Description of a Production Model of the Tangential Abrasive Dehulling Device And Its Application to Breeders' Samples[1]

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ABSTRACT

A production model of a small-sample laboratory dehuller, the Tangential Abrasive Dehulling Device (TADD), used to simulate abrasive dehulling equipment, is described. Abrasion is provided by a horizontally mounted grinding wheel or other abrasive, which rotates below and in close proximity to bottomless sample cups mounted in a sample-cup plate. As the grinding wheel rotates, seeds roll freely in the cups and are dehulled as they contact the abrasive surface. Bran material passes beneath the sample cups and is expelled. Up to 12 samples (ranging in size from single seeds to approximately 30 g) can be dehulled simultaneously. Larger quantities (up to approximately 2 kg) of fewer samples can also be dehulled by selection of an appropriate sample-cup plate or the single-track plate. Operating parameters affecting dehulling performance included speed of the grinding wheel, quantity of seed in the sample cups, and the clearance between the grinding wheel and the bottom edge of the sample cups. Grain hardness can be assessed by using grain depth measurements taken directly in the sample cup in lieu of sample weighing. Many cereals, legumes, and oilseeds varying widely in size and shape have been dehulled in the TADD. The TADD is also useful for seed scarification, degluming, and for assessing seed coat durability and dehulling quality.

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Plant breeders are often interested in improving or at least maintaining the milling quality of grain varieties under development. Generally, only limited supplies of breeding stock are available and, therefore, plant breeding laboratories must use laboratory mills to evaluate milling quality. The laboratory mill simulates the main processes of a commercial mill. Occasionally, commercial millers also use laboratory mills to assess the suitability of a particular grain lot or variety for processing. For example, in the wheat milling industry, break and reduction roller mills are used to produce flour. To predict the milling performance of wheat in these roller mills, the Buhler laboratory mill (AACC method 26-20, 1983) is often used.

Abrasive dehulling, employing a horizontally or vertically mounted grinding wheel, or an abrasive cone or cylinder, is used in preference to roller milling for polishing rice (Araullo et al 1976), pearling barley, and dehulling sorghum (Reichert 1982), millet (Reichert and Youngs 1976), and a wide variety of legume grains (Reichert et al 1984, Kurien 1984). The objective of abrasive dehulling is to remove the outer layers (hull) of the seed, thereby reducing the fiber and tannin content (Deshpande et al 1982a) and improving the appearance, texture, cooking quality (Kon et al 1973), functional properties (Deshpande et al 1982b), palatability, and digestibility of the grain.

Several laboratory mills have been constructed to simulate the action of abrasive dehulling equipment. The Strong-Scott laboratory pearler or modifications thereof (Rooney and Sullins 1969) and equipment such as the Satake grain testing mill (Convanich and de Padua 1973) are the most commonly used laboratory pearlers. In these pearlers, dehulling is accomplished by the action of a grinding wheel (or other abrasive), usually rotating within 0.76 cm of a circular metal screen. The intense action produced by the grinding wheel tends to shatter larger-sized seeds (e.g., field peas) or seeds which have a softer texture. A Udy Cyclo-Tec grinding mill has been modified to provide an abrasive action suitable for dehulling grain (Shepherd 1979). One disadvantage common to all commercially available laboratory mills is that only one sample at a time can be processed.

The objective of this work was to develop a small-sample laboratory dehuller for rapidly and reproducibly dehulling as many as 12 grain samples simultaneously. A system for assessing grain hardness without the need for any weighing measurements was also developed for the machine. The dehuller, known as the Tangential Abrasive Dehulling Device (TADD), has been extensively field tested and is now commercially available in Canada. The dehuller is based on the principle of tangential abrasion, which has been used previously by several investigators (Hogan et al 1964, Normand et al 1965, Barber 1972). This principle is embodied in many of the large-scale abrasive dehullers such as the vertical shelling machine or the Decomatic dehuller described by Reichert (1982). The development of the TADD involved construction of crude prototype models that have been described previously (Oomah et al 1981, Reichert et al 1982).

MATERIALS AND METHODS

Grain Samples

Hard red spring wheat (*Triticum aestivum* cv. Benito) was obtained from Early Seed and Feed Ltd., Saskatoon, Saskatchewan. Sorghum grain (*Sorghum bicolor* cv. P570) was obtained from King Grain Ltd., Chatham, Ontario. Seed moisture contents were equilibrated to 7.2 and 6.9% for wheat and sorghum, respectively.

TADD Components and Operation

The TADD (Fig. 1) is presently manufactured as model 4E-230 by Venables Machine Works Ltd. (502-50th Street East, Saskatoon, Saskatchewan, Canada, S7K 6L9). The grinding wheel was manufactured by Norton Canada Inc. (P.O. Box 3008, Hamilton, Ontario, L8L 7Y5) according to the following specifications: A36L5VBE, 10-in. diameter, 3/8-in. thick, 1 in. arbor, V-sides, 9 ORD, diam. + 0.005, thick.+ 0.005. The machined aluminum disk, to which an abrasive cloth was fixed, was 10 in. in diameter and 9/32 in. thick with a 1-in. arbor. The heavy-duty, adhesive-backed, abrasive cloths (Shur-Stik disks) were purchased from Merit Abrasive Products Inc. (201 W. Manville, P.O. Box 5447, Compton, CA 90224). To provide a close fit between the sample cups and the horizontally mounted abrasive, the cups on each sample-cup plate were ground in situ using an 80-grit resin-bonded Shur-Stik disk fixed to the aluminum disk.

The effect of operating variables—namely, the size of clearance between the bottom edge of the sample cups and the abrasive disk

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and the speed of rotation of the abrasive disk—were investigated using 20 g of grain in each of the cups in the eight-sample plate. An 80-grit, resin-bonded Shur-Stik disk fixed to an aluminum disk was used as the abrasive. After dehulling for a certain time interval, the dehulled seeds were removed from the sample cups using the vacuum aspirating device described by Oomah et al (1981). This device simultaneously collected and cleaned the dehulled grain, removing any residual fine material that had not escaped under the sample cups. The dehulled grain was weighed and the weight loss (%) was designated as the yield of bran. Results for the eight samples were averaged. The effect of the quantity of grain per sample cup was investigated using the same procedure only varying the amount of wheat from 5 to 30 g.

Hardness Determination by Grain Depth Measurement

The change in sample depth, measured with a stainless steel plunger assembly in the sample cup, was converted to yield of bran by a calibration curve prepared in the following manner: 1) Three 20-g samples of each of 25 varieties of sorghum grain were weighed in turn into the sample cups of the 12-sample plate. 2) The initial depth of the grain was measured with the plunger and ruler assembly. The plunger was lowered onto the grain mass and rotated one complete revolution to level the grain. The ruler was inserted into the slot and the plunger pushed to the left side of the sample cup before the measurement was taken. 3) The samples were dehulled (A36L5VBE grinding wheel) for 4 min. 4) The final height of the grain was measured using the procedure in (2), and values for the initial minus the final height (ΔH) were calculated. 5) The dehulled grain was weighed to determine the yield of bran, which was plotted against ΔH.

RESULTS AND DISCUSSION

TADD Components and Operation

The production model of the TADD, complete with a 12-sample plate that allows up to 12 different samples of grain to be dehulled simultaneously, is shown in Figure 1A. Abrasion is provided by a rotating, horizontally mounted grinding wheel (Fig. 1B), but an abrasive cloth bonded to the surface of an aluminum disk can also be used. The sample-cup plate is positioned so that the bottom edges of the stainless-steel sample cups are within 0.25–0.38 mm of the grinding wheel. The bottomless sample cups contain the grain, which rests on the surface of the grinding wheel. Lowering the hinged lid onto the sample cups prevents seeds from escaping during operation. The timer automatically controls the duration of a run, during which the grains roll freely in the sample cups and are dehulled as they come into contact with the grinding wheel. The grinding wheel also produces a uniform mixing action that moves the seeds from the bottom to the top of the sample cup. Hulls and other fine material (the bran) escape beneath the sample cups and are blown into the collecting bag by the fan. An electromagnetic brake instantaneously stops the rotation of the grinding wheel after the run time has elasped, usually 1–5 min depending on the type of grain and the abrasive. Dehulled grains are removed from the sample cups with a vacuum aspirating device as described by Oomah et al (1981). Aspirating 12 dehulled grain samples from the sample cups into individual containers, weighing, and recording requires 2–3 min.

The cross-section of the TADD (Fig. 2) shows how the grinding wheel is sandwiched securely between the fan and the driving disk. This assembly is mounted directly onto the threaded shaft of the electromagnetic brake, itself coupled directly to a 0.37-kW electric motor. During operation, the airstream produced by the rotating fan draws bran material underneath the sample cups and off the surface of the grinding wheel into the base, and ultimately into the bran exhaust port. The clearance between the bottom edge of the sample cups and the grinding wheel is adjusted with shims placed between the driving disk and the brake. The time required to adjust this clearance or to change grinding wheels is about 10 min.

The clearance between the bottom edge of the sample cups and the grinding wheel determines the size of the particles that escape under the cups and thus affects the yield of bran (Fig. 3). The yield of bran after dehulling a high-tannin sorghum variety in the TADD for 2 min was linearly related to the size of the clearance ($Y = 6.07X + 8.88$, $r = 0.98$, $P < 0.01$), whereas the yield of bran after similarly dehulling wheat (3 min) was not affected until the clearance exceeded 1 mm. This difference in response is due to the fragile nature of the sorghum grain, which results in the generation of broken grain and many small particles that escape under the sample cups. Wheat is considerably harder than sorghum and tends to be pearled uniformly with little generation of broken grain. For consistent dehulling results, especially for softer grains, it is

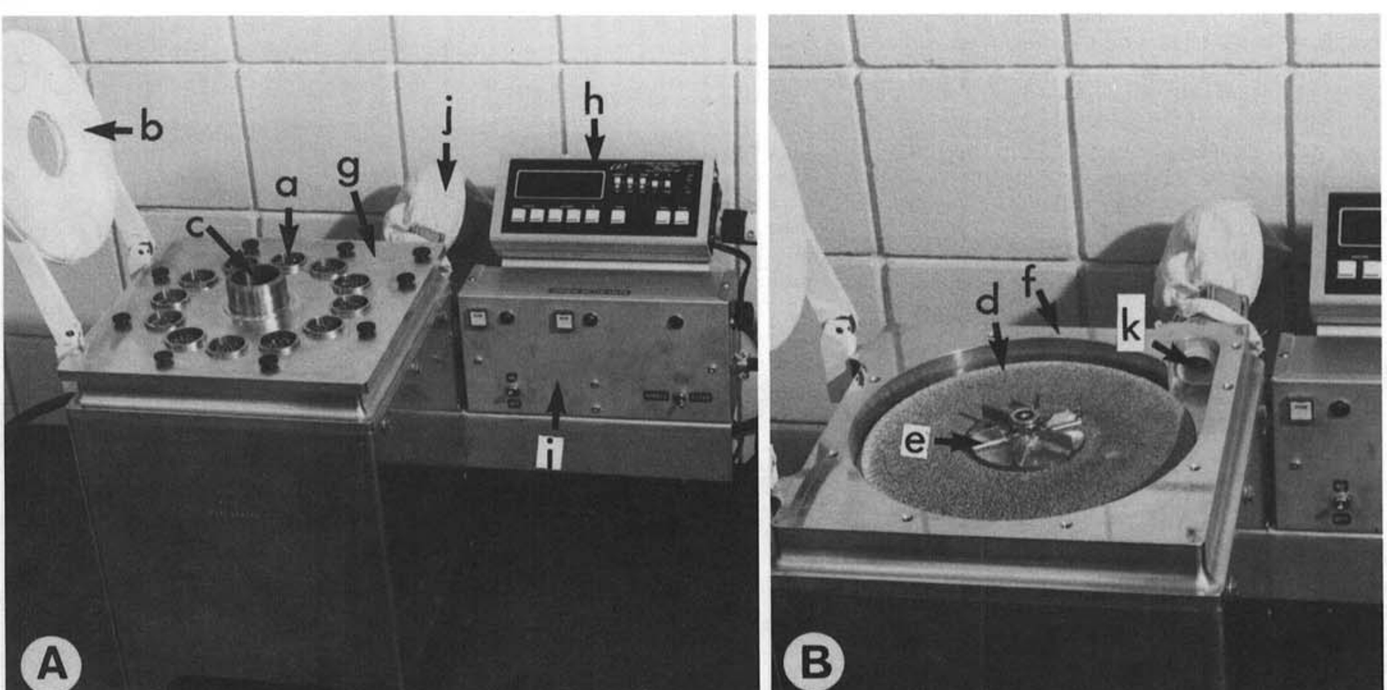

Fig. 1. The Tangential Abrasive Dehulling Device **A,** with and **B,** without the 12-sample plate: **a,** grain in sample cup; **b,** hinged lid; **c,** air inlet port; **d,** grinding wheel; **e,** fan; **f,** base; **g,** 12-sample plate; **h,** timer; **i,** control panel; **j,** bran collection bag; and **k,** bran exhaust port.

important to maintain a constant clearance between the bottom edge of the sample cups and the grinding wheel. In practice, this clearance is easily maintained.

A variety of interchangeable sample-cup plates (5-, 8-, and 12-cup) accommodate variable quantities of grain (Fig. 4). This feature is desirable, because the minimum sample size required to obtain a representative sample of seeds for determination of dehulling quality varies considerably depending on the size of the seed. For example, 10-g of quinoa seeds (*Chenopodium quinoa* Willd.) contains approximately 2,800 seeds, whereas 10 g of a large-seeded variety of broad beans (*Vicia faba major* L.) contains only about seven seeds. The dehulling quality of small, intermediate, and very large seeds can be satisfactorily determined with the 12-, eight-, and five-cup plates, respectively. The dimensions and capacities of the sample cups are given in Table I.

For dehulling a single sample of a large quantity of grain, a single-track plate with a capacity of 1,960 g of sorghum grain was developed (Fig. 5 and Table I). The height of the ring in the cover plate is adjusted with three large screws, which controls the effective space in which the grain is free to move. Decreasing this space increases the dehulling rate.

Generally, the smaller the quantity of grain in the sample cup, the faster the rate of dehulling, because each seed spends more time in

TABLE I
Physical Characteristics of the Sample-Cup Plates and the Single-Track Plate for the Tangential Abrasive Dehulling Device

No. of Cups per Plate	Inside Cup Diameter or Track Width (cm)	Height (cm)	Abrasive Area (cm^2)	Volume (cm^3)	Maximum[a] Cup Capacity (g)	Maximum[a] Capacity (g)
5	6.83	3.49	36.6	127.7	97	485
8	5.56	3.49	24.3	84.8	64	512
12	3.65	3.49	10.5	36.6	28	336
Single-track plate	15.2	6.5	396	2,574	···	1,960

[a]Determined using sorghum grain.

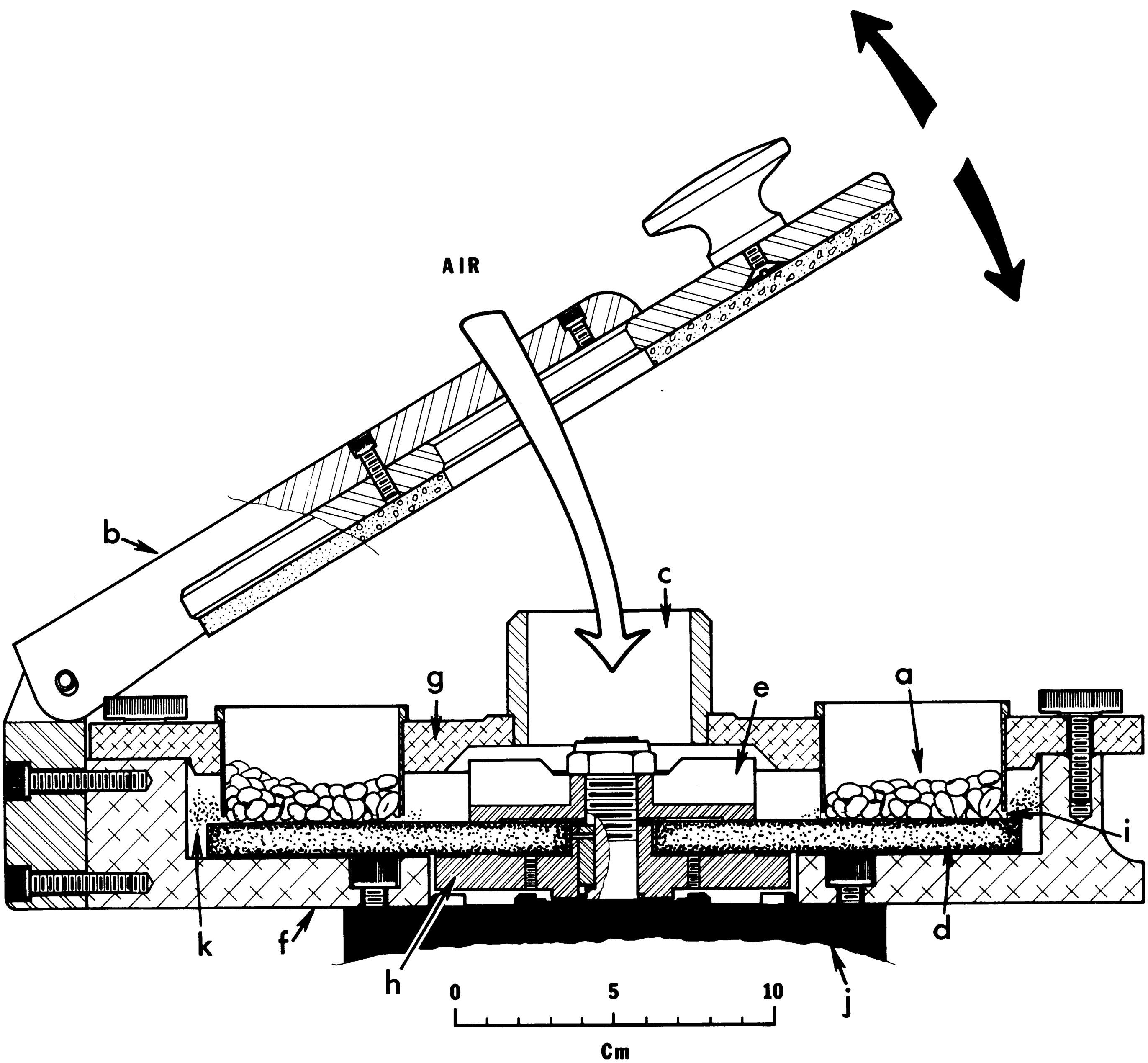

Fig. 2. Cross-section of the tangential abrasive dehulling device illustrating air movement and **a,** grain in sample cup; **b,** hinged lid; **c,** air inlet port; **d,** grinding wheel; **e,** fan; **f,** base; **g,** eight-sample plate; **h,** driving disk; **i,** gap between bottom of sample cup and grinding wheel (exaggerated for clarity); **j,** brake; and **k,** bran.

contact with the grinding wheel (Fig. 6). This effect was more pronounced when less than 10 g of wheat was used in the cups of the eight-sample plate. To ensure thorough mixing and uniform dehulling of grain, the quantity in each sample cup should not exceed approximately three-quarters of its maximum capacity. As little as a single seed can be effectively dehulled.

The grinding wheel and the aluminum disk/abrasive combination were manufactured according to strict specifications to ensure a flat and uniform surface. This makes it possible to maintain a small, constant clearance between the abrasive surface and the bottom edge of the sample cups, thus ensuring reproducibility both within and among sample cups (coefficient of variation = 0.58 and 0.65%, respectively; yield of wheat bran = 29.2 and 29.1%, respectively). Abrasive surfaces suitable for the TADD vary considerably in their effectiveness and longevity (*unpublished data*).

Although the TADD is normally equipped with a standard, single-speed motor (1,750 rpm at 60 Hz, 1,450 rpm at 50 Hz), a variable speed option is possible. In the range of 1,000–3,000 rpm, the yield of bran after dehulling sorghum and wheat was linearly related ($Y = 0.00940X - 3.82$, $r = 0.999$, $P < 0.01$ and $Y = 0.0178X - 10.1$, $r = 0.997$, $P < 0.01$, respectively) to the speed of the disk (Fig. 7). For speeds greater than 2,485 rpm, the aluminum disk/abrasive combination must be used because the grinding wheel is considered unsafe above this speed.

Applications of the TADD

The TADD is useful for rapidly preparing dehulled grain samples. It can also be used qualitatively or quantitatively to determine grain hardness and dehulling quality. The latter can be subjectively evaluated on only a few seeds. To accurately assess grain hardness or dehulling quality, all samples should be equilibrated to a similar moisture content before analysis in the TADD. After dehulling 12 seed samples for a suitable period of time, the dehulled seeds can be visually scored for dehulling quality by comparing them directly in the sample cups. By weighing the dehulled grain to determine the yield of bran, a quantitative measure of grain hardness is obtained. This measure of grain hardness is commonly referred to as a pearling index, which Kirleis and Crosby (1982) found correlated well with percent vitreousness and kernel density of sorghum seeds, as well as particle size index, another measure of kernel hardness. The pearling index (measured as the percent kernel removed) has also been used by Shepherd (1982) and others.

To eliminate the weight measurements in the determination of bran yield, a system measuring depth of grain samples in the sample cups of the TADD was developed. The system was based on the observation that the height of the grain sample remaining in the cups after dehulling a particular sorghum variety was dependent upon the hardness of that variety. A stainless steel plunger (70 mm in length, 36.3 mm in diameter) was fabricated to fit snugly, but without binding, into the cups of the 12-sample plate (Fig. 8). The reduction of sample height after dehulling is measured with a ruler (± 0.1 mm) inserted into a slot in the plunger. The measurement is taken at the top edge of the plunger with the ruler resting on the top lip of the sample cup. The yield of bran obtained by dehulling 25 different sorghum varieties was found to be directly correlated ($r = 0.997$, $P < 0.01$) to the change in depth of the grain (Fig. 9). The necessity of measuring the initial depth of each grain sample is eliminated by introducing the same volume of grain into each sample cup. A constant volume measuring container consisting of a shortened centrifuge tube (inside diameter = 2.55 cm) was employed, that when filled to the top with sorghum grain and leveled with a ruler contained 19.95 g ($n = 40$ different sorghum varieties, SD = 0.14) of grain. Using this container, the initial sample depth measurement of 120 different sorghum varieties was found to be 62.3 mm (SD = 0.53).

By employing the concept of changes in sample depth, the yield of bran can be determined without the use of a weighing scale in four steps: 1) Grain is scooped into the constant volume measuring container and the top leveled with a ruler. 2) The grain is poured into a cup of the 12-sample plate and dehulled (4 min). 3) The grain depth is measured using the stainless steel plunger and ruler and is subtracted from the standard initial depth measurement (62.3 mm). 4) The change in depth is used to obtain the yield of bran from the calibration curve. This method was successfully used to rapidly screen (in duplicate) 1,768 high-tannin sorghum grain varieties (Mwasaru 1985). The difference between the value for the yield of grain obtained by weight measurements and that from depth measurements using a calibration curve averaged 2.3% for 25 sorghum samples.

The TADD is also useful for scarification of seed to increase the rate of water absorption, and for rapid degluming of seed. Scarification can be accomplished by using a fine grit abrasive surface which slowly and uniformly perforates the hull layers. Degluming of sorghum seed was accomplished by using the single-track plate. The grinding wheel was replaced by the aluminum disk,

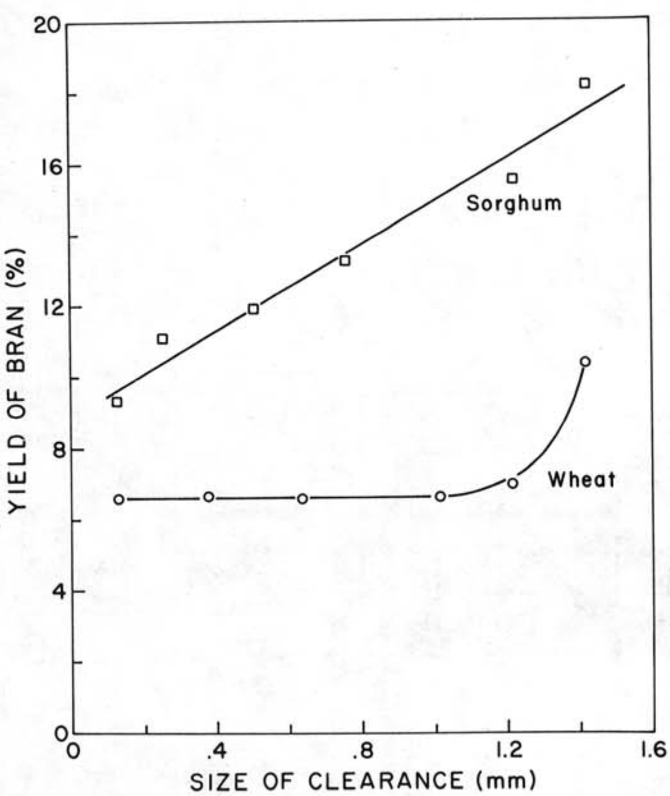

Fig. 3. Effect of the size of clearance (mm) between the bottom edge of the sample cups and the abrasive disk on the yield of bran (%) generated by dehulling (1,750 rpm) sorghum (2 min) and wheat (3 min).

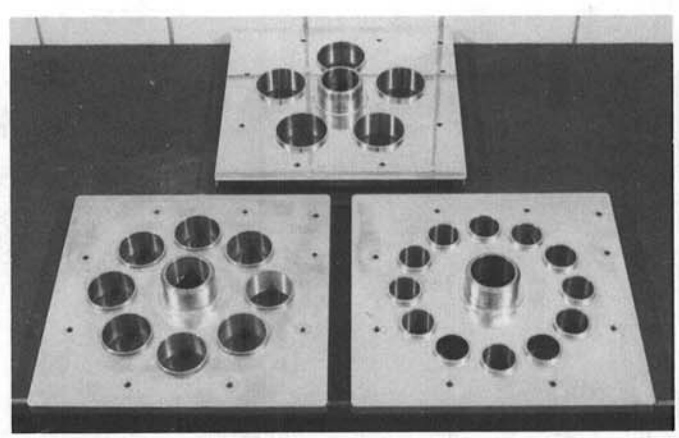

Fig. 4. The five-, eight-, and 12-cup sample plates available for the Tangential Abrasive Dehulling Device.

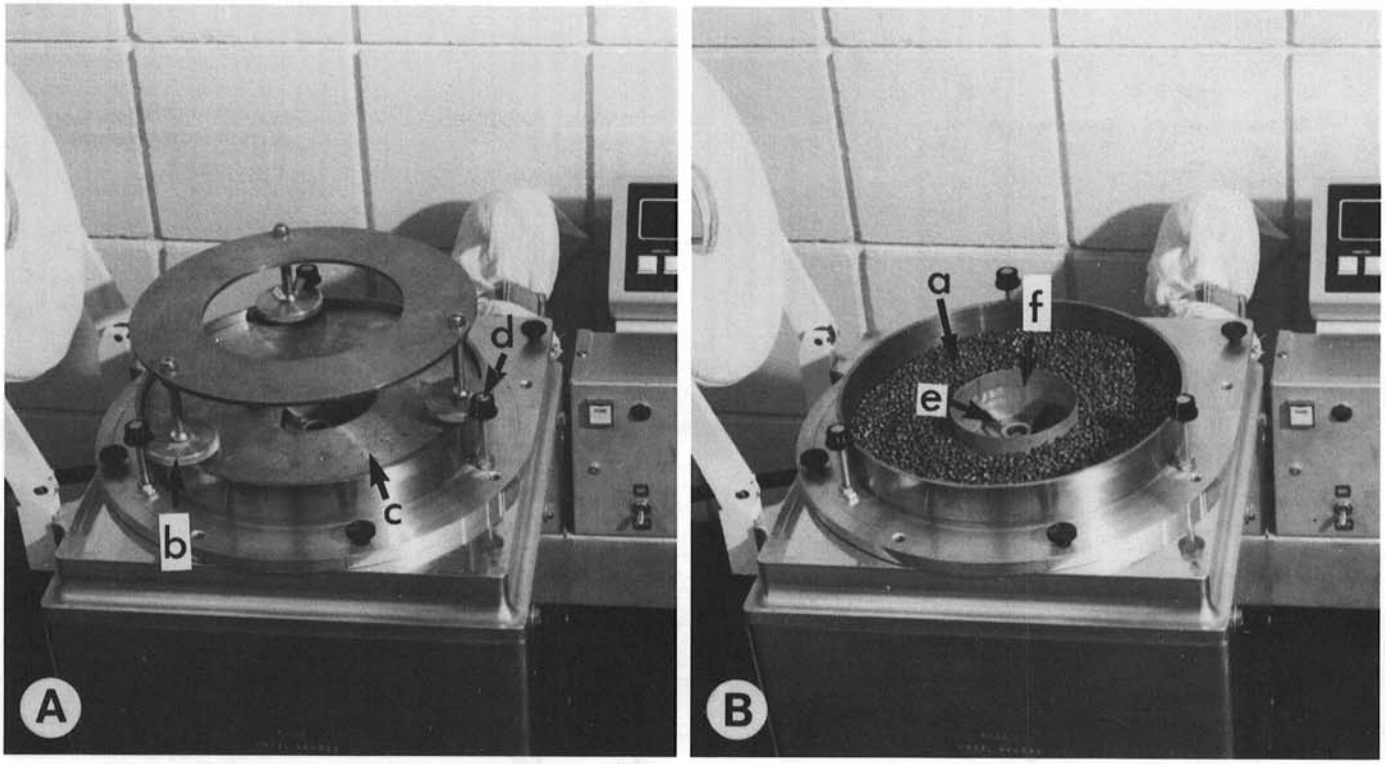

Fig. 5. Photograph illustrating the single-track plate mounted on the Tangential Abrasive Dehulling Device **A,** with and **B,** without the cover plate; **a,** grain in track; **b,** adjustable nut used for regulating the height of the ring, **c,** above the grain; **d,** retaining knob used to secure the adjustable nut; **e,** fan; and **f,** fan well.

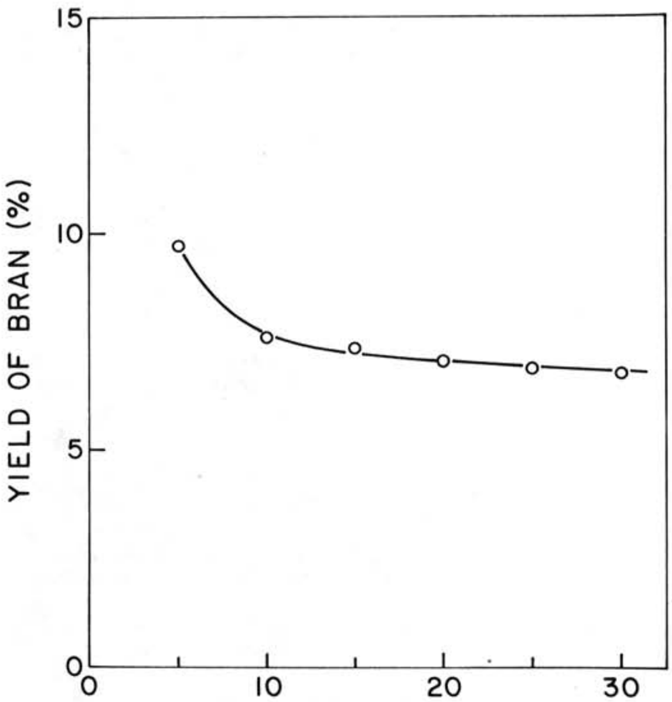

Fig. 6. Effect of the quantity of wheat per sample cup on the yield of bran (%) generated by dehulling (1,750 rpm) for 3 min. Clearance between bottom of sample cup and abrasive disk was 0.25 mm.

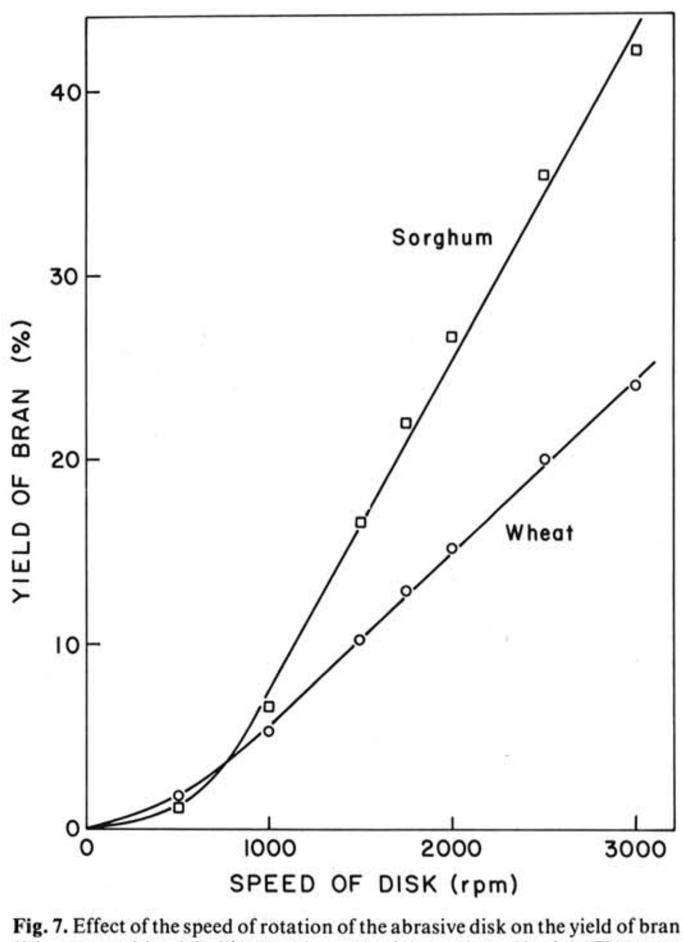

Fig. 7. Effect of the speed of rotation of the abrasive disk on the yield of bran (%) generated by dehulling sorghum (4 min) or wheat (6 min). Clearance between bottom of sample cup and abrasive disk was 0.25 mm.

Fig. 8. Relative grain height measurement (50.8 mm) taken in a sample cup with the stainless steel plunger and ruler.

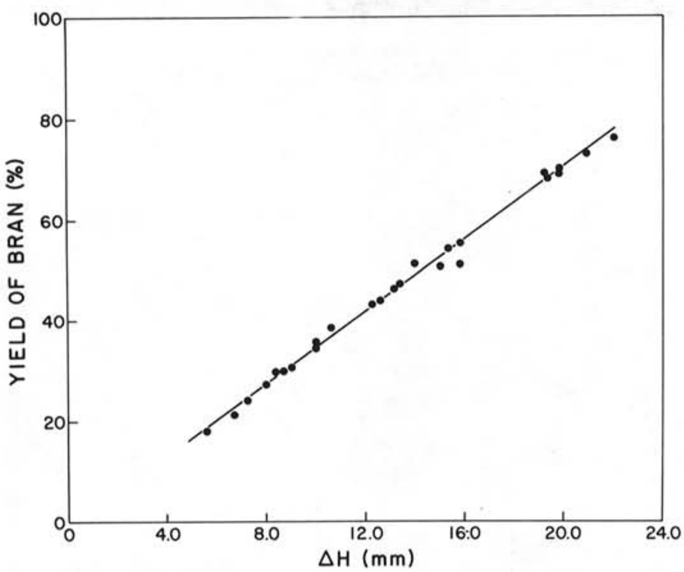

Fig. 9. Calibration curve relating the change in sorghum grain depth (Δ H) to the bran yield (%). Yield of bran (%) = 3.55 ΔH − 0.88, $r = 0.997$, $P < 0.01$, $n = 25$ sorghum varieties.

to which was bonded a rubber pad (1/8 in. thick). The space between the rubber surface and the ring (also fitted with a rubber pad) of the cover plate was maintained at 1.2 cm for degluming 70 g samples of sorghum in 10 sec. Glumes and seed were subsequently separated with an air separation device. Fitted with the rubberized aluminum disk and 8-sample plate (instead of the single-track plate), the TADD was also used to assess the seed coat durability (resistance to cracking) of field peas (Ehiwe 1985). A vertical force (68 g) was applied to peas (25 seeds) in the cups to accelerate the rate of seed coat breakage. After operating the TADD for a suitable period of time, seed damage was evaluated. Pea varieties which exhibited less damage were considered more durable. Seed coat durability is also an important quality factor in other legumes such as soybeans and navy beans, and this method may be applicable.

The TADD has been extensively tested in our laboratory and three international institutions to ensure that the equipment is reliable and durable. It has found applications in the dehulling, scarification, and deawning of grain, and in assessing dehulling quality, seed coat durability, and grain hardness for a wide range of cereals, legumes, and oilseeds. These include sorghum, wheat, barley, lentil, field pea, rice, quinoa, millet, mung bean, cowpea, sunflower, pigeon pea, faba bean, canola, navy bean, soybean, velvet bean, and tamarind bean. Some of these seeds could not be effectively tested with any other type of equipment.

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