Changes in Sorghum Starch During Parboiling[1]

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ABSTRACT

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Sorghum grains varying in grain hardness or endosperm texture (soft and intermediate) and starch composition (nonwaxy and waxy) were parboiled. Whole grain (one volume) and water (three volumes) were boiled, soaked for 12 hr, and brought to boil again (boil-soak-boil process) or, alternatively, soaked overnight and boiled for 10 min (soak-boil process). The grain was dried at room temperature and decorticated. Parboiled kernels were darker, denser, smaller, and harder than nonparboiled kernels. Parboiling decreased starch crystallinity and starch dispersion in hot water. Parboiled grain with soft endosperm texture contained less dispersible and soluble starch than parboiled grain with intermediate endosperm texture. The physical characteristics of the waxy cultivar were changed after parboiling; however, starch solubility and crystallinity decreased only slightly. Pasting properties of waxy sorghum were not changed as dramatically by parboiling as were those of nonwaxy cultivars. Apparently, the absence of amylose in waxy starch substantially decreased retrogradation of starch polymers.

Parboiling of rice is one of the most widespread food processes in the world. The hydrothermal process consists of soaking rough rice in water until it is saturated, draining the excess water, steaming or otherwise heating the grain to partially gelatinize the starch, and drying (Bhattacharya 1985).

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the most important staple foods in arid regions unsuitable for the cultivation of other crops. In 1989, world sorghum production was estimated at 58.0 million metric tonnes. Asia, North America, and Africa produced 32.7, 27.1, and 24.1% of the world's sorghum, respectively (FAO 1990). Rooney and Serna-Saldivar (1991) indicated that 30% of world production is consumed directly by humans, primarily as traditional foods. Sorghum is used as a substitute for rice in Mali and India (Subramanian et al 1982). In India, the ricelike product called *annam* or *soru* accounts for 10% of the total sorghum grain produced. Similar products have also been reported in Bangladesh (*khicuri*), Botswana (*lehata wagen*), China (*kaohang mi fan*), Ethiopia (*nufio*), and Nigeria (*oko baba*) (Subramanian and Jambunathan 1980). In most African countries, special types of sorghum with very hard, flinty endosperm are dehulled and used as a rice substitute. However, these special sorghums have small kernel size and low agronomic yields. Parboiling could allow consumers to use higher yield sorghums with intermediate or soft endosperm texture.

Young et al (1990) adapted rice technology to produce a parboiled sorghum called SORI (SOrghum RIcelike product). The modified process was simply boiling, soaking for 12 hr, reboiling, and air-drying. Parboiled sorghum was then decorticated. The most important benefits of parboiling sorghum were: 1) increased yield of decorticated sorghum; 2) reduced amounts of broken kernels during decortication; 3) improved texture of the boiled product (i.e., cooked SORI had a firmer, less-sticky texture compared to nonparboiled cooked sorghum); and 4) increased shelf-stability. The major disadvantage of parboiling is the energy the process uses, because the SORI needs longer cooking time than the raw grain. However, the decorticated grain can be cracked into various sizes of grits to produce a wide array of products for use in different food preparations such as thick porridges (*couscous* and *tô*), making it a more diversified, marketable product. Parboiling trials conducted in Mali, at the village level, have shown that well-accepted products can be obtained by soaking the sorghum overnight, boiling it, and drying it. This saves energy and time and makes the process more practical (*unpublished data*).

The physicochemical changes in sorghum starch during parboiling that are responsible for the improved characteristics have not been determined. Therefore, the objective of this study was to evaluate the effects of parboiling on starch crystallinity, birefringence, pasting properties, and dispersion in hot water using sorghum cultivars with different endosperm texture and starch composition.

MATERIALS AND METHODS

Sample Preparation

Three sorghum cultivars with different endosperm texture were used in this study. In sorghum, endosperm texture refers to the proportion of hard to soft endosperm in the kernel. Grain samples of Dorado (nonwaxy, intermediate endosperm texture), P721Q (nonwaxy, higher lysine, soft endosperm texture), and ATx630* R3338 (waxy, intermediate endosperm texture) (Table I) grown at Halfway, TX, in 1987, were parboiled using two methods.

Method I. Soak-boil (SB). Washed, whole grain (one volume) was soaked overnight in tap water (three volumes) and boiled in the same solution for 10 min at a rate of 5°C/min in an 11-L steam-jacketed cooker (model TDC/2-20, Groen Div., Dover Corp., Elk Grove Village, IL).

Method II. Boil-soak-boil (BSB). Washed, whole grain was brought to boil as in method I, soaked overnight, and brought to boil again in the same solution.

The grain samples from both methods were dried for 48 hr

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at 25°C on wire screens in an air-conditioned room. Dried grains were decorticated for 6 min using a Tangential Abrasive Dehulling Device (TADD), (model 4E-115, Venables Machine Works Ltd. Saskatoon, Saskatchewan, Canada), equipped with an eight-sample-cup plate. Moisture content of both parboiled and raw grain was 11.0 ± 0.5% at the time of decortication. Color, density, 1,000-kernel weight, and hardness were determined according to Young et al (1990). Length of 12 kernels was measured with a caliper and averaged.

Analytical Methods

Potential for molecular dispersion of raw and parboiled sorghum starch at 85°C was measured by high-perfomance size-exclusion chromatography (HPSEC) (Jackson et al 1988). Measurement of the molecular dispersion of starch in sorghum at temperatures near gelatinization (85°C) was carried out to determine the effects of parboiling without introducing any other factor, such as a severe heat treatment, that could distort the parboiling effects. Flour (0.50 g) was moistened with methanol (0.5 ml) and brought to a volume of 100 ml with water. Suspensions (10 ml) were treated at 85°C for 10 min, equilibrated at 50°C, sonicated, centrifuged, filtered through 5-μm nylon filters, and injected into the HPSEC system.

Starch crystallinity of raw and parboiled sorghums equilibrated at 91.0% rh was determined with Cu K_α radiation on a Philips X-ray diffractometer. Operation was at 35 kV and 15 mA over 2–32° The *d*-spacing was computed according to Bragg's law (Nara et al 1978).

Pasting viscosity of samples (10% solids) was determined in triplicate using a Brabender Viscoamylograph (type VAV, model 3042, C. W. Brabender Instruments, Inc., South Hackensack, NJ) equipped with a 125-cm·g sensitivity cartridge and a small amylograph cup rotating at 75 rpm. The amylograph cycle was set for 30 min of heating from 50 to 95°C, 30 min of holding at 95°C, and 30 min of cooling from 95 to 50°C. A resistance to one stirring was reported in Brabender units (BU). Onset of gelatinization temperature was taken as the temperature (°C) at which the viscosity increase begins to be perceptible.

The starch modified by the heat treatment is enzyme susceptible starch (ESS). The amount of ESS was determined after enzyme hydrolysis of 200 mg of flour suspended in an aqueous buffer (Khan et al 1980). Fungal glucoamylase (EC 3.2.1.3.; 1,4-α-D glucan glucohydrolase) was used for the hydrolysis. Glucose liberated by the hydrolysis was measured by an automated colorimetric method using immobilized hexokinase (Technicon 1978).

Loss of starch birefringence was evaluated using water-glycerol suspensions of uncooked and parboiled sorghums. The determinations used polarized light from a Zeiss Universal microscope equipped with neutral density filters and a 100-W tungsten lamp.

RESULTS AND DISCUSSION

Physical Characteristics

Dry, decorticated, parboiled sorghum kernels were significantly darker than the control samples (Table II). Increased darkness of parboiled sorghum might be partly attributed to browning reactions, although pigments in sorghum pericarp, especially those cultivars with purple plant color, also darken the grain. Jayanarayanan (1964) reported that Maillard browning reactions were primarily responsible for the darker color of parboiled rice.

Parboiled sorghum grains had significantly ($P < 0.05$) higher bulk density than the corresponding raw grains (Table II). The higher density of parboiled grain, combined with the smaller kernel size of parboiled sorghum (Table II), suggested that most of the air spaces inside the kernel had been eliminated, yielding the typical translucent appearance of parboiled grain. Microscopic studies (*not shown*) confirmed that air spaces (voids) were generally eliminated. Average kernel weight decreased because of

TABLE I
Descriptive Characteristics of Sorghum Kernels

	Pericarp			Endosperm			
Cultivars	Color	Thickness[a]	Pigmented Testa	Color	Type	Texture[b]	Glume Color
P721Q[c]	White	3	No	Nonyellow	Nonwaxy	5	Purple
Dorado	White	4	No	Nonyellow	Nonwaxy	3	Tan
ATx630*R3338	White	1	No	Nonyellow	Waxy	3	Purple

[a] Subjective evaluation of thickness on a scale of 1 = thin, 3 = intermediate, and 5 = thick.
[b] Subjective evaluation of hardness index on a scale of 1 = hard/corneous, 3 = intermediate, and 5 = soft/floury.
[c] Higher lysine cultivar.

TABLE II
Physicochemical Characteristics of Sorghum Kernels

	Color[a]				Kernel	1,000-Kernel	Hardness[b]	
Cultivar	*L*	*a*	*b*	Density (g/cm³)	Length (mm)	Weight (g)	(% of removal)	ESS[c]
P721Q								
Control	58	4.1	17.4	1.29	0.40	24.2	46.4	423
SB[d]	42	4.4	16.3	1.35	0.38	23.8	9.9	723
BSB	39	3.4	13.1	1.38	0.37	23.4	8.6	812
Tukey's HSD[e]	0.1	0.3	0.3	0.03	0.02	0.9	0.7	38.3
Dorado								
Control	59	2.5	16.4	1.37	0.44	36.2	19.9	519
SB	42	4.3	17.8	1.38	0.40	35.3	11.6	527
BSB	38	3.6	14.3	1.40	0.40	34.2	9.0	695
Tukey's HSD	0.2	0.2	0.2	0.03	0.02	0.7	0.4	40.6
ATx630*R3338								
Control	55	4.2	18.4	1.37	0.47	31.6	15.0	478
SB	44	4.3	16.8	1.39	0.45	30.8	10.0	833
BSB	40	4.0	14.8	1.41	0.43	30.5	7.5	836
Tukey's HSD	0.3	0.2	0.2	0.03	0.01	0.6	0.5	35.3

[a] Hunterlab color scale: *L* = lightness, *a* = red-green chroma, *b* = yellow-blue chroma.
[b] Determined by decortication of 10 g of sorghum during 4 min in a tangential abrasive dehulling device.
[c] Enzyme susceptible starch (mg of gluclose/g of starch), means within rows with the same letter are not significantly different at $P < 0.05$.
[d] SB = soak-boil process, BSB = boil-soak boil process.
[e] Tukey's (HSD) studentized range test ($\alpha = 0.05$).

solids lost during the parboiling process. Kernel hardness increased after parboiling. The soft-endosperm cultivar (P721Q) had the greatest improvement in hardness and density. Young et al (1990) indicated that parboiling increased the decortication yield (percent of remaining material after 6 min of abrasive grinding) and reduced the quantity of broken kernels. The physical characteristics of the softer endosperm sorghums were more modified by parboiling than those of the harder endosperm sorghums.

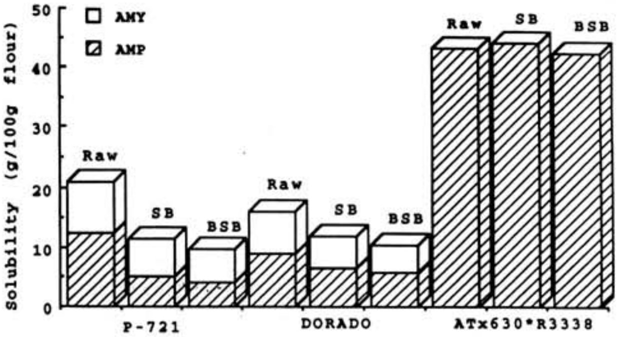

Fig. 1. Starch solubility (g/100 g of flour) extracted at 85°C of P721Q, Dorado, and ATx630*R3338 sorghums after soak-boil (SB) and boil-soak-boil (BSB) processes. LSD ($P < 0.05 = 2.6$). amy = amylose, amp = amylopectin.

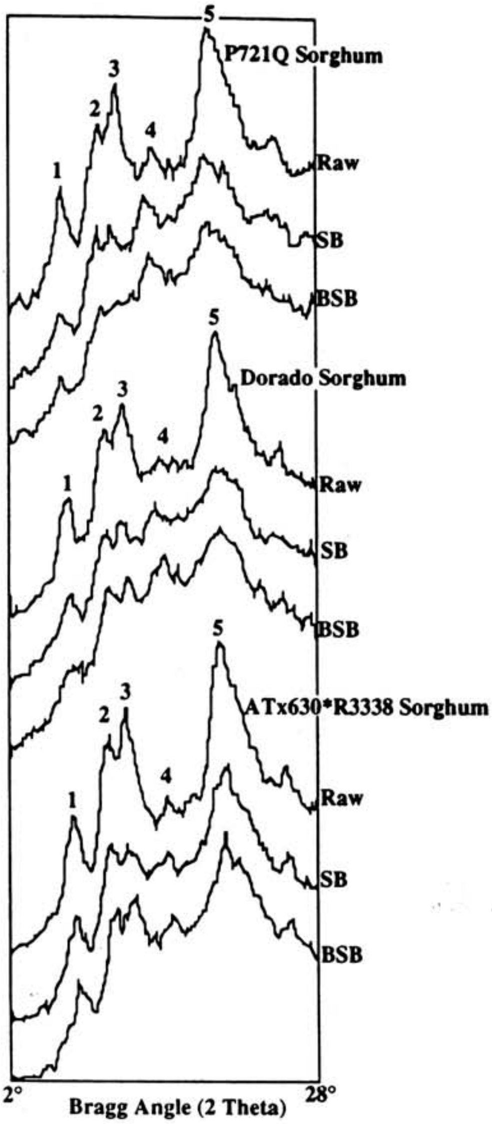

Fig. 2. Comparison of X-ray diffraction patterns of P721Q, Dorado, and ATx630*R3338 sorghums. SB = soak-boil process. BSB = boil-soak-boil process.

Starch Dispersion

Parboiling decreased the starch dispersion of nonwaxy cultivars (P721Q and Dorado) in water at 85°C (Fig. 1). The uncooked sorghum with a floury endosperm texture (P721Q) had more molecularly dispersible starch than that observed in the intermediate-texture cultivar (Dorado), presumably because starch in the floury endosperm has a lower gelatinization temperature (Cagampang and Kirleis 1985). The starch dispersion of the waxy cultivar was not significantly affected by parboiling, possibly because waxy starch contains no amylose. It is well known that amylose retrogrades more rapidly than amylopectin. Priestley (1976) indicated that resistance of starch to swelling and solubilization in hot water were the primary changes in parboiled rice flour.

The relative proportion of amylose and amylopectin did not change significantly after parboiling of sorghum (Fig. 1). Apparently, the treatments were not severe enough to produce any change. Mahanta and Bhattacharya (1989) chromatographically fractionated raw and parboiled rice starch and indicated that in the parboiled rice the amount of fraction I (amylopectin) decreased, while the amount of fraction II (amylose) increased. This change increased with more severe processing. They concluded that thermal degradation of starch must be considered another contributor to the properties of parboiled rice.

Parboiling did not affect the average molecular weight of starch polymers (amylopectin and amylose) extracted at 85°C. Raghavendra Rao and Juliano (1970) reported no appreciable decrease

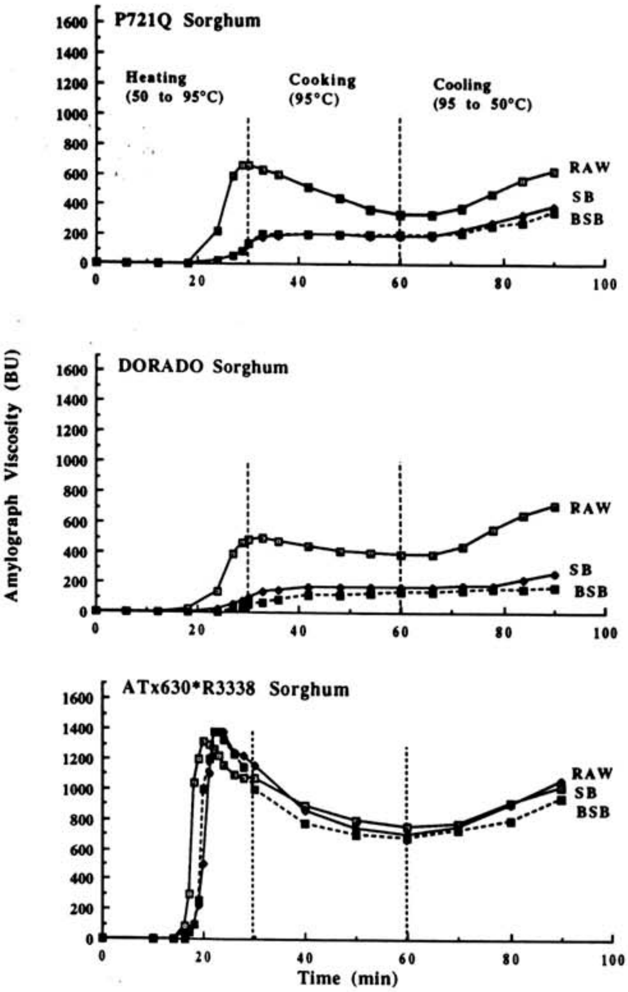

Fig. 3. Effect of parboiling on amylograph pasting behavior of P721Q, Dorado, and ATx630*R3338 sorghums. SB = soak-boil process. BSB = boil-soak-boil process.

in the molecular size of rice starch and protein as a result of parboiling. Biswas and Juliano (1988) indicated some starch degradation during parboiling, but such a degradation was not extensive enough to reduce the apparent amylose content of parboiled rice.

Starch Crystallinity

Intensities of A-type starch crystals (peaks 1–5, Fig. 2) in all cultivars were significantly reduced or attenuated by both the SB and the BSB processing treatments. The decrease of peak intensities indicated that starch was partially gelatinized during both processes. Cultivars containing nonwaxy starch (Dorado and P721Q) had a higher peak 4 (d ~4.42 Å) after processing. This peak is part of the V-pattern associated with the amylose-lipid complex (Zobel 1964). SB and BSB processing caused P721Q to develop more amylose-lipid complex than the other cultivars. This indicates that either more amylose leached during processing of P721Q, or more lipids were available for complexing, or better reaction conditions were present. The lower gelatinization temperature of starch isolated from the floury endosperm and the less compact cellular structure of floury endosperm (Cagampang and Kirleis 1985) both support the observation that more amylose-lipid complex was able to form in P721Q.

Starch Viscosity

Cooking viscosity of waxy sorghum increased more rapidly than regular sorghums, attained a higher peak viscosity, and broke down faster and more extensively than nonwaxy sorghums. Waxy sorghum showed a little increase in setback viscosity during cooling (Fig. 3).

Onset gelatinization temperature for nonwaxy parboiled sorghums increased 3°C ± 0.5 for SB-P721Q, 7°C ± 0.4 for BSB-P721Q, 10°C ± 1.2 for SB-Dorado, and 14°C ± 1.1 for BSB-Dorado. Gelatinization temperatures of BSB-processed waxy sorghum was 3–4°C higher than those of uncooked and SB-processed sorghums. Amylograph peak viscosity of nonwaxy sorghums (Dorado and P721Q) decreased substantially after both parboiling processes. The same trends of decreasing viscosities, higher pasting temperatures, and peak heights shifted to higher temperatures or longer times, were reported for parboiled rice (Ali and Bhattacharya 1980). They concluded that, above the gelatinization temperature, starch granules in parboiled rice flour hydrate more slowly and swell less than those in raw rice flour but below the gelatinization temperature they swell more (Bhattacharya and Ali 1985). Parboiled waxy sorghum required higher temperatures to attain similar viscosities.

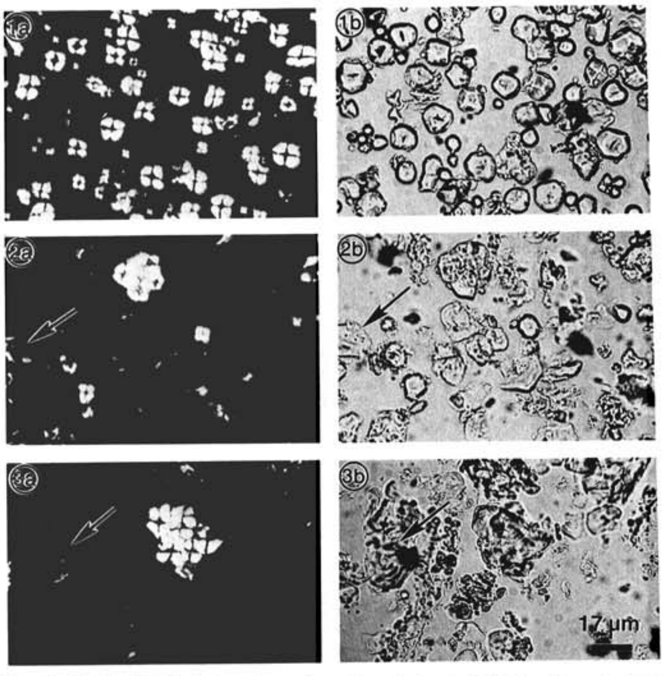

Fig. 4. Brightfield (left column) and polarized (right column) light micrographs of Dorado sorghum. **1a** and **1b**, raw sorghum; **2a** and **2b**, soak-boil (SB)-processed grain; and **3a** and **3b**, boil-soak-boil (BSB)-processed grain. Arrows indicate partially gelatinized starch granules.

The nonwaxy cultivars exhibited a moderate increase in setback viscosity, indicating some reassociation of starch polymers. The parboiled waxy samples, however, had very stable viscosities that increased only slightly to moderately during cooking and cooling.

Enzyme Susceptibility of Starch (ESS)

Parboiling increased the ESS of all sorghum cultivars (Table II). BSB processing increased ESS values more than the SB process. The starch fraction of the soft endosperm cultivar (P721Q) was affected more extensively by the parboiling treatments than was the cultivar with equal amounts of corneous and floury endosperm textures.

Starch Birefringence

A loss of birefringence (<15%) was observed in starch granules after SB processing of Dorado, as shown in Figure 4. (Micrographs of P721Q and ATx630*R3338 presented similar effects and are not shown.) About 20–30% of the birefringent granules viewed had diffuse or partial "Maltese" crosses with enlarged dark centers, indicating partial gelatinization.

The starch granules from BSB-processed kernels were swollen and tended to form agglomerates that were difficult to disperse. They had fewer birefringent starch granules than SB-processed kernels (Fig. 4). Loss of birefringence was noticed in both the center and the perimeter of the granules, which indicated more extensive gelatinization than that caused by the SB process. Many starch granules that retained birefringence (60–70%) had less than one-third of the original amount of birefringence.

CONCLUSIONS

Parboiling induced partial starch gelatinization, which decreased starch solubility in water at temperatures above the gelatinization range. Starch crystallinity, pasting properties, and microstructure were also modified during parboiling. As a result, the endosperm texture of sorghum was strengthened, increasing the decortication yield of parboiled sorghum and firming the texture of the cooked sorghum.

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