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Development of a Motorized Soybean Dehulling Machine for Small Scale Farmers

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Abstract: Soybean has been recognized as so versatile that can be processed into a wide variety of food products the soybean can be dried and wet processed. Soybean is also a valuable source of edible oil and excellent source of protein useful for both human and animal feeding. Protein is very important and is required for growth, repair of muscles and nutritional balance. The intake of soybean that is gaining acceptability both by the rural and urban dwellers calls for development of de-hulling machine to reduce the drudgery that involved in traditional method of de-hulling the beans. The de-hulling of soybean machine was based on abrasion between the beans and the wall of the de-hulling chamber and between the beans. The machine consists of the inlet hopper, the de-hulling chamber which included the barrel and the auger specially designed to create abrasion on the beans as it is carrying them towards the outlet end, 1HP geared motor with pulley and belt to make up the transmission unit. The overall dimensions of the machine are 460mm x 750mm x 250mm. The machine has de-hulling capacity of 40.00 to 54.55 Kg/hr and efficiency of 87% to 93% with the highest efficiency gotten when 2Kg of the samples were soaked for five hours before dehulling. The output result falls within economic range, therefore it is recommended for small soybeans processors.

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I. INTRODUCTION

Soybean [*Glycine max (L.) Merr.*] is an important oil seed belonging to the family leguminosae is usually grown as a food crop[1]. The oil is produced almost entirely for human consumption, while the meal is mainly used as animal feed. Soybean is mainly cultivated for its seeds, used commercially as human food and livestock feed and for the extraction of oil[2]. The oil is produced almost entirely for human consumption, while the meal is mainly used as animal feed[3]. The unit operation involved in traditional method are soaking, de-hulling, milling, cooking, flaking e.t.c as shown in figure 1, but de-hulling tends to be the most tedious and time consuming in the unit operation. De-hulling involves removal of the fibrous seed coat that tightly envelops the cotyledons. In other words, de-hulling may be described as the efficient and complete removal of the outer layers enveloping the cotyledons from the kernel leaving a seed coat free cotyledon[4]. Mortar and pestle, hand rubbing and grinding stone are used in the olden days to de-hull the seed which thereby give room for a better way of de-hulling which brings about the mechanical way. Many mechanical machinery have been done in the past, example are attrition-type de-hullers[5], abrasive de-hullers such as the tangential abrasive de-hulling device[6].

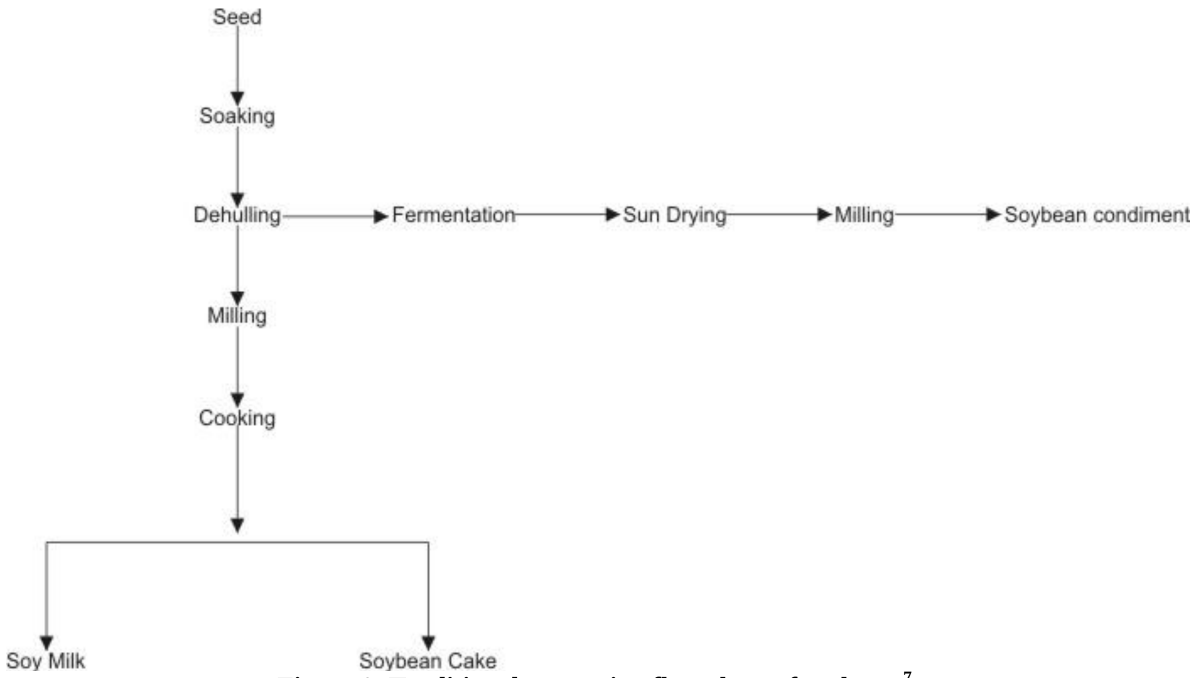

Figure 1: Traditional processing flow chart of soybean.[7]

II. MATERIAL AND METHODS

Design Considerations

The factors considered for selection of materials for the fabrication included the cost of the machine, so as to enhance its use of materials, power sustainability, reliability, workability requirement and the efficiency labour requirement in operating the machine. Also, considered in the design was the ease of replacement of component parts in case of damage or failure and the durability of the materials, corrosion resistance, rigidity, strength and rust. The materials selected to suite the design considerations are shown in Table 1.

Table 1: Material selection for the fabrication of the machine

S/N	MACHINE COMPONENTS	SUITABLE ENGINEERING MATERIAL	CRITERIA FOR MATERIAL SELECTION	MATERIAL SELECTED	REMARKS
1.	Hopper a. Side plates, partition plates, front and rear cover b. Frame	Galvanized sheet, stainless steel and aluminum sheet. Mild steel and square pipe angle iron.	Corrosion resistance, workability and cost. Strength, rigidity and lightness	Galvanized metal sheet Angle Iron	Corrosion and cost effectiveness Strength
2	Sharf	Medium carbon steel	Availability, cost and strength	Medium carbon steel	Availability and cost effectiveness
3	Pulley	Cast iron, mild steel, wood forged iron and aluminum	Strength, availability, and cost	Cast iron	Strong and readily available
4	Belt	Rubber and leather	Strength and flexibility	Rubber	Flexibility and strength
5	Bearing	P205	Axial loading and radial loading	Pillow bearing	Accommodate e both axial and radial loading

Machine conception

The motorized soybean de-hulling machine developed, is sub-divided in four units namely; the hopper, de-hulling chamber, the outlet and the power unit.

Mode of operation of the machine

The motorized soybean de-hulling machine was developed using abrasion force. The machine consists of a two hopper (water inlet and seed inlet), two semi-concentric cylinders (one perforated to allow the hull to pass through it and the other not perforated) and a driving mechanism. De-hulling takes place in the annular space between rotating shaft and stationary cylinder.

Design Calculations

The Hopper Design: The hopper was designed based on the volume of frustrum of a pyramid (Figure 1). The volume of the frustrum of a pyramid can be obtained as follows:

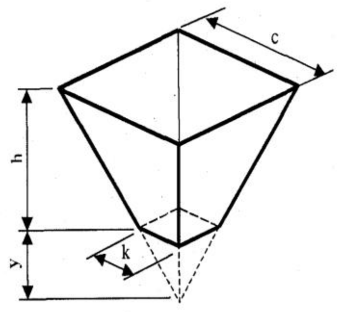

Figure 2: Shape of the hopper

Volume of the big pyramid = $\frac{1}{3}c^2(h+y)$ (1)

Volume of the small pyramid = $\frac{1}{3}k^2y$ (2)

Volume of the frustrum = $\frac{1}{3}[c^2(h+y) - k^2y]$ (3)

Where:
h = Height of frustum (250 mm)
y = Height of small pyramid
c = Length of one side of the square base of the big pyramid (250 mm)
k = Length of one side of the square base of the small pyramid (100mm)

Capacity of Hopper = $\frac{Volume\ \ of\ Hopper}{Volume\ \ of\ Soybe\ an}$ (4)

The pulley

To determine the speed of the driven pulley, the relationship given by[8] was adopted

$$nd = ND \quad (5)$$

Where d = diameter of the small pulley
n = speed of the small pulley
N = desired speed of the big pulley
D = desired diameter of the big pulley

Belt Length

The length of the belt will be determined using the equation below:

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) - \frac{(D_2 - D_1)^2}{4C} \quad (6)$$

Where:
L = total length of the belt (mm)
D_1 = diameter of driven pulley (mm)
D_2 = diameter of driving pulley (mm)
C = distance between the centers of the two pulleys (mm)

The Belt Drive

Belts are used to transmit power in equipment. It requires close spacing and centre distance. It transmits power from motor to the shaft making the center distance between motor and shaft to be adjustable.
The twisting moment (T) was given as:

$$T = (T_1 - T_2)x\,R \quad (7)$$

Where:
T_1 = Tension in the tight side
T_2 = slack side of the belt
R = Radius of the pulley

Tension ratio for an open belt was calculated using equation (8)

Let $2.3log\left(\frac{T_1}{T_2}\right) = \mu\pi$ (8)

Where: μ is the coefficient of friction between rubber belt and mild steel pulley given by 0.3.

***The Shaft*:**

The shaft was made from mild steel with the following parameters:
Yield strength of the material, $Y = 320\ N/mm^2$
Ultimate tensile strength, $S_{ut} = 580\ N/mm^2$

Since the loading of soybeans seed is not strong, it was assumed that load was applied gradually,
The combined shock and fatigue factor applied to bending moment, $K_m = 1.0$
The combined shock and fatigue factor applied to torsional moment, $K_t = 1.5$
The motor rating is *750 W* at *1440 rpm*.
And if keyways are present, it will reduce to 23% and the shear stress of the shaft will be 84MPa = 84Nmm^2.
The co-efficient fraction between the belt and pulley is 0.3 and the angle of lap of the belt is 180^0.The diameter of the pulley is 130mm.

$$T = \frac{60 \text{ x P}}{2 \; x \; \pi \; x \; N} \qquad (9)$$

Where:
T = Twisting moment
P = Power rating of the motor
N= Speed of the shaft

Critical speed of the shaft (ω_s):
The critical speed of the shaft was determined by equation (10) given by [8]

$$\omega_s = = \sqrt{\frac{48EI}{ML^2}} \qquad (10)$$

Where:
E is the Modulus of elasticity of steel
I is the moment of inertia given by $\left(\frac{\pi d^4}{64}\right)$
L is the shaft length.

Dehulling chamber design
The dehulling chamber was assumed to be a thin walled cylinder, the targential stress perpendicular to the axis of the cylinder is given in equation (11) as:

$$\sigma = \frac{\text{pd}_{\text{dc}}}{2t} \qquad (11)$$

Where:
σ = perpendicular of hoop stress, assumed to be the maximum tensile stress the cylinder is subjected to at failure by yield.
P = Internal pressure
t = Thickness of dehulling chamber
d_{dc} = internal diameter of dehulling chamber

Also, $\sigma \;=\; S_{all} \;=\; \frac{(0.5\, S_y)}{N} \qquad (12)$

Where:
S_{all} = allowable shear stress
N = factor of safety
S_y = Yield stress

Volume of dehulling chamber
This is given by

$$V_{dc} \;=\; \pi\, r_{dc}\, 2 l_{dc} \qquad (13)$$

Where: r_{dc}=radius of dehulling chamber
l_{dc} = length of dehulling chamber

Machine Parts
The Hopper: it consists of two hoppers (one for water and the other is for the seed). This is where the soybean and the water are conveyed into the dehulling chamber. It is made of plate of thickness 2mm in a pyramid shape.
The Dehulling Chamber: It contains the shaft coupled with auger which will dehull the soybean. The dehulling chamber consist of two half cylinders fabricated together. The first half cylinder is perforated with a 7mm drill bit to allow the chaff to move out through the side outlet.
The Outlet Unit: The machine has two outlets; one at rear side and the other located in the front of the machine. The side outlet will convey the chaff out of the machine and the front outlet will convey the dehulled soybean out of the machine.
The Power Unit: An electric motor is used to power this machine. It will be connected to the power source (electricity) and also connected to the machine through a v-belt through the pulley system.

Test procedure

The soybean dehulling machine was fabricated and tested in other to know the capacity and the efficiency of the machine. Three different quantities of soybean (1.5Kg, 2Kg and 2.5Kg) were soaked for 3 hours, 4 hours and 5 hours. After that, it was fed into the dehulling chamber of the machine. The efficiency and machine capacity was determined for each quantity of soybean and each soaking time as shown in equation (14) and (15) respectively given by [9].

$$The\ efficiency = \frac{Total\ number\ of\ dehulled\ seeds}{Sum\ total\ number\ of\ seeds}\ x\ 100\ \% \qquad (14)$$

$$The\ machine\ capacity\ \left(\frac{Kg}{hr}\right) = \frac{Throughput}{Time\ taken\ to\ dehull} \qquad (15)$$

III. RESULT

The soybean dehulling machine was fabricated and the materials of construction have been listed. Figure 3a and 3b shows the orthographic projection of the machine.

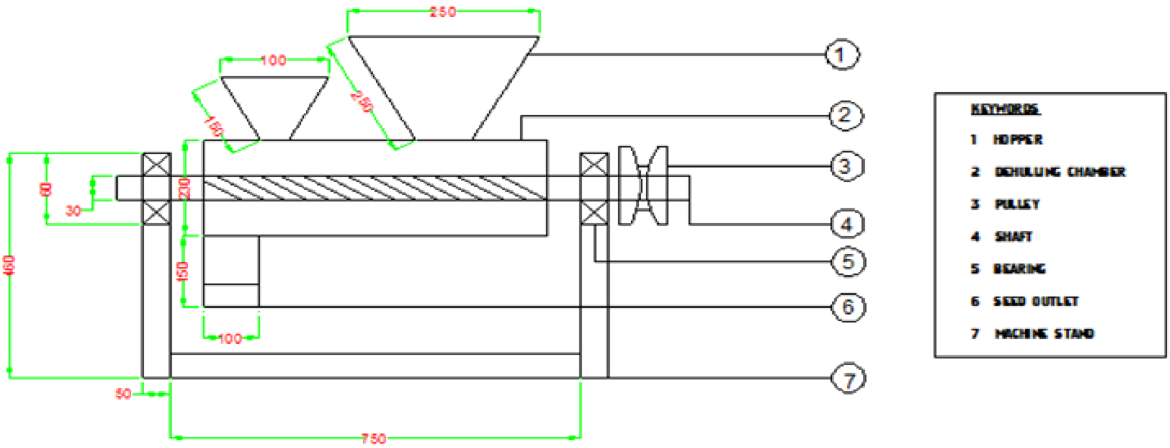

Figure 3a: Orthographic projection (side view) of the soybean dehulling machine. (All dimensions in mm).

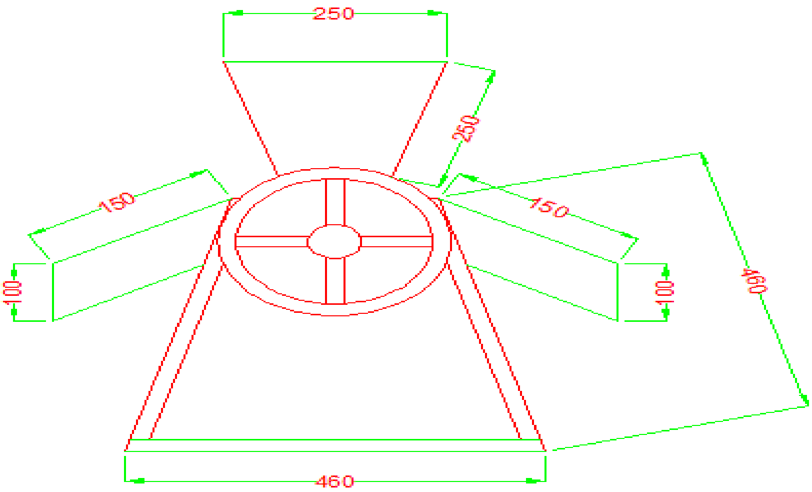

Figure 3b: Orthographic projection **(**End view) of the soybean dehulling machine. All dimension in mm.

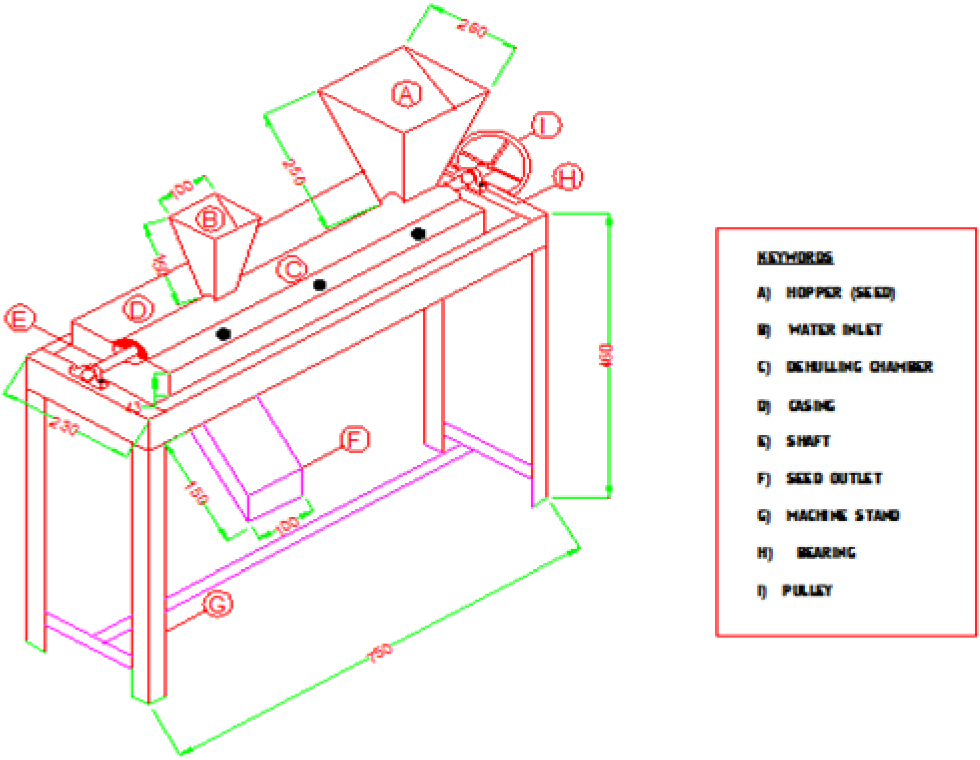

Figure 4: Isometric view of the soybean dehulling machine constructed. All dimension in mm.

IV. DISCUSSION

The soybean dehulling machine was tested and the result was shown in Table 2.

Table 2: Performance evaluation of the soybean dehuller showing efficiency and machine capacity.

Test	Quantity of soybean (Kg)	Soaking time (hr)	Dehulling time (s)	Percentage of dehulled soybean (%)	Machine capacity (Kg/hr)
1	1.5	3	135	87	40.00
	1.5	4	128	90	42.19
	1.5	5	120	92	45.00
2	2.0	3	161	89	44.72
	2.0	4	152	91	47.37
	2.0	5	140	93	51.43
3	2.5	3	188	89	47.87
	2.5	4	174	90	51.72
	2.5	5	165	92	54.55

From Table 2, the dehulling time decreases as the soaking time increases and increases as the quantity of soybean increases. The efficiency of the machine ranges from 87% to 93%, the highest efficiency was gotten when 2Kg of soybeans was soaked for five hours before dehulling. The machine capacity also increased as soaking time increases.

V. CONCLUSION

The motorized soybean dehulling machine was designed and fabricated. It was able to dehull the grains and separate the chaffs from the grains. Due to the non-complexity of the machine, it can be used by small scale farmers to enable efficient dehulling of soybean for further processing. It will also minimize time, energy and cost involved in traditional processing of soybeans.

The efficiency of the machine ranges from 87% to 93% with the highest efficiency gotten when 2Kg of soybeans was soaked for five hours. It was therefore recommended that the users of this machine should soak for five hours before dehulling.

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