Design, Development and Performance Evaluation of CIAE-Millet Mill

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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 to into useful machinery (Bernard et al., 1999). The principle and procedure in design and construction of millet mill machine are explained as below.

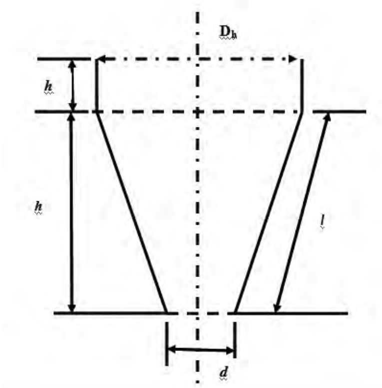
(i) Dehulling Operation

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 set-up study. The concepts and ideas were imparted in design of each component and using CREO ELEMENTS / PRO, the model and detailed CAD were prepared.

(ii) Pneumatic Suction Arrangement

Pneumatic suction arrangement is effective for separation of lighter materials like husk and products in powdery form from small seeded minor millets (Balasubramanian, 2007). Due to lighter weight of millet husk, pneumatic system consisting of a fan with increased speed of air to suck the husk from the hulled mass was operated by taking power from main rotor shaft. The blower was positioned in the suitable place to suck the husk from the grain outlet chute. The suction air velocity was kept higher than the terminal velocity of the husk and powdery materials. The high speed air makes the product to flow in the air stream to grain outlet. The design of the pneumatic suction arrangement was based on the aerodynamic properties of the material velocity, determined by sucking the husk with suitable blower design and distance moved per unit time was determined. It becomes important to have efficient millet mill machine to ensure not only the processed millet availability but also in right quantity.

Fig. 1 Hopper



(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
Phase: Single
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 (Eq.1)

$$V_h = [\pi(D^2_h - d^2)h] / 12 \qquad (1)$$

Where, $h = l \cos\varphi$ (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 (Eq. 2) for required speed ratio as

$$D_r = (D_m N_m) / N_r \qquad (2)$$

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 (Eq. 3) according to Khurmi and Gupta (2004).

$$L = \pi/2\,(D_1 - D_2) + 2X + (D_1 + D_2)^2 / 4x \qquad (3)$$

These parameters are represented in **Fig. 2**.

(iv) Arc of Contact

The arc of contact, β, is given by (Eq. 4) as suggested by Anon (1994)

$$\beta = 180° - 60°\,[(D_1 - D_2) / x] \qquad (4)$$

(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)

$T = (\pi / 16)\tau d^3$. (5)

$T = (T_1 - T_2)R$ (6)

Where,

$T_1 = T_m - T_c$ (7)

$T_m = \sigma a$ (8)

(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,

(Area of triangle 1) + (Area of triangle 2) + (Area of triange 3) (9)

$a = t/2[(b - x) / 2) + xt + t/2[(b - x) / 2]$ (10)

$a = [(b - x) / 2]t + xt$ (11)

Also, centrifugal tension, T_c was determined (Eq. 12)

$T_c = mV_l^2$ (12)

$m = \rho a$ (13)

From **Table 4**, density was found to be 1140 kg/m^3.

$V_l = (\pi DN) / 60$ (14)

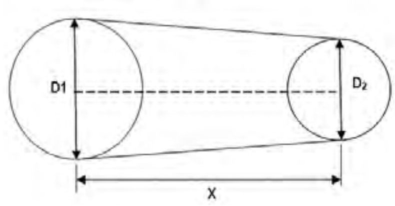
For a V-belt drive, tension ratio is given (Eq. 15) as

$(T_1 - T_c) / (T_2 - T_c) = e^{\mu}\theta \operatorname{cosec}\alpha / 2$ (15)

From **Table 3**, coefficient of friction between belt (rubber) and pulley (dry cast iron) was taken as 0.30. By considering the small pulley, θ was calculated (Eq. 16) as

$\theta = [180 - 2 \sin^{-1}((D_1 - D_2) / 2x)]$ $\pi/180$ rad (16)

Fig. 2 Open belt drive



(vii) Power Transmission by Belt

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

$P_b = (T_1 - T_2)V$ (17)

(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)

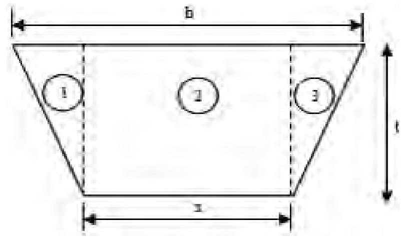
$P = Qg\ Hf$ (18)

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.

Fig. 3 Cross-section of V-belt



(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 closed for steam-heating, 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**).

Table 1 Dimensions of standard V-belts

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

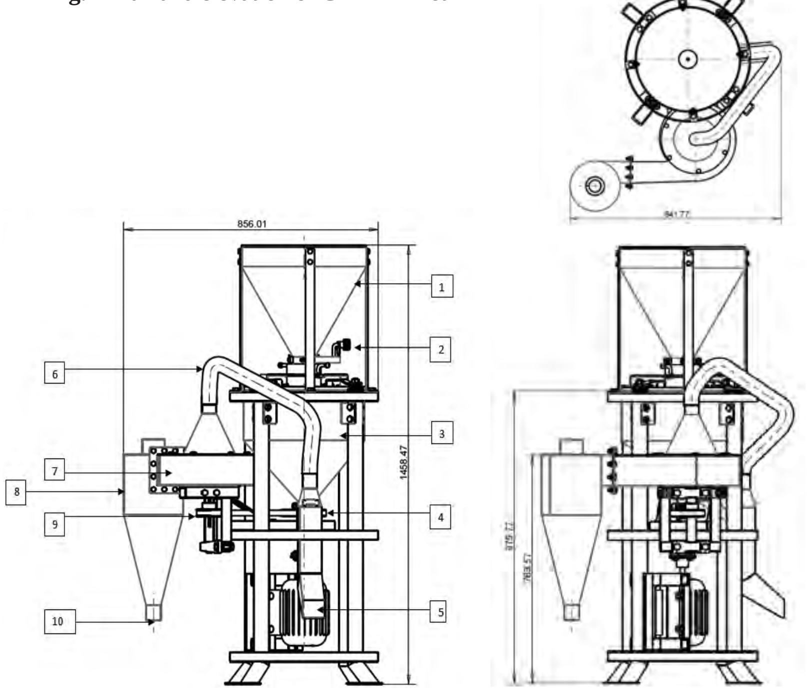
Table 2 Density of belt materials

Material of belt	Mass density (kg/m^3)
Leather	1,000
Double woven belt	1,250
Rubber	1,140
Canvass	1,220
Balata	1,110
Single woven belt	1,170

Table 3 Coefficient of friction between belt and pulley

Belt material	Pulley material						
	Dry	Wet	Greasy	Wood	Compress-ed paper	Leather face	Rubber face
Leather oak tanned	0.25	0.2	0.15	0.3	0.33	0.38	0.40
Leather chrome tanned	0.35	0.32	0.22	0.4	0.45	0.48	0.50
Convass-stitched	0.20	0.15	0.12	0.23	0.25	0.27	0.30
Cotton woven	0.22	0.15	0.12	0.25	0.28	0.27	0.30
Rubber	0.30	0.18	-	0.32	0.35	0.40	0.42
Balata	0.32	0.20	-	0.35	0.38	0.40	0.42

Fig. 4 Plan and elevation of CIAE-Millet Mill



C. Determination of moisture content

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

$$m = (w_i - w_f) / W_i \times 100 \qquad (19)$$

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).

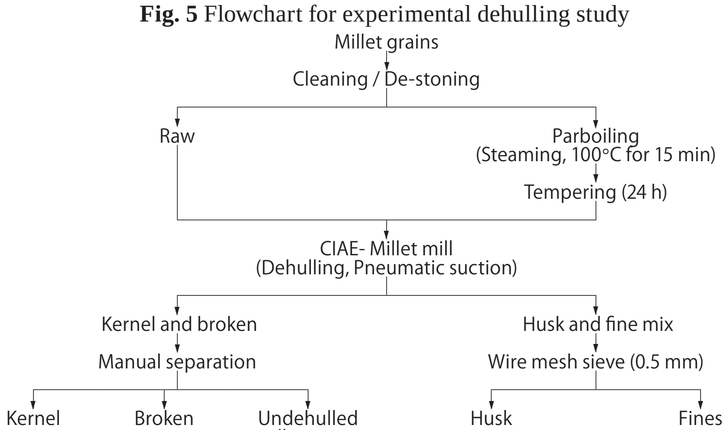
E. Test at Load

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, coefficient 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 (η)

The dehulling index was calculated using the following equation:

Fig. 5 Flowchart for experimental dehulling study



$$\eta = [(m_k + m_h) - (m_{ud} + m_b)] / m_i \qquad (20)$$

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_{uh}) 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.

$$M_h = m_h / m_i \qquad (21)$$

(iii) Effectiveness of dehulling (E_d)

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

$$E_d = m_{ud} / m_i \qquad (22)$$

(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.

$$Y_b = m_b / m_i \qquad (23)$$

(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.

$$Y_f = m_f / m_i \qquad (24)$$

(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.

$$Q_d = m_k / m_i \qquad (25)$$

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

This can be calculated using the following equation:

$$Cdh = 100[1 - (Y_b + E_d + Y_f)] \qquad (26)$$

(viii) Overall Dehulling Efficiency (η_o)

This is calculated using the following relationship:

$$\eta_o = (M_h + Q_d) \times C_{dh} \qquad (27)$$

(ix) Cleaning Efficiency (C_e)

This can be calculated using the following equation:

$$C_e = m_w / m_k \quad (28)$$

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 blades 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 × 105 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 × 842 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 4**. The overall specifications of the millet mill are shown in **Table 5**.

Table 4 Design specification/parameter

Component	Assumed parameters	Designed parameters
Electric motor	From shaft, pulley and capacity design	1,440 rpm, 1.0 Hp
Pulley		
Pulley (large)	OD = 150 mm, ID = 110 mm	OD = 150 mm, ID= 110 mm
Pulley (small)	OD = 84.5 mm, ID = 44.5 mm	OD = 84.5 mm, ID =44.5 mm
Hopper	h = 487.71 mm, D_h = 412mm	V = 3.715 × 10 5 mm^3
Speed ratio		
Main shaft	N = 1,440 rpm, D = 34 mm	N_r = 960 rpm, D= 34 mm.
Blower shaft	Double the rotation of the main shaft, 30 mm diameter	1,920 rpm, d = 30 mm
Diameter of shaft	T= 323 Nm	T = 323 N_m, D = 34 mm
Centre distance between pulley	D = 150, d = 84.5	x = 320 mm
Belt	D = 150, d = 84.5, x = 320.	L= 1,110 mm
Processing chamber	Dia. =407 mm, h = 366 mm	V = 6.23 × 106 mm^3
Grinding wheel (upper)	D = 300 mm	V = 2.668 × 106 mm^3
Grinding wheel (lower)	D = 300 mm	V = 2.838 × 106 mm^3
Arc of contact	D = 150, d = 84.5, x = 320	β = 167.7°
Power requirement	240 V, I = 2.5	460 watt

Table 5 Specification of CIAE-Millet Mill

Name of the machine	CIAE-MILLET MILL
Mode of operation	Continuous type
Overall dimension (mm)	860 × 842 × 1,460
Feed hopper	
Top (mm)	421
Base (mm)	75
Height (mm)	420.71
Emptying angle (°)	34.88
Grinding wheel	
Upper wheel diameter (mm)	300 × 40 × 38.1
Lower wheel diameter (mm)	300 × 40 × 38.1
Power unit (Electric motor)	
Power rating, (HP)	1 hp, single phase motor
Working speed (rpm)	960
Suction/blower speed (rpm)	1,920
Capacity (kg/h)	100-110
Weight (kg)	112 (excluding motor)
Floor area (mm)	860 × 842
Purpose	Dehulling of minor millets (with or without bran)
Working principle	Gentle abrasion & (aerodynamic) cyclone separator
Coefficient of dehulling (%)	70-85
Feed moisture (% wb)	10-12

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 banyard millet, respectively. Similarly, the coefficient of dehulling was the highest in foxtail millet followd 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

Table 6 Performance of dehuller on raw and parboiled millets

Millet	Moisture content at dehulling (%, w.b.)	Dehulling index (η)	Degree of dehulling (M_h)	Effectiveness of dehulling (E_d)	Yield of broken (Y_b)	Yield of fine (Y_f)	Quality of dehulling (Q_d)	Overall dehulling efficiency (η_o)	Cleaning efficiency (C_e. %)	Coefficient of dehulling (C_{dh})
Raw										
Foxtail millet	9.30	0.840	21.800	0.001	0.146	0.003	76.867	83.95	81.01	85.083
Little millet	11.06	0.799	30.733	0.001	0.147	0.032	63.967	77.67	77.02	82.013
Kodo millet	9.25	0.753	31.333	0.007	0.227	0.003	66.667	75.42	66.00	76.960
Proso millet	10.83	0.785	23.967	0.005	0.213	0.008	76.333	77.70	72.14	77.470
Barnyard millet	9.85	0.711	30.733	0.004	0.269	0.018	67.600	69.76	60.21	70.943
Parboiled										
Foxtail millet	12.18	0.851	22.800	0.003	0.129	0.003	75.233	85.15	82.90	86.857
Little millet	13.28	0.794	27.567	0.001	0.173	0.013	69.200	78.68	75.05	81.313
Kodo millet	10.79	0.793	31.900	0.002	0.189	0.003	66.533	79.30	71.54	80.563
Proso millet	12.02	0.847	21.800	0.013	0.115	0.004	75.600	84.58	84.83	86.837
Barnyard millet	11.11	0.728	31.433	0.003	0.247	0.013	66.400	72.07	62.75	73.667

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_h: Diameter of the upper opening of hopper
D_m: 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_1: Tight side tension (N)
T_2 : Slack side tension (N)
T_c: 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
Vh: Volume of hopper (mm^3)
X : Centre distance of pulleys (mm)
x: bottom width of the belt
α: Groove angle (34°)
θ: Angle of wrap (radian)
μ: Coefficient of friction between belt and pulley
ρ: Density of belt material (rubber, kg/m^3)
φ: Angle of repose
β: Arc of contact
τ: Torsional shear stress (42 MPa)
σ: Maximum allowable stress of belt (2.8 MPa)
Q_g: Gravimetric throughput capacity
f: Power factor
m_h: Mass of hull (kg)
m_{ud}: Mass of undehulled kernel (kg)
m_b: Mass of broken (kg)
m_i: Initial weight of sample taken for dehulling (kg)
m_w: Mass of whole grain (kg)
m_f: mass of fine (kg)
M_h: Degree of dehulling
E_d: Effectiveness of dehulling
Y_b: Yield of broken
Y_f: Yield of fine

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