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Decorticating Sorghum To Concentrate Healthy Phytochemicals

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The growing prominence of nutrition-related health problems demands strategies that explore nontraditional natural ingredients to expand healthy food alternatives. Specialty sorghums were decorticated using a tangential abrasive dehulling device (TADD) to remove successive bran layers, which were collected at 1 min intervals and analyzed for phenols, tannins, 3-deoxyanthocyanins, dietary fiber, and antioxidant activity. The first two bran fractions had the highest levels of phenols and antioxidant activity (3−6 times as compared to whole grain). Brown (tannin-containing) and black sorghums had at least 10 times higher antioxidant activity than white sorghum or red wheat brans. Black sorghums had the highest 3-deoxyanthocyanin content (up to 19 mg/g bran). Dietary fiber in sorghum brans ranged between 36 and 45%, as compared to 48% for wheat bran. Specialty sorghum brans are rich in valuable dietary components and present promising opportunities for improving health attributes of food.

KEYWORDS: Sorghum; tannins; phenolic compounds; 3-deoxyanthocyanins; natural antioxidants; dietary fiber; functional foods

INTRODUCTION

Consistent consumption of foods that contain significant levels of phytochemicals and dietary fiber correlates with tangible health benefits. For example, whole grain consumption is known to help in reducing cases of heart disease, diabetes, and other chronic diseases, due to components in their brans, especially dietary fiber and phytochemicals (*1*, *2*). It is important to enhance the consumption of healthy food by increasing the variety of foods rich in beneficial compounds and improving processing technology to enhance their organoleptic appeal. Cereal-based foods present an especially enticing opportunity since they are the most widely and consistently consumed components of diets all over the world.

Specialty sorghums have high levels of phytochemicals, including proanthocyanidins (*3*, *4*), 3-deoxyanthocyanins (*5*−*7*), phenolic acids (*8*), phytosterols (*9*), and policosanols (*10*) in their bran layers. In addition, sorghum bran is rich in dietary fiber (*11*). These sorghum bran fractions are potentially useful ingredients in various functional food applications and were shown to produce desirable attributes (e.g., attractive natural color) without adversely affecting other sensory properties of foods such as bread, cookies, and expanded snacks (*12*−*14*). These sorghum ingredients are bound to play a crucial role in food applications given the increasing need for a diversified functional food base. However, to ensure their economic potential, the sorghum components must be separated in an efficient manner. A clean separation of endosperm from the bran fraction ensures that the bran has the maximum concentration of desirable components and the grits (endosperm) are clean enough for other food applications. This work documents the concentration of phenolic compounds in specialty sorghum bran through abrasive milling (decortication).

MATERIALS AND METHODS

Sorghum Samples. Pigmented sorghums with high levels of proanthocyanidins (*3*) and 3-deoxyanthocyanins (*6*, *7*) were used for the study. Sorghum samples were grown in Texas in 1999 and included high tannin brown sorghums, sumac and ATx623 × SC103 (SC103); black sorghum (Tx430 variety) grown in College Station (Tx430-CS) and Vega (Tx430-V), TX; food grade white sorghum, ATx631 × RTx436 (white); and commercial red wheat bran (ADM Milling Co., Overland Park, KS) were used for comparison. **Table 1** summarizes the physical characteristics of these sorghums. The moisture content of the grains ranged from 12.7 to 13.1%.

Sample Decortication. Sorghum decortication used procedures described by Awika et al. (*15*). Cleaned representative sorghum samples were decorticated using the tangential abrasive dehulling device (TADD) (model 4E-230, Venable Machine Works, Saskatoon, Canada) for a total of 6 min to obtain successive bran fractions at 1 min intervals (first, second, third, fourth, fifth, and sixth fractions). The bran fractions were collected separately after each minute. Decorticated grain was also collected after every decortication interval (1 min) using a sample collector attached to a vacuum, weighed, and evaluated for color, before being returned to the decorticator. The percent removal was calculated as [initial sample weight − decorticated grit weight/initial sample weight] × 100. The successive bran fractions were analyzed for phenols, proanthocyanins, and anthocyanins to determine fractions with the highest concentration of these compounds.

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Table 1. Physical Properties of Sorghums Grain Samples

sample	testa	pericarp thickness[a]	kernel shape[b]	kernel diameter[c]	TKW[d] (g)	SKH[e]
sumac	yes	2	1	1.7	15.2	79.5
SC103	yes	3	3	1.8	24.8	68.8
Tx430-CS	no	5	2	2.7	38.8	65.5
Tx430-V	no	5	2	2.5	34.1	61.9
white	no	2	2	2.2	26.5	72.1
CV %				4.8	5.5	10.7

[a] Pericarp thickness (1 = thin, 5 = thick). [b] 1 = spherical, 5 = flat. [c] Kernel diameter (mm); thousand kernel weight. [e] Single kernel hardness index (mean of 300 kernels).

Physical Parameters. Kernel size (diameter), single kernel hardness index, and thousand kernel weights were measured using the single kernel characterization system (model SKCS 4100, Perten Instruments Inc., Reno, Nevada). The instrument gives mean data based on 300 kernels. Analyses were conducted in quadruplicates.

Color (L = lightness; $+a$ = red, $-a$ = green; $+b$ = yellow, $-b$ = blue) of whole and decorticated grains was measured using a colorimeter (model CR-310 Minolta Co. Ltd., Ramsey, NJ). Kernel shape and pericarp thickness were visually determined using the scale reported by Waniska et al. (*8*). The moisture content was measured using the AACC oven method 44-15A (*16*). Dietary fiber was determined by the Prosky method (*17*).

Sample Extraction for Phenolic and Antioxidant Assay. *Sample Extraction.* All samples were ground through a cyclotec mill (UDY Corp., Fort Collins, CO) (1 mm mesh) prior to extraction. Aqueous acetone (70%) was used as a solvent for phenols and antioxidant activity, while 1% HCl acidified methanol was used as a solvent for 3-deoxyanthocyanin extraction (*7*). The extraction procedure involved the addition of 10 mL of solvent to a 0.5 g sample in 50 mL centrifuge tubes and shaking of the samples for 2 h at low speed in an Eberbach shaker (Eberbach Corp., MI). Samples were then stored at −20 °C in the dark overnight to allow for maximum diffusion of phenolics from the cellular matrix. Samples were then equilibrated to room temperature and centrifuged at 2790*g* for 10 min in a Sorvall SS-34 rotor and centrifuge (Du Pont Instruments, Wilmington, DE) and decanted. Each sample residue was rinsed with two additional 10 mL volumes of solvent with shaking for 5 min, centrifuging at 2790*g* for 10 min as above, and decanting in each case. The three aliquots were mixed and stored at −20 °C in the dark until analyzed.

Analytical Procedures. The modified Folin−Ciocalteu method of Kaluza et al. (*18*) was used to determine phenols. This method measures the redox potential of the phenolic compounds. Gallic acid was used as standard. The modified vanillin−HCl method of Price et al. (*19*) was used to estimate tannin content. This method is based on the ability of flavanols to react with vanillin in the presence of mineral acids to produce a red color. Blanks were used to remove color interference from anthocyanins and other pigments. 3-Deoxyanthocyanins were measured using the method described by Awika et al. (*7*). Antioxidant capacity measurements (ABTS, DPPH, and ORAC) were performed as detailed by Awika et al. (*3*). All analyses were replicated three times.

RESULTS AND DISCUSSION

Decortication Behavior of Sorghum Samples. The decortication behavior of the samples analyzed followed the same general trend reported by Awika et al. (*15*). The harder sorghum samples [as measured by the SKCS (**Table 1**)] were generally more resistant to material removal. Kernel shape, diameter, and size did not affect the rate of material removal. The rate of material removal increased with an increase in decortication time for the brown and white sorghums (**Figure 1**), mostly due to increased endosperm breakage with removal of subsequent bran layers. The black sorghums, however, behaved differently; the rate of material removal for this sorghum variety was much faster at the initial stages of decortication and tended to decrease

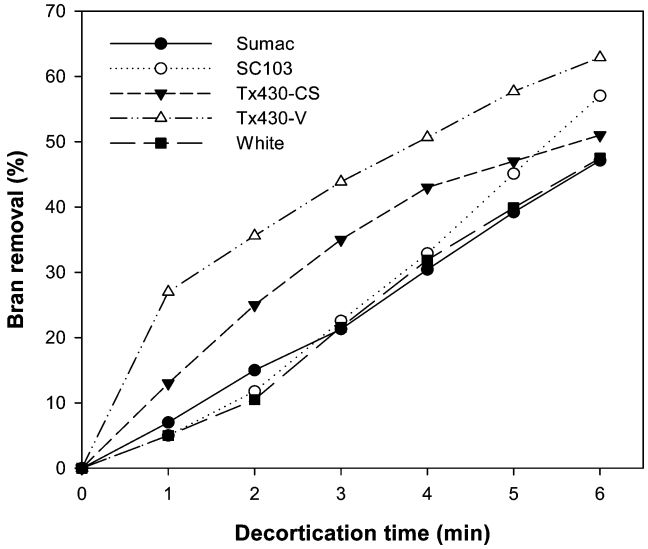

Figure 1. Material removal from sorghums through decortication with an abrasive TADD dehuller. Data based on means of three replications; coefficient of variability = 2.5%.

Figure 2. Representative samples of (top to bottom): white, brown (SC103), and black (Tx430-V) sorghums; (**a**) whole grain, (**b**) decorticate for 2 min, and (**c**) decorticated for 4 min.

with increasing decortication time (**Figure 1**). This sorghum variety has a thick pericarp (**Table 1**) that tends to come off more easily during decortication. The phenomenon was more apparent for the black sorghum variety grown in Vega, TX (Tx430-V). For this sample, the bran was unusually easy to remove and came off almost completely during the first minute of decortication (**Figure 2**). This sorghum had a lightness (L value) almost similar to that of the nonpigmented white food type sorghum after the first minute of decortication (**Figure 3**). We did not observe such behavior among the other sorghum varieties when compared across environments (data not shown). Because the black sorghum variety has economic potential due to high levels of the rare and stable 3-deoxyanthocyanin pigments in its bran (*7*), the ease of bran removal adds a distinct economic benefit, since less energy is required to isolate the bran and concentrate the compounds. At the same time, the

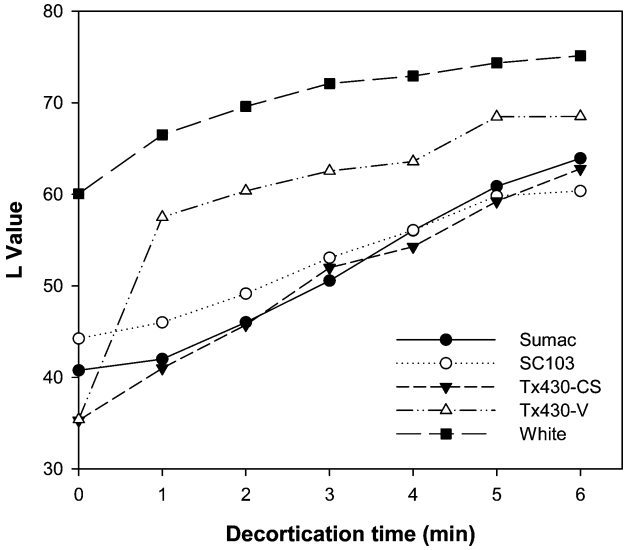

Figure 3. Effect of decortication on the *L* (lightness) value of the decorticated grain. Samples were decorticated using an abrasive TADD dehuller. Data based on means of three replications; coefficient of variation = 1.8%.

decorticated grain (**Figure 2**) is light enough for use in various food applications without causing a discoloration problem. It is important to find out what environmental factors enhance this "loose bran" phenomenon in the black sorghum to optimize its economic potential.

Unlike other sorghum varieties, the brown sorghum samples did not show a significant increase in lightness value after the first minute of decortication (**Figure 3**) despite 7−9% material removed at this point (**Figure 1**). This was because these sorghums have a tannin-containing pigmented testa layer beneath the pericarp (*20*), which is typically darker than the pericarp, and was exposed in the first minute of decortication. The testa layer was removed by subsequent decortication, increasing the lightness of decorticated brown sorghums.

In general, the pigmented sorghum can be decorticated to increase the *L* value of decorticated grain, which can be used for various food applications. The black sorghum shows the greatest promise in this regard. However, conditions were not optimized in this study to ensure the most efficient bran removal. Modification of conditions prior to decortication, e.g., tempering, can significantly improve the efficiency of bran removal from all of the sorghum varieties. This would result in relatively pure brans that can be used directly for health food applications.

Concentration of Phenolic Compounds in Bran Fractions. The brown (tannin-containing) sorghums had the highest levels of freely extractable phenols, whereas the black sorghums had the highest levels of 3-deoxyanthocyanins (**Table 2**). The concentration of phenols in bran after decortication followed a similar trend for the sorghums without a pigmented testa (i.e., the black and white varieties) where the highest concentration was in the 1st fraction (after 1 min of decortication) (**Figure 4**). This was expected since this fraction had the least endosperm contamination due to minimal breakage at initial stages of decortication. As decortication progressed, the rate of endosperm exposure and breakage increased, which diluted the phenol concentration in the bran. In addition, less bran material was left with successive decortications, further reducing phenol concentration. However, for the brown sorghums (sumac and SC103), the highest concentration of phenols was achieved in the 2nd fraction (**Figure 4**). Proanthocyanidins are typically located in the testa layer below the pericarp of these sorghums

Table 2. Phenolic Content and Antioxidant Activity of Sorghum Samples

				antioxidant activity[d]		
sample	phenols[a]	3-deoxy[b]	tannins[c]	ABTS	DPPH	ORAC
sumac (brown)	22.5	1.3	50.1	240	202	878
SC103 (brown)	13.5	0.5	28.2	114	103	515
Tx430-CS (black)	7.6	2.7	ND	89	49.0	219
Tx430-V (black)	9.8	3.1	ND	104	52.6	271
white	0.8	trace	ND	9.8	6.2	22.2
CV %				3.2	4.6	5.1

[a] mg GAE/g. [b] mg LE/g. [c] mg CE/g. [d] μmol Trolox equivalents/g; ND, not detected. All values reported on dry basis.

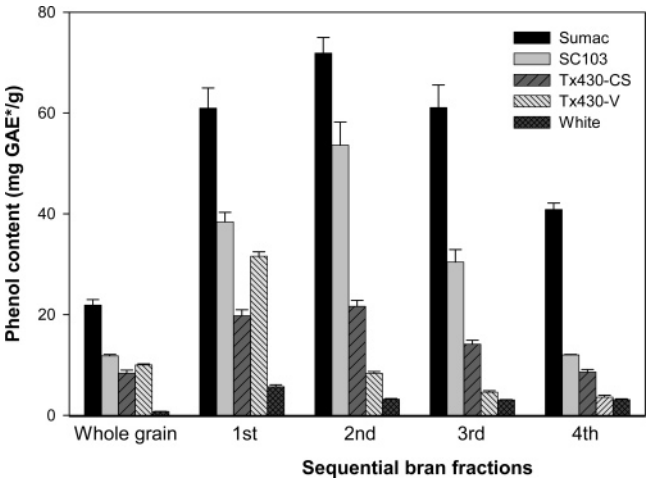

Figure 4. Phenol concentration in sorghum bran fractions due to decortication. Samples were decorticated using a TADD abrasive dehuller. GAE: gallic acid equivalents, dry basis; error bars represent standard deviation.

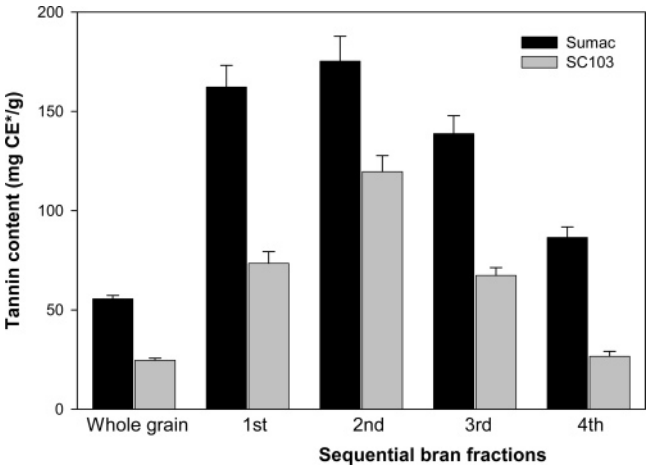

Figure 5. Tannin levels in sequential bran fractions of brown sorghums. Samples were decorticated using a TADD abrasive dehuller. CE: catechin equivalents, dry basis; error bars represent standard deviation. No tannins were found in black and white sorghums.

(*20*). The higher phenol levels in the 2nd fractions indicated that the testa layer had higher levels of readily extractable phenols than the pericarp, which agrees with ref *21*. The levels of proanthocyanidins (tannins) in the brown sorghum bran fractions were also most abundant in the 2nd layer (**Figure 5**).

In general, the highest phenol concentrations (3−6 times) were achieved in the 1st and 2nd bran fractions. The white sorghum bran fractions had phenol levels much lower than those

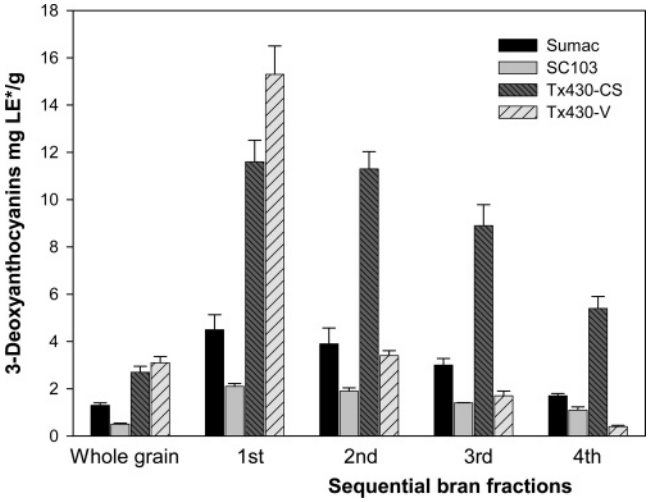

Figure 6. Concentration of 3-deoxyanthocyanin in sequential sorghum bran fractions. Samples were decorticated using a TADD abrasive dehuller. LE: luteolinidin equivalents, dry basis; error bars represent standard deviation.

measured in the black and brown sorghums brans. The pigmented sorghum varieties are a superior source of these beneficial compounds.

The concentration of sorghum pigments (3-deoxyanthocyanins) followed a similar trend to the phenols, with the highest concentration achieved in the 1st fraction, followed by a decrease in subsequent fractions (**Figure 6**). The black sorghum brans had significantly higher 3-deoxyanthocyanin levels than the brown sorghum varieties. The black sorghum is a potentially useful source of natural food colorants (*6*, *7*). The 3-deoxyanthocyanins are especially promising ingredients for food applications due to their exceptional pigment stability as compared to anthocyanins (*7*, *22*). The black sorghum produced approximately 15 g of the rare 3-deoxyanthocyanins/kg bran. This is higher than what is typically obtained from some commercial sources of anthocyanins (e.g., red cabbage and purple carrots) (*23*). The ease of decortication of the black sorghum shows that these 3-deoxyanthocyanins can be economically concentrated from sorghum further enhancing their commercial potential. The white sorghum did not have detectable levels of 3-deoxyanthocyanins.

Dietary Fiber and Antioxidant Properties of Optimally Obtained Bran Fractions. The concentration of antioxidants in bran fractions followed the same pattern observed for phenols (data not shown). This was expected since phenols are the major contributors of antioxidant activity in sorghum (*3*). On the basis of phenolic content and antioxidant activity observed in the separate bran fractions, 2 min was determined as the "optimal" decortication time for all samples except Tx430-V. For this sample, the optimal decortication time was 1 min due to the ease of its bran removal.

The dietary fiber contents of the optimally decorticated brans (38−45%) were 4−6 times the levels measured in the grains (**Table 3**). Even though the average dietary fiber level in the sorghum brans was lower than that in wheat bran (48%), this does not imply that wheat bran is a superior source of dietary fiber since sorghum decortication conditions were not optimized to ensure the most efficient separation of bran from grain. However, the levels of dietary fiber observed in the sorghum brans indicate that they are also a useful source of these valuable dietary components.

In both grains and optimally obtained brans, the brown (tannin-containing) sorghums had the highest antioxidant activity

Table 3. Antioxidant (ABTS) Activity and Dietary Fiber Levels in Optimally Decorticated[a] Bran and Whole Grain

	ABTS activity[b]		dietary fiber[c]	
sample	grain	bran	grain	bran
sumac	240	890	11.1	44.5
SC103	114	510	10.2	40.3
Tx430-CS	89	341	9.8	42.9
Tx430-V	104	378	9.8	45.3
white sorg	9.8	30.1	6.3	38.3
red wheat[d]	10.6	36.3	ND	47.6
CV %	3.2	4.3		

[a] Combined 1st and 2nd bran fractions. [b] μmol Trolox equivalents/g, dry basis; only ABTS data are reported here since it correlates strongly with the other antioxidant methods and is the most suitable for sorghum products (*3*). [c] Percent, dry basis, Prosky method (*17*). [d] Commercial red wheat bran obtained from ADM Milling Co. (Overland Park, KS); ND, not determined.

(**Table 3**) due to the presence of tannins. Sorghum tannins are known powerful antioxidants (*3*, *24*, *25*) with potentially beneficial biological properties (*26*−*28*). These sorghum fractions are potentially useful for various health applications (*29*). The black sorghum bran also had high antioxidant activity (about 10 times) relative to the white sorghum bran and red wheat bran (**Table 3**). This was mostly due to their high 3-deoxyanthocyanin content (*7*). In addition to their antioxidant properties, the structure of the 3-deoxyanthocyanins was proposed as a possible advantage in terms of increased affinity (bonding) to oligonucleotides, a necessary step in DNA triplex stabilization property of anthocyanins (*30*). Thus, black sorghum presents promising opportunities for improving health attributes of food.

The growing prominence of chronic nutrition-related health problems demandd that we explore alternative, nontraditional sources of healthy dietary components. Specialty sorghums present a promising opportunity due to the high levels of beneficial phenolic compounds and dietary fiber in their brans. It is essential to explore processing technologies that can effectively employ these components to produce healthy foods that are organoleptically acceptable to consumers.

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