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Development and performance evaluation of pedal operated dehuller for black soybean

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ABSTRACT : Black soybean is a food source which contains high quality protein and does not contain cholesterol and saturated fatty acids. It is rich in vitamin and minerals and has significant medicinal effect. In India, traditional method of dehusking the black soybean is hand operated grindstone (Chakki). In grindstone, main disadvantage is the incomplete dehulling of the beans. This method of dehusking is also tedious and time consuming process. Therefore post harvest management and processing of black soybean are very important and hence an effort has been made to develop a pedal operated dehuller for Uttarakhand women with the help of anthropometric data. Dehuller works on the principle of shearing force where black soybean passes through between the grind stone roller and concave surface of perforated mild steel sheet and power would be provided through pedal to the machine. The different components were designed and best dehulling efficiency of the machine was 72.08 per cent at 10 per cent moisture content and 25kg/h feed rate with payback period of 1.67year. This machine is basically designed for Uttarakhand small women farmers and can generate employment.

KEY WORDS : Black soybean, Pedal operated machine, Design components, Payback period

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Black soybean (*Glycine max* L.) is an important food crop of northern India especially Uttarakhand. Black seed-coat soybean, locally known as *Bhat/ Bhatmash*, is grown in Kumaon region and in its neighbouring states and countries in the Himalayas (Shah, 2006). It has been traditionally grown on a small scale in Himanchal Pradesh, Kumaon hills of Uttarakhand, Eastern Bengal and parts of central India (Singh, 2006). India contributes 4 per cent of the soybean production to the total world production. In Uttarakhand, during 2012-13 area, production and yield of soybean has been reported as 5548 hectares, 4981 tonnes and 8.978 quintal/hectare, respectively. On the other side as Garhwal region produces 785 tonnes with productivity of 6.456 quintal/hectare in 1216 hectares area whereas kumaon region produces 4196 tonnes with productivity of 9.686 quintal/hectare in 4332 hectares area (Anonymous, 2013). The common practice to utilize *Bhatt* is as whole grain. Before consumption, it is either roasted or popped like corn and used as snack in winter or soaked and then cooked as pulse. It is also used as *Dubke (karhi)* after grinding and boiling. The products of *Bhatt* as pulse and Dubke are highly nutritious and a majority of people prefer. It is also used as cattle feed. *Lagili, Thumri*and *Bhangrail* are the main local varieties of *Bhatt* grown in Himalayan region. Black soybean consists of husk and kernel, but kernels mainly consumed as an important source of dietary protein, oil and fibre. In India, mainly in rural areas of Uttarakhand, for removing the husk from black soybean, women generally use hand operated grindstone (Chakki). In grindstone, main disadvantage is the incomplete dehulling of the beans. This method of dehusking is also tedious and time consuming process.

At present, there is no dehusker /dehuller available which can be used by the people. Motor operated dehullers have been also developed but that are not efficient in rural areas. Therefore keeping in view the above facts that there is needed to develop an efficient pedal operated black soybean dehuller unit to save the time and labour. The structure of soybean seed makes it susceptible to split and breakage during mechanical handling. The knowledge of the physical and mechanical properties of the agricultural products is of fundamental importance for design, dimensioning, manufacturing, and operating different equipment used in post harvest and main processing operations of these products (Gupta and Sharma*,* 2009).Therefore, the physical properties are of great importance in designing of drying and storage as well as handling equipments. As the dehulling process is the most critical and delicate step for achieving high-quality kernels, mechanical properties of black soybean is a pre-requisite for the design and development of a pedal operated black soybean dehuller machine. There is needed to develop an efficient pedal operated black soybean dehuller that will be helpful for the rural area's women of Uttarakhand. It should have the highest dehulling efficiency and very minute chances for the damaging the kernel during dehulling as well as highest splitting efficiency of black soybean and maximum yield of whole kernels. Pedal operated dehuller will also beneficial for women's health concern. This machine will save the electrical energy because it does not contain any motor. It can encourage the women empowerment in rural areas. It will easy to handle the machine. To comely with this, The design is based on the principles of shearing force where black soybean pass through in between the iron roller and concave surface of iron and power will be provided through the manual operated pedal will be designed and fabricated (Chand *et al.,*2013).

■ METHODOLOGY

Design of components of machine:

The different design dimensions were selected for feed hopper, power transmitted shaft, grinding wheel, cylinder shaft, pulley, cyclone separator, cycle frame, belt drive and power requirements, the different parts of developed dehuller for black soybean are shown in Fig. A as follows:

Feed hopper:

Feed hopper is a semi-automatic feeding system which has the capacity to hold food in addition to that in the feeding trough associated with the feeder. The feed hopper of conical shape with square cross section with capacity of 100 kg/h was made of mild steel sheet (IS: 2062-1999). The thickness of sheet used for fabrication was taken as 2 mm, the hopper had 360 x 360 mm square opening upto 50 mm from the top and there after it had trapezoidal shape upto 170 mm depth with bottom opening area of 50 x 50 mm at the bottom. The discharge end of the hopper was connected to dehusking unit.

Grinding wheel:

The six numbers of grinding wheel of cylindrical shape (KING- A46, medium size Premier abrasive Pvt. Ltd., Amritsar) with dimensions as 200 mm diameter and thickness 31.75 mm was used for grinding of black soybean**.** The grinding wheel was mounted on a 25 mm mild steel shaft supported on ball bearing at each end.

Concave of cylinder:

The concave clearance was decided as per the diameter of kernels was considered which varied from 3 to 5.5 mm. Hence, the concave clearance was kept constant 5 mm and the size of circular opening of mild steel mesh/ sieve for concave was about 1.5 mm. The grinding wheels were covered with concave perforated sieve having diameter of 210 mm.

Cylinder cover:

A cylindrical shaped cover was made of mild steel sheet of thickness 2 mm over the grinding wheel and perforated sheet having a circumference of 725 mm and 230 mm diameter. It had bottom opening of trapezoidal shape up to 100 mm depth, and bottom opening area 65 x 65 mm at the bottom of the machine through which powder materials come out from the bottom opening. There is discharge chute which was made of mild steel sheet of thickness 2 mm and it had conical tapered shape. The chute was 200 mm long with 100 mm input and 70

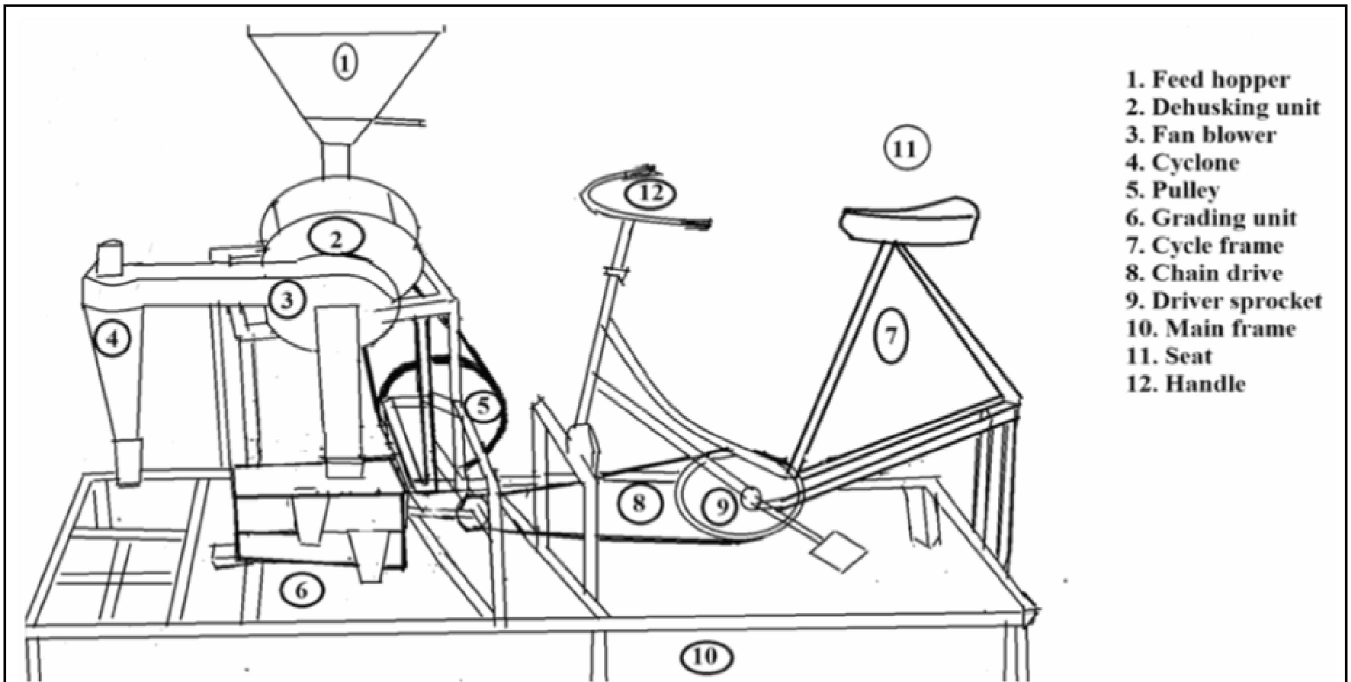

Fig. A : Isometric view of black soybean dehuller

mm output end width. Through the discharge chute dehulled material was collected into grading unit.

Design of cylinder shaft:

The shaft is a rotating machine element used to transmit power from one point to another, and it was designed on the basis of strength, rigidity and stiffness. When design the shaft then it was taken into consideration, and may be subjected to twisting and bending moment. According to the Gbabo *et al.* (2013), the maximum permissible working stress, diameter and Torque of the shaft is calculated using the relationship as

$$\sigma = 16\,T / \pi d^3 \quad d = \sqrt[3]{16T / \pi\sigma} \quad \text{and} \quad T = \frac{NP \times 4500}{2\,\pi\,N} \qquad (1)$$

where, σ = Maximum permissible work stress (N/m), T = Torque of the shaft, d = Diameter of shaft (mm) and N = Speed of the pedal operated pulley (rpm)

For the factor of safety, 20 per cent of the calculated diameter was added to the calculated shaft diameter.

Torsional deflection of the shaft:

Torsional deflection of the shaft is a measure of the degree of twist per unit length, and shaft will experience due to an applied torque and its units are taken in deg./ft/in.-lb. Torsional deflection of the shaft was determined to know the angle of deviation of the shaft and to ensure the minimal angle of deviation and shear stress determined using the formula of Gbabo *et al.* (2013).

$$\alpha = \frac{584\,\tau\,l}{D^4\,\eta} \qquad (2)$$

$$\tau = \left(\frac{D}{2.26}\right)^4 = 14973.60\text{ N mm} \qquad (3)$$

where, α = angular deflection of shaft (degree), l = Length of shaft (mm), η = Modulus elasticity of steel (N/mm) and D = Diameter of shaft (mm)

Design of cyclone separator:

Cyclone separator is a large-scale, atmospheric wind-and-pressure system characterized by low pressure at its centre and by circular wind motion, counter clockwise in the Northern Hemisphere, clockwise in the Southern Hemisphere. Cyclone is mainly used for removing the husk from kernels with the help of blower fan. According to Stone (1997) the design of cyclone is as follows with the assumptions made for design of cyclone separator. Input flow rate = 110 m^3 /h, Design inlet velocity = 6 m/s and Air density = 1.2925 kg/m^3

(ISO 2533:1975). The dimensions of the cyclone separator to remove the husk during the processing of the black soybean determined using the formula:

$$\text{Diameter} \quad (D) = \sqrt{\left(\text{inlet} \ \frac{\text{area}}{0.125}\right)}/3.25 \qquad (4)$$

Inlet height (a) = D /2 (m), Inlet width (b) = D x 0.25 (m), Outlet length (s) = D x 0.625 (m), Outlet diameter (De) = D / 2 (m), Overall height (H) = D x 4 (m) and Dust outlet area (B) = D x 0.25 (m)

Design of pulley:

Pulley is a wheel with a grooved rim around which a cord passes, which acts to change the direction of a force applied to the cord and is used to raise heavy weights that receives energy from the driver pulley via the belt. The driver pulley is a fixed pulley in a belt drive system that receives energy from the power source and transfers it to the driven pulley via the belt. Measurement of speed of pulleys was calculated by using digital tachometer. The dehuller was consisting two pulleys, one was machine pulley which was driven pulley and another was pedal operated pulley which was driver pulley, connected by rubber fabric V-belt (Khurmi and Gupta, 2004). The ratio of the driver pulley to the driven pulley calculated using formula as

$$N_1 / N_2 = D_2 / D_1 \qquad (5)$$

where, N_1 = Speed of the pedal operated pulley (rpm), N_2 = Speed of the machine pulley (rpm), D_2 = Diameter of the machine pulley (mm) and D_1 = Diameter of the pedal operated pulley (mm).

Design of belt drive:

Belt drive is a mechanism in which power is transmitted by the movement of a continuous flexible belt. A V-belt is a belt with a flat bottom and tapered sides that transmits motion between two pulleys. Multiple V-belts are often used together in order to increase carrying power. Single V-belt is a type of V-belt that can be used for light-duty applications, such as those that transmit less than 1 hp. Single V-belts are also known as fractional horsepower V-belts. Length of belt is calculated by equation (Khurmi and Gupta, 2004) and pulley centre distance (C) was calculated using formula of Amiebenomo *et al*. (2013).

$$L = 2C + 1.57(D + d) + \frac{(D - d)}{4C} \qquad (6)$$

$$C = (D - d)^2 / 8 + [(D - d)^2 / 8 - L/4 + 0.3925 (D + d)]^{1/2} \qquad (7)$$

Belt speed:

Belt speed is a section of belt that moves past a fixed point within a given point in time. It was calculated by the formula (Khurmi and Gupta, 2004)

$$V = \frac{\pi DN}{60} \qquad (8)$$

where, V = Speed of belt, m/sec, D = Diameter of the larger pulley and N = Speed of the pulley

Angle of wrap:

On a band brake mechanism, the distance, expressed in degrees, that the brake band wraps around the brake flange is known as Angle of wrap explained by Khurmi and Gupta (2004).

$$\theta_a = \sin^{-1} \frac{R - r}{c} \qquad (9)$$

where, R =Radius of the larger pulley (mm), r = Radius of the smaller pulley (mm) and C = distance between the driving and driven pulley (mm)

Tension on belt:

Tension on belt is a pulling force that is directed away from the object and attempts to move, stretch, or elongate the object. Belt drive systems must operate under proper tension to transfer power effectively, and calculated by the formula given below (Khurmi and Gupta 2004)

$$T_1 / T_2 = e^{F\theta 1} \qquad (10)$$

$$\text{Power} = (T_1 - T_2) \times V \qquad (11)$$

where, T_1 = Tension at tight side (N), T_2 = Tension at slack side (N), 1] θ_1 = Angle of wrap of the smaller pulley (radian), Friction factor (F) and belt speed (V)

Bicycle frame:

The machine is mainly designed for women of rural area. Thus on the basis of anthropometric data of Uttarakhand women, the cycle frame was designed. The anthropometric data of Uttarakhand women was collected from department of Family Resource Management, College of Home Science, G.B. Pant University of Agriculture and Technology, Pantnagar. For designing the cycle frame, the maximum and normal working area data of women with horizontal plane and sitting position were taken into account. Maximum working area of women in horizontal plane was taken

48 cm, and the distance between seat and cycle handle was taken in between 40 to 44 cm. The maximum knee height of women age group 20 - 30 years was 46.85 cm and maximum popliteal height was 39.2 cm, the height was 40 to 44 cm taken into account from seat to cycle pedal for easily operating the machine by the women (AICRP, 1996). Driving and driven gear was having 48 and 22 teeth respectively. Cycle chain of pitch 10 mm and 120 numbers of links was used to design purpose.

Total power requirement:

Total power requirement was calculated by adding the power required to drive shaft (P_s), power required to dehulling the black soybean (P_h) and power required to driving the pulley (P_p) as suggested by Gbabo *et al.* (2013).

$$\text{Total power (kW)} = P = P_s + P_h + P_p \qquad (12)$$

Determination of dependent parameters to evaluate the performance of the machine:

Dehulling efficiency:

Dehulling efficiency is percentage of splited and hulled sample to the total mass of the sample. Dehulling efficiency was calculated using following formula given by Sanya *et al.* (2013).

$$\text{Dehulling efficiency} = \left[\frac{(M_k + M_h) - (M_u + M_b)}{M_s}\right] * 100 \qquad (13)$$

where, M_s = Mass of sample (g), M_k = Mass of kernel (g), M_u = Mass of unhulled (g), M_h = Mass of husk (g) and M_b = Mass of broken (g)

Payback period:

The pay back period focuses on the cost investment. It represents the amount of the time taken for a capital budgeting project to recover its initial cost. The payback period of the black soybean dehuller for dehulling the black soybean which was determined and measured in years as suggested by the researcher Newnan (1983).

$$I_d = \frac{B[(1+i)^n - 1]}{[i(1+i)^n]} \qquad (14)$$

where, I_d = Initial investment (Rs.), B = Annual net investment benefits (Rs.), i = Interest rate (%) and n = Payback period (years)

■ RESULTS AND DISCUSSION

The dehuller of capacity 25kg/h was designed and fabricated in the Department of Post-Harvest Process and Food Engineering, College of Technology, G. B. Pant University of Agriculture and Technology, Pantnagar basically for Uttarakhand women those who are interested to increase their income at home. After the development, the performance of dehuller was evaluated as dehulling efficiency (%) by taking two independent variables such moisture content and feed rate. As results obtained after the experiments that minimum dehulling efficiency was found to be 62.8 per cent at moisture content 11 per cent (wb) and feed rate of 27 kg/hr because it was due to high moisture and high feed rate of black soybean during dehulling, and reduced rpm of cylinder shaft and unhulled black soybean grains were found more. The maximum dehulling efficiency was found to be 72.8 per cent, at moisture content 10 per cent (wb) and feed rate of 25 kg/hr because it was obtained due to optimum moisture content and feed rate.

Statistical analysis of dehulling efficiency:

The model was checked using a numerical method employing the co-efficient of determination R^2, adjusted R^2 and then calculated as shown in Eq. (15), R^2 indicates how much of the observed variability in the data was accounted by the model while R^2-adj modifies R^2 by taking into account the number of covariate or predictors in the model. The response surface model was developed with values of R^2 higher than 0.90 says 0.9797 it shows least residual error (3.82) found in the fitted quadratic model. Furthermore, R^2-adj (0.9652) value was observed to be relatively close to the R^2 (0.9797) value, it insures a relatively satisfactory adjustment of the quadratic model to the experimental data. The co-efficient of variation of dehulling efficiency was found to be 1.09 %; it shows minimum variability in data fitted in the model due to higher value of mean (68.08 %). Model was found highly significant ($p<0.01$) because of the F-value (67.72) was greater than F- table value (7.46). Therefore, second order model regression eq. (15) was found to be adequate for describing dehulling efficiency of the machine.

$$\text{Dehulling efficiency (\%)} = 72.40 - 1.17X_1 - 1.53X_2 - 0.20X_1X_2 - 3.94X_1^2 - 3.09X_2^2 \qquad (15)$$

The variables of the models are X_1 and X_2 are the moisture content and feed rate, respectively. From the above equation, the dehulling efficiency increased due to decrease the moisture content of the black soybean as well as same behaviour is of feed rate. In Equation

Table 1 : Calculation of cost for pedal operated dehuller		
The fixed cost of fabrication of black soybean dehuller was Rs. 27027.00/-(approx)		
Annual cost		
1.	**Fixed cost**	
	Depreciation	Rs. 2432.50 per year
	Interest (12% per annum)	Rs. 1783.80 per year
	Housing @ 1 %	Rs. 148.65 per year
	Insurance and taxes @ 2 %	Rs. 297.30 per year
2.	**Variable cost**	
	Repair and maintenance (2% of initial investment)	Rs. 540.00 per year
	Labour wages (Rs. 200 per day for 2 person) (600 working hr./year)	Rs. 30000.00 per year
3.	Total annual cost (1+2)	Rs. 35202.25
4.	Cost of black soybean	Rs. 50.00 per kg
5.	Capacity of the machine	25.4 kg per hour
6.	Dehulling charge of black soybean	Rs. 3.5 per kg
7.	Gross annual benefit (5×6)	Rs. 53340.00 per year
8.	Annual net benefit (7-3)	Rs. 18137.75 per year
9.	Benefit cost ratio	1.51
10.	Payback period	1.67 year

16 the coefficients with one factor *i.e.* the ones in front of X_1 and X_2 represent the effect of that particular factor, while the coefficient with two factors *i.e.* the ones in front X_1X_2 those with second order terms *i.e.* X_1^2 and X_2^2 represents the interaction between two factors and the quadratic effects, respectively the positive sign in front of the terms indicates a synergistic effect while the negative sign shows the antagonistic effect.

Cost analysis:

For the success and commercialization of any new technology, it is essential to know whether the technology is economical viable or not. Therefore, an attempt was made to evaluate economics of the developed black soybean dehuller. Different economic indicators were being used to economic analysis and hence the calculation of total and annual cost of the machine is given in Table 1.

Conclusion:

A pedal operated dehuller was designed and developed for dehulling black soybean. The total cost of the machine was Rs. 27027.00 and the weight of the unit was 90kg. Its capacity and dehulling efficiency was 25kg/h and 72.8 %. It could be operated by a single person and this machine is more useful to those people who start small business and get benefitted.

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