Laboratory Abrasive Decorticating Mill—Influence of Machine and Operating Variables

A. D. SHEPHERD, Western Regional Research Center, Science and Education Administration, U.S. Department of Agriculture,[1] Berkeley, CA 94710

ABSTRACT

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A laboratory decorticating mill was studied to determine the effects of machine variables (surface, grit, impeller blade count, and speed of rotation) and an operational variable (sample size) on decortication of a corneous white grain sorghum, Funk G-766W. When other variables were fixed, increasing sample size (5–30 g) decreased the degree of decortication. Sample size had no significant effect on breakage when milling was to a constant 10% removed. When degree of decortication was fixed at about 10% (by varying time only), using coarse rather than fine abrasive, the amount of broken grain decreased. The influence of impeller speed and blade count on breakage was studied by fixing all other variables except time, which was varied to produce 10% decortication. A family of curves representing different blade counts was generated when percent broken was plotted vs impeller speed. Breakage was lowest and nearly constant at low speed, regardless of blade count. Breakage increased as speed was raised but increased most with two blades and least with twelve. These data are useful in selecting machine and operating variables and in designing other mills.

The versatility of the laboratory abrasive decorticating mill (Shepherd 1979) results from the possibility of selecting among several options of machine and operating variables. The abrasive surface, the size and number of blades on the impeller, the size of perforations in the screen and the rotation speed of the impeller may all be selected, as may the operational variables time and sample size. The present study was designed to determine how these variables influence performance so that optimum selection among them can be made.

MATERIALS AND METHODS

Sorghum

Funk G-766W hybrid grain sorghum was readied for use by sizing, cleaning, and handpicking as previously described (Shepherd 1979). The resulting clean, uniform lot was subsampled in a sample splitter for each decorticating run.

Procedure

The samples were milled as described previously (Shepherd 1979). Before weighing the contents of the two receivers, a small

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adjustment was made: 1) the contents of the second receiver were screened over a 40-mesh screen (425 μm); 2) the overs were blown very gently in a seed blower; 3) the throughs of the 40-mesh screen and the lights from the seed blower were added to the contents of the first receiver. The transferred weight averaged only a few hundredths of a gram, but the material was obviously misplaced in the second receiver, which contained polished grain.

Percent Removed

The net adjusted weight of the contents of the first receiver divided by the sample weight times 100 was called percent removed.

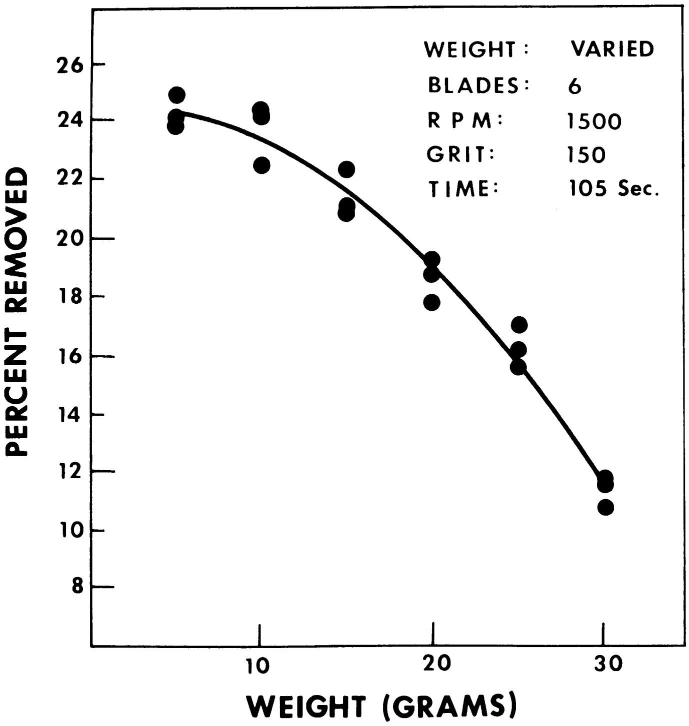

Fig. 1. Relationship between percent removed and sample size.

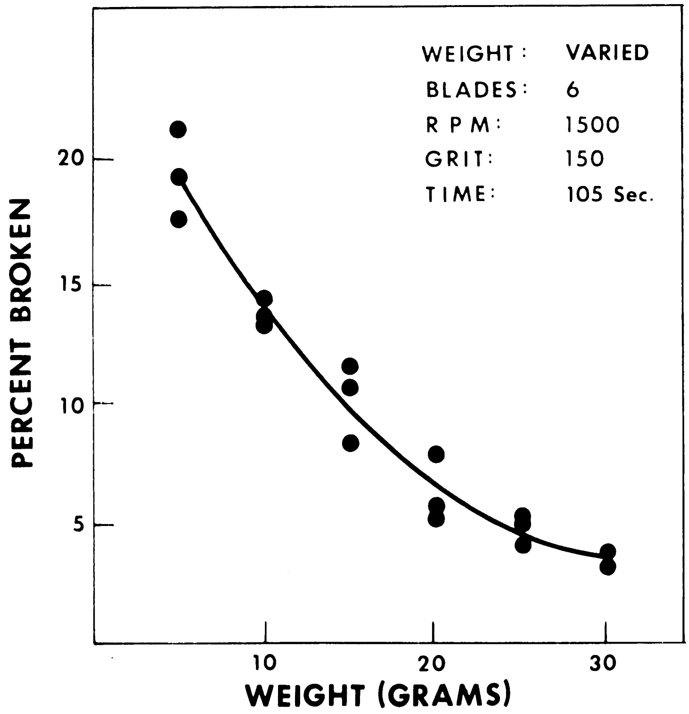

Fig. 2. Relationship between percent broken and sample size.

Percent Broken

The contents of the second receiver after adjustment was inspected and particles smaller than two thirds of a whole grain were considered broken. The weight of brokens divided by the adjusted weight of the contents of the second receiver times 100 was called percent broken.

Experiments

Sample Weight. All of the machine and operating variables other than weight of sample were fixed: abrasive, 150 grit; blade count, 6; screen, 2.4-mm (3/32-in.) round perforations; speed, 1,500 rpm; and time, 105 sec. Sample weight was varied from 5 to 30 g by 5-g increments. Three replicate determinations were made.

Another experiment was conducted in which all of the machine and operating variables other than sample weight and time were fixed: abrasive, 60 grit; blade count, 12; screen, 2.4-mm (3/32-in.) round perforations; and speed, 1,500 rpm. Sample weight was varied from 5 to 30 g by 5-g increments. Times were selected for the first replication based on previous experience. Times were adjusted for the second, third, and fourth replications so that at each sample weight at least one observation would be on either side of 10% removed and at least one time would be repeated.

Abrasive Surface. All of the machine and operating variables other than surface grit and time were fixed: sample size, 10 g; blade count, 6; speed, 1,500 rpm; and screen, 2.4-mm (3/32-in.) round perforations. Surface grit and time were paired to give about 10% removed: 60 grit, 25 sec; 80 grit, 35 sec; 150 grit, 65 sec; and 240 grit, 70 sec.

Impeller Speed and Blade Count. Machine and operating variables were fixed: sample size, 10 g; surface grit, 60; and screen, 2.4 mm (3/32-in.) round perforations. The rpm, blade count, and time were varied systematically. All 20 combinations of four levels of rpm (1,500, 1,800, 2,100, and 2,400) and five blade counts (2, 3, 4, 6, 12) were run at times selected to provide an estimated 10% removal based on some preliminary milling runs.

RESULTS AND DISCUSSION

Influence of Weight of Sample

The relationship of percent removed versus sample size can be represented by the quadratic equation

TABLE I
Effect of Sample Size on Percent Broken at 10% Removed

Sample Size (g)	Replication	Time (sec)	Removed (%)	Broken (%)
5	1	35	10.8	2.0
	2	30	10.2	2.5
	3	25	9.4	1.3
	4	30	10.0	3.4
10	1	40	9.0	1.9
	2	45	11.0	3.6
	3	40	10.3	2.3
	4	40	10.4	2.4
15	1	50	9.5	2.2
	2	55	10.5	3.8
	3	50	10.0	2.9
	4	50	9.3	2.1
20	1	60	9.2	2.6
	2	65	10.0	2.7
	3	70	11.8	3.9
	4	65	11.6	2.9
25	1	70	8.3	2.0
	2	85	11.0	2.9
	3	80	10.9	2.9
	4	80	10.4	2.0
30	1	80	7.5	1.9
	2	110	12.3	4.0
	3	95	10.7	2.7
	4	95	9.8	1.9

$$r = 24.53 + 0.0276W - 0.0154W^2 \quad (R^2 = 0.98)$$

where r = percent removed and W = sample weight in grams (Fig. 1).

The relationship of percent broken versus sample size can be represented by the quadratic equation

$$b = 25.65 - 1.39W + 0.0219W^2 \quad (R^2 = 0.97)$$

where b = percent broken (Fig. 2).

These graphs show about a twofold range for percent removed for the extreme sample sizes and about fivefold range for percent broken. The coefficients of variation (3.9 and 11.4, respectively) show percent broken to be subject to greater variability than percent removed.

The effect of sample size had to be related to percent removal and percent broken. In this experiment, the relationship between percent removed and percent broken was confounded with sample size and could not be determined. Therefore, in another experiment, all of the machine and operating variables other than sample weight and time were fixed. The data are presented in Table I.

Percent removed was first looked upon as a function of sample weight and time, which may be represented by the equation

$$r = 6.07 - 0.236W - 0.00593W^2 + 0.174t \quad (R^2 = 0.80)$$

where t = time. Reduction of the first three terms to one term (a) results in a linear equation for each weight: r = a + 0.174t (Table II).

Analysis of percent broken as a function of sample weight and percent removed gives the equation

$$b = -1.99 + 0.453r \quad (R^2 = 0.47).$$

Sample weight exhibits no significant additional effect upon percent broken. Therefore, the estimated percent broken for all sample sizes, 5–30 g, at 10% removal is 2.54 with a 95% confidence interval of 2.32–2.76.

Influence of Abrasive Surface

Data for percent removed and percent broken at the four grit-time pairs given in Table III show that percent removed averaged around 10 and that means for percent broken trended downward from about 4.0 for the finest abrasive to about 2.0 for the coarsest abrasive.

Although a significant quadratic trend was found for percent removed by analysis of variance (*P* = 0.03), no significant adjustment due to percent removed was found when it was included as a covariant in the analysis of percent broken.

The relationship of percent broken versus grit is linear (Fig. 3) when grit is represented by the dimension of the mesh opening through which the grit was sized. The equation for the line is

$$b = 4.92 - 0.0110G \quad (R^2 = 0.55)$$

where G = grit (in micrometers).

Breakage with 60-mesh grit abrasive is almost half of that with 240-mesh. This seems reasonable when one sees that milling to provide 10% removed takes almost three times as long with 240-mesh grit as with 60-mesh, and that the kernels are constantly being subjected to the hazard of breakage.

TABLE II
Values for Equation[a] Relating Time and Sample Weight to Percent Removed

Sample Weight (g)	a[b]	Time for 10% Removed, r = 10 (sec)	95% Confidence Interval
5	−5.26	30.2	25.2, 34.9
10	−6.89	39.6	34.9, 44.0
15	−8.81	50.6	46.2, 54.9
20	−11.03	63.4	59.1, 67.7
25	−13.55	77.9	73.5, 82.4
30	−16.36	94.0	89.2, 99.2

[a] $r = a + 0.174t$, where r = percent removed and t = time in seconds.
[b] $a = 6.07 - 0.236W - 0.00593W^2$, where W = sample weight in grams.

Influence of Impeller Speed and Blade Count

Information on average percent removed for three replications of the entire series of 20 combinations are given in Table IV. Because of significant differences from 10% removed, the data required some adjustment. Data for percent broken determined on the same samples also required adjustment.

The data was subjected to multiple regression analysis with deletion of nonsignificant effects. Criteria for acceptance included

TABLE III
Effect of Grit on Percent Broken at 10% Removed

Grit/Time Pair					
Mesh					
Size	Opening (μm)	Time (sec)	Replication	Percent Removed[a]	Percent Broken[b]
240	60	70	1	8.9	4.0
			2	9.8	3.7
			3	10.7	4.7
			Mean	9.8	4.1
150	100	65	1	10.1	5.5
			2	10.2	3.8
			3	10.8	2.7
			Mean	10.4	4.0
80	180	35	1	10.4	2.5
			2	11.0	3.3
			3	10.6	2.8
			Mean	10.7	2.9
60	250	25	1	9.2	3.0
			2	9.7	2.1
			3	9.1	1.4
			Mean	9.3	2.2

[a] Coefficient of variation for means = 5.4.
[b] Coefficient of variation for means = 26.7.

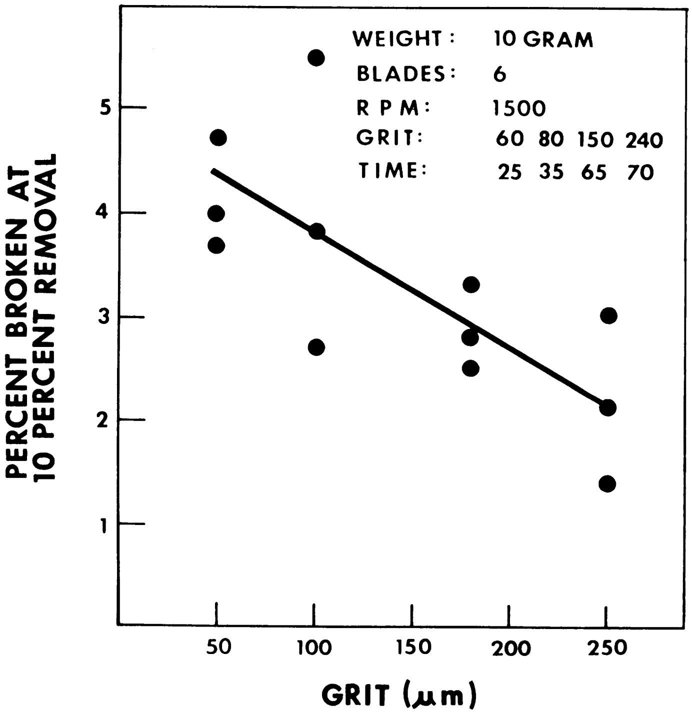

Fig. 3. Relationship between percent broken and grit. Grit is represented by dimension of mesh opening.

TABLE IV
Effect of Blade Count and Impeller Speed on Percent Removed and Percent Broken

Speed (rpm)	Blade Count 2	3	4	6	12
	Average Percent Removed[a,b]				
2,400	11.6	10.8	10.6	11.7	11.4
	(9)	(7)	(5)	(6)	(6)
2,100	10.4	9.6	8.4	10.4	10.3
	(14)	(11)	(9)	(9)	(10)
1,800	9.8	10.3	9.9	11.8	10.0
	(28)	(23)	(21)	(20)	(18)
1,500	9.5	10.2	9.9	10.7	9.2
	(60)	(50)	(45)	(41)	(33)
	Average Percent Broken[c]				
2,400	13.7	11.0	10.0	13.6	10.0
2,100	7.8	5.8	4.9	6.5	4.6
1,800	3.7	4.7	4.1	6.6	3.6
1,500	2.7	2.8	2.5	2.9	1.9

[a] Milling time, in seconds, is shown in parentheses.
[b] Coefficient of variation = 4.7.
[c] Coefficient of variation = 16.2.

a nonsignificant lack of fit test ($P = 0.19$) and random distribution in the residuals plot. The final model was

$$b_{10} = 0.900 - 1.72\,(\text{rpm}/100) + 0.486\,(\text{blade count}) + 1.39\,(\text{percent removed}) + 0.0692\,(\text{rpm}/100)^2 - 0.0326\,(\text{rpm}/100)\,(\text{blade count}) \quad (R^2 = 0.93)$$

where b_{10} = percent broken at 10% removal. Figure 4 indicates that at 1,500 rpm, breakage was about 2.7% and independent of blade count. As speed was increased, breakage also increased, most (11%) for two blades and least (8%) for twelve blades. This experiment reveals that in order to minimize percent broken, use of lower rotation speeds and a full complement of blades on the impeller is advantageous.

The laboratory abrasive decorticating mill allows selection among options for several variables. The present study analyzes the effects of some important possible selections, singly and in combination, to guide the operator toward selections that give optimum performance. This type of information will also aid in future machine design, whether for a routine milling test or a versatile research tool. With standard settings, the mill can be used for determining the milling characteristics for grain. Tests are currently underway with grain sorghum cultivars.

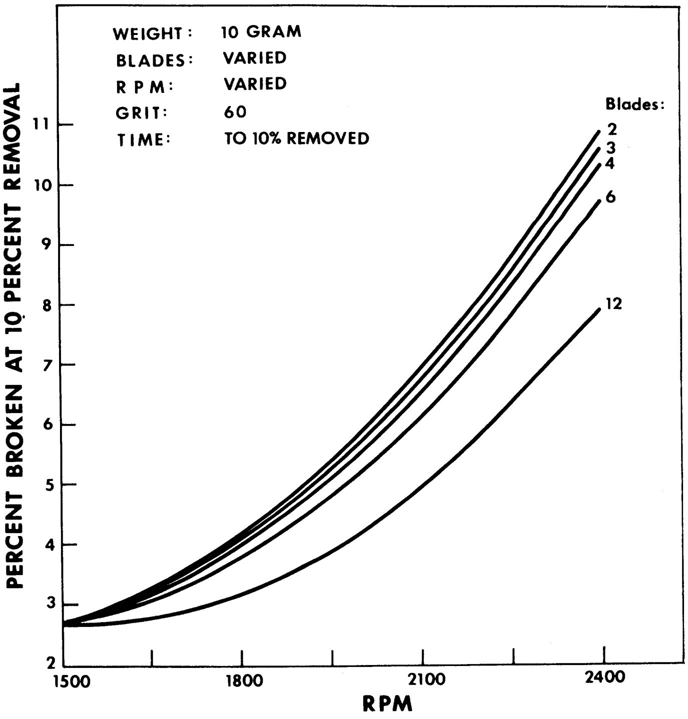

Fig. 4. Relationship between percent broken at 10% removal and impeller speed at several blade counts.

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LITERATURE CITED

SHEPHERD, A. D. 1979. Laboratory abrasive decorticating mill for small grains. Cereal Chem. 56:517.

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