Factors Affecting the Abrasive Dehulling Efficiency of High-Tannin Sorghum[1]

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ABSTRACT

High-tannin sorghum gives low yields when the grain is abrasively dehulled. Consequently, the factors affecting dehulling performance of this grain were investigated with a small-sample dehuller, the Tangential Abrasive Dehulling Device. Ten grinding wheels, which varied in grit size, grade, structure, and surface finish, were specially manufactured and tested on three soft-endosperm, high-tannin sorghum cultivars. Flour extraction (tannin), defined as 100 minus the required percent kernel removed to reduce the tannin content to 0.5%, ranged from 19 to 91%. All cultivars could be dehulled at low throughputs with flour extraction (tannin) greater than 70% by using a grinding wheel with a low disk abrasive index; a low index was achieved by decreasing the grit size, by increasing the grade or the structure, or by using grinding wheels with a smooth surface finish. The independent effects of grain tannin content, hardness, and shape on dehulling performance were investigated by testing lines that varied widely in one variable but were similar in the other two. Flour extraction (tannin) was significantly correlated with tannin content ($r = -0.98$, $P < 0.01$), hardness ($r = 0.84$, $P < 0.01$), and seed shape ($r = 0.74$, $P < 0.05$). Development of harder, rounder grain with the minimum tannin content required to confer bird-resistance or other desirable agronomic characteristics is required before high throughput, commercial processing of high-tannin sorghum would be viable.

Sorghum (*Sorghum bicolor* (L.) Moench) is an important staple in the semiarid zones of Africa, Asia, and South America because of its drought resistance and its ability to survive and yield grain during intermittent or continuous drought stress (Hulse et al 1980). Some sorghum genotypes that are characterized by high concentrations of polyphenolic compounds, commonly referred to as tannin, have been observed to possess agronomic advantages such as resistance to birds (Bullard and Elias 1980, Butler 1982, Subramanian et al 1983), preharvest germination (Harris and Burns 1970), and molding (Harris and Burns 1973, Hahn et al 1983). High-tannin sorghum cultivars, however, have been found to be nutritionally inferior when compared with low-tannin types of otherwise similar chemical composition (Jambunathan and Mertz 1973, Maxson et al 1973, Schaffert et al 1974, Muindi and Thomke 1981) due to the ability of the tannins to bind dietary proteins. Tannins are located in the testa (Earp at al 1983) but their occurrence in the pericarp has also been reported (Bullard et al 1981, Glennie 1983).

It is essential, especially in developing countries, to retain the agronomic advantages associated with the tannins and at the same time devise means of overcoming their deleterious nutritional effects. One method of achieving the latter is by mechanical abrasion of the tannin-containing layers using grinding wheels in horizontal or vertical type dehullers (Reichert 1982). Chibber et al (1978) showed that this was feasible, however, the yield of flour was low, and the protein loss was high due to the softness of the endosperm, which is characteristic of the vast majority of the high-tannin sorghum genotypes (Mwasaru 1985, Reichert et al 1988). To improve the yield of dehulled high-tannin grain, optimization of the mechanical dehulling process and improvement of grain characteristics is warranted. In this investigation, several variables known to affect the cutting or abrasive action of grinding wheels were studied: the size of the abrasive particles (grit size), the amount of bonding material that holds the abrasive particles in place (grade), the surface finish, and the relative density (structure) that is governed by the size and number of the air spaces in the grinding wheel (Lewis and Schleicher 1976). The grain characteristics studied were tannin content, hardness, and shape.

MATERIALS AND METHODS

Sorghum Grain

Three high-tannin sorghum cultivars (AR3003TX430 grown at the University of Arkansas, Fayetteville; X3055 from Senegal; and P570 obtained from King Grain Ltd., Chatham, Ontario) were used to study the effect of grinding wheel attributes on dehulling efficiency.

To independently investigate the effect of tannin content, hardness, and the shape of the grain on dehulling efficiency, lines varying widely in one variable but relatively constant in the other two were selected from 1,768 lines analyzed in a concurrent study (Reichert et al 1988).

Analytical Methods

The tannin content, abrasive hardness index (AHI), and seed shape were determined by methods described by Reichert et al (1988). The AHI is the time required to remove 1% of the kernel by abrasive dehulling; lines with harder grain have higher AHI values. Seed shape was rated on a scale of 1 to 5, where 1 indicates a spherical seed and 5 a flat one.

Dehulling Equipment and Procedure

The Tangential Abrasive Dehulling Device (TADD), employing a horizontally mounted grinding wheel, was used for all dehulling tests (Reichert et al 1986). The TADD was operated at 1,750 rpm for the study involving grinding wheels (Table I) and 1,450 rpm otherwise. The 12-cup dehulling plate was used throughout.

A series of grinding wheels that varied in composition and spatial arrangement of the abrasive was specially manufactured by the Norton Company of Canada, Hamilton, Ontario. Grinding wheels were manufactured according to the following specifications: 1-in. arbor; 9 ORD; diameter ±0.005 in.; thickness ±0.005 in.; ¼- or ⅜-in. thick; ground on one face and v-sided on the other face, resulting in a smooth (s-faced) and coarse (c-faced) surface finish, respectively. V-siding, which is accomplished by impinging lead shot on the face of the grinding wheel, exposes the abrasive grit by removing the bond material between the grit particles.

To investigate the effect of grinding wheel attributes on dehulling parameters, 10 g of grain was dehulled for at least four time intervals on both sides of the grinding wheel. The dehulled seed was removed from the sample cups using the vacuum aspirating device described by Oomah et al (1981). This device simultaneously collects and cleans the dehulled grain, removing

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any residual fine material that had not escaped under the sample cups. The dehulled grain was weighed, and the weight loss (%) reported as the percent kernel removed. The tannin content of the dehulled grain was determined, and the following parameters were calculated: disk abrasive index (DAI, % kernel removed/min), a measure of the abrasiveness of the grinding wheel, taken from the initial slope of the line obtained by plotting percent kernel removed versus the dehulling time (min); and flour extraction (tannin), defined as 100 minus the required percent kernel removed by dehulling to reduce the tannin content of the flour to 0.5%. Throughput (kg/hr) was calculated at this flour extraction (tannin) value.

RESULTS AND DISCUSSION

Grinding Wheel Attributes Affecting Dehulling Performance

Table I gives the specifications of 10 grinding wheels that were manufactured to investigate the effect of grinding wheel attributes on dehulling performance. Each grinding wheel is characterized by a designation (e.g., A36L5VBE-C) described in the table that denotes its composition and structure. The grinding wheels were composed of abrasive grains of either aluminum oxide (A) or silicon carbide (37C) bonded together in a clay material. Preliminary work (Mwasaru 1985) demonstrated that any differences in dehulling performance due to the abrasive grit type (A or 37C) or bond type (V or VBE) were either small or insignificant ($P<0.05$). The grinding wheels were tested on three cultivars of high-tannin sorghum that differed in grain hardness and tannin content. The abrasive hardness indexes (AHI) and tannin contents of AR3003TX430, X3055, and P570 were 6.1, 2.9, and 2.4 sec and 2.0, 2.5, and 3.7%, respectively. In comparison, the mean AHI for 21 noncolored sorghum lines (low-tannin) was found to be 15.7 sec (range = 8.9–26.2 sec), indicating that the high-tannin sorghums used in this study were very soft. A decrease in the grit size of the abrasive in the grinding wheel resulted in a decrease in the DAI for all three cultivars. This trend was particularly evident for the series of grinding wheels with a coarse surface finish. For the latter grinding wheels, the flour extraction (tannin) increased with decreasing grit size. All grinding wheels with a smooth surface finish tended to have a lower DAI and throughput and a higher flour extraction (tannin) than those with a coarse surface finish. Increasing the grade of the grinding wheel from L to Q while keeping the other characteristics the same (compare A36L5VBE and A36Q5VBE) decreased the DAI and increased the flour extraction (tannin). Increasing the structure of the grinding wheel from 5 to 8 while keeping the other characteristics the same (compare 37C24Q5V-C and 37C24Q8V-C) decreased the flour extraction (tannin). The DAI was negatively correlated to the flour extraction (tannin) for all three cultivars ($r = -0.79$, $P<0.01$, $n = 10$, AR3003TX430; $r = -0.91$, $P<0.01$, $n = 10$, X3055; $r = -0.93$, $P<0.01$, $n = 10$, P570); this relationship indicates that the flour extraction (tannin) can be increased by decreasing DAI, which can be accomplished by decreasing the grit size, by increasing the grade or the structure, or by using grinding wheels with a smooth surface finish. The DAI was positively correlated to the throughput for AR3003TX430 and X3055 ($r = 0.82$, $P<0.01$, $n = 10$, and $r = 0.78$, $P<0.01$, $n = 10$, respectively) but not for P570 ($P>0.05$), which suggests that for two of the three cultivars in this study throughput could be increased by increasing DAI.

It is apparent that it is possible to efficiently dehull very soft high-tannin sorghum cultivars using an appropriate combination of grinding wheel attributes. For example, X3055 and P570 could be dehulled with a flour extraction (tannin) of greater than 70% using an A36Q5VBE-S grinding wheel. Unfortunately, the throughput using this grinding wheel was very low. In commercial production, both high flour extraction and high throughput are desired. Obviously, grain characteristics must be improved to achieve this purpose.

Grain Characteristics Affecting Dehulling Performance

The tannin content (range of 1.1–6.9%) of sorghum lines with similar hardness (AHI = 12.0–12.9 sec) and shape (4 or 5) was negatively correlated ($r = -0.98$, $P<0.01$, $n = 18$) with flour extraction (tannin) (Fig. 1). Cultivars with a higher tannin content required considerably longer dehulling times to reduce the tannin

TABLE I
Effect of Compositional and Structural Attributes of the Grinding Wheel on the Disk Abrasive Index, Flour Extraction (tannin), and Throughput in Dehulling Three High-Tannin Sorghum Lines

	Grinding Wheel Description[a]						Disk Abrasive Index (% kernel removed/min)			Flour Extraction (tannin)[b] (%)			Throughput (kg/hr)		
Under Investigation	Grit Type[c]	Size[d] (Tyler mesh)	Grade[e]	Structure[f]	Bond Type[g]	Surface Finish[h]	AR3003TX430	X3055	P570	AR3003TX430	X3055	P570	AR3003TX430	X3055	P570
Grit size, grade, and surface finish	A	24	L	5	VBE	C	15.1	36.1	45.5	72	42	19	2.9	1.6	0.5
	A	36	L	5	VBE	C	11.9	24.8	30.8	83	45	29	4.1	1.3	0.6
	A	36	Q	5	VBE	C	5.9	15.5	15.2	88	59	46	3.0	1.4	0.8
	A	46	L	5	VBE	C	8.5	19.8	19.9	90	63	52	4.8	2.2	1.4
	A	24	L	5	VBE	S	1.6	4.5	4.9	87	63	48	0.8	0.6	0.4
	A	36	L	5	VBE	S	1.2	2.8	3.2	88	66	59	0.7	0.5	0.4
	A	36	Q	5	VBE	S	0.1	0.1	0.1	91	79	74	0.08	0.06	0.05
	A	46	L	5	VBE	S	1.3	3.0	3.7	88	69	62	0.7	0.5	0.5
Structure	37C	24	Q	5	V	C	11.0	24.2	28.0	82	46	33	3.7	1.2	0.8
	37C	24	Q	8	V	C	8.2	18.3	20.2	86	57	38	3.6	1.7	0.7
LSD[i] (C-finish)							0.7	1.0	1.2	1.2	1.9	1.9	0.2	0.2	0.2
LSD[i] (S-finish)							0.1	0.3	0.1	1.6	1.3	1.5	0.03	0.04	0.02

[a] Designations according to American standard wheel markings (Lewis and Schleicher 1976).
[b] Flour extraction (tannin) = 100 − % kernel removed to reduce the tannin content to 0.5%.
[c] A = Aluminum oxide, 37C = silicon carbide.
[d] Tyler mesh sizes of 24, 36, and 46 correspond to mean particle diameters of 840, 736, and 484 μm.
[e] Rated on a scale of A (soft) to Z (hard). Harder grinding wheels contain relatively more bonding material.
[f] Rated on a scale of 0 (dense) to 16 (open). Grinding wheels with a more open structure contain relatively more or larger air spaces.
[g] V = Vitrified bond, BE = bond modification peculiar to the Norton Company of Canada.
[h] C = Coarse, S = smooth.
[i] Least significant difference ($P<0.05$).

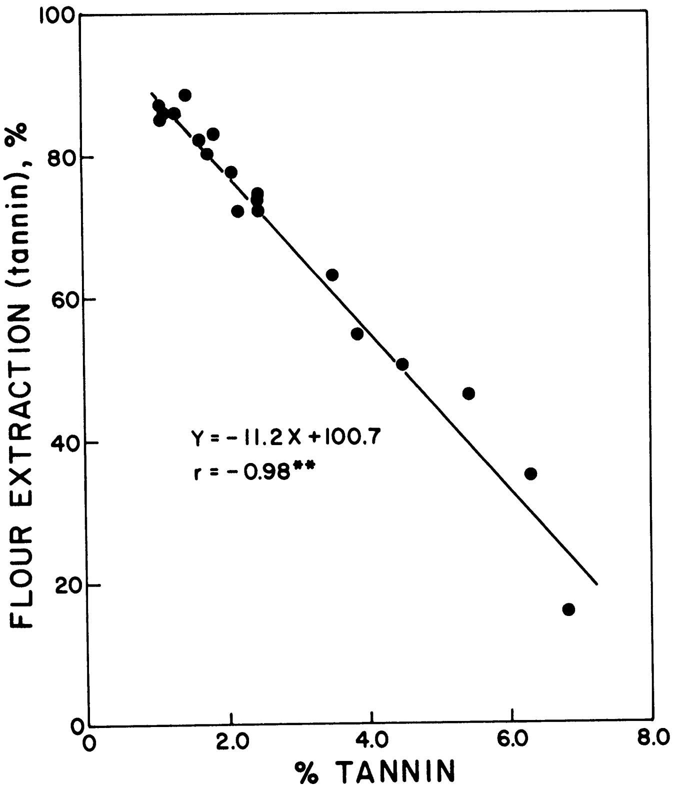

Fig. 1. The effect of tannin content of sorghum lines with similar hardness (AHI = 12.0–12.9 sec) and shape (4 or 5) on flour extraction (tannin). ** = Significant at the 1% level of probability.

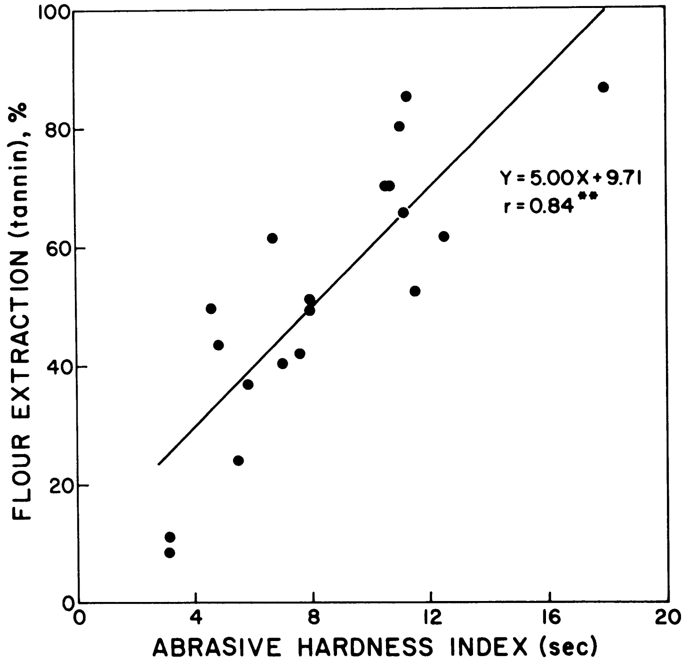

Fig. 2. The effect of grain hardness (measured as abrasive hardness index) of sorghum lines with similar tannin content (3.5–4.0%) and shape (4 or 5) on flour extraction (tannin). ** = Significant at the 1% level of probability.

content to 0.5% ($r = 0.93$ for tannin content [x] versus dehulling time [y], $P<0.01, n = 18, y = 1.61 + 0.647x$). This would account, at least in part, for the lower flour extraction (tannin) of these lines, because longer dehulling times result in greater kernel breakage (Shepherd 1981) and loss of endosperm as fines.

The grain hardness (range of AHI = 3.1–18.0) of cultivars with similar tannin content (3.5–4.0%) and shape (4 or 5) was positively correlated ($r = 0.84$, $P<0.01$, $n = 19$) with flour extraction (tannin) (Fig. 2). An AHI of at least 12.1 was required to achieve a flour extraction of 70% (calculated from the regression equation). These results concur with previous results (Kirleis and Crosby 1982, Murty et al 1984) indicating that cultivars with harder endosperm gave higher yields when abrasively dehulled than those with softer endosperm.

The seed shape (range of 3–5) of cultivars with similar tannin content (2.0–2.5%) and grain hardness (AHI = 9.5–11.5 sec) was negatively correlated ($r = -0.74$, $P<0.05$, $n = 9$) with flour extraction (tannin) (Table II), which indicates that cultivars with more rounded grain gave higher flour extractions (tannin) when abrasively dehulled. It was not possible to identify lines with a seed shape of 1 or 2 with tannin content between 2.0 and 2.5% and AHI between 9.5 and 11.5, even though 1,768 lines were evaluated (Mwasaru 1985, Reichert et al 1988).

TABLE II
Effect of Seed Shape of Sorghum Lines with Similar Tannin Content and Hardness[a] on Flour Extraction (tannin)

Line (IS Number)	Seed Shape[b]	Flour Extraction (tannin) (%)
2504	5	65.0
8959	5	57.0
7217	5	55.2
9279	4	72.5
15063	4	70.0
9494	4	64.0
7125	4	77.2
9946	4	65.0
11089	3	75.0

[a]Tannin content = 2.0–2.5%, and abrasive hardness index = 9.5–11.5 sec.
[b]Seed shape was rated on a scale of 1–5, where 1 = round and 5 = flat.

CONCLUSIONS

Very soft, high-tannin sorghum cultivars were effectively dehulled to flour extractions (tannin) greater than 70% by using abrasive grinding wheels with low DAI values. However, the throughputs were low. A low DAI could be achieved by decreasing the grit size, by increasing the grade or the structure, or by using grinding wheels with a smooth surface finish. A higher throughput could be achieved by using grinding wheels with higher DAI values in combination with cultivars that were lower in tannin content, harder, or rounder. Such cultivars need to be developed before tannin removal from high-tannin sorghums by abrasive dehulling becomes commercially feasible.

The magnitude of the correlation coefficient between flour extraction (tannin) and tannin content ($r = -0.98$), grain hardness ($r = 0.84$), and seed shape ($r = 0.74$) may indicate the relative importance of these three factors for abrasive dehulling. A program of selection of high-tannin cultivars that are particularly appropriate for abrasive dehulling should probably first attempt to decrease tannin content to the minimum level required to confer desirable agronomic characteristics, such as bird resistance (this level has not been established), secondly increase grain hardness, and thirdly develop rounder grain.

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