DEHULLING CEREAL GRAINS AND GRAIN LEGUMES FOR DEVELOPING COUNTRIES. I. QUANTITATIVE COMPARISON BETWEEN ATTRITION- AND ABRASIVE-TYPE MILLS[1,2]

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ABSTRACT

Two commercial mills, an attrition and an abrasive type, were quantitatively compared with a laboratory model Strong-Scott barley pearler in the dehulling of pigmented Nigerian sorghums and millets. Reflectance values (450 nm) of the flours obtained from the mills at various degrees of dehulling were measured. Graphs of these reflectance values *vs.* the percentage of kernel removed with each of the dehullers illustrated that the laboratory pearler was the most efficient, being able to remove most color with least loss of material. The abrasive mill was comparable with the laboratory pearler, but the attrition mill was much less efficient. Kernel-cracking analysis as well as throughputs to be expected at various degrees of dehulling indicated that the abrasive mill is generally more suitable for dehulling Nigerian sorghums and millets.

In conjunction with a "Village Scale" pilot milling operation in Maiduguri, Nigeria, our laboratory has been studying mechanical dehulling of pigmented Nigerian sorghums and millets. A variety of dehulling equipment is presently available incorporating either abrasive, attrition, or roller-milling principles. Abrasive-type machines employing carborundum stones or other abrasive devices have been the subject of most investigations, while the other two types of mills have received relatively little attention.

Hogan *et al.* (1) and Normand *et al.* (2) used a tangential abrasive device to remove successive layers from a variety of grains. Hahn (3), Rooney *et al.* (4), Stringfellow and Peplinski (5), and Anderson *et al.* (6) used barley pearlers or similar machines to dehull sorghums. Investigators at the Central Food Technological Research Institute in Mysore, India (7,8) and also at the Northern Regional Research Laboratory in Peoria, Illinois (9) tested rice hullers and polishers on sorghum and found that they are reasonably successful. Others used wire brush-type mills (10,11) and peelers (12) to remove the bran and in some cases the germ from sorghum grain.

Roller milling of sorghums has been reviewed by Hahn (13), who concluded that their usefulness was limited due to the final color and speckiness of the flour.

An attrition-type dehuller was recently tested by deMan *et al.* (14) and found to give excellent results in the dehulling of sorghums and millets. The unique feature of this Palyi Compact Mill is that the attrition plates are fitted with saw-tooth blades which provide the dehulling action. Subsequently, the grains are subjected to an abrasive action by a drum rotating in a cylindrical screen. Finally, an air separator divides the hulls from the kernels.

In the present investigation, this attrition-type mill is quantitatively compared with two abrasive units; namely, a laboratory scale Strong-Scott barley pearler and a George O. Hill grain thresher. The latter is a new commercial abrasive unit

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designed for the threshing of grains such as barley and oats, and it was modified in our laboratory to provide a pearling action. The three units, the attrition mill, the pearler, and the abrasive mill were compared in terms of efficiency as measured by flour color *vs.* material removal, kernel cracking, and throughput.

MATERIALS AND METHODS

A red, branned sorghum variety and a green, branned millet were obtained from Maiduguri, Nigeria, and dehulled at moisture levels of 8.0 and 8.6%, respectively. A brief description of each dehuller and the manner in which it was operated to obtain various extraction levels follows.

Attrition Mill

Since deMan's work (14), a modification has been added to the machine by the manufacturer to improve the treatment of grains following the initial action of the attrition plates. After leaving the plates, grains pass into a cylindrical head where a drum rubs the grains against a cylindrical metal screen. Fines, considered as part of the hull fraction, pass through the screen. The modification is an adjustable cover plate which controls the exit of grains from the cylindrical head. By adjusting the distance between the cover plate and the extended edges of the metal screen, it is possible to vary the retention time in the head as illustrated in Fig. 1.

To investigate the effectiveness of the two sawtoothed attrition plates alone, the cover plate was turned back completely. Ten-pound lots of grain were dehulled at four plate spacings for sorghum and at three plate spacings for millet to produce extraction levels between 68 and 93%, at a rotating plate speed of 990 rpm. The air separator unit was set at half open. Throughputs were calculated on the basis of the time required to process the 10-lb lots.

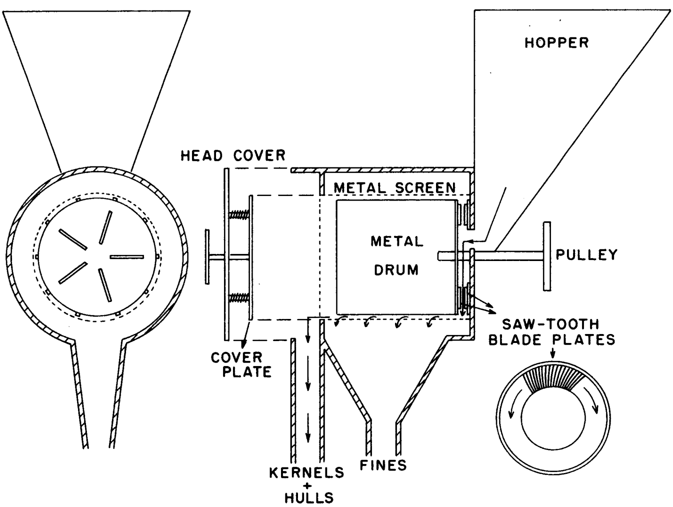

Fig. 1. Schematic of the dehulling plates and head of the attrition mill.

The effectiveness of the modification to the cylindrical head used in conjunction with the attrition plates was also investigated using 10-lb lots. The plates were adjusted to the spacing which previously had produced the highest extraction level for the two grains. The distance between the cover plate and the extended edges of the metal screen was then varied to see what effect this had on the extraction level and the quality of the dehulled grain.

Abrasive Mill

The body of the abrasive mill shown in Fig. 2 contains thirteen 12-in. diameter carborundum stones, driven at speeds up to approximately 2000 rpm. In a continuous operation, grains are fed into the machine through a hopper located at one end and, after the action of the stones, are released through an overflow outlet near the other end. The amount of the kernel removed as fines will depend on the retention time in the mill which, in turn, depends on the rate at which grains are fed into the machine. The fines are removed by aspiration through a port in the top of the unit during the dehulling operation.

In the present experiments, the mill was operated on a batch basis without the use of air aspiration while dehulling. Forty pounds of grain was loaded into the machine and the stones rotated at 1050 rpm for 1 or 2 min for sorghum and millet, respectively. The grain was then released and passed through the air separator (setting = 1/2) on the attrition mill to remove the fines. The dehulled grain was sampled and reintroduced into the mill for another increment of time. This procedure was repeated four times for the two grains to produce cumulative extraction levels of approximately 70%. Throughputs were calculated in lb/hr on

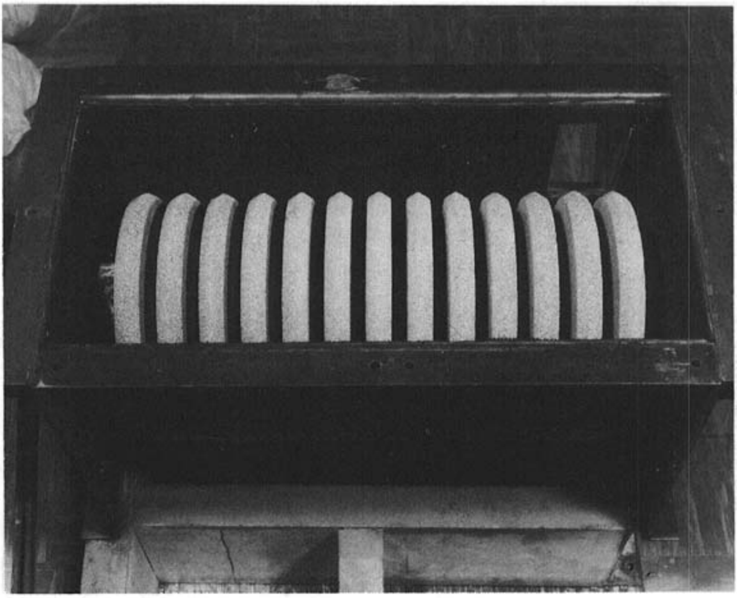

Fig. 2. Top view of the interior of the rubber-lined abrasive mill, illustrating carborundum stones and overflow outlet.

the basis of the retention time, assuming a 40-lb holdup.

Laboratory Pearler

The metal screen surrounding the single carborundum stone in the pearler was covered with a thin piece of rubber to prevent small seeds from passing through. Twenty-five grams of sorghum or millet was pearled at 1725 rpm for varying retention times, released, and then sifted on a 20-mesh screen to remove the fines.

The three dehullers are illustrated in Fig. 3. The abrasive mill is shown complete with cyclone and aspiration fan. The air aspiration unit used to clean grains from both abrasive and attrition mills is shown on the latter directly below the cylindrical dehulling head.

Flour Reflectance Measurements

Dehulled grain samples from the attrition and abrasive mills were sifted on a 20-mesh screen to remove a small amount of fines which the air separator had missed. Total extraction levels based on air aspiration plus this sieving were then calculated. Twenty-gram samples of the dehulled grains were ground for 2 min in a Chemical Rubber Co. micro-mill and then well mixed. Reflectance measurements were taken on a Hitachi Perkin-Elmer spectrophotometer with a diffuse reflectance attachment. Flours were packed as firmly as possible into glass cells with a spatula and compared to a MgO reference standard. Twenty samples of a millet flour packed in this way had a mean absorbance of 0.361 and a per cent standard deviation of 0.78.

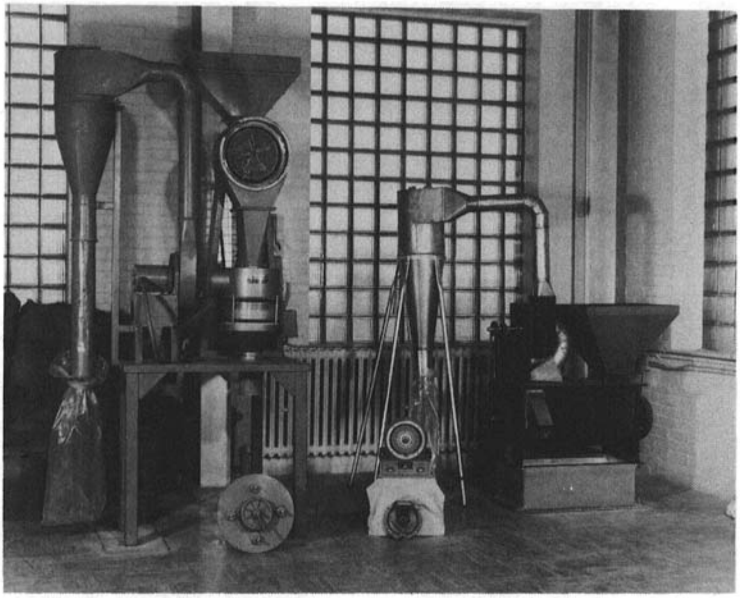

Fig. 3. Complete attrition mill, laboratory pearler, and abrasive mill. The head cover on the attrition mill and the front cover for the laboratory pearler have been removed and are shown in front of their respective mills.

Kernel-Cracking Analysis

The percentage of cracked kernels was determined by sifting 100 g of the dehulled grains in a Ro-Tap shaker for 3 min, on 12- and 7-mesh screens for millet and sorghum, respectively. The weight percentage of kernels passing through these screens gave a relative measure of cracked kernels.

RESULTS AND DISCUSSION

Figure 4 illustrates the differences in flour reflectance between whole and dehulled sorghums at wavelengths between 350 and 750 nm. The differences are largest between 350 and 550 nm, and 450 nm was chosen as the wavelength to compare the flours from the dehulling tests. Millets gave a response similar to sorghums.

Figure 5 shows the flour color *vs.* percentage of kernel removed from sorghum using the three dehullers. The laboratory pearler removed the most color with least loss of material, while the abrasive mill was comparable in this respect. The attrition mill was less efficient in terms of color removal. To put these results into perspective, a sample of sorghum flour dehulled in the traditional mortar and pestle fashion was obtained from Nigeria and the reflectance at 450 nm was measured. To obtain this flour reflectance, represented by the horizontal line, losses of approximately 21, 23, and, by extrapolation, 44% of the kernel would be expected with the pearler, abrasive, and attrition mills, respectively.

Color removal from pigmented millets is illustrated in Fig. 6. The laboratory pearler and abrasive mill were able to lighten millet considerably more efficiently

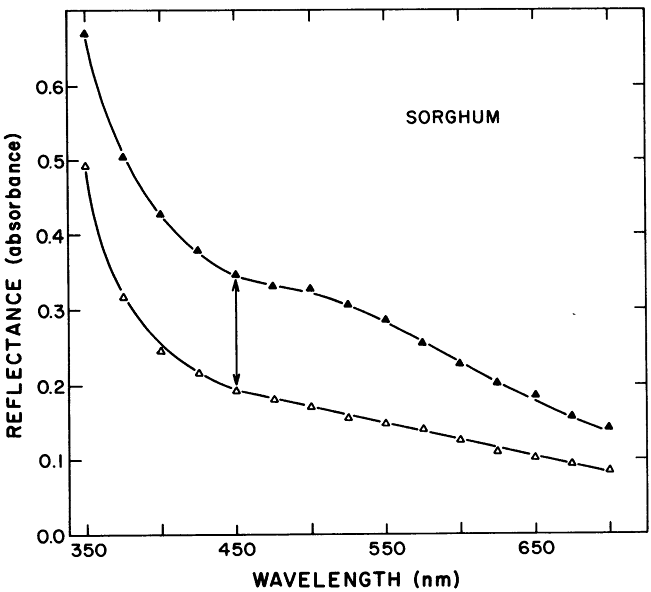

Fig. 4. Reflectance wavelength scans of whole and dehulled sorghum flours. (▲) Whole sorghum, and (Δ) 31.1% kernel removed.

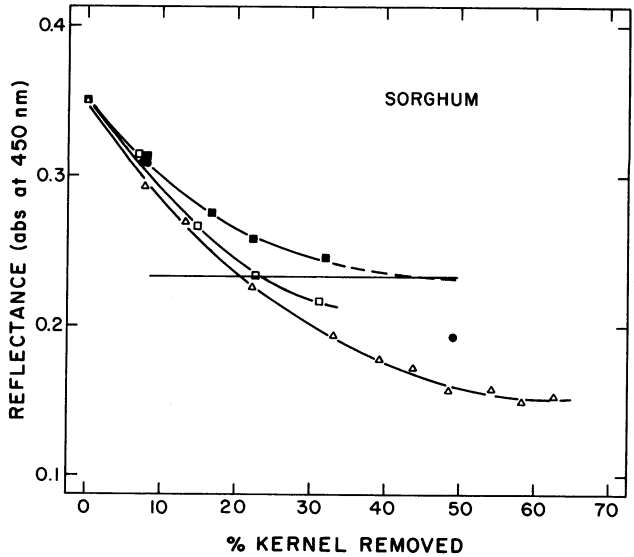

Fig. 5. Effect of dehulling on sorghum flour reflectance (450 nm). (■) Attrition mill (plates only), (•) attrition mill (modified head and attrition plates), (□) abrasive mill, and (Δ) laboratory pearler.

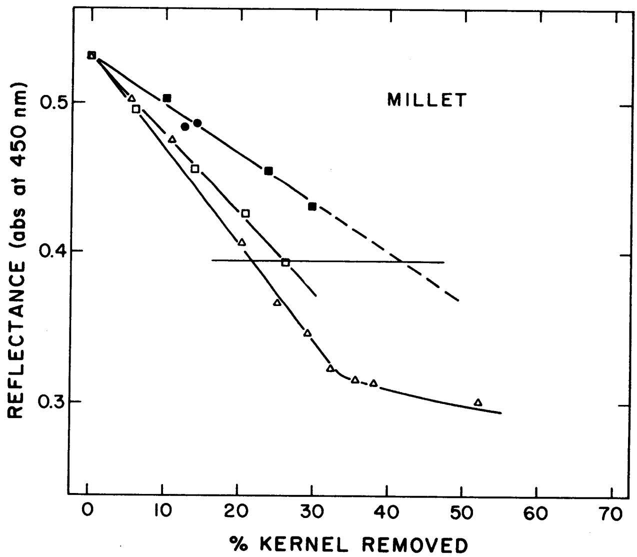

Fig. 6. Effect of dehulling on millet flour reflectance (450 nm). (■) Attrition mill (plates only), (•) attrition mill (modified head and attrition plates), (□) abrasive mill, and (Δ) laboratory pearler.

than the attrition-type mill. To produce flour comparable in color to traditionally dehulled millet, it would be necessary to remove approximately 22, 26, and, by extrapolation, 42% of the kernel with the pearler, abrasive, and attrition mills, respectively.

The kernel-cracking analysis partly explains the differences in relative efficiencies of the mills. Figures 7 and 8 show that there are significant differences

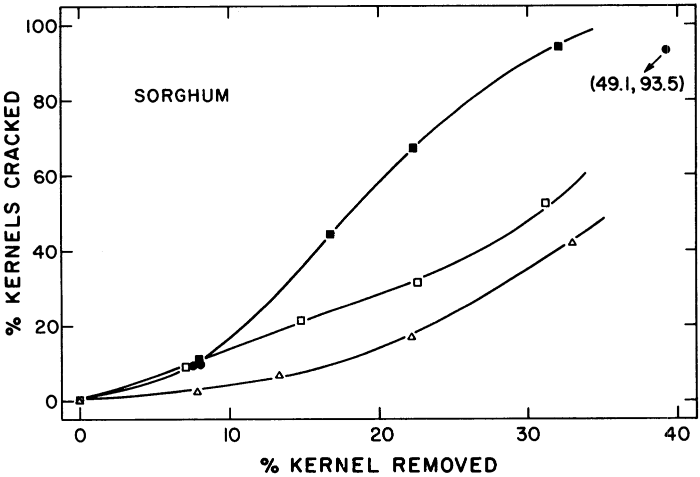

Fig. 7. Effect of dehulling on sorghum kernel cracking. (■) Attrition mill (plates only), (•) attrition mill (modified head and attrition plates), (□) abrasive mill, and (Δ) laboratory pearler.

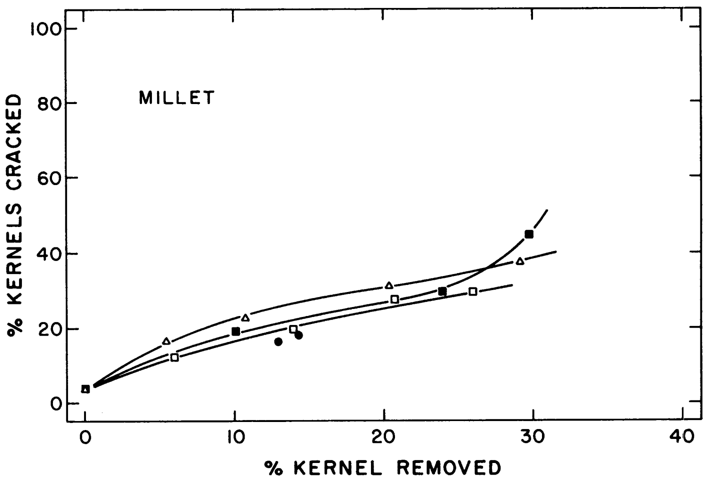

Fig. 8. Effect of dehulling on millet kernel cracking. (■) Attrition mill (plates only), (•) attrition mill (modified head and attrition plates), (□) abrasive mill, and (Δ) laboratory pearler.

in kernel cracking in dehulling sorghum with the three dehullers, while little difference is observed in dehulling millets. The pearling test has been used (15) as a relative indicator of hardness of grains, and Fig. 9 demonstrates that at all retention times in the pearler, more material is removed as fines from sorghum than millet. Millet is thus harder than sorghum and less likely to crack under the pressure of carborundum stones or attrition plates. In the case of the more fragile sorghum kernels, however, it is apparent from Fig. 7 that the attrition mill cracks more of the kernels at all extraction levels than do either of the abrasive-type mills. In removing 25% of the kernel with the three dehullers, approximately 23, 36, and 76% of the kernels would be cracked with the pearler, abrasive, and attrition mills, respectively. More cracking leads to material removal from all parts of the kernel rather than from the peripheral regions only and hence contributes to less efficient dehulling. In the case of millet, it is likely that the sharp teeth of the attrition mill dig deeper than the carborundum stones and remove relatively more endosperm material while dehulling.

Throughputs

Figures 10 and 11 illustrate the throughputs at various extraction levels with the two commercial units. In dehulling sorghums, throughputs of approximately 200 lb/hr and 730 lb/hr would be expected with the attrition and abrasive mills, respectively, if 25% of the kernel were removed. Throughputs of approximately 60 lb/hr and 360 lb/hr, respectively, would be expected if the same amount were removed from millet with each mill.

Effectiveness of the Head Modification on the Attrition Mill

Three points on Figs. 5, 7, and 10 and two points on Figs. 6, 8, and 11 illustrate

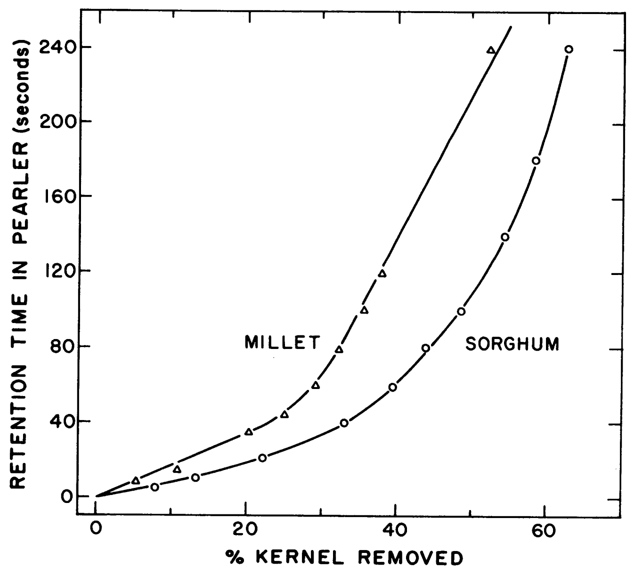

Fig. 9. Retention time in pearler *vs*. percentage of kernel removed.

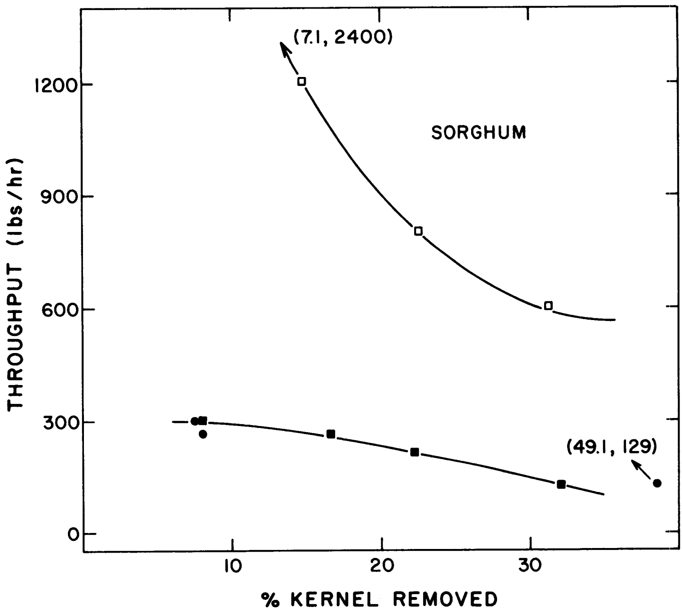

Fig. 10. Throughputs in dehulling sorghum with the commercial units. (■) Attrition mill (plates only), (•) attrition mill (modified head and attrition plates), and (□) abrasive mill.

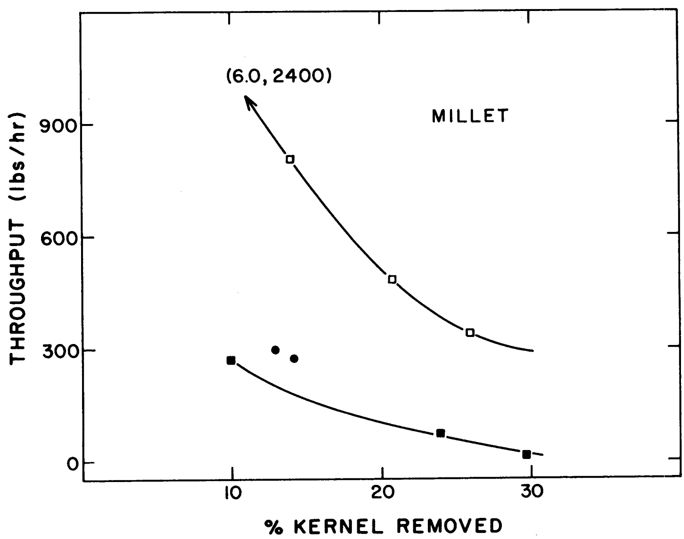

Fig. 11. Throughputs in dehulling millets with the commercial units. (■) Attrition mill (plates only), (•) attrition mill (modified head and attrition plates), and (□) abrasive mill.

the effect of varying the distance between the cover plate and the extended edges of the metal screen. The first two settings used on both millet and sorghum grains produced results that were not significantly different from those obtained when the attrition plates were used alone. In the case of sorghum, closing the cover plate another 0.012 in. resulted in a light-colored product but with a loss of 49.1%. In the case of millet, closing the cover plate another 0.016 in. resulted in plugging the head. It is doubtful whether this modification would be useful for dehulling sorghum and millet because of the difficulty of maintaining the very exact tolerances required.

CONCLUSIONS

On the basis of relative efficiencies in terms of color removal and also kernel cracking and throughput data, the abrasive-type mill is favored for the dehulling of Nigerian sorghums and millets. Other considerations such as relative size, maintenance requirements, and relative simplicity also favor the abrasive- over the attrition-type mill for a "Village Scale" milling operation.

Acknowledgments

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