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Design and development of maize cob de-husker cum Sheller

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Abstract
A detail survey was conducted in selected district namely Rajnandgaon, Kanker and Kondagaon of Chhattisgarh state, to study on dehusking and shelling of maize under existing machineries or practices. On the basis of survey there is need of a compact dehusking cum shelling unit. A small portable single phase electric operated dehusker cum sheller was design and developed at SVCAET & RS with the help of M/s Punjab Agriculture Engineering, Dhamtari in year 2017-18. The portable medium size (600 kg/h capacity) electric motor (2.24 kW) operated Maize Dehusker cum Sheller was designed to resolve the issue by considering engineering properties of maize. The rectangular shaped machine having overall dimension length (610 mm), width (390 mm) and height (650 mm) made off up 35×35×5 mm angle iron. The selected operational parameters *viz*, cylinder peripheral speed (9 m/s), concave clearance (25 mm) and feed rate (600 kg/h) were studied for machine-performance and seed-quality parameters. The performance of machine under these parameters show the maximum dehusking was observed 99.00% with zero stalk cutting length at 10.63% moisture content, whereas 98.98% was found out at 1.91 m/s roller speed and at 800 kg/h feed rate. The minimum blower loss (1.37%) was obtained with roller speed (1.7 m/s) and at a feed rate of 600 kg/h. The maximum shelling efficiency (>98.86%) was obtained at cylinder speed of 7.35 m/s and feed rate of 800 kg/h at 14.12% moisture content. The minimum broken loss (0.63%) was obtained at 6.62 m/s cylinder speed and 12.14% moisture content. The minimum unshelled grain percentage was found as 1.04 at 6.62 m/s at 12.14%, cylinder speed and moisture content respectively. The seed germination percentage was found in the range of 91.12 to 95.79% for the developed maize dehusker Sheller. Overall machine performance was found satisfactory for maize dehusking cum shelling operation as well as to produce the maize grains for seeding purpose.

Keywords: Design, maize cob, dehusker, dehusking, and shelling

Introduction
Maize (*Zea mays* L.) is an important cereal crop grown all over the world for human and animal consumption. It is called "Queen of cereals" because of its highest genetic yield potential (Sinha *et al.*, 2019) [11] and "King of fodder due to its role in human and animal nutrition. In India, the production of maize witnessed a significant increase of more than 16.6 times from a mere 1.73 million tons in 1950-51 to 28.75 million tons in 2018-19. Presently, it occupies 9.23 million hectares area with the productivity of 2.71 tons/hectare (Anonymous, 2019) [2]. In Chhattisgarh, maize is a *Kharif* season crop and second most important crop next to paddy in terms of both area and production. It occupies 119.63 thousands hectare land with the productivity of 2566 kg/ha in *Kharif* 2017-18. (Anonymous 2020) [1]. One of the most important crop processing activities is threshing or shelling, which is used to extract the grains from the ear heads and prepare the quality for sale. Farmers must introduce advancements in technologies that meet their needs in order to increase their benefit from maize crop. Making maize crop into high-quality types not only increases farmers' net profits, but also extends the useful life of maize products. (Nwakaire *et al.*, 2011) [6]. Maize cobs are manually plucked by hand, and then harvested cobs are dried in the open yard to reduce moisture content by up to 15% to 21% (db). The common shelling and dehusking methods, such as rubbing crop cobs against each other, rubbing on bricks, stone, and wire mesh with an iron cylinder, are time-consuming and drudgery, and crop exposure to natural hazards such as rain, fire, livestock, birds, and insects over time results in losses in quantity and quality of grains. (Naveenkumar 2011) [5]. Dehusking is removing the outer sheath and shelling for kernels from ear heads are also part of maize harvesting. Dehusking is the process of separating the husk from the ear head without damaging the seeds, and shelling is the process of removing the maize kernel from the cob. (Oriaku, *et al.*, 2014) [7].

A maize dehusker cum sheller could be develop, considering the following facts. It should be portable easy to carry from one place to other, electric power operated, as source of power cheap and pollution free, according to crop characteristics and system parameters (Dula, 2019) [3]. The machine could have a capacity of 500 to 800 kg per hour, with optimal dehusking and shelling efficiency, and is best suited for marginal, small and medium farmers.

Materials and Methods

The engineering properties of maize and the details of procedure adopted for design, development, performance evaluation and optimizing operating parameters of Maize Cob De-husker cum Sheller have been presented in this chapter. This work carried out in SVCAET&RS, IGKV Raipur.

Design and Development of Power Operated Maize Dehusker cum Sheller

During the development of power operated maize dehusker cum sheller, it was kept in mind that the equipment should be suitable for small, marginal and medium farmers for output capacity in between 800 to 1000 kg/h. It was also kept in mind that the machine should be operated by a single phase electric motor as it is easily available in state of Chhattisgarh. The machine should be low cost so that the poor farmers could afford it for self use and for custom hiring.

Working principle

A dehusker removes the husk from cob and this is done with the help of two rubber roller rotating in opposite directions and at different speeds, the difference of surface speeds of two rubber rolls develop a shearing force on cob surface resulting in the opening and breaking of husk. Similarly surface of the rubber rolls rotating at lower speed tries to hold the cob but the faster rubber roll pushes the grain resulting in shelling of breaking of husk (Fig.1).

Design of rollers

During survey and study on the morph physical characteristics of the whole maize cob it was found that the maize cob was surrounded with layer by layer with 6 to 20 sheaths attached to stalk. It was assumed maximum number of sheath should be de-husked from the de-husking unit. Following design considerations were undertaken for designing of the dehusker roller

Maximum number of sheath per cob = 20

Required speed of the lugged rubber roller = 20 revolution per sec

If, the retention time from tip of the roller to end was kept 3 second then required speed will be reduced to 1/3rd of required rotation per sec i.e. =20/3=6.67 revolution per second (rps)

Hence the speed of the lugged rubber roller should be kept more than 6.66 rps taking factor of safety of 1.5 times it should be kept at 9 rps = 9x60=540 rpm.

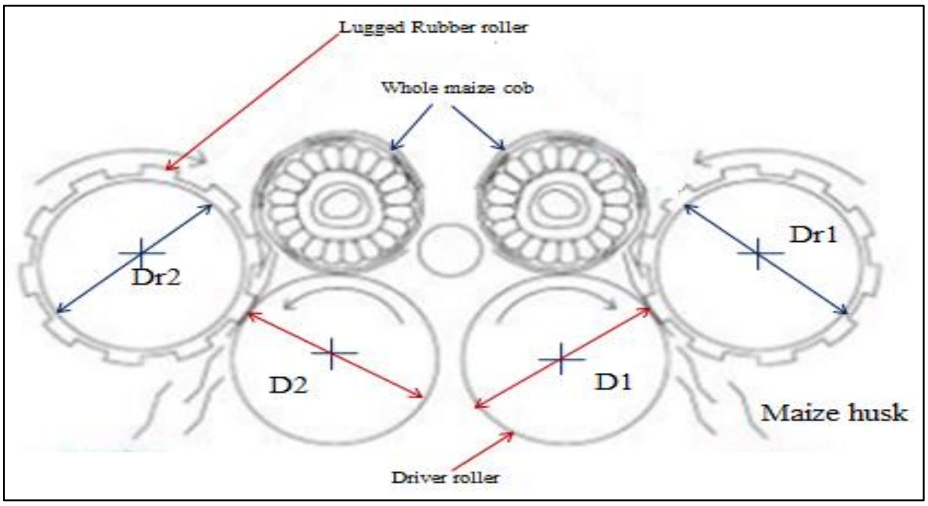

Fig 1: Lugged rubber roller Dehusking mechanism

Rotation per minute for driver screw auger = 540

Rotation per minute for driven screw auger = 540 (as countershaft gear is used)

Rotation for lugged rubber roller attached to the driven as well as driven auger = 540 rpm

Diameter of driver pulley (d_1) = 55 mm

Diameter of driven pulley (d_2) = 290 mm

RPM of driver pulley (N_1) = 3000

The speed of the driven pulley (N_2) was calculated by using Formula given by Khurmi and Gupta (2005) [4] as follows

$$N_2 = \frac{d_1 N_1}{d_2}$$

N_2 = 568

To avoid chocking and move the maize cob in forwards direction a screw type rubber roller is directly in contact with lugged roller. The pitch of driver and driven roller is 80 mm.

Design of dehusker main shaft

The main shaft on which roller and lugged roller are mounted is subjected to torsion loading and bending moment in combination (Fig. 2). Hence, according to the maximum shear stress theory (Guest theory); the equivalent twisting moment of the shaft is given by

$$T_e = \sqrt{\left((K_{m\times}M_p)^2 + (K_t \times T)^2\right)}$$

$$T_e = \frac{\pi \times d^3 \times \tau}{16}$$

Where
T_e = Equivalent twisting moment, N-m;
M_{bm} = Bending moment, N-m;
τ = Torque to be transmitted, N-m;
t = Maximum shear stress of the shaft material, N/m^2;
K_m = Combined shock and impact factors for bending moment;
K_t = Combined shock and impact factors for twisting moment; and
d = Diameter of main shaft, m.

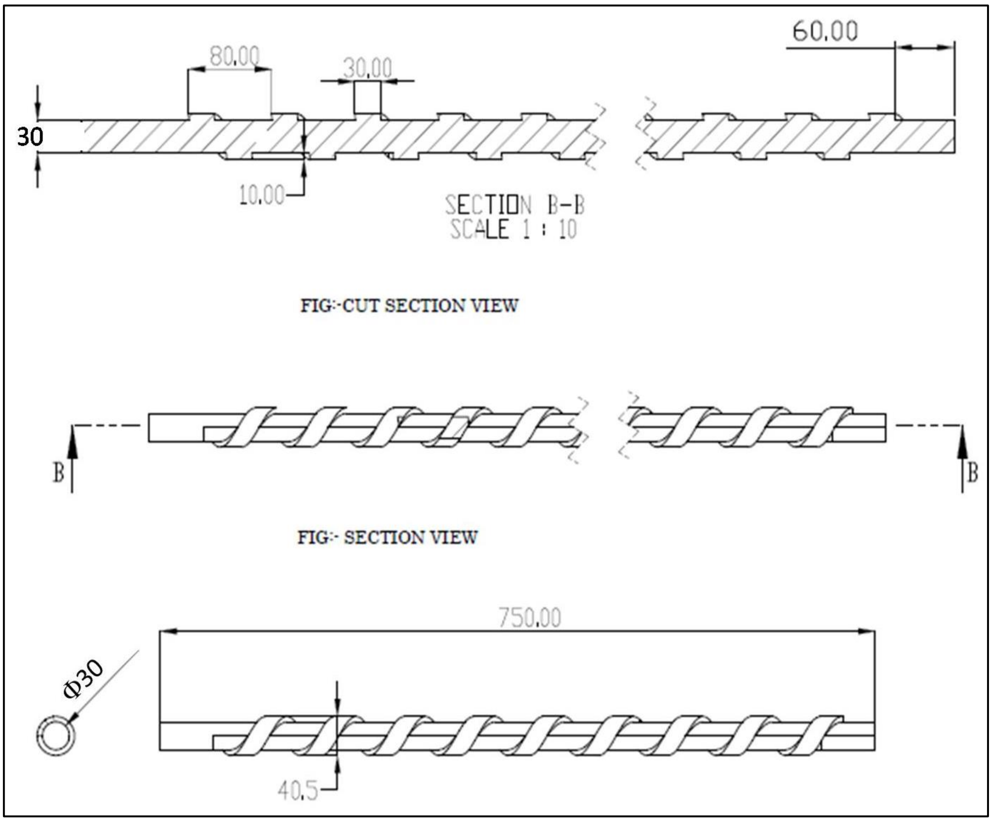

Fig 2: Auto CAD drawing of dehusker main shaft

Length of roller
The length of roller is determining by using Winkler formula given by

$$q = \frac{0.25 \times R_b \times n \times l_d \times k}{1+\delta'}$$

Where
q = Feed rate of thresher, kg/sec;
R_b = Number of pitch;
N = Shaft speed meter per second;
l_d = Length of shaft, m;
k = 0.17-0.32 kg per meter length of shaft; and
δ' = 1/δ =(0.67).
Let k=0.25 kg/m

Therefore, re-arranging the Eq. and putting all values we get

$$l_d = \frac{0.227 \times 1.667}{0.25 \times 6 \times 1.94 \times 0.25} = 0.52 \text{ m}$$

Thus, considering 1.5 times of factor of safety the roller length was kept 750 mm.

Main Frame
For supporting threshing assembly and power transmission unit, a rectangular shaped frame was fabricated of length 610 width 390 mm and height 650 made of 35 mm × 35 mm × 5 mm angle iron. The 25×25× 3 size of MS angle iron was welded across all the members of frame to reinforce the frame. On which dehusking, aspirator cum blower and sheller unit was mounted.

Design of hopper
It was assumed that the volume of feed rate will be carried out at a constant rate of q_v. Hence, if the feeding interval is assumed to be two minute i.e. retention time required for next feeding.
Volume feed rate of maize cobs, (q_v)

$$q_v = \frac{q}{\rho_b} \times 60 \times t$$

Where
q_v= Volume feed rate of maize cobs, m^3/min;
q = Feeding rate kg/s; and
ρ_b = bulk density of maize cob, kg/m^3.
t = Retention time at hopper manually (i.e. 30sec)

Top cover
In order to enhance the easy flow of the maize cobs along with husk which create more abrasion, the top cylinder cover was made in trapezoidal shape using MS sheet of having size (LWT) of 750 ×310 × 1.5 mm. Holes were provided to avoid vacuum during dehusking and a stopper was attached at the end to increase the retention time (Fig. 3).

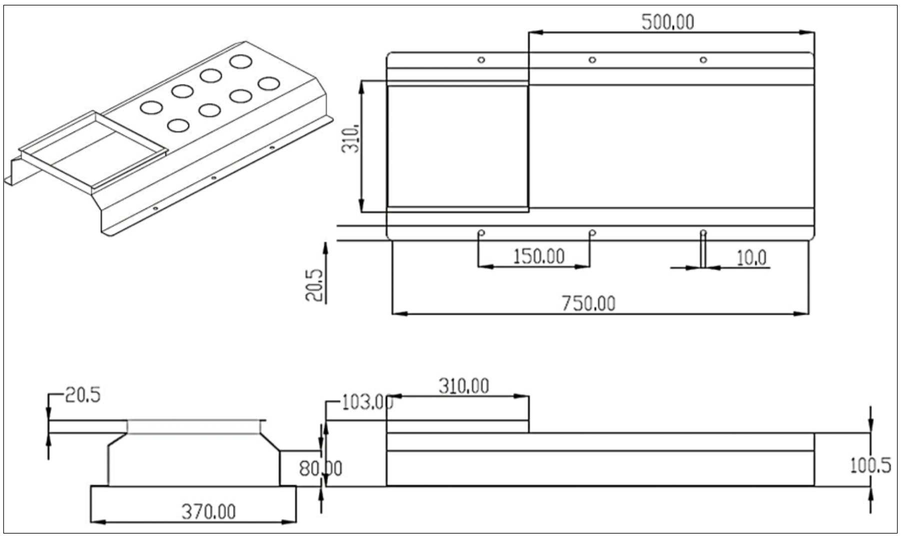

Fig 3: Top cover of dehusking unit

Aspirator cum blower

The requirement of the air discharge through a aspirator blower can be estimated as following formula in terms of, (D) and (B_w). Therefore, actual air flow rate (Q_A) can be estimated as mentioned by Joshi (1981).

$$Q_A = A_v \times D \times B_w$$

Where

Q_A = Quantity of air discharge.m^3/s;
A_v= Air velocity, m/s;
D = Depth of air stream cleaning; and
B_w = Width over which air is required for cleaning, m

Shelling cylinder

After dehusking the de-husked maize passes through the threshing zone between the axial flow cylinder and the concave. The shelling unit consists of impact type beater i.e. peg type. This feature of the axial flow threshing technique allows for additional retention time during continuous feeding. When designing the cylinder, the varied engineering properties of maize cobs and grains.

The length of cylinder of axial flow maize sheller was decided by using following equation given by Singh, (2010) [9].

$$q = q_o\, lM$$

Where

q = Feed rate, kg/s;
q_0 =Permissible feed rate, kg/s;
l= Cylinder length, m; and
M =Number of beaters.

Determination of shelling cylinder diameter

On the basis of review the recommended cylinder speed of shelling cylinder for maize crop is 9 m/s (Varshney *et al.*, 2004) [12]. Considering the average value for design of shelling cylinder is 9 m/s.

The peripheral speed, u is given by

$$u = \frac{\pi D_C N_C}{60}$$

Where

D_c= diameter of the cylinder, m, and
N_c = cylinder speed, r/min

Design of peg cross-section

The peg attached is subjected to different kinds of forces while engaged in threshing action. The pre-dominant forces are caused due to bending and twisting moments. The effect of these forces is considered here to determine the section of a peg for the design of the threshing cylinder. From the available literature, a round section of peg is selected for its effective threshing of maize crop.

Design of shaft when subjected to twisting moment

Shaft of diameter determine using equation;

$$\frac{T}{J} = \frac{\tau}{r}$$

Where,
T = Twisting moment (or torque) acting upon the shaft, N-m;
J = Polar moment of inertia of the shaft about the axis of rotation, m^4;
τ = Torsional shear stress.
(Value of τ taken as 42 MPa for mild steel, Khurmi and Gupta, 2005) [4],
r = Distance from neutral axis to the outer most fiber (d/2 Where d is the diameter of the shaft)
We know that for round solid shaft, polar moment of inertia,

$$J = \frac{\pi}{32} \times d^4$$

d =22 mm

Design of shaft when subjected to bending moment

Bending moment on shaft, then the maximum stress (tensile or compressive) is given by the bending equation.

$$\frac{M}{I} = \frac{\sigma_b}{y}$$

Where

M = Bending moment (59802 N-mm taken from bending moment);
I = Moment of inertia of cross-sectional area of the shaft about the axis of rotation;

σ_b = Bending stress (100 N-mm (Khurmi and Gupta, 2005) [5]; and
Y = Distance from neutral axis to the outer-most fibre.
D = 24 mm
The sheller shaft subjected to twisting and bending moment were found to be 21 mm and 24 mm. considering factor of safety 1.5 times, 35 mm diameter shaft was taken for shelling cylinder.

Impact force experienced by a peg during threshing
According to Goryachkin drum theory (1936), the energy required to thresh by impact is given by

$$N_1 = \frac{qu^2}{(1-f)}$$

Where
N_1 = Energy required to thresh, N-m;
q = Feed rate, kg/s;
u = Peripheral speed, m/s, and
f = Wear coefficient (0.7 - 0.9).
Hence the impact force is

$$P_1 = \frac{N_1}{u}$$

Where,
P_1= Impact force, N;

$$P_1 = \frac{0.277 \times 7.21}{(1-0.9)} = 19.9\text{N}$$

Concave assembly
The concave component is positioned on the bottom side of the cylinder and provides space for maize shelling. It is made up of three bend (half circle) MS flats (25x5 mm) for support, square rods (8x8mm), and two MS flats (25x5 mm) on both top surfaces to reinforce the frame. Four equal portions of 8 mm × 8 mm square rods for a total length of 580 mm were welded onto the inner surface of the flat along the cylinder rotation axis. The square rods were added to increase the amount of friction on the cobs, which also aided in the removal of the grain and husk. On the upper four corners, the entire concave was supported (Fig. 4). The bottom of the concave was fitted with a 600mmx 20 mmΦ perforated sieve for easy grain discharge.

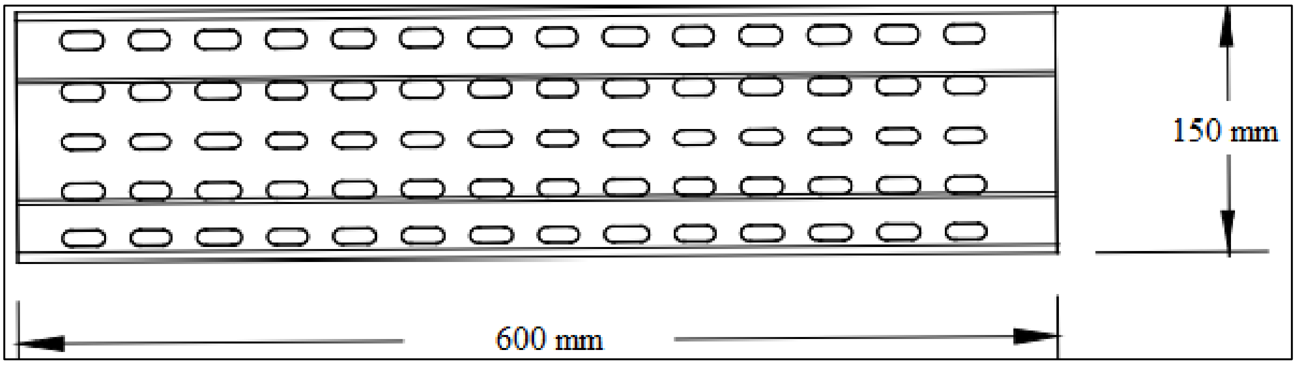

Fig 4: Concave drawing fitted in maize shelling unit

Power Source
The power source was selected on the basis of output capacity and cylinder speeds. As the capacity and speed increases power requirements also increases (Singh *et al.*, 2011) [10].
The power requirement for the de-husker cum sheller was calculated by using formula given by Sharma, (2007) [8].

$$P = \left[\frac{\frac{q(v_2-v_1)v}{1-C_f}+mv+mv^3}{1000}\right]$$

Where
P = Power requirement for operation of thresher, kW;
q = Feed rate, kg/sec;
v_1 = Initial velocity of plants, m/sec≅3m/sec;
v_2 = Velocity of plants mass after impact;
v = Peripheral velocity of threshing drum, m/sec i.e 8.66m/s;
C_f = Coefficient of friction between straw and thresher ≅ 0.6 (assume);
m = A constant ≅ 0.85-0.9 N per 100 kg weight of threshing drum; and
n = A constant ≅ 0.065 N-sec^2/m^2.
Velocity of maize after impact (v_2) given by

$$v_2 = \alpha \cdot v$$

Where
α = 0.7 to 0.85; and
v = peripheral velocity of threshing drum, m/sec i.e 8.66m/s.
P = 2.1 kW

Hence, after calculating the power requirements for prototype the selection of the power source was done as per availability of higher side i.e. 2.24 kW electric motor for maize dehusker cum sheller unit (Chaudhary, 2016 and Chillur and Kumar 2018). All the parts of developed maize dehusker cum sheller were shown in Fig. 5

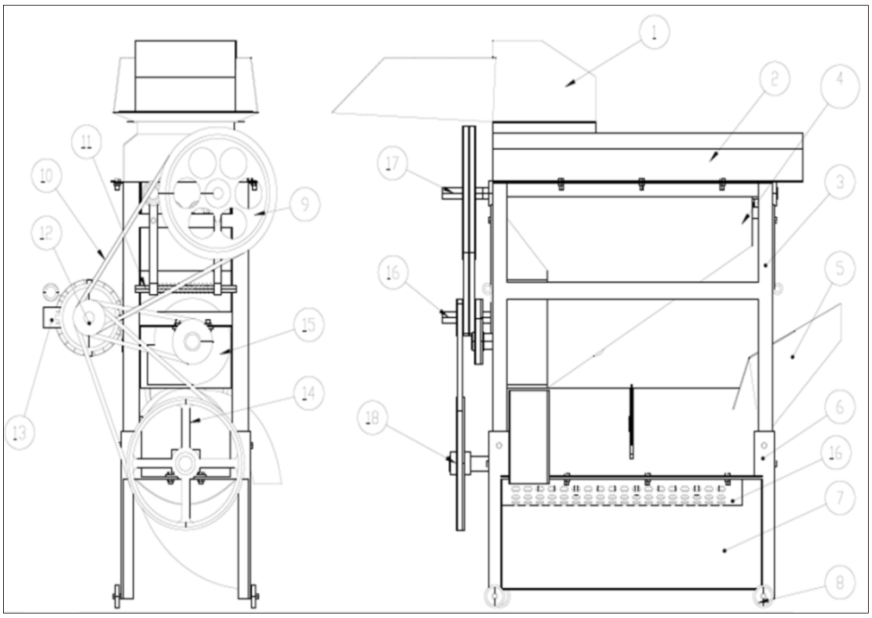

Fig 5: Maize dehusker cum Sheller

(1) Dehusker Hopper
(2) Top cover
(3) Main frame
(4) Husk collector
(5) Sheller hopper
(6) Concave setting
(7) Concave assembly
(8) Wheel
(9) Dehusker pulley
(10) 'V' Belt
(11) Roller tension setting
(12) Main pulley
(13) Electric motor
(14) Sheller pulley
(15) Aspirator cum blower
(16) Motor shaft
(17) Roller shaft
(18) Sheller shaft

Results and Discussion

To address the problem of shortage of labor and high cost machinery in rural and semi urban areas, manual implement is required. So, a single phase electric operated maize shelling and dehusking machine was developed which would be easy to operate and require low maintenance and simultaneously overcome the problems of food safety and hygiene.

The machine was electric operated and could be operated at various speeds. Diameter of driver pulley (d_1) = 55 mm, Diameter of driven pulley (d_2) = 290 mm, RPM of driver pulley (N_1) = 3000. To avoid chocking and move the maize cob in forwards direction a screw type rubber roller is directly in contact with lugged roller. The pitch of driver and driven roller is 80 mm. Considering factor of safety 1.5 times we select roller main shaft is 30mm. The roller length was kept 750 mm. The designed volume of hopper is suitable for handling the desired volume of maize cob (v = 0.027m^3. As, $v > q_v$). The length of cob, number of pegs fixed alternately in each row 6 and 5 numbers on shaft act as threshing element of prototype. The peg consecutive distance in each rows was fixed as 100 mm. The pegs were arranged in zigzag manner on rows. Dimension of each round peg was of 15mm × 50 mm. The cylinder diameter including pegs is 280 mm. The sheller shaft subjected to twisting and bending moment were found to be 21 mm and 24 mm. considering factor of safety 1.5 times, 35 mm diameter shaft was taken for shelling cylinder. The energy required to thresh by impact is 19.9 N. The power requirements for prototype the selection of the power source was done as per availability of higher side i.e. 2.24 kW electric motor for maize dehusker cum sheller unit. Hence a pulley of 300 mm size was selected and provided on the roller shaft.

The effect of stalk cutting length and moisture content on dehusking was evaluated in threshing yard with rubber roller mechanism with four level of moisture content as main factor *viz*. 9.42, 10.63, 11.48 and 12.93% (db) and four levels of stalk cutting length, 0, 15, 30 and 30mm and above. The dehusking efficiency was found to be increases as moisture content of husk increased from 9.42 to 10.63 m/s, but it decreases after 10.63m/s. whereas, with increase in moisture content from 10.63 to 12.93%. The data indicates that the dehusking efficiency ranged from 96.00 to 99.00 per cent within the range of variable studied. The highest dehusking efficiency was achieved 99.00% when the machine

The machine was tested with three level of roller speed as main factor *viz*. 1.7, 1.91, and 2.08 m/s and three level of feed rate 600, 800, 1000kg/h. The dehusking efficiency was found to be increased as roller speed increased from 1.7 to 1.91m/s, but it decreases after 1.91 m/s. whereas, with increase in feed rate from 600 to 800kg/h, it increases significantly (α=0.05). The data indicates that the dehusking efficiency ranged from 97.35 to 98.98 per cent within the range of variable studied. The highest dehusking efficiency was achieved 98.98% at 1.91 m/s roller speed when the machine was set at 800kg/h feed rate. Whereas, lowest dehusking efficiency was recorded at 2.08 m/s roller speed at 600 kg/h feed rate. Similar type of observation was found by Oriaku *et al*. 2014 [7].

The machine was tested with three level of cylinder speed as main factor and three level of feed rate to study the effect of the independent parameters on shelling efficiency. The shelling efficiency was affected with cylinder speed and feed rate (Chilur and Kumar 2018). The shelling efficiency was found to be increased with increase in cylinder peripheral speed from 6.62 to 7.35 m/s, but decreases after 7.35 m/s. Whereas, with increase in feed rate from 600 to 800 kg/h, the shelling efficiency increase significantly (α=0.05) but decrease after 800kg/h. The data indicates that the shelling efficiency ranged from 98.05 to 98.86 per cent within the range of variables studied. The highest shelling efficiency was achieved 98.86per cent at cylinder speed of 7.35 m/s when the machine was set at feed rate of 800 kg/h. Many researchers have found a similar trend in threshing of different crops including maize, Singh, 2010 [9], Akubuo, 2002 and Aremu *et al*. 2015.

Conclusions

1. A prototype for maize dehusking cum shelling unit was developed successfully with 30 mm concave clearance, 7.35 m/s cylinder speed, 1.91 m/s roller speed and works efficiently for dehusking cum shelling of maize cobs.
2. The maximum shelling efficiency (>98.86%) was obtained at cylinder speed of 7.35 m/s, feed rate of 800 kg/h at 14.12% moisture content.
3. The maximum dehusking was observed 99.00% with zero stalk cutting length at 10.63% moisture content roller speed whereas 98.98% was found out at 1.91 m/s roller speed and at 800 kg/h feed rate.

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