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Design, Fabrication and Testing of Proso Millet De-husking Machine

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Abstract
Though Proso Millet is a staple food in many regions of Nepal due to its high nutrient content, it is not cultivated on a large scale because of difficulty in processing.This millet cannot be de-husked with the machines available for larger grains and appropriate de-husking machines for Proso millets are also not available. So, this research aims to design, fabricate and test a Proso Millet de-husking machine. This machine has the following units – feeding, rolling, de-husking and separating unit. The Proso millet passes through the rolling unit where it is abraded by two shafts and is de-husked in the de-husking unit. The Proso grain is separated from the chaff by passing the mixture through a current of air supplied by a fan. The materials used for the fabrication of the machine were selected based on the design considerations and analyses of its components. The components of the machine were selected locally and machined to specifications using machines such as the lathe, grinding machine, etc. The parts of the machine were assembled at the welding and fabrication workshop and testing was done considering opening of control valve, clearance of rollers and speed ratio as the testing parameters. When tested, at the half opening of control volume of machine maintained at speed ratio of 1:2 of pulley and motor with clearance of 1.75mm between the rollers used, the maximum overall efficiency of nearly 60% was obtained. The financial and risk analysis shows the feasibility of commercialization of the machine.

Keywords
Proso Millet – Dehusking – Machine Design

1. Introduction

The common names of Proso Millet are common millet, broom corn millet, white millet, yellow hog millet, Hershey, prove millet, panic millet, brown corn, French millet.Panicum species form one of the largest genera of grasses which include more than 400 species[1]. Within this genus, two species are of economic importance, these are Proso millet, (Panicummiliacium) and little millet (Panicumsumatrense) Proso millet is an annual grass, but isn't closely related to other millets such as pearl, foxtail, finger or the barnyard millets. Proso Millet is a short season crop and because of its small root system has a low water requirement. The seeds are very small and oval in shape. They are approx. 3mm long and 2mm wide.[10] Seed color is wide ranging and can be white, cream, yellow, orange, red, and black through to brown.Proso millet is the primary millet in the world import and export market. It is used for human consumption in many parts of the world, and is a significant food source for millions of people. In Europe and the U.S.A. it is used primarily as a bird and livestock feed [4]. The protein values compare favorably with sorghum and wheat and are higher than corn. Proso also has considerably higher fiber levels, due to attached hulls [7].

The de-husking of Proso millet has been considered as a problem by the farmers as it cannot be de-husked with the machines and also appropriate de-husking machines are not available. In the prospect of the nutritional value and socio-economic impact of the Proso millet, the development of proper husking machine is much necessary. The development and the promotion of the Proso millet de-husking machine would create the opportunity of consuming the De-husked Proso millet locally fulfilling the food demand of the people in mountain region and health benefits. Statistical survey has not assessed the useful estimates of the production, consumption, marketing, etc. of Proso millet.

Traditionally, the dehusking of Proso millet is done in a mortar and the separation of the chaff from the grain is done by washing with water, or winnowing. The traditional method of processing takes 1 hour to dehusk 1kg – 2kg of Proso millet. [2]

The purpose of this work was to design, fabricate and test Proso millet de-husking machine that is safe and economical in operation for the use of the local farmer. The other specific objectives includes the study of existing technology of different minor millets de-husking machine, to design, draw and fabricate machine components of Proso Millet de-husking machine using locally available materials and to perform testing and analysis of the fabricated de-husking machine. Some of the assumptions and limitations considered during fabrication were that the direction of rollers was not altered to attain the de-husked Proso millet. Also besides nylon rod, other materials cannot be used for roller operation since the weight of the roller highly affects the de-husking property of the machine. And the machine has not been tested under different moisture content of Proso millet.

2. Methodology

Design and drawing

Conceptualization of mechanism and design aspects with the selection of the most appropriate mechanism was done. The initial step of designs of the machine was derived, analyzed as necessary by the use of Solid works 2015 for sketch, dimensioning and 3D modeling. To achieve the set objectives, machine is structured into four units: feeding, rolling, and separation units.

Fabrication and assembly

Types of loads and its magnitude that different parts have to bear were identified and calculated and selection of material was made accordingly. With the application of appropriate processes, resources and tool, the Proso millet de-husking machine was fabricated by selecting suitable materials for each component. Some of them were manufactured in the workshop and some of them were bought from the market. All the parts that were made and bought was assembled as per assembly drawing (refer appendix).

Testing and analysis

The machine was tested for the de-husking of Proso millet. The prototype was tested for the evaluation of its overall performance in terms of productivity. Conclusions were drawn based on the analysis of the prototype and suitable recommendations are given.

3. Design and Fabrication

3.1 Machine units and component design

Machine units

The machine is structured into three different units performing specific function as described below:

- Feeding unit (Hooper): This unit is made up of a hopper, and a sieve for removing impurities such as metallic particle, stones, etc. which are larger than the Proso millet. Proso millet is fed into the hopper manually. The hopper is made of metal sheets.
- Rolling unit (Roller): This unit consists of a pair of rollers with a clearance between them, rolling at a speed ratio of 1.5:1. This enables frictional forces to be developed in the system, causing the Proso millet to be abraded.
- Separation unit: This unit has an electrically operated blower and collectors for de-husked Proso millet and the husk. The blowing was achieved through the fan. A variable resistor for adjusting the speed of the fan was incorporated.

Component design

The components were designed based on established theories and principles, considering the loading of each member as follows:

- Motor: A motor power of 380 watt was assumed for power requirement. So, throughout the design of all the components, it is taken as the input power to the machine and considers all frictional losses to be negligible. Normally, a 380 watt motor has a speed of 1400 rpm. So, that input speed in the design calculations was taken. But the speed will be 700 rpm when it is being driven.

- Belt drive: Belts are employed to transmit power from one shaft to another. The V-belt was chosen because of its numerous advantages such as compactness, quietness in operation, ease of mounting and removing, positive drive, and so on; and because the shafts between which power is being transmitted are relatively close. Refer appendix for design procedure and calculations.
- Hopper: The hopper is designed so that the input grains could easily flow into the central part of the impeller and also to control the flow rate of the input grain. Inflow mass rate (m) was assumed through study. Refer appendix for design procedure and calculations.
- Rollers: The standard nylon rods were selected to use as rollers for the machine. The radius of the rollers was determined previously. Refer appendix for design procedure and calculations.
- Shaft: The shaft is subjected to both torsion and bending moments. Based on strength, the diameter of the shaft was therefore obtained theoretically using Goodman's criteria.Refer appendix for design procedure and calculations.
- Bearing:The single-row deep-groove bearing were employed for the shaft and rollers as it will take radial load as well as some thrust load.Refer appendix for design procedure and calculations.
- Separation unit:An electrically operated fan was used to provide the air required to separate the seed from the husk. Refer appendix for design procedure and calculations.

3.2 Fabrication and assembly

Fabrication of components

- Frame: The iron rods used in the frame are available in a standard size. The rods were marked according to the calculated sizes. And then the rods were cut into required lengths. The rod pieces were arc welded at required spots to build the frame. The top portion of the frame was made by welding four L shaped parts of required length to form a rectangular shape. The legs of the frame are the L shaped iron rods welded at an angle with the top of required length. The support (flat iron) for the frame at the base in order to prevent the expansion is welded.
- Cover: The required size of metal sheet was marked. According to the marking the sheet metal was then cut. The sheet metal was then bended in the bending machine at the radius as per calculations. The cross section at the inlet to the roller (i.e. a rectangular cross section) was marked at the calculated location. The inlet hole was then made by cutting the portion with the cutting tool.

  Overall dimension: length = 360 mm, Diameter = 320mm; Material: mild steel

  Cross sections: semi circular
- Hopper: The sheet metal was marked according to the calculated size. The marked sheet metal was then cut with the help of cutting tool. Four different parts were cut into respective sizes. The parts were then arc welded forming a rectangular hopper with the calculated opening and outlet.

  Overall dimension: inlet = 300×300 (in mm), outlet = 180×15 (in mm); Material: mild steel

  Cross section: Rectangular
- Shaft: The shafts have been cut into required lengths using a power hacksaw. The ends of the shafts have been turned on a lathe machine.

  Dimensions: ϕ = 25mm, 20mm and 18mm; Material: Cold-rolled low carbon mild steel
- Cast iron pulleys: Standard sized cast iron pulleys have been used as the main driver and driven pulley respectively.

  Overall dimension: ϕ = 2"and 4"; Material: White cast iron; Method of production: Sand casting
- Roller: For the roller nylon rod of calculated length was cut using the power hacksaw. The rod

was then rolled in the Lathe machine to attain the calculated diameter of the roller.

Overall dimension: diameter = 100mm; Length = 300mm; Material: nylon rod

- Collector: First of all the sheet metal was marked according to the calculated size. The marked sheet metal was then cut with the help of cutting tool. Four different parts were cut into respective sizes. The parts were then arc welded forming a rectangular collector with the calculated opening and outlet.

  Overall dimension: Inlet = 320mm × 350mm; Length = 180mm × 50mm; Material: mild steel

Assembly

The fabricated machine components were assembled as per the drawing shown in the appendix.

4. Testing and analysis

For the testing procedure, a weighted sample of Proso millet seeds were placed in the hopper and then slowly the inlet was opened allowing the seeds to pass into the roller. After that the final output was collected from the outlet and further analyzed.The tests were conducted with the variation in speed ratio, clearance and number of repetition. The test was done for discrete samples each of 100 grams.

The overall efficiency of the machine was calculated in terms of de-husking efficiency and separation efficiency of the machine.

The dehusking efficiency of the machine is given as,

$$\frac{Dehuskedmass + Huskmass}{Totalinputmass} \times 100\%$$

And the Separation efficiency of the machine is given as,

$$\frac{Huskmass}{0.2 \times (Dehuskedmass + Huskmass)} \times 100\%$$

Hence, the overall efficiency of the Machine is given as,

Overall de-husking efficiency = De-husking efficiency × Separation efficiency

The test experiments and result analysis shows that

- As flow rate decreases, the de-husking efficiency increases considerably
- The efficiency of the machine increases by the increasing number of repetitions of the de-husking operations

The maximum efficiency was obtained under test condition in half opening of control volume of machine at speed ratio of 1:2 of pulley and motor with clearance of 1.75mm between the rollers (refer appendix for test result). The overall efficiency obtained was about sixty percent with de-husking efficiency of sixty two percent.

Based on the productivity of maximum efficiency, financial analysis of the machine was carried out and the Net Present Value (NPV) of the machine was positive. The risk analysis done also shows the certainty of NPV to be positive is about 92.3%.

5. Conclusions

The conclusions that are deduced from the project can be summarized in the points below as:

- The existing technology of different minor millets for de-husking purpose was studied and the most appropriate de-husking principle was identified
- After performing the experiments and studies, Proso millet de-husking machine has been designed and fabricated
- The tests were conducted with the variation in speed ratio, clearance and number of repetition. The test was done for discrete samples each of 100 grams. From the experiments done during testing the best result was gained at half opening of control volume of machine 1:2 speed ratio of pulley and motor with clearance 1.75mm between the rollers.The overall efficiency obtained was about sixty percent with de-husking efficiency of sixty two percent.

6. Recommendation

Some recommendations drawn after the completion of the project can be listed in the points as:

- Performance testing can be done using other types of rollers like rubber, metallic etc. and in different moisture content of the Proso millet grains.
- The roller used shouldn't melt while machining and light weight roller should be used.
- The testing should be done with the variations in the roller design parameters such as size, profile of the roller and others.

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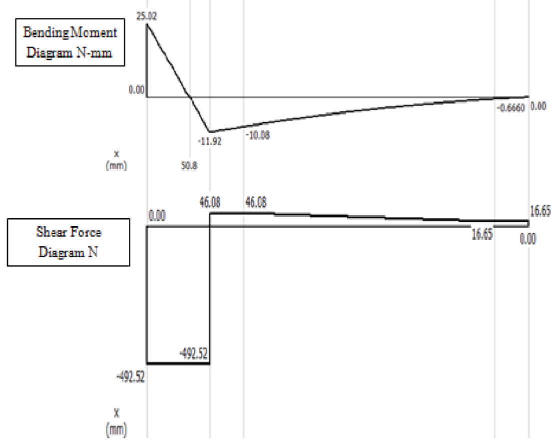
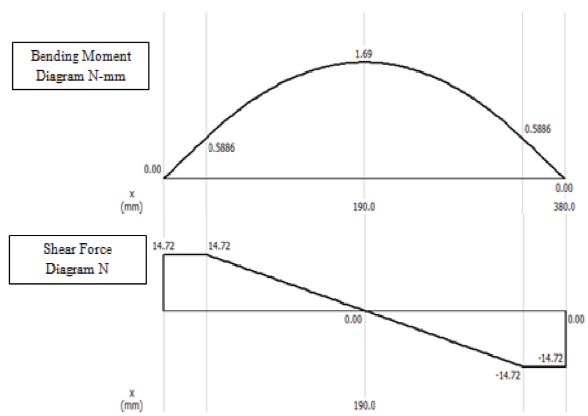
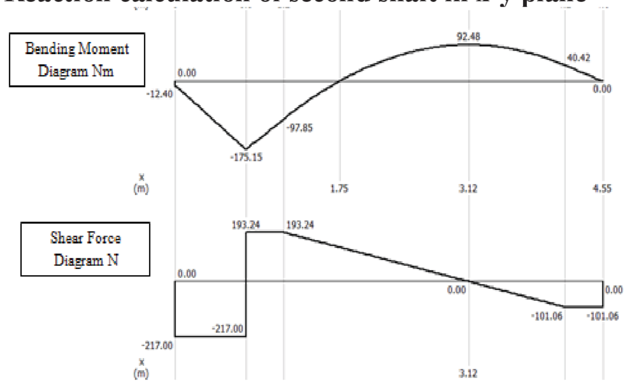
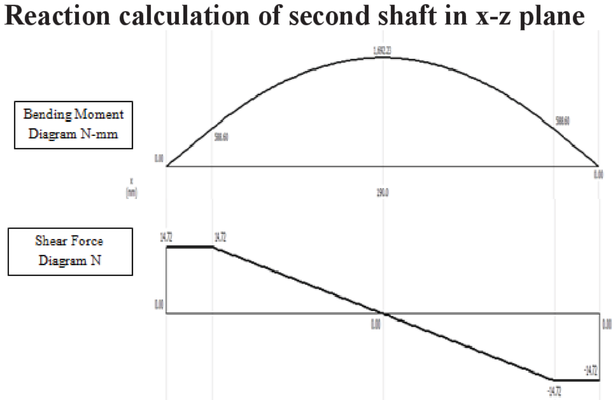
APPENDIX

Table 1: APPENDIX

Design Analysis

Inputs	**Calculations**	**Outputs**
Motor power, P = 380 watt/0.5 hp Speed of motor ($N1$) = 1400 rpm Assumptions: Specific weight of belt = 1.5×10−5 N/mm^3 Endurance limit for belt =10 N/$mm2$ Modulus of elasticity for belt =90 N/mm^2	**Design of belt and pulley** *Belt tensions* $F_1 = F_c + \frac{\Delta F \exp(0.5123\theta)}{\exp(0.5123\theta)-1}$=2.256 $+\frac{\Delta F \exp(0.5123\times3.67)}{\exp(0.5123\times3.67)-1}$ = 158.37 N $F_2 = F_1$- ΔF = 158.37- 124.25 = 34.12 N Now, $T_1 = F_1 + \frac{4.45}{39.37}\frac{K_b}{d} = F_1 + \frac{4.45}{39.37} \times \frac{576}{0.05}$ = 1143.39 N $T_2 = F_1 + \frac{4.45}{39.37}\frac{K_b}{D} = F_1 + \frac{4.45}{39.37} \times \frac{576}{0.1}$ = 650.88 N *Belt length* L_p=2*C+π*(D+d)/2+$(D-d)^2$/4*C [3] =1497 mm ∴Selection of belt=1497-45 =1452 mm=58 in Hence, B-58 was selected.(Machine design data book)	T_1 = 1143.39 N T_2 = 650.88 N L= 1452mm
Assumed data: Coefficient of friction, μ = 0.466 Inflow mass rate (ṁ) = 210kg/hr = 305kg/min Bulk density,ψ= 640 kg/m^3 d= 2 cm, D= 34 cm, h= 38 cm	**Design of Hopper** Angle of repose,θ Tan$\theta = \frac{2\times height\ of\ heap}{diameter\ of\ heap}$ tanθ= μ θ= 25° ,So we takeθ= 67° Using Johansson equation, ṁ=ψ × $\frac{\pi d^2}{4} \times \sqrt{(g \times \frac{d}{4} \times \tan\theta)}$ [8] Tanθ= $\frac{D}{n+a}$ and Tanθ=$\frac{D}{a}$	Rectangular hopper Calculated sizes: Inlet: Length=30 cm Width=30 cm Outlet: Length=18cm Width=0.15cm
Mass of the roller, m= 3kg nylon roller density, ρ= 1500 kg/m^3 Assuming no torque loss	**Design of roller** *length of roller* ρ =$\frac{m}{v}$= $\frac{4}{\pi r^2}\frac{1}{l}$ l= 30 cm V=ω×r=73.3×0.05=3.67 m/s F_n=808 N; F_t=$\frac{\tau}{radius}$=104N ($\tau = motor\ torque \times speed\ ratio$) Weight (W) =m×g=3×9.81=29.43 N For the second roller: F_n=454 N; F_t=$\frac{\tau}{radius}$=78 N (τ = first roller torque × speed ratio) W=m×g=29.43N	Length= 30 cm Forces on first roller F_n=808 N F_t= 104 N Forces on second roller F_n=454 N F_t= 78N Weight = 29.43 N
Select 1020 CD material for shaft Assuming, K_t=1.7 K_{ts} = 1.5 K_f= K_t, K_{fs}=K_{ts}	**Design of shaft** **Main shaft:** Maximum bending moment BM_{max} = 25.02 Nm Maximum torque, T_{max}= 25.02 Nm From design data book, Ultimate tensile strength, S_{ut}= 469 Mpa Se= $K_a \times K_b \times K_c \times K_d \times K_e \times K_f \times S_{e'}$ =186 Mpa	T_{max}= 25.02Nm BM_{max}= 25.02Nm d= 25mm Stepped diameter:

K_c=K_d=K_e=1 Assume, K_b= 0.99 Factor of safety, n = 5	Ka=aSut^b =0.883(a= 4.51, b= -0.265) Using Goodman's criteria, d=($\frac{16n}{\pi}\{\frac{1}{Se}[4(Kf\ Ma)^2+3\ (Kfs\ Ta)^2]^{0.5}+\frac{1}{Sut}[4(Kf\ Mm)^2+3\ (Kfs\ Tm)^2]^{0.5}\})^{1/3}$ [5] = 25 mm Reaction calculation of main shaft in x-y plane  Reaction calculation of main shaft in x-z plane 	Diameter of 1st stepped part: d= 20mm
select 1020 CD material for shaft Ultimate tensile strength,Sut= 469 Mpa Assuming, Kt=1.7 Kts = 1.5 Kf= Kt, Kfs=Kts Kc=Kd=Ke=1 Assume, Kb= 0.99 Also assuming factor of safety, n = 5	**Secondary shaft:** Maximum bending moment BM_{max} = 2.39 Nm Maximum torque, Tmax= 2.39 Nm Ultimate tensile strength,Sut= 469 Mpa Ka=aSut^b =0.883(a= 4.51, b= -0.265) Se= Ka×Kb×Kc×Kd×Ke×Kf× Se'=186 Mpa Using Goodman's criteria, d=($\frac{16n}{\pi}\{\frac{1}{Se}[4(Kf\ Ma)^2+3\ (Kfs\ Ta)^2]^{0.5}+\frac{1}{Sut}[4(Kf\ Mm)^2+3\ (Kfs\ Tm)^2]^{0.5}\})^{1/3}$ [5] = 25mm	T_{max}= 2.39Nm BM_{max}=2.39Nm d=25 mm Diameter of 2nd stepped part: d= 18mm

	Reaction calculation of second shaft in x-y plane  **Reaction calculation of second shaft in x-z plane**  	
Select single row -02 series deep groove bearing of bore diameter 20mm. From Design data book, Catalog rating, C_{10}=1270N assume reliability, R≥0.9	**Design of Bearing** Maximum desired radial load= 538.8 N $C_{10}= F_D(\frac{X_D}{X_0+(\theta-X_0)(1-R_D)^{1/b}})^{1/a}$ [3] On solving, X_D= 7.922 Now, $X_D=\frac{L}{90\times10^6}$ [3] Life, l_D = 712990441.7hours From Data Dimensions and load rating for single-row 02-series Deep groove	Numbers of Bearings= 4 C_{10} = 12.7 KN Bore = 20 mm Outer diameter = 47 mm Width = 14 mm Shoulder diameter: d_s = 25 mm d_h= 41 mm Fillet radius = 1 mm
F= 1.45×10^{-3}N d= 2 cm ρ=640 kg/m^3	**Design of Fan** Mass flow rate of Proso millet and husk=0.4g/sec Mass flow rate of husk=4.8×10^{-5}kg/sec Mass flow rate of de-husked grain=3.2×10^{-4} Velocity with which grains fall The exit velocity from the roller = 3.63m/sec Therefore, force required to separate the husk from the grain= $F_{Husk}+F_{grain}$= 1.45×10^{-3}N	The velocity of the air required= 0.384m/sec.

	The velocity of the air required = $\sqrt{\frac{4F}{\rho\pi d^2}}$ [4] = 0.384m/sec	

Table 2: Best Test result

Experiment 2

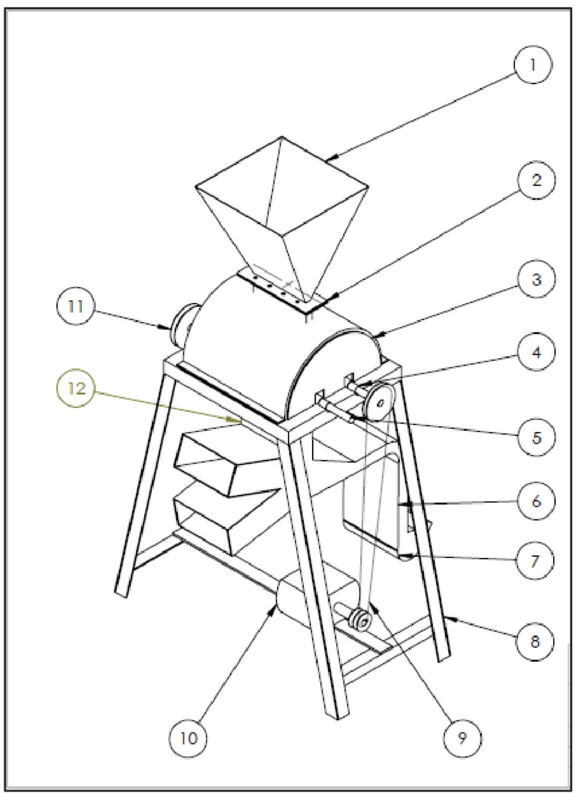
Condition Half opening

Speed Ratio 1:2

Number of Repetitions 5

Clearance 1.75

Sample	Input	Output					Efficiency		
	Mass	Mass	Losses	ehusked Ma	Unhusked Mass	Husk	Dehusking	Separation	overall efficiency
1	100	96	4	54	30	12	0.66	0.90909091	0.6
2	100	94	6	51	32	11	0.62	0.88709677	0.55
3	100	97	3	54	32	11	0.65	0.84615385	0.55



PART LIST

12	Collector	1	Mild Steel	Butt joint Weld
11	Pulley	2	-	Purchased
10	Motor	1	-	Purchased
9	Belt	1	B-Belt	Purchased
8	Frame	1	Mild steel	Butt joint Weld
7	Suction Fan	1	Mild steel	Butt joint Weld
6	Duct	3	Mild Steel	Butt joint Weld
5	Shaft	2	Mild Steel	Machined and tight fit
4	Bearing	4	-	Purchased
3	Motor	1	-	Purchased
2	Volume Controller	1	Mild steel	Butt joint Weld
1	Hopper	1	Mild steel	Butt joint Weld
Part no.	Part Name	Quantity	Material	Process

Figure 1: 3D drawing of Proso millet dehusking Machine with part list