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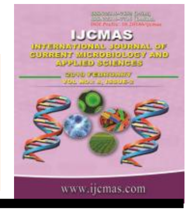

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Effect of Moisture and Machine Parameters on De-husking Efficiency of Kodo Millet

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A B S T R A C T

Studies on engineering properties of variety JK 41 Kodo (*Paspalum scrobiculatum* L.) was conduct at 12 and 14 % moisture content wet basis (w.b). The average length, width, thickness, size and sphericity of Kodo millet at 12% moisture content (w.b) were 2.69 mm, 2.02 mm, 1.31 mm, 1.92 mm and 71.68 % respectively. However, the average values of length, width, thickness, size and sphericity of Kodo millet at 14% moisture content (w.b) were 2.80 mm, 2.39 mm, 1.39 mm, 2.09 mm, and 74.76% respectively. It was observed that the bulk density of Kodo millet decreased with increase in moisture content. The average value of bulk density of Kodo millet at 12% and 14% moisture content were 957.23 and 954.81 kg/m^3, respectively (Balasubramanian and Vishwanathan, 2010) also observed that the bulk density of millets decreased linearly with increment the moisture content. The average value of angle of repose for the Kodo millet increased from 26.23^0 to 26.50^0 with increment in moisture content (w.b.) from 12% and 14% (Sirsat and Patel, 2008; Balasubramanian and Vishwanathan, 2010) also observed the increment in angle of repose of Kodo millet with increment in moisture content. The Kodo millet de-husker composed of three basic units i.e. feeding unit, de-husking unit and discharge unit. The maximum de-husking efficiency of 75.29% and 72.51% for pretreated Kodo millet at 14% moisture content (w.b.) with 1.5 mm and 2.00 mm clearance between the abrasive surfaces, was obtained at 380 rpm respectively at the feed rate of 12 kg/hr. Cost of de-husking per kilogram of Kodo millet was Rs. 5.60.

Keywords

Millet, Kodo, De-husker, Efficiency.

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Introduction

Kodo millet (*Paspalum scrobiculatum* L.) is nutritionally superior and good source of protein, carbohydrate, minerals, fibers, vitamins and micronutrients which make it suitable for industrial scale utilization in food stuff. The husk on the minor millet is tightly attached with the endosperm thereby making its removal difficult during de-husking operation. Traditionally the minor millets are de-husked manually with help of wooden mortar and pestle and grinding stone. The milling of Kodo millet is still being performed by hand/foot pounding. The processing is labour intensive and time consuming process. An effort has been made to mechanize the de-hulling of Kodo millets to reduce the drudgery of processing operation. 100 kg/hr de-husking capacity millet de-husker has been designed by Central Institute of Agricultural Engineering (CIAE), Bhopal (Anon, 2013). The de-hulling efficiency of the machine is about 95 per cent. A multigrain centrifugal de-huller with 100 kg/hr capacity was developed by TNAU. The machine de-hulling efficiency is 95 percent. Vivek thresher-cum-pearler was designed and developed by PHET, VAPKAS, Almora centre with capacity of 60 kg/hr (Dixit *et al.,* 2011). Mid capacity, non-portability and high capital investment are some of the impediments in popularization of existing Kodo millet de-husker. The study was planned to develop a small capacity Kodo millet de-husker suitable for farm processing of Kodo millets, performance evaluation of developed Kodo millet de-husk and to determine the cost of de-hulling operation.

Materials and Methods

Description of Kodo millet de-husker

The Kodo millet de-husker has three basic units i.e. feeding unit, de-husking unit and discharge unit. It consists of a steady metallic frame, feed hopper, de-husking unit (de-husking roller and outer hollow punched cylinder), adjustment screw for clearance adjustment, bearings, pulley, belt, starter cum controller and electric motor. The machine occupied a floor area of 0.7 m × 0.4 m and its height is 1.1 m. Kodo millet de-husker is shown in Figure 1 and 2.

Mechanism of operation of de-husker

Kodo millet de-husker, was designed which utilizes the abrasion and frictional forces generated by the rotation of the abrasive surface of the de-husking roller unit along with the inter-granular frictional forces generated due to movement of the grains shown in figure 3. The required abrasion forces in de-husker will be generated by rotating an inner abrasive roller fitted inside a concentric fixed abrasive outer cylinder.

The present investigation was undertaken to study some of the physical/engineering properties and to evaluate the performance of Kodo millet de-husker. To evaluate the performance of the developed Kodo millet de-husker, raw Kodo millets of variety JK 41, were procured from local market. Kodo millets were cleaned before the performance evaluation. Moisture content of procured Kodo millet was 11.2% (w.b). The sorted samples were then soaked in water at 30^{0}C for 2 hour and were drained and dried in shade for 5 hour in ambient condition. It was reported that 12 % (w.b) to 14 % (w.b) were optimum moisture content for milling of Grains and millets (Azalinia *et al.,* 2002). Samples of 12% (w.b) and 14% (w.b) moisture content were prepared by the addition of calculated amount of water through mist spray. From the experimental point of view, 9 ml and 31.25 ml of water were required to convert 1 kg of Kodo millet at 11.2 % (w.b) to make the samples at 12 % (w.b) and 14 % (w.b), respectively

Different properties of Kodo millet such as moisture content, size, angle of repose, bulk density, were determined using standard techniques.

Moisture content

Moisture content of the sample was determined by hot air oven method (Ranganna, 1995). A test sample of 5 g was kept at 100°C in a hot air digital oven (Radical Scientific Equipment’s Pvt. Ltd., RSTI-101) having an accuracy of 2-3^{0}C for 24 hours. After 24 hour the sample was taken out and placed in a desiccator for cooling at ambient temperature.

After cooling, the weight of the dried sample was determined precisely in electronic weighing balance (Ishida UBH-620E Lab Balance) of accuracy 0.001g. The loss in weight was determined and moisture content was calculated using the following expression:

Moisture content % (w.b) =

$$\frac{\text{Weight of moisture}}{\text{Total Weight of Grain}} \times 100 \text{ ....Eq 1}$$

Size

For the measurement of Length (a), Width (b) and Thickness (c), of Kodo grains randomly 25 grains were taken vernier caliper with least count of 0.01 mm was used for measurement of size of grains. Size, also called as equivalent diameter, was measured by using the method recommended by (Sahay and Singh, 2001).

$$D_g = (a \times b \times c)^{1/3} \text{ .... Eq 2}$$

D_g = size, mm
a = Length, mm
b = width, mm
c = Thickness, mm

Sphericity

It is the ratio of the diameter of a sphere of same volume as that of the particle and the diameter of the smallest circumscribing sphere or generally the largest diameter of the particle (Sahay and Singh, 2001).

$$S = (a \times b \times c)^{1/3} / a \text{ .... Eq 3}$$

a = largest intercept
b = largest intercept perpendicular to a
c = largest intercept perpendicular to a and b

Bulk density

Bulk density was determined by filling a measuring cylinder of 100 cc with grains, striking off the top level and then weighing the grains on an electronic weighing balance (Ishida UBH-620E Lab Balance) of accuracy 0.001g. The ratio of weight of the sample and volume occupied by it is expressed as the bulk density, g/cc (Joshi *et al.*, 1993).

$$B_d = W / V \text{ .... Eq 4}$$

Where,
B_d = Bulk density, g/cc;
W = Weight of Kodo, g;
V = Volume of Kodo, cc.

Angle of repose

The angle of repose was measured by slump cone method (Mandhyan *et al.*, 1987). A cylinder was filled up to top with sample and inverted on a plane (paper) surface. The paper was taken out gradually and cylinder was raised vertically, thus conical shape of the material was formed. Angle of repose was calculated by using the following expression: (Sahay and Singh, 1994).

$$\emptyset = \tan^{-1}\frac{2(H_a - H_b)}{D_b} \text{ .... Eq 5}$$

Where,
$\emptyset$ = Angle of repose, °
H_a = height of the cone, cm
H_b = height of the platform, cm
D_b = diameter of the platform, cm

Economic analysis of Kodo Millet De-husker

Rational choice of agricultural machines is necessary as a condition of high efficiency of farm mechanization. When making decision about purchasing of machine the potential buyer takes into consideration several factors. One of most important is the price of the machine. The price determines first of all investment cost, but it also affects such elements of operation costs like depreciation, interest and storage. However, not always more expensive machine creates higher unitary costs. Sometimes operation costs of advanced, more reliable and productive machine are lower as compared to a less expensive, but also less reliable and less productive one. Therefore, the choice of machine should be preceded by a careful economic analysis.

Results and Discussion

Engineering properties of kodo millet

Various engineering properties viz. size, sphericity, bulk density and angle of repose of Kodo millet were determined at 12 and 14% moisture content (w.b).

Size and sphericity of kodo millet

From Table 1 and 2 it is clear that the size and sphericity of Kodo millet increased slightly with the increment in the moisture content. The average length, width, thickness, size and sphericity of Kodo millet at 12% moisture content (w.b) were 2.69 mm, 2.02 mm, 1.31 mm, 1.92 mm and 71.68 % respectively. However, the average values of length, width, thickness, size and sphericity of Kodo millet at 14% moisture content (w.b) were 2.80 mm, 2.39 mm, 1.39 mm, 2.09 mm, and 74.76% respectively. The increment in size and sphericity may be attributed to the presence of moisture inside the kernel causing slight expansion of kernels. Similar trends were observed by (Edward *et al.,* 2002).

Bulk density of kodo millet

Table 3 represents the bulk density of Kodo millet at 12% and 14% moisture content (w.b). It was observed that the bulk density of Kodo millet decreased with increase in moisture content. The average value of bulk density of Kodo millet at 12 and 14% moisture content were 957.23 and 954.81 kg/m3, respectively. It is an important parameter for designing of feed hopper and discharge chute of processing machineries.

Angle of repose for the Kodo millet

The results obtained are presented in Table 4. It is evident from the data that the average value of angle of repose for the Kodo millet increased from 26.23^0 to 26.50^0 with increment in moisture content (w.b.) from 12% and 14%. (Balasubramanian and Vishwanathan, 2010; Shirsat *et al.,* 2008) also observed the increment in angle of repose of Kodo millet with increment in moisture content. Angle of repose of Kodo millet was used to decide angle of inclined surfaces of trapezoidal shaped feed hopper and inclination of de-husking unit.

Performance evaluation of the de-husking unit

For performance evaluation of de-husking unit, Kodo millet was fed to the de-husking unit at 12 kg/hr feed rate. Performance of Kodo millet de-husker, was evaluated at 340, 360, 380 rpm with 1.5 mm and 2.00 mm clearance between the outer indented cylinder and inner rotating de-husking roller.

Selection of feed rate

Feed rate was calculated by measuring the time taken in minutes to pass the Kodo millet through feed hopper having feed slit clearance of 4mm as shown in table 5.

Selection of rotational speed of de-husker

Selection of rotational speed of de-husking roller was decided on the basis of the parameters such as rotational speed of the electric motor, diameters of the motor's pulley and the pulley mounted on the shaft. During trials, it was observed that the maximum de-husking of Kodo millet was at rotational speeds of de-husker 340, 360 and 380 rpm.

Selection of clearance between inner de-husking roller and outer indented cylinder

The clearance between the outer indented cylinder and the inner de-husking roller of Kodo millet de-husker was decided based on the size and sphericity of the Kodo millet.

Effect of rotational speed of de-husker, moisture content, clearance on de-husking efficiency

The de-husking efficiency of Kodo millet de-husker was dependent on speed of rotation of the inner de-husking roller, moisture content of the feed and the clearance between the outer indented cylinder and the inner de-husking roller. Coefficient of wholeness and de-husking efficiency were calculated by using the Eq. 6 and 7 respectively.

Calculation of de-husking efficiency

De-husking efficiency was calculated by following expression:

(De-husking) % = {1- (wt. of unhusked grains /wt. of total grains after de-husking)} × E_{wk} × 100 ………. Eq 6

Where,

Coefficient of wholeness (E_{wk}) = {wt. of whole kernels/ (wt. of whole kernels + wt. of brokens)} …………. Eq 7

Table.1 Size and Sphericity of Kodo millet at 12% moisture content (w.b)

Number of observation	Length (mm)	Width (mm)	Thickness (mm)	Size (mm)	Sphericity %
1	2.40	2.21	1.25	1.87	77.91
2	2.57	2.14	1.58	2.05	79.76
3	2.65	1.95	1.16	1.81	68.30
4	2.67	2.03	1.48	2.00	74.90
5	2.45	2.28	1.32	1.95	79.59
6	2.51	2.29	1.40	2.01	80.07
7	2.45	1.82	1.22	1.75	71.42
8	2.97	2.02	1.23	1.95	65.65
9	2.77	1.97	1.34	1.94	70.03
10	2.84	2.15	1.47	2.07	72.88
11	2.80	1.89	1.38	1.94	69.28
12	2.70	1.72	1.58	1.95	72.22
13	2.76	2.06	1.30	1.95	70.65
14	2.37	2.07	1.29	1.85	78.05
15	2.77	2.15	1.28	1.97	71.11
16	2.67	2.05	1.27	1.91	71.53
17	2.88	1.67	1.02	1.69	58.68
18	2.58	1.73	1.13	1.72	66.66
19	3.00	1.83	1.30	1.92	64.00
20	3.01	2.02	1.33	2.01	66.77
21	2.59	2.38	1.31	2.00	77.22
22	2.78	2.11	1.38	2.01	72.30
23	2.59	1.87	1.26	1.83	70.65
24	2.49	2.16	1.30	1.91	76.70
25	2.99	1.98	1.29	1.97	65.88
Average	**2.69**	**2.02**	**1.31**	**1.92**	**71.68**

Table.2 Size and sphericity of kodo millet at 14% moisture content (w.b)

Number of observation	Length (mm)	Width (mm)	Thickness (mm)	Size (mm)	Sphericity %
1	2.74	2.23	1.45	2.01	73.35
2	2.82	2.38	1.58	2.19	77.65
3	2.76	2.28	1.36	2.04	73.91
4	2.79	2.19	1.48	2.08	74.55
5	2.94	2.78	1.52	2.31	78.57
6	2.61	2.29	1.40	2.03	77.77
7	2.83	2.42	1.32	2.08	73.49
8	2.97	2.62	1.53	2.28	76.76
9	2.77	2.67	1.34	2.14	77.25
10	2.84	2.15	1.47	2.07	72.88
11	2.98	2.29	1.38	2.11	70.80
12	2.70	2.42	1.58	2.17	80.37
13	2.76	2.45	1.36	2.09	75.72
14	2.65	2.26	1.31	1.98	74.71
15	2.77	2.35	1.28	2.02	72.92
16	2.67	2.32	1.27	1.98	74.15
17	2.88	2.41	1.23	2.04	70.83
18	2.68	2.43	1.33	2.05	76.49
19	3.00	2.63	1.43	2.24	74.66
20	3.01	2.19	1.18	1.98	65.78
21	2.59	2.38	1.31	2.00	77.22
22	2.71	2.64	1.21	2.05	75.64
23	2.89	2.37	1.38	2.11	73.01
24	2.74	2.36	1.60	2.17	79.19
25	2.99	2.28	1.45	2.14	71.57
Average	**2.80**	**2.39**	**1.39**	**2.09**	**74.76**

Table.3 Bulk density of Kodo at 12 and 14% moisture content (w.b)

S. No. / M.C. (w.b.)	Bulk Density (kg/m^3)	
	12%	**14%**
1	958.77	955.63
2	956.02	954.77
3	956.93	952.79
4	957.77	954.93
5	956.69	955.95
Average	**957.23**	**954.81**

Table.4 Angle of repose (°) of Kodo millet

S. No. / M.C. (w.b.)	12%	14%
1.	26.58	26.82
2.	26.63	26.64
3.	26.32	25.89
4.	25.81	27.45
5.	25.85	25.72
Average	**26.23**	**26.50**

Table.5 Selection of feed rate

Feed 1 kg	Feed Slit Clearance (mm)	Time taken to pass through feed hopper (min)	Feed rate (kg/hr)
1	4	4 min 58 sec	12.08
1	4	4 min 56 sec	12.16
1	4	4 min 60 sec	12.01
Average			12.08

Table.6 Effect of de-husking roller rpm on the de-husking efficiency of raw Kodo at 12% m.c, clearance 1.5 mm and 2 m

				For Clearance 1.5 mm			
RPM	Feed Rate (kg/hr)	Wt. of Husk (gm)	Wt. of milled kodo (gm)	Wt. of unmilled kodo (gm)	Wt. of Broken (gm)	Coeff. of Wholeness (E_{wk})	Dehusking Efficiency (%)
340	12	115	1225	660	38	0.968	66.13
360	12	123	1257	620	42	0.966	68.01
380	12	133	1270	597	46	0.963	69.20
				For Clearance 2 mm			
340	12	90	1165	745	23	0.980	61.77
360	12	101	1185	714	25	0.978	63.22
380	12	112	1220	668	32	0.973	65.50

Table.7 Effect of de-husking roller on the de-husking efficiency of pretreated Kodo at 12% m.c (w.b), clearance 1.5 mm and 2 mm

				Clearance 1.5 mm			
RPM	Feed Rate (kg/hr)	Wt. of Husk (gm)	Wt. of Milled kodo (gm)	Wt. of Unmilled kodo (gm)	Wt. of Broken (gm)	Coeff. of Wholeness (E_{wk})	Dehusking Efficiency (%)
340	12	120	1280	600	26	0.979	68.70
360	12	135	1305	560	27	0.979	70.60
380	12	144	1320	536	36	0.972	71.90
				Clearance 2 mm			
340	12	112	1246	642	25	0.979	66.70
360	12	122	1258	620	28	0.977	67.74
380	12	134	1268	598	31	0.975	68.75

Table.8 Effect of de-husking roller on the de-husking efficiency of pretreated Kodo at 14% m.c., clearance 1.5 mm and 2 mm

				Clearance 1.5 mm			
RPM	Feed Rate (kg/hr)	Wt. of Husk (gm)	Wt. of Milled kodo (gm)	Wt. of Unmilled kodo (gm)	Wt. of Broken (gm)	Coeff. of Wholeness (E_{wk})	Dehusking Efficiency (%)
340	12	138	1310	552	40	0.969	71.27
360	12	145	1350	505	44	0.967	73.73
380	12	168	1360	472	55	0.959	75.29
				Clearance 2 mm			
340	12	125	1293	582	32	0.975	69.70
360	12	129	1310	561	39	0.97	71.10
380	12	140	1330	530	48	0.963	72.51

Fig.1 and 2 Isometric view of Kodo millet de-husker and developed Kodo millet de-husker

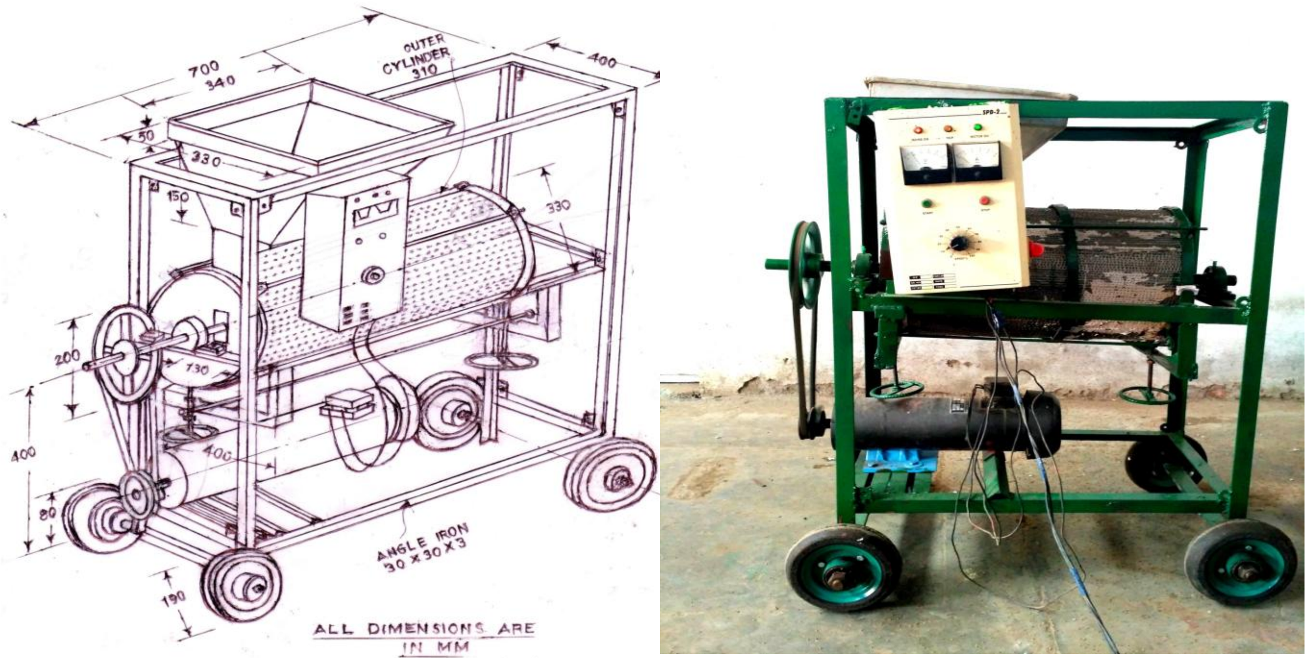


Fig.3 Forces acting on grain in de-husking unit

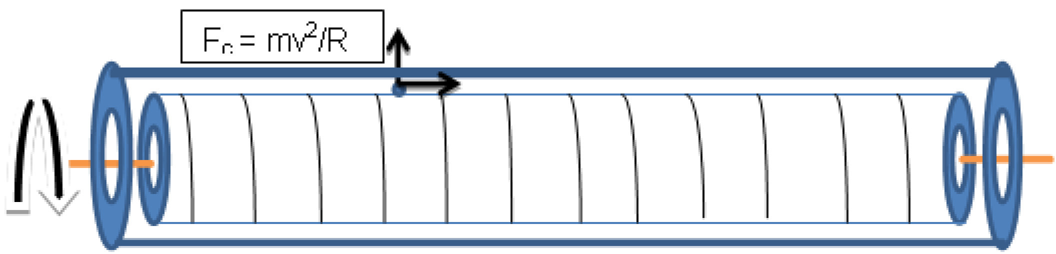


Fig.4 De-husking efficiency of raw Kodo millet at 12% m.c, at 1.5 mm and 2 mm clearance

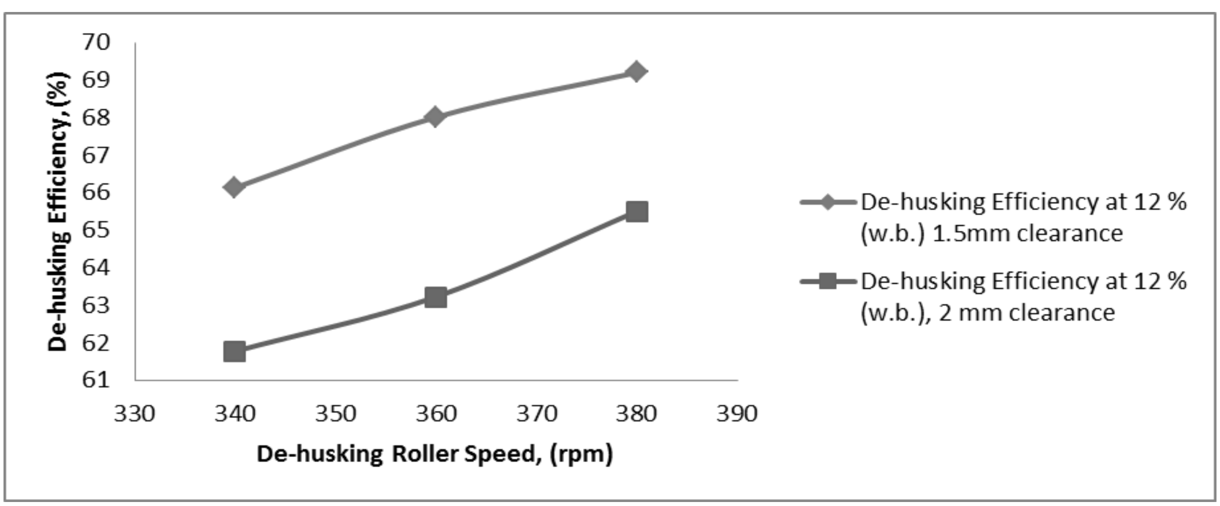


Fig.5 De-husking efficiency of pretreated Kodo at 12% m.c, 1.5 mm and 2 mm clearance

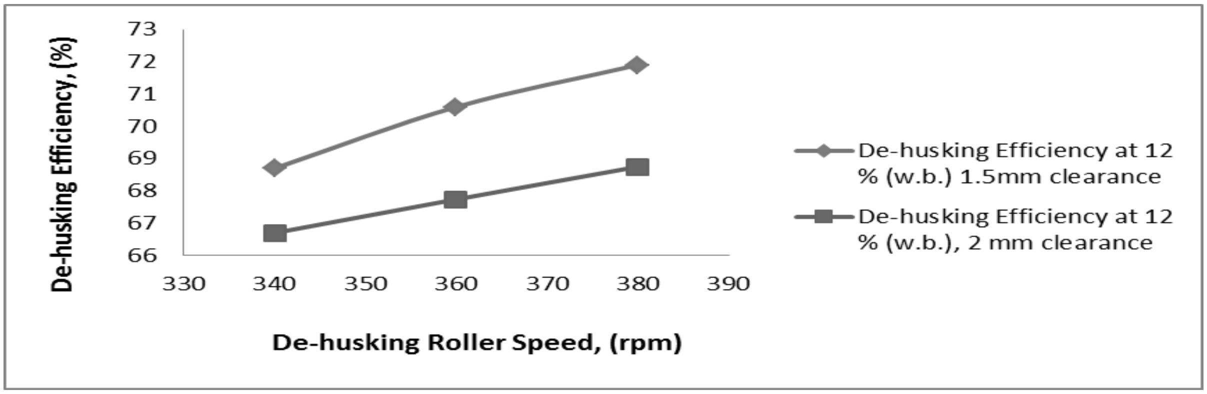


Fig.6 De-husking efficiency of pretreated Kodo at 1 4% m.c (w.b), with 1.50 mm and 2.00 mm clearance

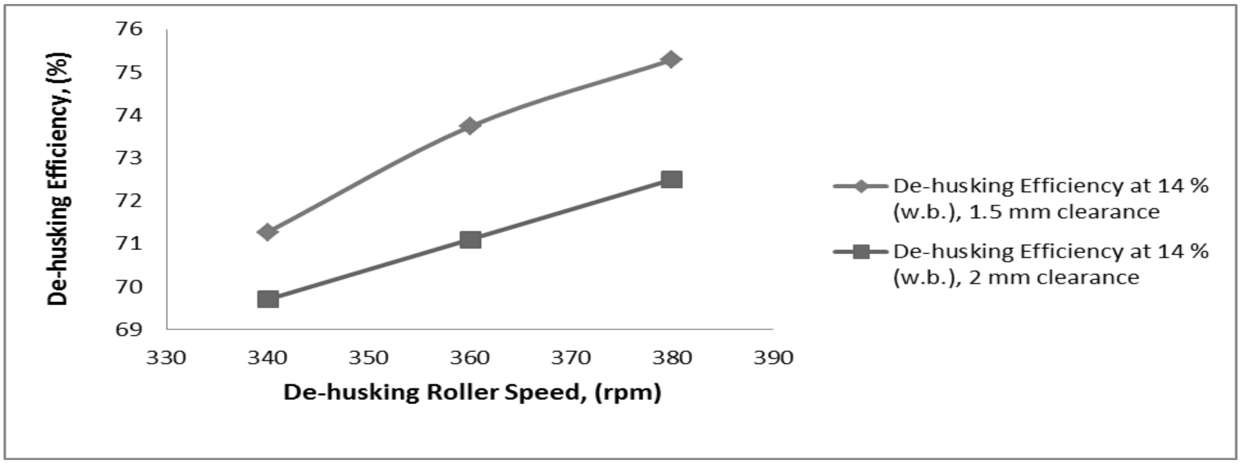
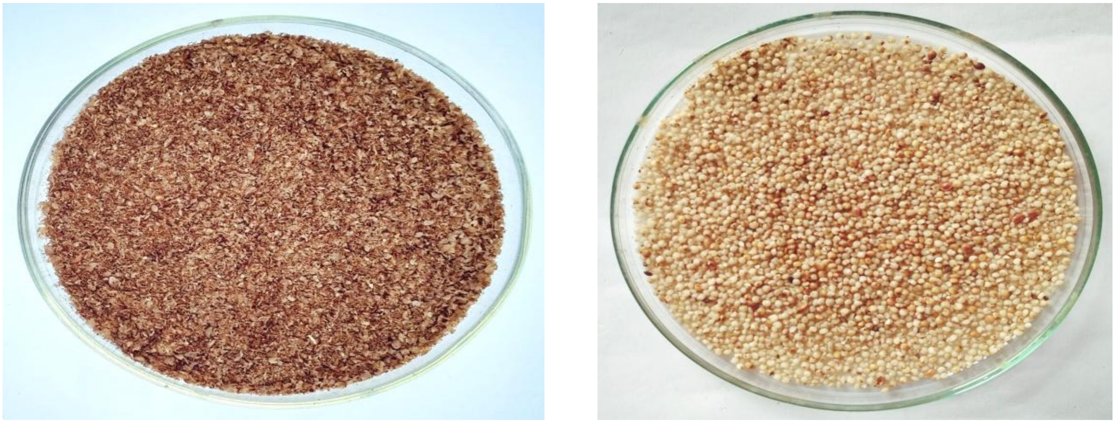


Fig.7 Various fraction of de-husked Kodo millet
(a) Husk Content at 380 rpm, (b) Milled Kodo at 380 rpm



De-husking efficiency of raw Kodo at 12% m.c. at 1.5 mm and 2 mm clearance

From Figure 4, it is cleared that for the same rpm of de-husking roller higher de-husking efficiency was obtained when the clearance between the outer indented cylinder and inner de-husking roller was kept smaller. At 340 rpm the de-husking efficiency was 66.13% and 61.77% when the clearance between the abrasive surfaces was 1.5 mm and 2 mm respectively. The maximum de-husking efficiency 69.2% was obtained at 380 rpm and 1.5 mm clearance between the abrasive surfaces. For a particular speed of de-husking roller the weight of broken decreased marginally when the clearance between abrasive surfaces increased e.g. at 360 rpm of de-husking roller, weight of broken were 42 gm and 25 gm with 1.5 mm and 2.00 mm clearance, respectively (Table 6).

De-husking efficiency of pretreated Kodo at 12% m.c., 1.5 mm and 2 mm clearance

From Figure 5, it is clear that for the same speed of de-husking roller, there was an increment in de-husking efficiency, when the 1.5 mm clearance was maintained between the inner de-husking roller and the outer indented cylinder e.g. at 340 rpm the de-husking efficiency was 68.70% and 66.70% when the clearance between the abrasive surfaces was 1.5 mm and 2 mm, respectively.

The maximum de-husking efficiency (71.90%) was observed at 380 rpm in 1.5 mm clearance between the abrasive surfaces. The weight of broken decreased linearly when the clearance between abrasive surfaces increased at the particular rpm of de-husking roller e.g. at 360 rpm of de-husking roller, weight of broken were 28 gm and 27 gm with 1.5 mm and 2.00 mm clearance, respectively (Table 7).

De-husking efficiency of pretreated Kodo at 14% m.c. (w.b), with 1.50 mm and 2.00 mm clearance

From Figure 4, 5 and 6 it is clear that among all trials conducted the maximum de-husking of 75.29% is obtained at 380 rpm of inner de-husking roller at 1.5 mm clearance as shown in various fraction of de-husked Kodo millet (Fig. 7a) Husk Content at 380 rpm (Fig. 7a, b) Milled Kodo at 380 rpm. For same speed of de-husking roller, there was an increment in de-husking efficiency with an decrement in clearance between the abrasive surfaces, e.g. at 340 rpm the de-husking efficiency was 71.27% and 69.70% when the clearance between the abrasive surfaces was 1.5 mm and 2 mm respectively.

For a particular speed of de-husking roller the weight of broken decreased marginally when the clearance between abrasive surfaces increased e.g. at 360 rpm of de-husking roller, weight of broken were 44 gm and 39 gm with 1.5 mm and 2.00 mm clearance, respectively (Table 8).

Cost analysis of kodo de-husking

Following assumptions have been made when building the model. The maximum hours of machine work during the useful life amounts to 2000. 10 years standard useful life has been assumed.

Therefore, the annual use of least 200 hours was necessary so that each machine could work out 2000 hours during its useful life. In case of annual use higher than 200 hours, the number of years of the useful life becomes relatively lower. Instead, in a case of a lower annual use of machines, the useful life can be prolonged up to maximum 20 years, followed by increase of the coefficient of repair costs related to the price of the machine by 30%.

Input information and assumptions

Cost of machine (Rs.)	- 25000.00
Life of machine	- 10 years
Interest rate (per annum)	- 15 %
Salvage value	- 10 %
Operation time	- 8 hr/day
Semi-skilled labour	- 200 Rs/day
Raw material	- 15 Rs./kg
Power (motor)	- 1.5 KW
Cost of housing	- 500 Rs./month
No. of labour required	- 1
Main product recovery	- 75 %
By product recovery	- 25 %
Market rate of millet de-husking	- 8 Rs./kg
Operation period	- 100 days/year
Electricity charge	- 6.50 Rs./KW-hr
Maintenance cost	- 2000 Rs./year

Financial analysis

Working Capital Requirement (Annual) (Rs.) = Labour Charges for Working Days (Rs./year) + Stock (Rs./year) + Electricity Charges (Rs/year)

= (1× 25 ×12 × 200) + (12 × 8 × 15 × 300) + (300 × 6 × 6.5)

= 503700

Annual Fixed Cost (Rs.) = Depreciation + Interest + Maintenance Cost + Housing Cost + Interest on Working Capital

= (2500 + 3750 + 2000 +6000 + 75555)

Annual Fixed Cost (Rs.) = 89805

Capital investment (Rs.) = Cost of equipment + 30% of working capital

= 25000 + 151110

Capital investment (Rs.) = 176110

Hourly variable cost (Rs.) = 503700/2400

= 209.875

Total annual cost (Rs.) = Annual fixed cost + Annual variable cost

= 89805 + 503700

= 593505

Cost of operation (Rs.) = Total annual cost / working

hour
= 593505/2400
= 247.29

Processing cost (Rs./kg) = (Cost of operation – material cost)/ capacity
= (247.29 – 180)/12
= 5.60

In conclusion, it is clear that among all the trials conducted the pretreated Kodo millet at 14% m.c, (w.b) with 1.50 mm clearance, the maximum de-husking efficiency of 75.29% was determined at 380 rpm, while at 340 rpm and 360 rpm the de-husking efficiency were 71.27% and 73.73% respectively. However, for pretreated Kodo millet at 14% m.c, (w.b) with 2.00 mm clearance, when the speed of de-husking roller increased from 340 to 380 rpm the de-husking efficiency increased from 69.70% to 72.51%. De-husking efficiency of Kodo millet de-husker ranged from 72.5% to 75.29%. Cost of de-husking per Kilogram of kodo millet was Rs. 5.60.

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