

Development of a Low Cost Machine for Improved Sorghum Dehulling Efficiency

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Abstract

A Pedal operated sorghum dehuller for dehulling tempered grain was developed and tested for its performance using two sorghum varieties (Dionje and Jumbo). The use of short tempering duration (10 – 15 minutes) followed by a short resting period (5 – 10 Minutes) to ensured that all the tempering moisture was absorbed into the grain before the grain was introduced into the dehuller thus eliminating the clogging problem usually associated with conventional abrasive dehullers. This facilitated the removal of the seed coat from the endosperm. The obtained results showed that the developed dehuller was able to achieve high dehulling efficiency (90.1% for Jumbo and 83.4 for Dionje) and high recovery levels compared to conventional abrasive dehullers (45.6 for Jumbo and 40.3% for Dionje). The quality of the dehulled grain was also much higher as indicated by the low ash content, low crude fibre content and superior colour of the flour obtained from the grain dehulled in the developed dehuller compared to flour from grain dehulled using conventional abrasive dehullers. These results demonstrate that it is possible to achieve high quality dehulled sorghum product and high dehulling efficiency by incorporating simple and cheap traditional pre-treatments in the mechanical dehulling process. Accordingly, the developed pedal operated dehuller could be very appropriate for small scale sorghum farmers and consumers in the rural areas where spare parts, electrical power and competent technicians to run and maintain the conventional abrasive dehullers are limited.

Key Words: Sorghum, grain tempering, dehuller, dehulling efficiency

Introduction

Sorghum (*Sorghum bicolor*) is a major cereal crop for food security in semi-arid Tropical and sub-Tropical regions where the annual rainfall is on average 400–800 mm (Makindara *et al.*, 2013). In Tanzania, it is grown by small scale farmers mostly in Dodoma, Singida, Manyara, Mwanza, Shinyanga, Tabora, Ruvuma, Mtwara, and Lindi regions (Rohrbach and Kiriwaggulu, 2001). Due to its economic importance, significant efforts have been taken to improve the production of sorghum. As such, sorghum production has increased from 38,000 ha in 1986 to 890,000 ha in 2005 with productivity ranging from 0.9 to 1.1 tons per ha and annual production of 0.61 million tons (Monyo *et al.*, 2002). Likewise, sorghum varieties have also been improved to increase productivity and also their resistance toward diseases as well as drought (Monyo *et al.*, 2002). Despite the increase in

production, limited effort has been taken to improve sorghum processing technologies, particularly, for small scale rural farmers.

Sorghum intended for human consumption needs to be dehulled. The dehulling process is a crucial step as it removes the seed coat, which has high crude fibre and often contains pigments as well as anti-nutritional factors such as tannins and phytic acid (Awika *et al.*, 2003; Chibber *et al.*, 1978). In Tanzania, sorghum dehulling process is commonly accomplished either by hand pounding of tempered grain using pestle and mortar or mechanically using abrasive type dehullers. The traditional hand pounding method is slow and laborious process. Abrasive dehullers are much faster and less tedious compared to traditional hand pounding method. However, its main problem is that, it causes excessive loss of endosperm in the bran fraction through kernels breakage (Mwasaru *et al.*, 1988). Because the seed coat is tightly attached to the endosperm, its removal by abrasion requires

high compressive force. This can result in breakage of the grain kernels even before the seed coat is removed. The nature of abrasive dehulling is such that materials are removed from all over the outer layers of broken particles as fines which get mixed with the bran making it difficult to separate thus leading to high loss of endosperm, poor dehulling efficiency and hence low quality end product. This problem is more serious in the case of soft sorghum varieties (Mwasaru *et al.*, 1988).

Sorghum can be dehulled with less loss and at higher dehulling efficiency than is possible with the current mechanical abrasive dehullers if proper pre-treatment procedures and appropriate dehulling equipment could be developed. Simple pre-treatments such as tempering have been used for centuries and with a great success in traditional dehulling system to facilitate the removal of the seed coat from endosperm (Egounlety and Aworh, 2003). Incorporation of the pre-treatments commonly used in the traditional dehulling system in mechanical dehulling systems could make it possible to use only a fraction of the force required during the removal of the seed coat from the endosperm (Lazaro and Favier, 2005). This will result in faster and complete seed coat removal from the endosperm and reduce the breakage of grain during the dehulling process thus leading to high recovery rate, improved dehulling efficiency, flour quality and saving on the energy cost.

To date, however, it has not been possible to successfully incorporate these simple pre-treatment principles in the mechanical dehulling systems mainly due to the fact that the combination of moisture and fine bran produced during the abrasive dehulling process, tend to clog the sieving systems used in the mechanical dehullers hence depressing both throughput capacity and efficiency. Also, the abrasive effect of the dehulling disks or stones used in these machines tends to diminish with addition of water, which causes deposition of a layer of fine wet bran on the surface of the disks as dehulling progresses, leading to low dehulling capacity and efficiency. Furthermore, many of the grinding stones and disks used in these dehullers are made by pressing stone materials together using adhesive materials which are dissolved by water. Hence presence of moisture damages the disks.

Successful development of an efficient small-scale dehuller for tempered grain which can overcome the problems associated with current abrasive dehullers will eliminate much of the daily drudgery that is currently associated with the traditional processing of sorghum in rural areas and hence increase the acceptability of sorghum products. Tempering technology is well established throughout the sorghum producing area. Therefore, the introduction of such dehullers will be complimenting the indigenous technology and hence will have a higher chance of being adopted compared to other types of dehullers. Similarly, the fact that most of the current dehullers use electric motors or diesel engines, both of which are very costly in terms of running and maintenance cost, is another good reason for introducing a dehuller which is manually operated. Therefore, in this study, a low cost pedal operated machine for dehulling tempered sorghum was designed, constructed and tested for its efficiency.

Materials and methods

Grain samples, tempering and conditioning

Two sorghum varieties, Jumbo (soft, red grain variety) and Dionje (hard, white grain variety) obtained from the local market in Morogoro municipal were used to test the dehulling efficiency of the fabricated dehuller. The samples were sorted, cleaned to remove the damaged grains and foreign matter. The samples were analysed for moisture content using the oven dry method. The initial moisture content of the grain was found to be 13% dry basis (db). Testing of the fabricated machine was conducted at the Department of Agricultural Engineering and Land Planning of Sokoine University of Agriculture.

The grain was tempered by soaking (1000g of grain) in 2 litres of tap water for 15 minutes (Lazaro and Favier, 2005). After soaking, water was decanted out and a small portion of sample was taken for moisture content measurement while the remainder was placed in a closed container to allow the surface moisture to be absorbed into the grain. During this period the grain were mixed by shaking the container after every 2 minutes until all the surface moisture was absorbed into the grain (visual observation). The final moisture content of the grain was then determined. The tempered grain was used for evaluation of the performance of the developed

pedal operated sorghum dehuller.

Design consideration of the sorghum dehuller

To be able to design an efficient manually operated sorghum dehuller for tempered grain, the following factors were taken into consideration: (1) the machine should be able to dehull tempered grain effectively without clogging, (2) the dehulling surfaces should not be affected by water or moisture, (3) the dehuller should be simple, easy to operate and maintain without necessarily requiring highly trained personnel (4) the dehuller should be reasonably cheap but durable and spare parts should be locally available and at affordable cost.

Figures 1 and 2 depict the schematic drawings and sectional views of the pedal operated dehuller. The main parts of the dehuller consist of; drum, concave plate, hopper, dehulled grain exit chute, supporting frame, bicycle drive system, and hand support. The dehuller drum was made of mild steel cylinder (360 mm long and 136 mm inside diameter) (Figure 3). These dimensions allowed optimum balance between machine throughput capacity and average human capabilities in terms of energy used in operating the machine. The drum was welded with still bars to form a new type of dehulling surface not affected by moisture (Figure 4). The bars were arranged in such a way that as the drum rotates they help to push the grains forward towards the dehulled grain outlet (Figure 1). In addition, the bars acted as a rough abrasive surface to the grain kernels in contact with the drum surface when the dehuller was in operation. This helped to increase the inter-locking within the grain mass between the drum surface and the concave, thus increasing the dehulling efficiency. The concave consisted of two stainless steel plates 3 mm thick, one at the top and another at the bottom. The bottom plate was perforated to form a screen with rectangular holes (2 mm long and 1 mm width) in order to allow the dehulled seed coats and fines to pass out of the dehuller. The drum was fixed to the supporting frame using a mild steel drive shaft (20 mm diameter) running through the axis of the drum. The drive shaft was then mounted on two horizontal bearings and fixed to a pulley (3) driven through a crossed v-belt (6) connected to a bicycle wheel ring (7) mounted on the dehuller frame between the dehuller drum and the driver. A drive sprocket (9) mounted on the bicycle wheel

ring was then connected to the sprocket (11) on bicycle pedal ring using a bicycle chain (Figure 1). The sprocket and bicycle wheel system were included in the design to increase the speed of the pulley (3) and also to reduce the energy required by the operator for optimal operation of the dehuller. The bicycle pedal wheel, the drive sprocket, and the bicycle wheel ring were all connected in such a way that they were on the same axis. A bicycle seat (13) fixed on adjustable stand allow the operator to seat comfortably and pedal efficiently. A feed hopper (1) with 250×250 mm top dimensions and 50×50 mm bottom dimensions was fabricated from aluminium sheet 1 mm thick and was bolted on top of the dehuller drum.

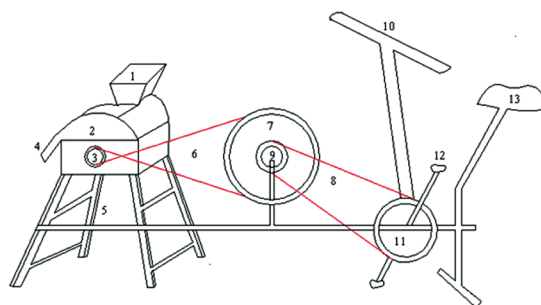


Figure 1: General overview of the pedal operated sorghum dehuller.

Legend: 1-hopper; 2- drum plate cover; 3-pulley; 4-dehulled sorghum exit chute; 5-supporting frame; 6-crossing V-belt; 7-bicycle ring; 8-bicycle chain; 9-drive sprocket; 10-hand supporting; 11-bicycle pedal ring; 12-bicycle pedal; 13-bicycle seat.

Dehulling mechanisms

The dehulling process was accomplished through abrasion between grain and grain, grain and dehuller drum surface and the concave. The jostling and rubbing of individual grain particles against each other and against the dehuller drum and concave surface as the drum rotates help to create the friction necessary to remove the already loosen seed coat from the grain. As the bicycle pedal rotate, it transmits the motion to freewheel. The freewheel rotates together with the bicycle ring. The increased diameter of bicycle ring (30 mm diameter) assisted in increasing the number of revolutions per minute (rpm) of the drum, but at the same time decreasing the torque. Hence, less human power was required to operate the machine. The increased revolution was transferred to the drum shaft by means of a V-belt

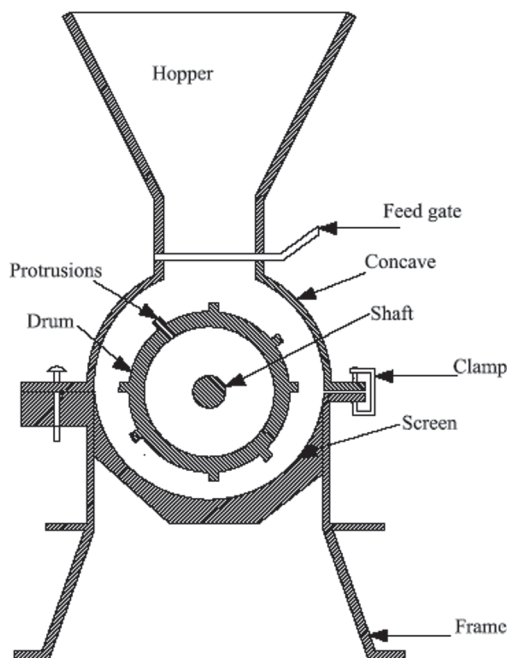


Figure 2: Pedal operated sorghum dehuller showing sectional view

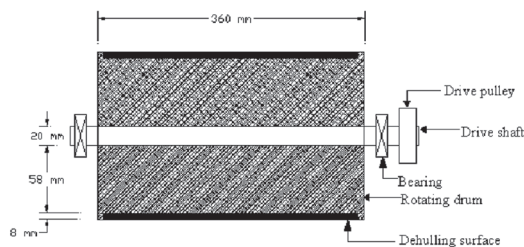


Figure 3: The drum assembly

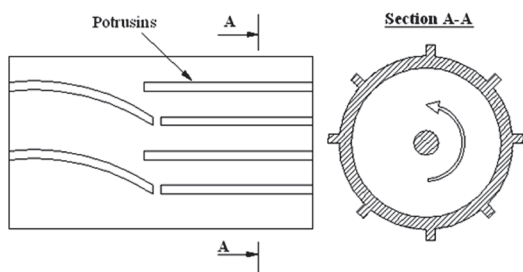


Figure 4: Dehulling surface of the pedal operated sorghum dehuller.

(Figure 1). The V-belt was crossed for the purpose of changing the rotation direction of the drum shaft from anticlockwise to clockwise direction.

Preliminary experiments showed that drum speed ranging between 300 and 350 rpm was attained by all operators without difficulties (data not shown). This range was sufficient to achieve high dehulling efficiency. An adjustment blade located at the bottom of the drum was used to adjust the gap between the drum and the concave so as to affect the required dehulling efficiency. Moving the blade in or out changes the drum - concave clearance hence enable to control the extent of dehulling. The blade was adjusted at optimal position which gave the best dehulling with maximum removal of the seed coat and minimal kernel breakage. The residence time for the grain in the dehuller (movement from the inlet to the exit chute) was approximately 30 seconds.

Testing of dehulling efficiency

After all the surface moisture had been absorbed, the tempered grain was fed into the dehuller and dehulled. The time for dehulling was recorded using a stopwatch. A tangential Abrasive Dehulling Device (TADD) which is a laboratory mechanical dehulling device simulating the working principle for the current mechanical dehullers was also included for comparison between the current mechanical dehullers and the developed dehuller. The dehulling efficiency and percent breakage were calculated using Equations 1 and 2, respectively.

$$DE = \frac{N_{GD}}{N_{GF}} \times 100\% \quad (1)$$

$$BE = \frac{N_{GB}}{N_{GF}} \times 100\% \quad (2)$$

Where: DE is the Dehulling efficiency (%)

N_{GD} is weight of dehulled grain (kg)

N_{GF} is the weight of grain fed into the machine (kg)

BE is percentage of breakage (%)

N_{GB} is the weight of broken grain (kg).

Proximate analysis and flour colour determination

The dehulled samples from the developed pedal operated dehuller, the TADD and a hand dehulled sample from each sorghum variety were taken and ground into flour using a hummer mill (series 22,

Schutte Buffalo, New York) for proximate analysis and colour evaluation. Proximate composition (protein, fat, ash and crude fibre) of the samples was determined according to AACC standards (American Association of Cereal Chemists, 1995). Flour colour measurements were carried out using Lovibond Flour Colour Grader developed by Kent-Jones and Martin, (The Tintometer Ltd, Salisbury). This colour grader determines the whiteness and brightness of the milled flour sample by measuring the reflectance of flour-water slurry. The flour colour depends on the inherent whiteness of the grain endosperm, and the amount of the bran contamination present in the sample. The aim of the colour test was to determine which dehulling system was able to remove most of the bran and hence the colour from the flour samples, especially from the coloured sorghum variety. The tempered grain from each variety was also hand peeled to achieve 100% removal of the seed coat from the grain. The hand peeled sample was used as control during colour comparison of different samples processed by dehullers. The results of the colour test are usually given as flour colour grade units. The lower the value of the colour grade the whiter the flour.

Data and statistical analysis

The dehulling experiments were performed in three replicates. The average values and standard deviation (average \pm standard deviation) was used to present the results. One-way-analysis of variance (ANOVA) was employed to evaluate the statistical significance of dehulling efficiency, proximate, and colour differences between the two sorghum varieties and between the two dehulling systems. The hypothesis was accepted or rejected at 95% confidence level.

Results and discussions

Moisture content of tempered grains

The time taken by Dionje and Jumbo sorghum varieties to absorb the tempering water and the amount of moisture adsorbed during the tempering period is shown in Table 1. After 15 minutes of soaking, the hard variety (Dionje) showed significantly lower moisture adsorption (8.1% db at 30°C and 70% RH) compared to the soft variety Jumbo (12.2%db). It was also observed that Dionje took more time (52 min) to completely adsorb surface moisture compared to Jumbo (35 minutes). Despite

the longer time taken by Dionje, the final moisture content for Dionje variety was significantly lower (23.3%) compared to Jumbo variety (27.7%). No attempt was made to hold a constant time for surface moisture absorption between the two sorghum varieties. Rather an effort was made to ensure that all surface moisture was absorbed through constant mixing before the grain was introduced into the dehuller. It was very important to make sure all surface moisture is absorbed before the grain is fed into the dehuller so as to avoid introducing excessive moisture into the dehuller, as this might have led to clogging problem

Table 1: Moisture content absorbed in two varieties of sorghum during tempering

	Dionje	Jumbo
Soaking time (min)	15	15
Absorption time (min)	52	35
(%) Moisture absorbed after soaking	8.1 \pm 0.8b	12.2 \pm 0.4a
Final grain moisture content after tempering (% d.b)	23.2 \pm 1.1b	27.9 \pm 0.5a

a, b Means values in the same row differed significantly at $p < 0.05$

Effect of tempering on dehulling efficiency

The dehulling efficiency of the developed pedal operated sorghum dehuller and TADD for the two varieties (Dionje and Jumbo) is depicted in Figure 5. The dehulling system of TADD works better for un-tempered grains (Mwasaru et al., 1988). Since tempering can result into clogging (Chen et al., 2013), un-tempered samples were used for the evaluation of its performance. For the developed dehuller, the dehulling efficiency for Dionje was significantly lower (83.4%) compared to Jumbo (90.1%). This indicates that the seed coat in the Jumbo variety (thick seed coat) was easier to remove than that of Dionje variety (thin seed coat). These results are in agreement with the traditional dehulling method and those reported by Mwasaru et al., (1988). In the case of TADD, The dehulling efficiency of Jumbo variety was also superior to that of Dionje variety as shown in Figure 5. These data were comparable to those reported in the literature (Lawton and Faubion, 1989).

Interestingly, the dehulling efficiency was

considerably higher for the developed dehuller compared to conventional dehulling method represented by TADD for all sorghum varieties tested in this research (Figure 5). Furthermore, grain breakage was lower for the developed dehuller (1.1–2.1%) compared to TADD (2.7–4.1%). Also it was observed that it was possible to recover most of the broken particles during the aspirating stage thus reducing the actual loss of endosperm. These results demonstrate that the dehulling efficiency could be improved by 45.6% just by incorporating simple pre-treatments such as tempering.

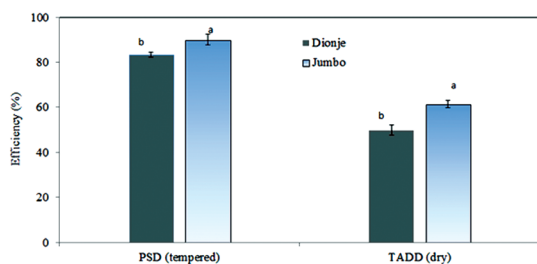


Figure 5: Dehulling efficiency of sorghum in pedal operated sorghum dehuller and tangential dehulling device (TADD) for Dionje and Jumbo varieties of sorghum. Pedal operated sorghum dehuller used tempered grains while TADD used dry grain. Inserted letters (a, b) shows values with different alphabet differed significantly at $p < 0.05$.

Comparisons of proximate analysis and flour colour grade of dehulled grains

Figure 6 shows the proximate composition of the dehulled grain using the developed pedal operated sorghum dehuller, TADD and undeulled grain, which was used as a control. The results show that the grain dehulled by the developed pedal operated sorghum dehuller had significantly lower ash, crude fibre and fat content compared to grain dehulled by the TADD and undeulled grain for both varieties. The low ash, crude fibre and fat content for grains dehulled by the pedal operated sorghum dehuller were attributed to the significant removal of the seed coat or hull from the endosperm. The sorghum hulls are characterised by high content crude fibre, ash and crude protein (Burns, 1971). The higher removal of the seed coat by the developed dehuller could be explained by the fact that adding water to the grain usually causes the germ to swell and pull

away from the cementing layer thus making it easy to remove during dehulling (Egounlety and Aworh, 2003). It can also be observed that the crude fibre for the pedal operated sorghum dehuller was lower compared to the TADD system in both varieties indicating that the fabricated sorghum dehuller was more efficient than TADD in removing the seed coat (which has high fibre content) from the grain kernel.

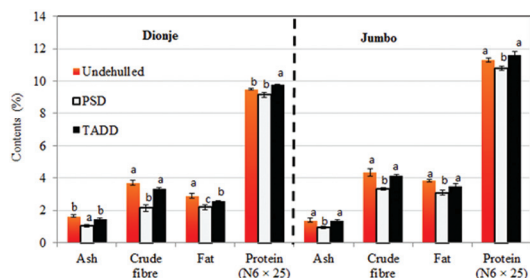


Figure 6: Proximate composition of sorghum grains from two varieties (Dionje and Jumbo) after dehulling. Letters (a, b, c) means values with different alphabet differed significantly at $p < 0.05$.

The flour colour grade was used to quantitatively compare the efficiency of the two dehulling systems in reducing colour in the dehulled grain. Colour reduction is an important factor in consumer acceptability of products produced from sorghum, especially from coloured sorghum varieties. The colour of sorghum flour from grains dehulled by the developed pedal operated sorghum dehuller and the TADD for both varieties differed significantly. The pedal operated sorghum dehuller performs better in colour removal (23.3–23.9% less) compared to the TADD for both varieties. This indicates that the fabricated sorghum dehuller was more efficient in removing of colour from the dehulled grain compared to the TADD.

Economic feasibility

The cost of fabrication for the pedal operated sorghum dehuller was 150,000/= Tanzania shillings which is within economic range of most small scale farmers and medium scale entrepreneurs in rural areas. Another important factor is that the developed machine does not need electricity or fuel to be operated. This makes it cheaper in operating cost than electrical or diesel operated sorghum dehuller. Furthermore, the maintenance costs are

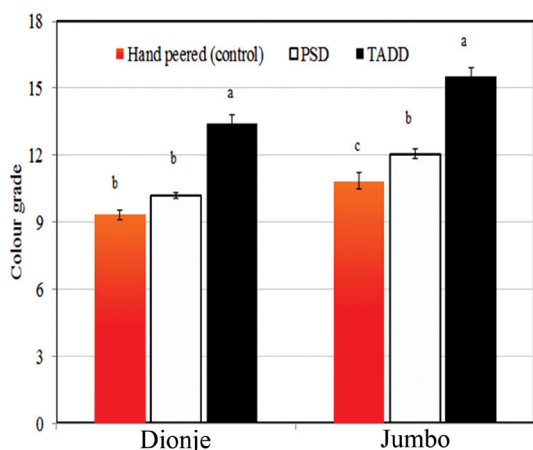


Figure 7: Colour grade of sorghum flour of the two varieties (Dionje and Jumbo) after being dehulled by pedal operated sorghum dehuller, TADD and hand peeled sample. Inserted letters (a, b, c) means values with different alphabet differed significantly at $p < 0.05$.

also expected to be low since spare parts can be fabricated locally and it does not require highly trained technicians for its maintenance.

Conclusions

A pedal operated sorghum dehuller combining basic principles from traditional and mechanical dehulling systems was developed. A dehulling surface not affected by moisture was incorporated into the dehuller making the dehulling of moist grain without clogging or damage associated with the conventional abrasive dehullers. The dehuller was tested for its performance using two sorghum varieties. The results obtained indicated that it was possible to obtain high recovery levels and high dehulling efficiency using this dehuller than conventional abrasive dehullers. Dehulling efficiency up to 90.1% was observed on the soft sorghum variety. This represents a 45.6% improvement in dehulling efficiency compared to the conventional method of dehulling of untreated sorghum. Significant improvement in terms of reduced ash content, crude fibre content, fat, and kernel breakage reduction as well as colour removal were also achieved by the developed pedal operated sorghum dehuller compared with the conventional abrasive dehulling methods. Other considerations such as, maintenance requirement and simplicity also favours the developed dehuller over the

conventional abrasive dehullers for village scale sorghum dehullers

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