Design, Development and Performance Evaluation of CIAE-Millet Mill

by
S. Balasubramanian*
Principal Scientist
ICAR-Central Institute of Agricultural Engineering
Regional Centre,
Coimbatore-641 003, Tamilnadu, INDIA
*Corresponding author: balaciphet@gmail.com

S. D. Deshpande
Ex-Principal Scientist
ICAR-Central Institute of Agricultural Engineering,
Bhopal–462 038, Madhya Pradesh, INDIA

I. R. Bothe
Assistant Professor
SP College of Food Technology,
Kharawate-Dahiwal-Chiplun-415 606,
Maharashtra, INDIA

Abstract
An eco-friendly CIAE-Millet Mill integrated with pneumatic suction arrangement was designed and developed. It simultaneously dehulls minor millets and separates the husk from the dehulled mass. It is a power operated (1 HP, single phase motor) with a main shaft speed of 960 rpm (for dehulling) and blower shaft speed of 1920 rpm (for pneumatic suction). Its capacity is 100 kg/h for all minor millets at 10-12% mc (wb). The overall dimensions of the machine are 860 mm × 842 mm × 1460 mm. The performance of CIAE-Millet mill was evaluated by using various types of minor millets. The result showed that the co efficient of dehulling is in the range of 70-85 %.

Keywords: CIAE-Millet Mill, minor millet, dehulling, pneumatic suction arrangement, dehulling efficiency.

Introduction
Millets are small-seeded spices crops; grow around the world for food and fodder. The term millet includes a number of small grained cereal grasses. Its agricultural importance arises from their hardiness, tolerance to extreme weather and could be grown with low inputs in low rainfall areas. Finger millet/ Ragi (Eleusine coracana), Foxtail millet/ Navane (Setaria italica), Little millet/ Saamai (Panicum miliare), Kodo millet/ Haraka (Paspalum scrobiculatum), Proso millet/ Panivaragu (Panicum miliaceum), Barnyard millet/ Banti (Echinochloa frumentacea) are the important millets cultivated largely in the Asian and African countries. Fonio (Digitaria exilis) and Tef (Eragrostic tef) are specific to Nigeria and Ethiopia, respectively (Jaybhaye et al., 2014).

Millets are nutritious food and they are rich in phytochemicals, fibre and minerals. There is an immense potential to process millet grains into value-added foods and beverages (Devi et al., 2011). Dehulling or decortication is the process of removing outer pericarp and hull (testa, seed coat) of cereal, legumes, and oilseeds. It plays most important role in utilizing the food grains in our daily diet. Although, dehulling although depends upon the methods and machinery used for the process; several factors such as environment agronomic aspects genotypes and pretreatment influence the dehulling process. Many reports has witnessed the drudgery involved in traditional dehulling method and emphasized as one of the major problems militating against the realization of the full potential of millets. The traditional way of dehulling millets in rural areas are by pounding the slightly moisturized millet grains in pestle and motor. Husk is not edible; therefore must be removed from the minor millets. Different types of dehulling equipment for cereals and legumes are available employing either abrasive, attrition, or roller-milling principles. The abrasive type machines employing carborundum stones or other abrasive devices have been tried mainly for millet dehulling by most researchers rather than other two types of mills. Therefore, there is a need for proper dehulling technique and machinery. Thus, the objective of this work is to design and develop an eco-friendly millet mill with improved efficiency.
involving less power with integrated actions of gentle attrition/abrasion and pneumatic suction arrangement.

Material and Methods

CIAE-Millet Mill of 100 kg/h capacity was designed and developed at ICAR-Central Institute of Agriculture Engineering, Bhopal, India. All the construction materials are locally sourced and the concepts and ideas are transformed into useful machinery (Bernard et al., 1999). The principle and procedure in design and construction of millet mill machine are explained as below.

(i) Dehulling Operation

The dehulling operation of husk from kernel was performed with a gentle pressure (abrasion/attrition) exerted for the millet grain to dehull in a single pass and to increase the efficiency. The dehulling action and energy requirement were worked out using selected abrasive stone/grinding wheel by our laboratory during the design of millet mill. Also, ease of design components and its replacement in case of damage or failure sufficiently rugged to function properly for a reasonably long period and cheap enough to be economically feasible were taken into consideration.

(iii) Design and Construction

A set number of design consideration points viz., cost of construction, power requirement of machine and operational labour requirement were carried out during the design of millet mill. Also, ease of design component parts and its replacement in case of damage or failure sufficiently rugged to function properly for a reasonably long period and cheap enough to be economically feasible were taken into consideration.

I. Theoretical Design and Material Selection

The materials for construction of millet mill are shaft, abrasive grinding wheel, pulley, belt, electric motor, bearing, and mild steel plates. These materials were selected based on the power requirement in dehulling of millets. Using the engineering properties data for all minor millets has various moisture content reported by Balasubramanian and Viswanathan (2010) and the laboratory data on power requirement for the dehulling was taken to design considerations.

(A) Electric Motor

An electric motor of the following specification was selected:
- Power (P): 0.75 kW (1 hp)
- Rotational speed (N): 1440 rpm
- Frequency: 50 Hz

(B) Hopper Design

Based on the angle of repose of different millets (Balasubramanian and Viswanathan, 2010) and on gravity discharge principle, volume of the hopper was estimated

\[ V_h = \frac{\pi(D_h^2 - d^2)h}{12} \]  

Where, \( h = l \cos \phi \) (see Fig. 1).

(C) Abrasive/Grinding Wheel

The abrasive grinding wheels of dimension 300 mm × 40 mm × 38.1 mm was selected with A 24 superlife V272 features.

(D) Selection of Transmission Drives

The power transmission drives used for the machine are belt and pulley (Table 1 and 2).

(i) Pulley or sheave

The rotor’s pulley diameter was selected for required speed ratio as

\[ D_r = \frac{(D_m \cdot N_m)}{N_r} \]  

The speed of rotor (shaft) was chosen as 960 rpm for grinding wheel (dehulling operation) and was doubled as 1920 rpm (husk separation) to generate enough air velocity greater than the critical velocity of husk to be conveyed and discharged in cyclone separator.

(ii) Belt

Based on the power transmitted (0.75 kW) and according to Indian Standards (IS: 2494-1974), belt type B was selected (Table 1).

(iii) Calculation of Belt Length

The belt length was calculated

\[ L = \frac{\pi}{2} (D_1 - D_2) + 2X + (D_1 + D_2)^2}{4x} \]  

These parameters are represented in Fig. 2.

(iv) Arc of Contact

The arc of contact, \( \beta \), is given by

\[ \beta = 180° - 60° \left[ \frac{(D_1 - D_2)}{x} \right] \]  

(v) Shaft
The shaft of millet mill rotates the bottom grinding wheel (960 rpm) and through another belt arrangement, a van blades of blower (1920 rpm) extended to a cyclone separator was designed. For a shaft subjected to twisting moment only, diameter of shaft can be obtained by using torsion equation (Eq. 5)

\[ T = \left( \frac{\pi}{16} \right) \tau d^3 \]  
\[ T = (T_1 - T_2)R \]  
\[ T_m = \sigma a \]  

\( T = (T_1 - T_2)R \)  
\( T_m = \sigma a \)

(vi) Determination of belts cross-sectional area

The cross-sectional area of belt was calculated (Fig. 3) from Table 3, top width (b = 17 mm), thickness (t = 11 mm) and by calculation, bottom width (x) was obtained as 8 mm. Thus,

\[ \text{Area of triangle 1} + \text{Area of triangle 2} + \text{Area of triangle 3} \]
\[ a = \frac{t}{2} \left( \frac{b - x}{2} \right) + xt + \frac{t}{2} \left( \frac{b - x}{2} \right) \]
\[ a = \left( \frac{b - x}{2} \right) t + xt \]

From Table 4, density was found to be 1140 kg/m³.

\[ V_1 = \frac{(\pi DN)}{60} \]

For a V-belt drive, tension ratio is given (Eq. 15) as

\[ \frac{T_1 - T_2}{T_2 - T_c} = e^\theta \csc \alpha / 2 \]

From Table 3, coefficient of friction between belt and pulley was calculated (Eq. 16) as

\[ \theta = [180 - 2 \sin^{-1}(D_1 - D_2) / 2x] \]

Table 1 Dimensions of standard V-belts

<table>
<thead>
<tr>
<th>Types of belt</th>
<th>Power ranges (kw)</th>
<th>Minimum pitch diameter of pulley (D, mm)</th>
<th>Top width (b, mm)</th>
<th>Thickness (t, mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.7 - 3.7</td>
<td>75</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>2 - 15</td>
<td>125</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>C</td>
<td>7.5 - 75</td>
<td>200</td>
<td>22</td>
<td>14</td>
</tr>
<tr>
<td>D</td>
<td>20 - 150</td>
<td>355</td>
<td>32</td>
<td>19</td>
</tr>
<tr>
<td>E</td>
<td>30 - 350</td>
<td>500</td>
<td>38</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 2 Density of belt materials

<table>
<thead>
<tr>
<th>Material of belt</th>
<th>Mass density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leather</td>
<td>1,000</td>
</tr>
<tr>
<td>Double woven belt</td>
<td>1,250</td>
</tr>
<tr>
<td>Rubber</td>
<td>1,140</td>
</tr>
<tr>
<td>Canvas</td>
<td>1,220</td>
</tr>
<tr>
<td>Balata</td>
<td>1,110</td>
</tr>
<tr>
<td>Single woven belt</td>
<td>1,170</td>
</tr>
</tbody>
</table>

Table 3 Coefficient of friction between belt and pulley

<table>
<thead>
<tr>
<th>Belt material</th>
<th>Pulley material</th>
<th>Dry</th>
<th>Wet</th>
<th>Greasy</th>
<th>Wood</th>
<th>Compressed paper</th>
<th>Leather face</th>
<th>Rubber face</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leather oak tanned</td>
<td>0.25</td>
<td>0.2</td>
<td>0.15</td>
<td>0.3</td>
<td>0.33</td>
<td>0.38</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Leather chrome tanned</td>
<td>0.35</td>
<td>0.32</td>
<td>0.22</td>
<td>0.4</td>
<td>0.45</td>
<td>0.48</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Convass-stitched</td>
<td>0.20</td>
<td>0.15</td>
<td>0.12</td>
<td>0.23</td>
<td>0.25</td>
<td>0.27</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Cotton woven</td>
<td>0.22</td>
<td>0.15</td>
<td>0.12</td>
<td>0.25</td>
<td>0.28</td>
<td>0.27</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Rubber</td>
<td>0.30</td>
<td>0.18</td>
<td>-</td>
<td>0.32</td>
<td>0.35</td>
<td>0.40</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>Balata</td>
<td>0.32</td>
<td>0.20</td>
<td>-</td>
<td>0.35</td>
<td>0.38</td>
<td>0.40</td>
<td>0.42</td>
<td></td>
</tr>
</tbody>
</table>

\( \frac{\pi}{180} \) rad  

(vii) Power Transmission by Belt

The power transmitted by belt was calculated (Eq. 17) as

\[ P_b = (T_1 - T_2)V \]

(E) Bearing

Based on type of load, the bearing support (static & dynamic) and shaft diameter, the ball rolling contact bearing of standard designation 307 was selected. It is a medium series bearing with bore (inside diameter) of 35 mm (Khurmi and Gupta, 2004)

(F) Power Requirement

The power requirement millet mill was obtained as (Eq. 22)

\[ P = Qg Hf \]

II. Performance Evaluation of Millets

A. Preparation of Raw Material

The contaminants for millets may be sand (soil), small stones, leaves, shrivelled seeds, off-type seeds, broken seeds, glumes, sticks, chaff, parts of stem, insects, animal hair, animal excreta (e.g. rat and insect faeces) and more annoyingly, metal pieces. Metal pieces, if not removed, may damage the sieves of milling machines if mechanized grinding is used.

(i) Raw Millets

The cleaning is done by destoner-cleaner-grader for the raw millets.

(ii) Parboiled Millets

For parboiled millets, boiler was filled with water to a level just above its bottom, and on top of the water, a wire net was placed to raise the samples above the water. The samples were then placed on the muslin cloth and the boiler was connected to the power source. The steaming was done for 15 min, samples were taken out and allowed to temper for 24 h (Fig. 5).

\[ T = \frac{(\pi / 16)d^3}{\tau} \]

\[ T = (T_1 - T_2)R \]

\[ T_m = \sigma a \]
C. Determination of moisture content

The key to post-production operations, grain moisture content is determined on wet basis as (Balasubramanian and Viswanathan, 2010).

\[ m = \frac{(w_i - w_f)}{W_i} \times 100 \] (19)

D. Testing of machine

The test carried out on millet mill to prove the conformity with requirement of relevant standard. The tests are checking of specifications, checking of materials and visual observation and provision for adjustment (NCAM, 1990).

E. Test at Load

Test under load was conducted to get the following data: dehulling index, degree of dehulling, effectiveness of dehulling, yield of the broken, yield of fine, quality of dehulling, overall dehulling efficiency and cleaning efficiency. The sample is analyzed for cracked and broken grains, undehulled grains, and clean grains. Analysis for cracked grains and broken grains is only made from the sample were taken at the specified grain outlet.

(i) Dehulling Index (\( \eta \))

The dehulling index was calculated using the following equation:

\[ \eta = \frac{[(m_k + m_b) - (m_{ad} + m_u)]}{m_i} \] (20)

The dehulling index may vary from a maximum value of +1 to a minimum of −1. A value of +1 indicates that the entire original grain sample is completely dehulled into two fractions of grain (\( m_b \)) and husk (\( m_h \)) with no fines and undehulled grains. A value of −1 indicates that the dehulling is not complete, thus the broken grains (\( m_f \)) and/or not dehulled (\( m_{uu} \)) at all (Ikebudu et al., 2000).

(ii) Degree of dehulling (\( M_h \))

The degree of hull removal is the ratio of mass of hull removed during dehulling to the initial mass of sample used for the dehulling process.

\[ M_h = \frac{m_h}{m_i} \] (21)

(iii) Effectiveness of dehulling (\( E_d \))

Effectiveness of dehulling is the ratio between the mass of the material remaining undeveloped and the initial mass of material taken for dehulling.

\[ E_d = \frac{m_{ad}}{m_i} \] (22)

(iv) Yield of broken (\( Y_b \))

It is the ratio between the mass of broken generated during dehulling and the initial mass of sample used for dehulling.

\[ Y_b = \frac{m_b}{m_i} \] (23)

(v) Yield of fine (\( Y_f \))

It is the ratio between the mass of fine generated during dehulling and the initial mass of sample used for dehulling.

\[ Y_f = \frac{m_f}{m_i} \] (24)

(vi) Quality of dehulling (\( Q_d \))

It can be calculated as ratio between the weight of dehulled kernel (both broken and whole) and initial weight of material taken for dehulling.

\[ Q_d = \frac{m_k}{m_i} \] (25)

(vii) Coefficient of dehulling (\( C_{dh} \))

This can be calculated using the following equation:

\[ C_{dh} = 100[1 - (Y_b + E_d + Y_f)] \] (26)

(viii) Overall Dehulling Efficiency (\( \eta_o \))

This is calculated using the following relationship:

\[ \eta_o = (M_h + Q_d) \times C_{dh} \] (27)
Cleaning Efficiency ($C_e$)
This can be calculated using the following equation:

$$C_e = \frac{m_n}{m_k} \tag{28}$$

Result and Discussion
The design parameters viz., assumed parameters and designed parameters of CIAE millet mill are shown in Table 4. The motor was selected on the basis of dehulling capacity and its power requirement. The shaft of millet mill rotates the bottom grinding wheel and through another belt arrangement, a van blade of blower extended to a cyclone separator was designed. The length and diameter of the shaft is 536 mm and 34 mm, respectively. The speed of rotor (shaft) was chosen as 960 rpm for grinding wheel and was doubled as 1920 rpm to generate enough air velocity greater than the critical velocity of husk to be conveyed and discharged at cyclone separator. The diameter of main shaft pulley is 150 mm and blower shaft pulley is 84.5 mm. The hopper was designed based on the dehulling capacity and bulk density of different millets. The volume of hopper is $3.7 \times 10^5 \text{ mm}^3$ (Table 4). The ball rolling contact bearing of standard designation 307 was selected. Thus, the designed millet mill requires floor area of $860 \times 842 \text{ mm}$ and having 112 kg weight (excluding motor).

The machine was designed as a vertical frame work assembly, a vertical rotary shaft extending in the vertical axis in the framework assembly and abrasive grinding wheel mounted on the shaft for rotation there with, a face to face mounted upper abrasive grinding wheel with fine turner to adjust the clearance between the pair of grinding wheel, to define in a dehulling chamber there between a hopper at the top of the framework assembly and a dividing part at the bottom of the dehulling chamber. The upper grinding wheel with spring suspension mechanism provide and the bottom rotary grinding wheel is fixed with the shaft the clearance in between the grinding wheel adjust with the help of spring by the upper grinding wheel, and it possible to dehull all minor millets with theoretical uniform. The dehulled grain and husk is pass through the discharge pipe and hence passes to outlet chute, where the suction output high. The husk from the kernel, then discharge cleaned kernel out from the grain outlet and the husk is transfer toward the cyclone by the pneumatic suction as shown in Fig. 4.

The machine was found to be dust free. The grinding wheel and other parts do not wear and runs smoothly. This machine can dehull the millets with and without bran layers, thus judicious dehulling operations be achieved by setting the clearance of grinding wheel to suit different millets by coarse and fine adjustments. The rotor shaft was checked for torsion and bending and found safe. The driving mechanism of rotor was designed in such a way that the v-belt was safe and was able to transmit required speed to the rotor from the motor. A pair of abrasive stone (grinding wheel) were provided, thus permitting a much broader range of application for millet grain size accommodation for dehulling and size reduction operations. The millet grain is fed between the grinding wheels and dehulling operation taken place in the horizontal plane. Thus, the exact clearance setting reduces the excessive heat generation during gentle abrasion/attrition requiring low power. Also, less time is required for the dehulling and due to the air-tight nature, dust spillage is minimized. An average dehulling efficiency of designed millet mill was obtained 80% with different minor millet. The design parameters of the millet mill are summarized in Table 5.

### Table 4 Design specification/parameter

<table>
<thead>
<tr>
<th>Component</th>
<th>Assumed parameters</th>
<th>Designed parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric motor</td>
<td>From shaft, pulley and capacity design</td>
<td>1,440 rpm, 1.0 Hp</td>
</tr>
<tr>
<td>Pulley</td>
<td>OD = 150 mm, ID = 110 mm</td>
<td>OD = 150 mm, ID = 110 mm</td>
</tr>
<tr>
<td>Pulley (large)</td>
<td>OD = 84.5 mm, ID = 44.5 mm</td>
<td>OD = 84.5 mm, ID = 44.5 mm</td>
</tr>
<tr>
<td>Pulley (small)</td>
<td>h = 487.71 mm, $D_a$ = 412 mm</td>
<td>V = 3.715 × 10^5 mm^3</td>
</tr>
<tr>
<td>Hopper</td>
<td>$N = 1,440 \text{ rpm}, D = 34 \text{ mm}$</td>
<td></td>
</tr>
<tr>
<td>Speed ratio</td>
<td>Double the rotation of the main shaft, 30 mm diameter</td>
<td></td>
</tr>
<tr>
<td>Main shaft</td>
<td>$T = 323 \text{ Nm}$</td>
<td></td>
</tr>
<tr>
<td>Diameter of shaft</td>
<td>$D = 150, d = 84.5$</td>
<td></td>
</tr>
<tr>
<td>Centre distance between pulley belt</td>
<td>$x = 320 \text{ mm}$</td>
<td></td>
</tr>
<tr>
<td>Processing chamber</td>
<td>$V = 6.23 \times 10^6 \text{ mm}^3$</td>
<td></td>
</tr>
<tr>
<td>Grinding wheel (upper)</td>
<td>$V = 2.668 \times 10^6 \text{ mm}^3$</td>
<td></td>
</tr>
<tr>
<td>Grinding wheel (lower)</td>
<td>$V = 2.838 \times 10^6 \text{ mm}^3$</td>
<td></td>
</tr>
<tr>
<td>Arc of contact</td>
<td>$\beta = 167.7^\circ$</td>
<td></td>
</tr>
<tr>
<td>Power requirement</td>
<td>240 V, $I = 2.5$</td>
<td>460 watt</td>
</tr>
</tbody>
</table>
Regarding the performance evaluation of designed mill at no load condition there was no marked oscillation during operation and presence of rattling sound is due to the contact of grain to the surface of the grinding wheel. During the test at load carried out to the different type of millets (100 kg) at different conditions (raw and parboiling) at constant rotation speed of grinding wheel. Different dehulling efficiencies were obtained from each type of millets at different condition and the averages of the efficiencies obtained are presented in Table 6. The moisture content of raw and parboiled millets ranged between 9.25-11.06% and 10.79-13.28% respectively. The overall dehulling efficiency of raw millet ranged from 83.95–69.76% and parboiled millets 85.15-72.07% and cleaning efficiencies higher in parboiled millets (84.83-62.75%) compared to raw millets (81.01-60.21%). Among the raw millet foxtail millet recorded highest coefficient of dehulling followed by little millet, proso millet, kodo millet and barnyard millet, respectively. Similarly, the coefficient of dehulling was the highest in foxtail millet followed by proso millet, kodo millet and barnyard millets. Despande and Khan (2007) reported that pre milling treatments (soy oil water and microbial consortium) play an important role in improving the dhal recovery by loosening the husk from the cotyledons. Nwaigwe et al. (2012) designed the cassava milling machine at a power of 3.7 kW, rotor speed of 1080 rpm, tested and found to have a milling efficiency of 82.3%. Opokul et al. (2003) stated that dehulling characteristics of pigeon pea and mung bean in abrasion type of dehulling increased the yield of dehulled cotyledons.

**Conclusion**

The CIAE-millet mill has been designed, fabricated, tested with a coefficient of dehulling as 70-85%. It operates with a 1 hp single phase electric motor. The integral suction arrangement provides the simultaneous separation of husk and dust particles from the dehulled mass from the grinding zone. The cyclone component provides a dust free i.e. eco-friendly environment during dehulling.

### Table 5 Specification of CIAE-Millet Mill

<table>
<thead>
<tr>
<th>Name of the machine</th>
<th>CIAE-MILLET MILL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of operation</td>
<td>Continuous type</td>
</tr>
<tr>
<td>Overall dimension (mm)</td>
<td>$860 \times 842 \times 1460$</td>
</tr>
<tr>
<td>Feed hopper</td>
<td></td>
</tr>
<tr>
<td>Top (mm)</td>
<td>421</td>
</tr>
<tr>
<td>Base (mm)</td>
<td>75</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>420.71</td>
</tr>
<tr>
<td>Emptying angle (°)</td>
<td>34.88</td>
</tr>
<tr>
<td>Grinding wheel</td>
<td></td>
</tr>
<tr>
<td>Upper wheel diameter (mm)</td>
<td>$300 \times 40 \times 38.1$</td>
</tr>
<tr>
<td>Lower wheel diameter (mm)</td>
<td>$300 \times 40 \times 38.1$</td>
</tr>
<tr>
<td>Power unit (Electric motor)</td>
<td>1 hp, single phase motor</td>
</tr>
<tr>
<td>Power rating, (HP)</td>
<td>960</td>
</tr>
<tr>
<td>Working speed (rpm)</td>
<td>1,920</td>
</tr>
<tr>
<td>Capacity (kg/h)</td>
<td>110</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>(excluding motor)</td>
</tr>
<tr>
<td>Floor area (mm)</td>
<td>$860 \times 842$</td>
</tr>
<tr>
<td>Purpose</td>
<td>Dehulling of minor millets (with or without bran)</td>
</tr>
<tr>
<td>Working principle</td>
<td>Gentle abrasion &amp; (aerodynamic) cyclone separator</td>
</tr>
<tr>
<td>Coefficient of dehulling (%)</td>
<td>70-85</td>
</tr>
<tr>
<td>Feed moisture (% wb)</td>
<td>10-12</td>
</tr>
</tbody>
</table>

### Table 6 Performance of dehuller on raw and parboiled millets

<table>
<thead>
<tr>
<th>Millet</th>
<th>Moisture content at dehulling (% wb)</th>
<th>Dehulling index ($\eta$)</th>
<th>Degree of dehulling ($M_\eta$)</th>
<th>Effectiveness of dehulling ($E_\eta$)</th>
<th>Yield of broken ($Y_0$)</th>
<th>Yield of fine ($Y_1$)</th>
<th>Quality of dehulling ($Q_0$)</th>
<th>Overall dehulling efficiency ($\eta_o$)</th>
<th>Cleaning efficiency ($C_e$ %)</th>
<th>Coefficient of dehulling ($C_{dh}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foxtail millet</td>
<td>9.30</td>
<td>0.840</td>
<td>21.800</td>
<td>0.001</td>
<td>0.146</td>
<td>0.003</td>
<td>76.867</td>
<td>83.95</td>
<td>81.01</td>
<td>85.083</td>
</tr>
<tr>
<td>Little millet</td>
<td>11.06</td>
<td>0.799</td>
<td>30.733</td>
<td>0.001</td>
<td>0.147</td>
<td>0.032</td>
<td>63.967</td>
<td>77.67</td>
<td>77.02</td>
<td>82.013</td>
</tr>
<tr>
<td>Kodo millet</td>
<td>9.25</td>
<td>0.753</td>
<td>31.333</td>
<td>0.007</td>
<td>0.227</td>
<td>0.003</td>
<td>66.667</td>
<td>75.42</td>
<td>66.00</td>
<td>76.960</td>
</tr>
<tr>
<td>Proso millet</td>
<td>10.83</td>
<td>0.785</td>
<td>23.967</td>
<td>0.005</td>
<td>0.213</td>
<td>0.008</td>
<td>76.333</td>
<td>77.70</td>
<td>72.14</td>
<td>77.470</td>
</tr>
<tr>
<td>Barnyard millet</td>
<td>9.85</td>
<td>0.711</td>
<td>30.733</td>
<td>0.004</td>
<td>0.269</td>
<td>0.018</td>
<td>67.600</td>
<td>69.76</td>
<td>60.21</td>
<td>70.943</td>
</tr>
<tr>
<td><strong>Parboiled</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foxtail millet</td>
<td>12.18</td>
<td>0.851</td>
<td>22.800</td>
<td>0.003</td>
<td>0.129</td>
<td>0.003</td>
<td>75.233</td>
<td>85.15</td>
<td>82.90</td>
<td>86.857</td>
</tr>
<tr>
<td>Little millet</td>
<td>13.28</td>
<td>0.794</td>
<td>27.567</td>
<td>0.001</td>
<td>0.173</td>
<td>0.013</td>
<td>69.200</td>
<td>78.68</td>
<td>75.05</td>
<td>81.313</td>
</tr>
<tr>
<td>Kodo millet</td>
<td>10.79</td>
<td>0.793</td>
<td>31.900</td>
<td>0.002</td>
<td>0.189</td>
<td>0.003</td>
<td>66.533</td>
<td>79.30</td>
<td>71.54</td>
<td>80.563</td>
</tr>
<tr>
<td>Proso millet</td>
<td>12.02</td>
<td>0.847</td>
<td>21.800</td>
<td>0.013</td>
<td>0.115</td>
<td>0.004</td>
<td>75.600</td>
<td>84.58</td>
<td>84.83</td>
<td>86.837</td>
</tr>
<tr>
<td>Barnyard millet</td>
<td>11.11</td>
<td>0.728</td>
<td>31.433</td>
<td>0.003</td>
<td>0.247</td>
<td>0.013</td>
<td>66.400</td>
<td>72.07</td>
<td>62.75</td>
<td>73.667</td>
</tr>
</tbody>
</table>
dehulling the small seeded minor millets. This machine has a provision for dehulling the millet with bran layer also. Thus, the millet mill when operated within the designed parameters will process 100 kg raw materials in an hour with judicious dehulling operations. The rate of dehulling of the machine was efficient compared to the traditional methods. This machine is able to dehull all types of minor millets irrespective of their sizes and shapes. However, the effectiveness of the machine is said to be dependent on the uniformity, size and moisture content of the millet grains.

Nomenclature

- $a$: Area of belt
- $d$: Diameter of shaft (mm)
- $D$: Diameter of processing chamber
- $d_1$: Diameter of disk
- $D_1$: Larger sheave diameter
- $D_2$: Smaller sheave diameter
- $D_{up}$: Diameter of the upper opening of hopper
- $D_{mw}$: Measure diameter of motor’s pulley
- $D_r$: Rotor’s pulley diameter
- $h$: Vertical height of hopper
- $H$: Height of lift
- $l$: Slant height of hopper
- $L$: Length of belt (in)
- $m$: Mass of belt per unit length
- $N_m$: Rotational speed of electric motor (1,440 rpm)
- $N_r$: Rotational speed of rotor (rpm)
- $R$: Radius of pulley (mm)
- $T$: Twisting moment (Nm)
- $t$: Thickness of hammer
- $T^t$: Tight side tension
- $T^s$: Slack side tension (Nm)
- $T^p$: Centrifugal tension (applicable for belt running at high speed)
- $T_m$: Maximum tension in belt (N)
- $V$: Velocity of air (m/s)
- $V_l$: linear speed of belt
- $V_h$: Volume of hopper (mm$^3$)
- $X$: Centre distance of pulleys (mm)
- $x$: bottom width of the belt
- $\alpha$: Groove angle (34°)
- $\theta$: Angle of wrap (radian)

$\mu$: Coefficient of friction between belt and pulley
$p$: Density of belt material (rubber, kg/m$^3$)
$\phi$: Angle of repose
$\beta$: Arc of contact
$\tau$: Torsional shear stress (42 MPa)
$\sigma$: Maximum allowable stress of belt (2.8 MPa)
$Q_g$: Gravimetric throughput capacity
$f$: Power factor
$m_h$: Mass of hull (kg)
$m_w$: Mass of whole grain (kg)
$m_b$: Mass of broken (kg)
$m_i$: Initial weight of sample taken for dehulling (kg)
$m_{uf}$: Mass of undehulled kernel (kg)
$m_{fb}$: Mass of fine (kg)
$M$: Degree of dehulling
$E_d$: Effectiveness of dehulling
$Y_b$: Yield of broken
$Y_f$: Yield of fine

REFERENCES


