaxy food type sorghum cultivar produced good quality granola after decortication, although the product was more firm than that made with whole, waxy flakes. Therefore, the composition of endosperm starch (amylose-amylopectin ratio) determined the behavior of the hybrids during flaking and subsequent processing. The utilization of whole grain has positive nutritional implications because the bran is retained in the product. It is also cost-effective as there are no by-products formed during processing. Micronized waxy flakes have potential applications in breakfast cereals and snacks because of their texture and flavor attributes.

The composition and processing of waxy sorghum granola products make them very versatile. The mixes can be formed into bars, cookies, or rice cake-like products, as well as bite-size snacks (clusters) just by including a shaping step in the manufacturing process. Sorghum molasses proved to be an acceptable natural sweetener with a unique flavor, which could be used as a sweetener in RTE-BC and snacks.

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LITERATURE CITED

AKINGBALA, J. O., and ROONEY, L. W. 1987. Pasting properties of sorghum starch. J. Food Proc. Preserv. 11: 13-24.

AL-KAHTANI, H. A. 1988. Processing of different wheat flour-supplemented sorghum flakes: Sensory, nutritional and microbiological evaluation. Food Chem. 33:138-149.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. The Association: St. Paul, MN.

ANDERSON, R. A., CONWAY, H. F., PFEIFER, V. F., and GRIFFIN, E. L. 1969. Gelatinization of corn grits by roll extrusion-cooking. Cereal Sci. Today 14:4-10.

ANONYMOUS. 1977. The Micronizer. Micronizing Company (UK) Ltd.: Framingham, Suffolk, England.

ASP, N. G., JOHANSSON, C. G., and HALLMER, H. 1983. Rapid enzymatic assay of insoluble and soluble dietary fiber. J. Agric. Food Chem. 31:482-486.

CAIRNS, P., LELOUP, V., MILES, M. J., RING, S. G., and MORRIS, V. J. 1990. Resistant starch: An X-ray diffraction study into the effect of enzymatic hydrolysis on amylose gels in vitro. J. Cereal Sci. 12: 203-206.

FAST, R. B. 1987. Breakfast cereals: Processed grains for human consumption. Cereal Foods World 32:241-244.

GOMEZ, M. H. 1987. Extrusion-cooking of sorghum. MS thesis. Texas A&M University: College Station, TX.

GOMEZ, M. H., WANISKA, R. D., ROONEY, L. W., and LUSAS, E. W. 1988. Extrusion-cooking of sorghum containing different amounts of amylose. J. Food Sci. 53:1818-1822.

JACKSON, D. D., CHOTO-OWEN, C., WANISKA, R. D., and ROONEY, L. W. 1988. Characterization of starch cooked in alkali by aqueous high performance size exclusion chromatography. Cereal Chem. 65:493-496.

JONES, D. D. 1992. Product and market dynamics in the international breakfast cereal industry. Cereal Foods World 37:357-360.

LIESSE, J. 1993. Kellogg, Alpo, top hot new products list. Advertising Age 64 (1): 14, 21.

LU, S. 1986. Sorghum based breakfast cereal. PhD dissertation. University of Nebraska, Lincoln, NE.

REICHERT, R. D., YOUNGS, C. G., and OMAN, B. D. 1982. Measurement of grain hardness and dehulling quality with a multisample tangential abrasive decortication device. Pages 186-193 in: Proceed. Int. Symp. on Sorghum Grain Quality. D. S. Murty and L. W. Rooney, eds. International Crops Research Institute for the Semi-Arid Tropics: Hyderabad, India.

ROONEY, L. W., and SERNA-SALDIVAR, S. O. 1990. Sorghum. Pages 233-270 in: Handbook of Cereal Science and Technology. Marcel Dekker: New York.

ROONEY, L. W., MILLER, F. R., and ROSENOW, D. T. 1992. JOWAR, a new cereal for food utilization. Cereal Foods World 37:565.

RUSNAK, B. A., CHOA-LIN, C., and ROONEY, L. W. 1980. Effect of micronizing on kernel characteristics of sorghum varieties with different endosperm type. J. Food Sci. 45:1529-1532.

RUSSELL, P. L., BERRY, C. S., and GREENWELL, P. 1989. Characterization of resistant starch from wheat and maize. J. Cereal Sci. 9:1-15.

SIEVERT, D., and POMERANZ, Y. 1989. Enzyme-resistant starch I. Characterization and evaluation by enzymatic, thermoanalytical, and microscopic methods. Cereal Chem. 66:342-347.

TECHNICON INDUSTRIAL SYSTEMS, INC. 1976. Method 334-74A/A. Tarrytown, NY.

TECHNICON INDUSTRIAL SYSTEMS, INC. 1979. Method SF4-0046FA8. Tarrytown, NY.

TESTER, R. F., and MORRISON, W. R. 1990. Swelling and gelatinization of cereal starches. I. Effects of amylopectin, amylose, and lipids. Cereal Chem. 67:551-557.

WÜRSCH, P. 1989. Starch in human nutrition. World Rev. Nutr. Diet. 60:199-256.

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