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Research Article

Development and Fabrication of Engine-operated Pulses Milling Machine

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Abstract

Despite Ethiopia being Africa's largest producer of pulse crops, the lack of a milling machine for processing pulse grains reduced the yield and benefits acquired. In order to prolong pulses' shelf life, keep them from spoiling, and maintain their nutritional value, processing is essential. Pulse processing facilitates a reduction of fibre and tannin contents and improvement in the appearance, texture, cooking quality, palatability, and digestibility of grain legumes. The purpose of this article is to design and build portable engine-powered grinding machines for faba beans, peas, and lentils. The pulses milling prototype was developed by considering the local availability of materials at Bako Agricultural Engineering Research Centre (BAERC) for pulses crops like faba bean, pea, and lentil. The manufactured prototype was easily portable and used for areas of Ethiopia where electric service was not available. The fabricated pulses milling prototype was made up of a frame, hopper, cleaning unit, and splitting unit. There were two emery discs in the splitting unit: a rotating type and a fixed stone. The machine was operated by four pulleys; two driving pulleys were mounted on the crankshaft of the engine, one driven pulley was mounted on the fan shaft, and one pulley was mounted on the main shaft. Finally, the prototype pulse milling machine needs 3.67 kW of total power to run.

Keywords

Pulses, Milling Machine, Faba Bean, Pea, Lentil

1. Introduction

Pulse crops were initially cultivated over 8000 years ago in a fertile region that extends from Turkey to Iran [1]. To ensure food and nutritional security in underdeveloped countries, pulses are considered to be vital crops. They serve as an excellent and cost-effective source of proteins and amino acids in diets around the globe. Due to their positive effects on the biological, chemical, and physical characteristics of the soil, pulses are often regarded as "soil-building" crops. Under the right circumstances, nitrogen fixation can supply 50% to 80% of the nitrogen needed by pulses, with the remaining amount coming from the soil or fertilizers [2].

Almost 96 million metric tons of pulses were produced worldwide in 2022, up slightly more than six million metric tons from 2021. Official government statistics released by the Central Statistics Agency (CSA) [3] estimate that 2.5 million metric tons of pulses are produced annually in Ethiopia. Ethiopia is one of the world's leading producers and exporters of pulses. It is the sixth-largest producer of chickpeas and the second-largest producer of faba beans after China. It is in the top five exporters of faba beans and among the top ten exporters of dry beans, peas, and chickpeas [4].

In order to prolong pulses' shelf life, keep them from

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spoiling, and maintain their nutritional value, processing is essential. Another important function of the process is to guarantee that the pulses are uniform in size and shape, which facilitates cooking and shortens cooking times. Pulse processing facilitates a reduction of fiber and tannin contents and improvement in the appearance, texture, cooking quality, palatability, and digestibility of grain legumes [5].

Despite Ethiopia being Africa's largest producer of pulse crops, the lack of a milling machine for processing pulse grains reduced the yield and benefits acquired. Because of this, farmers purchase split grain at a premium and sell dry whole grain at a discount. Nevertheless, the labor and material inputs needed to produce the product are always lost by farmers. Therefore, the purpose of this article is to design and build portable engine-powered grinding machines for faba beans, peas, and lentils.

2. Materials and Methods

2.1. Design Considerations

The pulses milling prototype was developed by considering the local availability of materials at Bako Agricultural Engineering Research Center (BAERC) for pulses crops like faba bean, pea, and lentil. The manufactured prototype was easily portable and used for areas of Ethiopia where electric service was not available.

2.2. Design and Fabrication of the Machine Components

2.2.1. Frame Design

The entire machine is supported by the frame. Using a 40 mm by 40 mm square pipe, it is a trapezoidal structure that measures 550 mm by 300 mm at the top and 700 mm by 550 mm at the base (Figure 1).

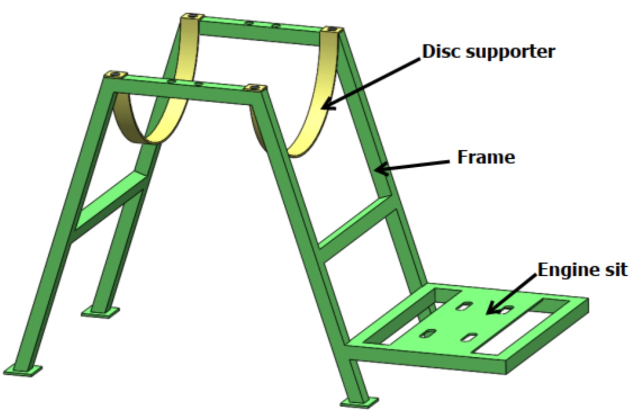

Figure 1. *Schematic design of the pulse milling frame.*

2.2.2. Fan Design

The fan had four straight blades that were enclosed in a casing and welded to a shaft. Sheets of 1.50 mm-thick metal were used to make the blades and case. The casing measured 450.00 mm in length and 300.00 mm in diameter (Figure 2). The blade was 440.00 mm long and 130.00 mm wide, and it was likewise composed of sheet metal that was 1.5 mm thick.

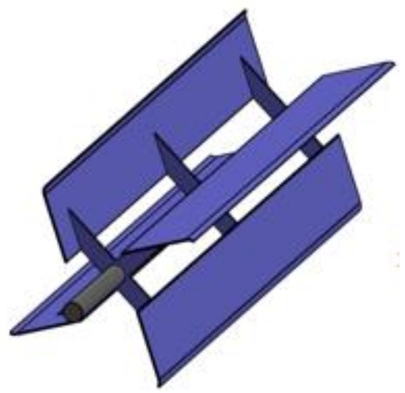

Figure 2. *The pictorial view of the fan.*

2.2.3. Hopper Design

The hopper used to hold the pulsed grains and keep the flow of the same steady was constructed from sheet metal that was 1 to 50 mm thick, as seen in Figure 3. The hopper's side slope was intended to be determined by the pulse grain's angle of repose and the coefficient of friction between the grains and the hopper.

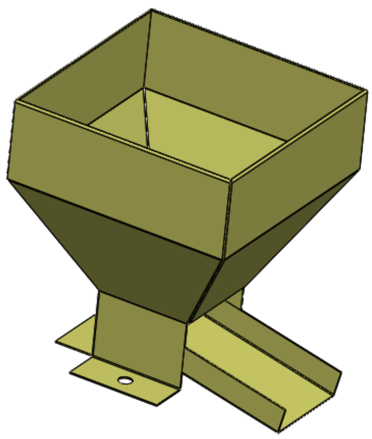

Figure 3. *Hopper of the pulse milling machine.*

2.2.4. The Splitting Unit

The splitting unit will have two stone discs, which are covered by sheet metal to seal the scattering of splits.

2.3. The Working Principle of Milling Pulses

The fabricated pulses milling prototype was made up of a frame, hopper, cleaning unit, and splitting unit (Figure 4). There were two emery discs in the splitting unit: a rotating type and a fixed disc. The clearance between emery discs can be changed by hand using the screw mechanism, which also allows the gap between the two discs to be increased or decreased. The device would use a diesel engine prime mover to generate power and be designed to separate the pulses according to the type of impact. The hopper received the raw pulse, which then descended to the chamber where the second disc abraded it as it rotated against the emery disc. The pulses are therefore split as a result of the disc's impact. The drum outlet allowed the split pulses to be expelled. We used to winnow and sieve to separate the husk and broken. Through the fan's airstream, the seeds were cleaned, and the split, clean pulses were then sent to the discharge outlet.

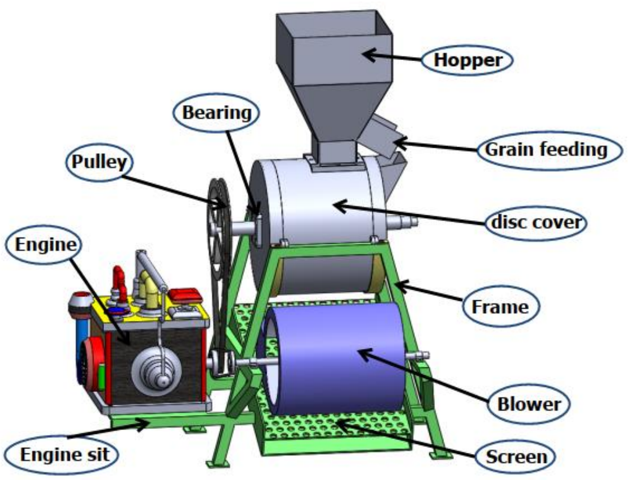

Figure 4. *Parts of the designed pulse milling machine.*

2.4. Design Analysis and Calculation

2.4.1. Selection of Pulleys and Determination of Pulley Diameters

The machine was operated by four pulleys; two driving pulleys were mounted on the crankshaft of the engine, one driven pulley was mounted on the fan shaft, and one pulley was mounted on the main shaft. Due to its availability and cost, aluminum pulleys were selected.

The diameter of pulleys, of the main pulley, may be determined from the relation by [6]:

$$\mathrm{N_1 D_1 = N_2 D_2} \tag{1}$$

where:

N_1= speed of prime mover (1600 rpm),

N_2= speed of driven pulley (650 rpm),

D_1 = diameter of prime mover pulley = 0.12 m,

D_2 = diameter of the driven pulley (m).

The diameter, D, of the fan pulley may be determined from the relation:

$$N_3 D_3 = N_4 D_4 \tag{2}$$

where:

N_3 = speed of prime mover pulley (1600 rpm),

D_3 = diameter of prime mover pulley (90 mm),

N_4 = speed of fan pulley (2050 rpm),

D_4 = diameter of fan pulley.

The diameters of pulleys on the crankshaft of the main shaft and fan shaft were calculated using Equation (1), (2), and found to be 300.00 and 70.00 mm, respectively.

2.4.2. Determination of Center Distance and Belt Length

The center distance between the two was considered, and the maximum center distance between the two was determined with an expression obtained by [7].

$$\mathrm{C_{max} = 2(D_2+D_1)} \tag{3}$$

Therefore, the maximum center distance between the main pulley and crankshaft and the crankshaft and blower pulley was calculated using Equation (3) and found to be 8400.00 and 320.00 mm, respectively.

The length of the belt between the main shaft and the engine is determined from the equation given by [8]:

$$L_1 = 2c_{max} + \frac{\pi(D_1 + D_2)}{2} + \frac{(D_2{}^2 - D_1{}^2)}{4c} \tag{4}$$

where:

L_1 = length of belts connecting the motor and main shaft in mm

c = distance between the centers of the pulley of the motor and the main shaft,

D_1 = diameter of the motor pulley, and

D_2 = diameter of the drum pulley,

The length, L_2, of the belt between the engine and fan is determined from the relation:

$$L_2 = 2c_{max} + \frac{\pi(D_3 + D_4)}{2} + \frac{(D_4{}^2 - D_3{}^2)}{4c} \tag{5}$$

where:

c_{max} = distance between centers of pulleys of fan and auger, $= 2(D_4 + D_3) = 600mm$,

D_3 = Diameter of the auger pulley,

D_4 = Diameter of the fan pulley, and

L_2 = length of belts connecting motor and fan shaft in mm.

The lengths of the belts required to transmit power were calculated using Equation (4), (5) and found to be 1521.90

and 573.70 mm. On the calculated lengths, belts with the nearest lengths were selected from the belt catalog. Hence, B 62 and B 22 ½ were used to transmit power from the engine to the blower.

2.4.3. Determination of the Belt Tension

The angle of contact, $ø_1$, for the belt on the main shaft pulley and motor [9]:

$$ø1 = (180^0 - 2sin^{-1}(\frac{D_2 - D_1}{c})x\frac{\pi}{180} \quad (6)$$

where:

D_2 = radius of motor pulley,

D_1 = radius of auger pulley,

c = center-to-center distance between the main pulley and motor, and

ø1 = 3.13 rad.

For a v-belt, the relationship between the tensions T_1 and T_2 in the belt is given by [8]:

$$\frac{T_1}{T_2} = e^{\mu\emptyset_1} \quad (7)$$

where:

μ= coefficient of friction = 0.3, and

$\emptyset_1$ = angle of contact on the smaller pulley.

The power required to rotate the belt was determined by the following equation (8).

$$P = (T_1 - T_2)V_b \quad (8)$$

where:

P = power required to operate the machine (3.72),

V_b = peripheral belt (9.42 m/s).

Therefore, the tension of the belt in the tight and slack sides of the belt between the main shaft and engine was estimated from Equation (7) and (8) and found to be 249.74 and 639.33 N, respectively.

The angle of contact, $ø_2$, for the belt around the engine and fan is given in equation [10]:

$$ø1 = (180^0 - 2sin^{-1}(\frac{r_4 - r_3}{c})x\frac{\pi}{180} \quad (9)$$

where:

r_4 = radius of fan pulley,

r_3 = radius of engine pulley,

c_2 = center distance of fan and engine pulleys, and

$\emptyset_2$ = 3.05 rad.

For a v-belt, the relationship between the tensions T_1 and T_2 in the belt is given by [11]:

$$\frac{T_3}{T_4} = e^{\mu\emptyset_2} \quad (10)$$

Finally, the tension of the belt in the tight and slack sides of the belt between the fan shaft and engine was estimated from Equation (8) and (10) and found to be 259.73 and 649.32 N, respectively.

2.4.4. Determination of Shaft Diameter

The diameter of a solid shaft with little to no axial loading can be determined using the ASME code [12].

$$d^3 = \frac{16}{\pi\delta}\left[\sqrt{(K_b M_b)^2 + (K_t T)^2}\right] \quad (11)$$

where:

d = diameter of the main shaft, mm;

δ = allowable shear stress (42N/mm^2 for shafts with keyways), according to ASME code;

K_b = 1.50 (constant);

M_b = maximum bending moment (KNm);

K_t = 1.0 (constant); and

T_t = maximum torsional moment (KNm).

The diameter of the main shaft and fan shaft was estimated to be 29.90 and 23.95 mm using Equation (11) with a factor of safety of 3.00. The closest standard diameter shaft, a stainless-steel shaft with a diameter of 30 and 25 mm, was chosen for the pulses milling machine's construction because the main shaft's calculated diameter did not fall within the range of standard shaft sizes.

2.5. Determination Required Power

The total power needed to run the prototype pulse grain milling machine includes the power needed to split pulse grains, overcome grain resistance, dehull grains, drive the blower assembly, drive the cracker drum assembly, generate an air current, and oscillate sieves.

2.5.1. Power Required to Generate an Air Current

The power required to generate an air current was calculated using Equation (12).

$$P_1 = \frac{H_T Q}{\eta} \quad (12)$$

where:

Q = Air discharge, m^3/s;

H_T = theoretical total pressure head developed, Pa; and

η = assuming transmission efficiency of the motor 95.00% - 98.00%.

2.5.2. Power Required to Drive the Blower Assembly

The power required to run the blower assembly was calculated as follows:

$$P_2 = \frac{2\pi \times N \times R_C \times M_C}{60}\left(g + \frac{2V_t^2}{D}\right) \quad (13)$$

where:

P_1 = power (W or kW);
N = speed of blower, rpm;
Mc = mass of blower assembly;
D = effective diameter of the blower, m;
r = radius of a driven pulley of the blower, m; and
V_t = peripheral velocity of blades, 9.42 m/s.

2.5.3. Power Required to Drive the Cracking Stone Assembly

The power required to run the unloaded stone was calculated by the following equation (14) [13]:

$$P_2 = \frac{2\pi \times N \times R_c \times M_C}{60}\left(g + \frac{2V_t^2}{D}\right) \tag{14}$$

where:
P_3 = power (W or kW);
N = speed of cracking stone, rpm;
Mc = mass of cracking stone assembly;
R_c = radius of cracking stone, m;
D = effective diameter of cracking stone, m; and
V_t = peripheral velocity of cracking stone, 10.99 m/s.

2.5.4. Power Required to Split Grain Pulses

The torque required to drive the splitting pulses of grain is given by -

$$T = F_R * r \tag{15}$$

where:
T = torque required to drive the splitting/cracking drum, Nm;
F_R = rupture force/impact force required to split the grain (145.4 N) [14];
r = radius of the cracking drum, 0.15 mm.

The power required to split pulse grains was calculated using Equation (16).

$$P_4 = T * \omega \tag{16}$$

where:
P_4 = power required (W); and
ω = angular speed of the stone (rad/s).

The power needed to rotate the stone, mill the pulse grains, dehull the grains, operate the blower assembly, and create an air current was determined to be 83.50, 143.50, 1204.26, and 1637.80 watts, respectively. The prototype pulse milling machine needs 3.67 kW of total power (Pt) to run. Consequently, a diesel engine with 5 horsepower was chosen.

3. Conclusion

The development and fabrication of a pulse milling machine has been successfully carried out by this work at the Bako Agricultural Engineering Research Center. The fabricated pulses milling prototype was made up of a frame, hopper, cleaning unit, and splitting unit. The machine was operated by four pulleys; two driving pulleys were mounted on the crankshaft of the engine, one driven pulley was mounted on the fan shaft, and one pulley was mounted on the main shaft. There were two emery discs in the splitting unit: a rotating type and a fixed disc. The power required to operate the pulse milling machine was 3.67 kW. Consequently, a diesel engine with 5 horsepower was chosen.

Abbreviations

ASME	American Society of Mechanical Engineering
BAERC	Bako Agricultural Engineering Research Centre
CSA	Central Statistics Agency

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Author Contributions

Teressa Diro: Conceptualization
Desta Abera: Methodology

Conflicts of Interest

We confirm that there are no known conflicts of interest regarding the publication of this manuscript.

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