Design and development of multi-crop thresher for North-western Himalayas

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ABSTRACT: Threshing is still a big problem for the majority of farmers in the hilly region. It is a process to detach and clean the grains from the ear head of crop plants. Grain threshing can either be done mechanically or by traditional methods. The traditional process of threshing of crops like wheat, rice, millet etc. is done by hands in which bunch of crop-panicles are beaten against a hard element like a wooden log, plank, bamboo-table, stone etc. This process involves lots of drudgeries, wastage of time and losses. Therefore, a unique multi-crop thresher has been developed and tested for threshing, separating and cleaning various crops. The machine was designed to be powered by one hp single phase electric motor. It can be used for threshing of all major crops being grown in the North-Western part of Himalayas. Threshing capacity of the machine for wheat, paddy, barnyard millet, finger millet and amaranth, was observed as 34, 75, 58, 54, and 30 kg/h, respectively. However, threshing efficiency for these crops was found to be greater than or equal to 98%. Cleaning efficiency for the above crops was more than 95%. This multi-crop thresher would benefit hill and small farmers by not only saving their time and labour but also increase the productivity of hill farmers and reduce the drudgery involved in the manual/traditional threshing operations.

Key words: Cleaning efficiency, hills, lightweight, multi-crop thresher, threshing efficiency

In the hilly region of North-western Himalayas, about 70% population is living in rural areas and depends directly or indirectly on agriculture. The region is suitable for cultivation of a wide range of agri-horticultural crops with a great potential for development. But the level of farm mechanization in the state is inferior with respect to the use of mechanical power and efficient tools and implements by the farmers. The undulating topography, small and irregular size of fields, lack of skilled manpower, inadequate facilities of repair and maintenance, the weak purchasing power of farmers and unavailability of improved farm machines and implements are some of the main reasons for the low level of mechanization in this region (Singh, 2014). About 91% operational holding falls under small and marginal (< 2 ha) category in the state. Threshing is a major process that is carried out after harvesting of grain crops. It involves the beating of the grains from the stalk (Nkama, 1992).

Threshing is still a big problem for the majority of the farmers in these hills. Grain threshing can either be done mechanically or by traditional methods. Traditional threshing of crops like wheat, rice, millet etc. is generally done by hands in which bunch of crop panicles are beaten against a hard element (e.g. a wooden bar log, plank, bamboo-table, stone etc.). In many countries of Asia and Africa, the crop is threshed by treading under feet by humans or animals. This results in some losses as the grains are broken or buried in the earth (Food Agency Organization, 1995). Hence, these traditional methods have been found to be uneconomical, time-consuming, energy-intensive (19.9 kJ/min), laborious and drudgery prone (Joshi, 1981, Hen, 1981, Singh *et al*., 2010, 2011 and 2015).

Mechanized threshing can reduce the drudgery of farmers and improve the quality of product. Different types of small, medium and large threshers are in existence for a long time. Of these threshers, some are hand-held, while others are pedal-operated. But due to heavyweight and poor performance, they have not been adopted to a significant extent (Chabrol *et al*., 1996). Hence, agricultural machinery utilization is very low. With the poor socio-economic condition of hill farmers, the large capacity threshers are inappropriate, and even the small size thresher with large scale sophistication is challenging for adoption. A number of studies have been done for threshing of various crops worldwide, but very few studies have reported about multi-crop threshers. Therefore, the development of thresher for all major crops was found necessary which can do threshing of these crops grown in hills.

Most of the farmers are small or marginal and cannot afford to procure large capacity threshers or a separate machine for different crops. They require low cost and light-weight machine, which can perform threshing for almost all major crops, like millet, paddy, wheat and amaranth. The main objective of this research work was to design and develop a machine for threshing of multiple crops being grown in hills.

MATERIALS AND METHODS

Physical properties of crops are very important for the design and development of the machine. Bhattacharya *et al*. (1972) studied the physical properties of paddy and rice. Tabatabaeefar (2003) studied moisture-dependent physical properties of wheat. Singh *et al*. (2010) studied the physical properties of barnyard millet. Baryeh (2002) evaluated different physical properties of millets and expressed as a function of moisture content between 5-22.5%. Abalone *et al.* (2004) studied the physical properties of amaranth seeds, while Kram and Szot (1999) studied its aerodynamic and geometric properties. The important crop/grain-related design parameters of multi-crop thresher such as mean diameter, moisture content, 1000 grain weight, bulk density, sphericity, angle of repose, terminal velocity, dynamic angle of repose, coefficient of static friction, etc., were collected from the review of available literature. Based on these parameters, the design of major components of the thresher has been finalized. The material of construction was carefully selected based on strength, availability, durability and low cost.

Machine Description

This thresher is comprised of three main units: the feeding unit, the threshing unit and the cleaning unit.

Feeding unit – It is hold on type thresher. The cutting mechanism is attached on a hopper and a provision has been made to allow only earhead into the threshing cylinder. A hinged plate in the feed hopper helps in stopping the grain shooting out through feed hopper during threshing.

Threshing unit - Threshing mechanism consists of a threshing cylinder and a concave. Threshing cylinder has a spike tooth with blades, wire loop and rasp-bar having canvas belt. For wheat threshing, multi-crop thresher fitted with a threshing cylinder of 340 mm diameter having spike tooth with blades, wire loop and rasp-bar having canvas belt. Round shaped 10 mm diameter spikes (36 Nos) are bolted in six rows with a single blade in each row on the drum. For minor millets and amaranth threshing, a threshing cylinder with rasp-bar having canvas belt for rubbing action was fabricated with an angle of 40×40×5 was used on the periphery of the cylinder. For paddy threshing, 48 wire loop of 4 mm diameter is bolted in six rows on the periphery of cylinder drum.

The cylinder top cover is semicircular and is made of mild steel sheet. Rods of 6 mm diameter are welded on the inner side of cover parallel to the axis to act as rubbing base for threshing of the crop. The concave made of 6 mm square bar with 9 mm gap, is fixed beneath the cylinder. Total 38 concave rods are welded equally spaced of 9 mm gap.

Cleaning unit: The cleaning unit consists of the blower and sieve shaker. An aspiratory blower is provided on a separate shaft behind the threshing cylinder. Straw and chaff from the top sieve are sucked by the blower and blown away to one side. Sieve shaker consists of two sieves with separate outlet and is suspended below the cylinder concave assembly on the main frame, through hangers. It is oscillated by an eccentric drive with provision for altering the amplitude of oscillations. The top sieve separates the heavier pieces of straw from grain and can be changed as per crop. The grain passes through the top sieve to middle sieve, which separates the grain from fine material and clean grain flows out from middle sieve outlet. Fine material passing through the middle sieve is collected at the bottom outlet.

The multi-crop threshing machine was designed to be made up of the following major parts.

i) Hopper: It is the part where the crop panicles are being fed into the threshing drum. The cutting mechanism is there, which consists of a circular blade that is attached on a separate shaft. The circular blade cuts the crop earhead; the only earhead enters into the cylinder. It is made of galvanizing material.
ii) Threshing chamber: It is the part where the grains are beaten out of the panicles and separated from the bulk of the straw.
iii) Threshing drum: It is the part made of galvanized material and it is housed inside the threshing chamber. It is made of mild steel material, has a length of 300 mm and diameter of 340 mm. A unique threshing drum has been developed, which consist of spike tooth with blades, wire loop and rasp-bar having a canvas belt (Figure 1). It accommodates the shaft on the concave with a clearance of 6 mm. The shaft rests on ball bearings of each end. Attached to one of the ends of the shaft is a pulley for the drive.
iv) Cleaning chamber: This is made up of two sieves that undergo to and fro motion and centrifugal fan which blows air into the sieves. Whilst the grain is moving over these sieves the air which is being blown through them disallows settling of trash on the sieve and anything lighter in weight than the grains.
v) Blower housing: It is made of mild steel. It accommodates the blower blade and the shaft. It has a length of 0.30 m and diameter of 0.244 m.
vi) Screen: It is the part that is made of mild steel material. It is concave in shape and perforated, with 0.30 m length and 0.232 m diameter.
vii) Power transmission system/Drive and driven assembly: This assembly consists of single-phase electric motor of one hp with shafts and pulleys unit, which is connected by a V-belt. A 3-step V-grooved pulley is fitted on a motor shaft and cylinder shaft. The smallest diameter step, i.e. 50 mm drives sieve mechanism through a V-belt and 203 mm diameter

pulley, fitted on sieve shaft. The second 76 mm diameter step on motor pulley drives blower mechanism through a V-belt and 127 mm diameter pulley, fitted on blower shaft. The third 101 mm diameter step on motor pulley drives cylinder through a V-belt and 127 mm diameter pulley, fitted on the cylinder shaft.

Working mode of the machine

A multi-crop thresher was developed for threshing of wheat, paddy, amaranth, and millets crops. The major components of the machine include threshing, separation and cleaning units. Threshing of different crops needs different principle. Wheat requires cutting and impact, paddy requires beating action, millet requires impact and abrasion and amaranth requires abrasion. Threshing of the wheat crop requires a large force. However, threshing of wheat earhead will require less force/moment. Threshing drum consists of spike tooth with a blade for wheat threshing, wire loop for paddy threshing and rasp-bar having canvas belt for threshing of millet and amaranth. For wheat, the threshing operation is achieved by the rotational motion of a cylinder fitted with spike tooth (pegs) with the blade above a stationary grid which results in the removal of the grains from the panicles and their separation from the bulk of the straw. After being beaten out, the grains fall through a concave grid into the cleaning unit which consists of two sieves that undergo reciprocating motion. Whilst the grains are moving over these sieves, a constant blast of air is being sent through them which blow out materials that are lighter than the grain. The machine was designed to be powered by a one hp single phase electric motor. The motor provides power to the threshing drum shaft. As the crop panicles are being fed into the threshing drum through the hopper, the grains are beaten out of the panicle and separated from the bulk of the straw. This is done by a cylinder fitted with beater pegs (for wheat) that rotates above a stationary grid known as a concave. The concave is also fitted with bars throughout its width, and it is between these bars and pegs of the cylinder that the grains are beaten out. The bulk of the grain falls through the concave grid into the cleaning unit which consists of two sieves that undergo to and fro shaking motion and a centrifugal fan blows air into the sieves. The top sieve helps to retain the chaff and allows the passage of the grains into the bottom sieve, called the grain sieve, which has holes that are of the grain size diameter. The purpose of the grain sieve is to carry out further separation of grain from trash, sand and broken grains. Whilst the grain is moving over these sieves the air which is blown through them from the blower disallows settling of trash and materials lighter in weight than the grains on the sieve. The grain pans beneath the grain sieve convey the grain (which are quite free from impurities) to the clean grain outlet for collection while the other pan transfers the broken grains and other materials that are smaller than the grain to the other outlet. It was tested to thresh, separate and clean the crop seeds of wheat, paddy, amaranth, and millets.

Design analysis

The design analysis was carried out with a view to evaluate the necessary design parameters, strength and size of materials for consideration in the selection of the various machine parts in order to avoid failure by excessive yielding and fatigue during the required working life of the machine.

Design of threshing drum:
Determination of the threshing drum diameter and length of drum

Crop	Cylinder speed (m/s)	Cylinder speed (rpm)
Wheat	20-30	550-1100
Paddy	16-25	675-1000

(Source: Is 9019-1979)

Crop	Cylinder speed (m/s)	Concave clearance (mm)
Wheat	21	10-15
Paddy	16	15-25
Millet	9	10-15
Sunflower (Amaranth)	11	15-20

(Source: Data book for agricultural machinery design, Varshney, 2004)

For multi-crop thresher peripheral speed of cylinder

As we know that, $v = \frac{\pi \times D \times N}{60}$

The diameter of the drum (D) is calculated by considering the peripheral speed of drum (N, rpm) for wheat, paddy, millets and amaranth crops. Also considering lightweight, the diameter of the drum is taken 340 mm.

Length of drum

The number of teeth or pegs N_p on the drum depends upon is working length

$$N_p = P\left(\frac{l_d}{a} + 1\right)$$

Where, N_p = Number of spike tooth or Pegs
a = Distance between adjacent path of the teeth, mm = 25 to 29 mm
P = Number of pitch of helix over which the teeth/pegs are located
l_d = Length of drum

Number of pitch of helix P is equal to half number of crossbars
Number of cross bars for Spike tooth $C_b = 6$

So number of pitch of helix $P = \frac{C_b}{2}$

By calculating length of drum is obtained 300 mm.

Design of Concave

The length of the concave is taken same as the length of the cylinder generally. But to increase efficiency and reduce losses, the length of the concave is taken little larger than the length of the cylinder. Length of concave is taken as 318 mm.

Surface area of concave:

$$\frac{\text{Arc length}}{\text{radius}} = 110 \times \frac{\pi}{180}$$

(radius = D/2)

$$\text{Arc length} = \frac{\text{radius}}{180} \times 110 \times \pi$$

Surface area = Arc length x length of concave

Determine the feed rate (q) of thresher on the basis of grain output and straw grain ratio (δ)

Using the relationship,

$$\delta = \frac{q_s}{q_g}$$

Where, δ = straw grain ratio
q_s = straw output
q_g=gain output

Let us calculate the feed rate for an output of 50 kg/h grain having straw gain ratio of 1.5.

$q_s = \delta \times q_g$
$= 1.5 \times 50 = 75$ kg/h

Feed rate $q = q_s + q_g$
$= 75 + 50 = 125$ kg/h $= 0.035$ kg/s

Power requirement of threshing:

$\mathbf{F = F_c + F_r}$ ………………………..............……… (1)

Where, F = Force needed for threshing the crop, N
F_c = Impact force of cylinder, N
F_r = Friction force, N

$F_c = q \times V$
$F_r = f \times F$

Where, f = Wearing coefficient (0.65 to 0.75 for rasp-bar)
Put the value of F_c and F_r in equation (1)
Therefore, $F = [q \times V/(1\text{-}f)]$

$P_1 = FxV = [q \times V^2/(1\text{-}f)]$ ……………….. (2)
$P_2 = A \times V + B \times V^3$ ……………….. (3)

Total power requirement, $P = P_1 + P_2 = [q \times V^2/(1\text{-}f)] + A \times V + B \times V^3$

Where, P_1 = Power required to overcome the useful resistance, W
P_2 = Power required to overcome the idle resistance, W
A = 0.8 to 0.9 N per meter length of rasp-bar
B = Coefficient that characterizes the shape of drum, density of air, and size of rasp-bar (0.065 $N.s^2/m^2$ per meter length of rasp-bar for D = 550mm)

Force analysis:

Impact forces experienced

$$F = \frac{N}{v} = \frac{q \times v^2}{(1 - f) \times v} = \frac{q \times v}{(1 - f)}$$

Where, q = feed rate of thresher, kg/s
v = peripheral velocity of threshing drum
f = wear coefficient (0.7 assume)
= 0.7-0.8 for peg tooth; 0.65-0.70 for rasp-bar

This force is assumed to be increase 8-10 times
$f_d = f \times 9$

The bending & twisting moment's
$m_{bc} = f_d \times lss$

Where f_d = design impact force, N
lss = length of strip support, mm

Design of shaft:

Design of drum shaft:

For hollow tube shaft the tube diameter is calculated from classic equation (Hen, 1981)

$$do^3 = \frac{16}{\pi \times Ss \times (1\text{-}k4)} \sqrt{\left\{\left[Cm \times M + \frac{F \times d_o \times (1+k2)}{8}\right] + (Ct \times T)^2\right\}}$$

Where, do = Tube outside diameter, mm (50)
di = Tube inside diameter, mm
k = do/di = 1.4
M = Bending moment, N-mm
Ss = Permissible shear stress, N/mm^2 (350)
T = Torsion moment, N-mm Cm,
Ct = Coefficients

As we know section modulus

$$Z = \frac{M_b}{\sigma_b}, \; Z = \frac{bd^2}{6}$$

$$\frac{M_b}{\sigma_b} = \frac{bd^2}{6} \Rightarrow d^2 = \frac{6M_b}{b\sigma_b}$$

$$d = \sqrt{\frac{6M_b}{b\sigma_b}}$$

d= thickness of the canvas support cross section

Torque transmitted by shaft

$$T = \frac{P_s \times 60}{2 \times N \times \pi}$$

Tangential load on pulley

$$F_{it} = \frac{2T}{d_{ip}}$$

As we know
$M_b = F_{it} \times X_i$

Shaft subjected to combined twisting moment & bending moment

According to maximum shear stress theory

$$\tau_{max} = \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\tau^2}$$

Where, σ_b= binding stress

$$\tau_{max} = \frac{1}{2}\sqrt{\left(\frac{32M}{\pi d^3}\right)^2 + 4\left(\frac{16T}{\pi d^3}\right)^2}$$

$$\tau_{max} = \frac{16}{\pi d^3}[\sqrt{M^2 + T^2}]$$

$$\frac{\pi}{16} \times \tau_{max} \times d^3 = \sqrt{M^2 + T^2}$$

$$T_e = \sqrt{M^2 + T^2}$$

Where, M = bending moment, T = twisting moment on shaft

$$T_e = \sqrt{M^2 + T^2} = \frac{\pi}{16} \times \tau \times d^3$$

$$\sigma_{b(max)} = \frac{1}{2}\sigma_b + \frac{1}{2}\sqrt{{\sigma_b}^2 + 4\tau^2} = \frac{32}{\pi d^3}[\frac{1}{2}(M + \sqrt{M^2 + T^2})]$$

$$\frac{\pi}{32} \times \sigma_{b\ max} \times d^3 = \frac{1}{2}[(M + \sqrt{M^2 + T^2})]$$

Equivalent twisting moment $M_e = \frac{1}{2}[(M + \sqrt{M^2 + T^2})] = \frac{\pi}{32} \times \sigma_b \times d^3$

Aspirator shaft

The Blower

The blower was designed using the physical and aerodynamic properties of the crops such as the shape, size and terminal velocity. It is located just under the hopper and opposite the slope of the tray. It is a centrifugal fan and is comprised of four straight impellers attached to the shaft, all in an in a volute casing. A pulley is attached to the shaft at one of the ends.

Power available to blower shaft = x %

P_b = *Power (hp)* x *x* (1hp = 746 watt)

$$P_b = \frac{2 \times \pi \times N_b \times T_b}{60}$$

$$\text{Torque, } T_b = \frac{P_b \times 60}{2 \times \pi \times N_b}$$

Let us assume diameter of flow pulley, D_b=200mm

Pulley has been mounted on the blower shaft at a distance of X_b

$$M_b = F_b \times X_b$$

$$\sqrt{(k_m M_b)^2 + (k_t T_b)^2} = \frac{\pi}{16} \times \tau \times d^3$$

$k_m = 1.5$, $k_t = 1.5$, $T_b = 2.15$ N – m $\tau = 45 \times 10^6$ N/m^2 (Assume)

Factor of safety = 3 (Assumed)

So, diameter of blower shaft d_b = 20 mm

Design of Aspirator

Let us assume that transmission efficiency from impeller to blower shaft ϵ_t = 0.80

So Power available for blowing

P_{bl} = Power of electric motor x 0.12 x transmission efficiency

V_t = Terminal velocity for seeds

Power required to flow

$$P_{bl} = \frac{\beta_a \times S_b \times n_b \times V_a^2}{2\eta} \times V_b$$

Surface area of each blade $S_b = \frac{P_{bl} \times 2 \times \eta}{\beta_a \times n_b \times V_a^2 \times V_b}$ (in m^2)

Where, Power available for blowing

P_{bl} = Power available for blowing

βa = bulk density of air = 1.2 kg/m^3

η = conversion effiency = 0.40

n_b =No. of blades in blower = 4

V_a =Velocity of air

V_b =Peripheral velocity of blower

As we know

$$V_b = \frac{\pi \times D_b \times N_b}{60}$$

Diameter of blower $D_{blower} = \frac{60 \times V_b}{\pi \times N_b}$

Volume flow rate of air $Q_b = \pi \times {R_b}^2 \times l_b \times N_b$

Where,

N_b = Speed of blower , rpm

l_b = The length of blower

R_b = Width

Table 1: Technical specifications of the multi-crop thresher

Dimension (l x w x h)	:	1228 X 791X 1250 mm
Cylinder size (mm)	:	340 diameter x 300 length
Beater size (mm)	:	10 diameter x 80, 18 No. and 10 diameter x 67, 18 No.
Wire loop diameter (mm)	:	4
Number of wire loops	:	48
Number of knife	:	6
Weight With sieve assembly	:	93.5 kg
Weight Without sieve assembly	:	60 kg
Size of aspirator	:	340 mm diameter, 4 blades
Power source	:	1 hp electric motor
Crops threshed	:	Paddy, wheat, barnyard millet, finger millet and amaranth

Table 2: Performance evaluation of CIAE lightweight Multi-crop thresher at VPKAS, Almora

Crop Commodity	Threshing drum speed (rpm)	Aspirator fan speed (rpm)	Threshing capacity, kg/h	Threshing efficiency (%)	Cleaning efficiency (%)
Amaranths	846	846	30	98	95
Finger Millet	1080	912	54.3	98.5	95.4
Barnyard millet	1080	912	58	99	96.2
Paddy	550	912	75.2	98	96.5
Wheat	550	912	34	98	99

Design of the pulley and belt

The nominal pitch length of the motor to threshing drum belt was determined in order to know the actual belt size that is needed to transfer power from the electric motor to the threshing drum. Therefore, according to Gupta and Khurmi, the nominal pitch length (L) is given as follows:

$$L = 2C + \frac{\pi}{2}\left(D_1 + D_2\right) + \left[\frac{\left(D_2 - D_1\right)^2}{4C}\right]$$

Where,
D_1 = diameter of the motor pulley (m)
D_2 = diameter of the threshing drum pulley (m)
C = the center distance between the motor pulley and the threshing drum shaft pulley, which is expressed as:

$$C = \left(\frac{D_2 + D_1}{2}\right) + D_1$$

Evaluation of the belt tension

In a vee-grooved pulley belt drive, the relationship between T_1 and T_2 is given by

$$2.3 \log \frac{T_1}{T_2} = \mu\theta \operatorname{cosec}\beta$$

Where, T_1 = the tension of the belt on the tight side.
T_2 = the tension of the belt on the slack side.
μ = the coefficient of friction between the belt and the pulley.
θ = the angle of contact or lap of belt between the two pulleys = 3.10 rad
2β = groove angle

The power transmitted by belt is given by

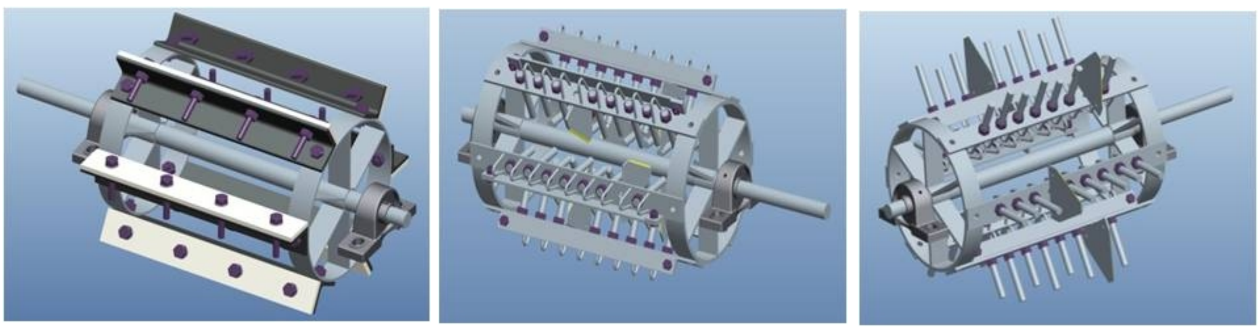
$$P = (T_1 - T_2) \times V$$

Where, P = the power transmitted by belt (watts)
T_1 = Tension in the tight side in N
T_2 = Tension in the slack side in N
V = Velocity of the belt (m/s)

Centrifugal tension T_c is given by, $T_c = mv^2$
When the centrifugal tension taken into account,
The total tension in the tight side = $T_1 + T_c$
The total tension in the slack side = $T_2 + T_c$

Multi-crop thresher developed on CAD, which consists of cylinder, concave, aspirator blower and sieve shaker. Based on the determined design parameters, a conceptual CAD model and drawings of light weight multi-crop thresher was developed as shown in Figure 2. The first prototype of light weight multi-crop thresher was fabricated in the research workshop of CIAE as per the CAD drawings (Figure 3). Technical specifications of the multi-crop thresher are shown in Table 1.

Preliminary testing of the developed prototype was done at CIAE then multi-crop thresher was sent to VPKAS, Almora for final evaluation. They evaluated developed prototype for threshing of wheat, paddy, minor millets (barnyard and finger millet only) and amaranth crop. Threshing capacity of the developed machine for wheat, paddy, barnyard millet, finger millet and amaranth were observed as 34, 75, 58, 54, and 30 kg/h, respectively. However, Threshing efficiency for these crops was greater than or equal to 98%, crops which are given below in Table 2. Cleaning efficiency for wheat, paddy, barnyard millet, finger millet and amaranth were observed more than 95%.



(a) (b) (c)

Figure 1: CAD model of threshing cylinder of multi crop thresher

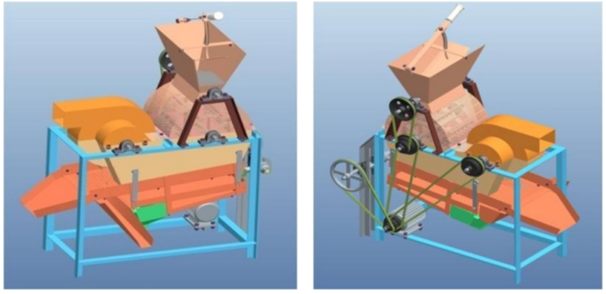


Figure 2: CAD design of multi-crop thresher

Figure 3: Prototype of multi-crop thresher

CONCLUSION

The design and fabrication of a multi-crop threshing machine has been successfully developed by using above methods and formula. The machine is capable of threshing of multiple crops (mainly wheat, paddy, millet and amaranth) and separation of stalk from grains with reduction in number of broken grains, thereby giving a better method of threshing than the traditional methods. Multi-crop light weight thresher has been developed having capacity for wheat (34 kg/h), paddy (75 kg/h), barnyard millet (58 kg/h), finger millet (54 kg/h) and amaranth crop (30 kg/h). Threshing efficiency for these crops was found greater than or equal to 98%. Cleaning efficiency for these crops were more than 95%.

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