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PERFORMANCE OF SMALL-SCALE MUNG BEAN (*VIGNA RADIATA WIL.*) SHELLING CUM CLEANING MACHINE

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Abstract

High-capacity shellers equate to high initial investment costs, unsuitable for most local mung bean farmers. This study developed a shelling cum cleaning machine to address the need for small-scale mung bean production. The design was registered in the Intellectual Property Office of the Philippines (IPOPHL) with a registration number of 3/23/051293. The machine performance was evaluated using speed and pod moisture content variations. Speed variations in the shelling and cleaning assembly were achieved using different pulley sizes at the shelling shaft, while moisture variations were tested using the oven-dry method from newly harvested and air-dried pods. It also assessed the economic performance of the machine to determine what ownership scheme is best for the farmers. It was concluded that satisfactory performance was obtained using a shelling speed of 600 rpm and 12% moisture content. The machine has an input capacity of 64.24 kg/hr, shelling capacity of 30.99 kg/hr, shelling efficiency of 97.84%, blower and separation efficiency of 95.51%, blower and separation losses of 5.29%, and unshelled losses of 2.16% and was affected significantly by the pod moisture content. The mechanically damaged kernel is 1.79% and is affected by both the speed and pod moisture content variations. On the other hand, the shelling recovery, scattering losses, and output purity are 91.01%, 1.53%, and 98.35%, respectively, and were not significantly affected. The machine cost is ₱14,675.00, and the operating cost is ₱0.80/kg. Considering a payback period of 1 year, processing 10,411 kg of inputs will break even all the costs at a custom rate of ₱1.00/kg.

Key words: *shelling cum cleaning machine, performance, moisture content, shaft, speed variations*

INTRODUCTION

Most of small farmers who dominate agriculture in the developing countries have not the financial resources to buy high capacity machinery [8].
For this reason, small farmers could be helped with innovations in small-sized machinery to improve productivity and diminish costs in various agricultural activities [5].
New strategies regarding agricultural mechanization are required to enhance sustainable production [9].
Mung bean (*Vigna radiata* Wilczek), locally known as "mongo" or "balatong" in the Philippines, is a leguminous crop among the cheapest sources of protein. Due to its nutritional value and nitrogen-fixing capabilities, it plays a significant role in the food, herbal, and agriculture industries [16, 13]. Mung bean is a good source of vitamins A, B1, B2, C, niacin, folate, iron, calcium, and zinc. Research showed that mung bean has anti-oxidant effects, antifungal and antimicrobial activity, anti-inflammatory activity, and activity against diabetes, hypertension,5and cancer [12].
Mung bean is a seasonal crop planted only after the rice crop during the dry season and is only available during the first half of the year [3]. In the crop production survey of the Philippines, released by the Philippine Statistics Authority, the Ilocos Region leads among the mung bean-producing areas, followed by Central Luzon and Western Visayas with a total production of 8.44 metric tons in the first quarter of 2024. Although the mung bean industry helps generate income and employment in the country, the decreasing domestic production has kept the country a net importer [1]. The

country's imports increased to 49 thousand metric tons in 2021 [2]. It is important to improve the productivity of grain legumes to address global challenges of food security [14]. Many farm operations in the Philippines are still done manually [4]. Recommendations to address the problems of the industry, which include, among others, the lack of storage facilities, inadequate supply of quality seeds, lack of established markets and credit facilities, and the entry of lower-priced legumes-based products, include the provisions for adequate research and development support on production, processing, and improvements on government credit-marketing support services that will promote productivity and link, and expand markets [1].

Low farm gate prices, high labor requirements, and losses for harvest and postharvest operations have contributed to the low profitability of mung bean farmers. In general, shelling is still done by manual threading, and the seeds are cleaned by winnowing [3]. Large-capacity shellers may not be appropriate because most mung bean farmers are engaged only in small-scale production. The average farm size is 1.29 ha, where 38% of the 5.56 million farms are under half a hectare [11]. Thus, to address the problem of the local mung bean industry, this study developed a small-capacity mung bean shelling cum cleaning machine.

MATERIALS AND METHODS

Design considerations

The mung bean shelling cum cleaning machine was designed based on the following considerations: (a) should be electric motor-driven and made from locally available materials; (b) safe to operate; (c) able to shell the harvested mung bean pods and clean by separating the shells and kernels; (d) the machine should only exhibit a maximum mechanical damaged kernel of 2%; (e) the machine should not produce noise of more than 92db; (f) can be operated by only one (1) laborer assigned for loading and bagging; and, (g) the break-even weight of the machine should be less than the volume of harvest of the farmer or an association to ensure ownership.

Machine parts and principle of operation

The designed machine comprises the hopper, frame, shelling, cleaning, and transmission assembly. It has an overall dimension of 1.6 m x 0.89 m x 0.93 m (L x W x H).

The machine is designed to be powered by a one (1) horsepower (hp) electric motor. Its power is transferred to the shelling unit and cleaning assembly with the aid of a belt and pulley connections.

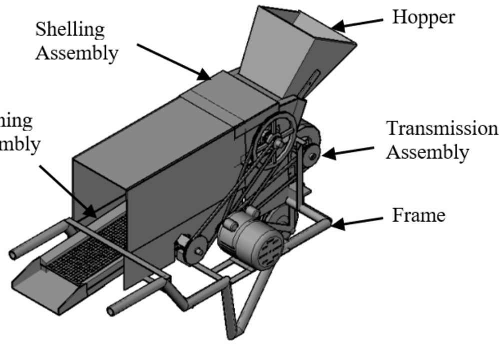

Fig. 1. Conceptualized design of the machine
Source: Original.

To determine the pulley diameter and the belt length of the transmission assembly, the following formulas were used [17]:

$$n_D D_D = n_d D_d \quad (1)$$

where:
n_D = speed of the driver pulley
D_D = diameter of the driver pulley
n_d = speed of the driven pulley
D_d = diameter of the driven pulley

$$L = 2C + \pi/2\,(D_D + D_d) + (D_D - D_d)^2/4C \quad (2)$$

where: L = belt length, inch
C = center distance between pulleys, inch.

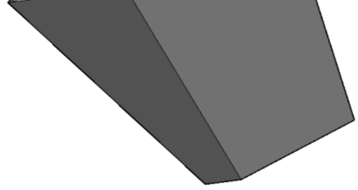

Fig. 2. Hopper design
Source: Original.

The machine requires only one (1) operator whose primary work is to load the pods into the hopper.
The hopper is designed to be continually fed with a feed regulator to avoid over-feeding during the operation.
The mung bean pods are then directed to the shelling assembly, which consists of a cylinder-concave mechanism responsible for the shelling process. The shelling drum is constructed from a 170 mm diameter metal pipe, with four equally spaced rubber around its circumference. The concave comprises flat bars and 8 mm round bars, which serve as rollers. These rollers are fitted with slats designed to allow the passage of shelled pods.

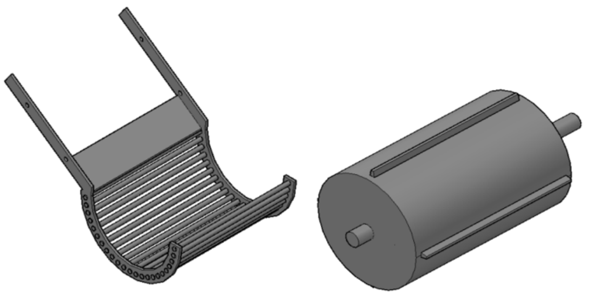

Fig. 3. (A) Shelling concave assembly and (B) cylinder drum design
Source: Original.

The mixture of kernels, shells, and other impurities is then discharged from the shelling unit through the concave slots and falls in the oscillating screen where kernels and small broken shells are separated from the large shells. Oscillation is achieved by attaching the sieve to a cam mechanism with a pulley speed of 220 rpm. Actual measurement of the kernels prompted using a screen with ¼ inch-diameter holes at the sieve.

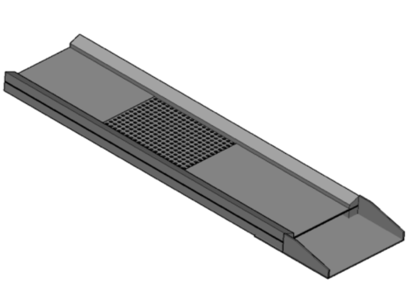

Fig. 4. Sieve assembly design
Source: Original.

Small broken shells and light impurities are separated from the kernels with the aid of the blower. The kernels are then discharged in the kernel outlet, and the shells are conveyed to a separate outlet located at the end of the sieve.
The kernels were collected by placing an appropriate container below the kernel outlet during the shelling operation. A sack can be attached to the shell outlet to prevent the shells from scattering.

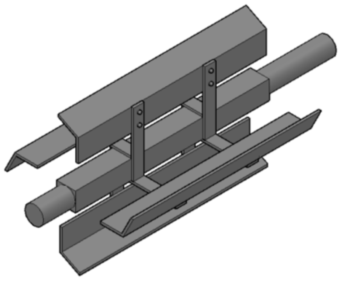

Fig. 5. Blower blade design
Source: Original.

Performance evaluation

After fabricating the major components of the machine following the design, preliminary tests were conducted to evaluate its operational efficiency. These tests served as an initial investigation to identify potential flaws in the machine and a guide for further improvements.
The test follows the Completely Randomized Design (CRD) experimental layout with speed and moisture content variations as the factors. There are two (2) speed settings (500 rpm and 600 rpm), and two different pod moisture contents (MC) (19% and 12% wet basis) were tested and replicated three (3) times. Trial runs were performed to assess the machine's performance. Statistical analysis using Analysis of Variance (ANOVA) was used to determine the best machine settings.
The final performance test was conducted at Bohol Island State University-Bilar Campus, Zamora, Bilar, Bohol, Philippines. Sample mung bean pods consist of one (1) kilogram per replication. The performance parameters determined during the tests are the following [12]:
Input Capacity: It refers to the weight of mung bean pods per unit loading time into the hopper, expressed in kilogram per hour.

$$\text{Input Capacity} = \frac{\text{Weight of mungbean pods}}{\text{Loading time}} \quad (3)$$

Shelling Capacity: It is the weight of shelled kernel received at the main kernel outlet per unit time of operation, expressed in kilogram per hour.

$$\text{Shelling Capacity} = \frac{\text{Weight of shelled kernel}}{\text{Operation time}} \quad (4)$$

Shelling Efficiency: It is the shelled kernel received at all outlets with respect to the total kernel input expressed as a percentage by weight.

$$\text{Shelling Efficiency} = \frac{W+B_L+S_L+SC_L}{W+L_T} \quad (5)$$

where:
W = weight of shelled kernel, kg
B_L =Blower loss, kg
S_L = Separation loss, kg
SC_L = Scattering loss, kg
L_T = Summation of all losses, kg

Blower and Separation Efficiency (BS_e): It is defined as the ratio of the weight of the shelled kernel to the shelled kernel plus blower losses expressed as percentage by weight.

$$BS_e = \frac{W}{W+B_L} \times 100 \quad (6)$$

Shelling Recovery (S_r): It is defined as the ratio of the weight of the cleaned shelled kernel collected at the main kernel outlet to the total kernel input expressed as a percentage by weight.

$$S_r = \frac{W}{W+L_T} \quad (7)$$

Output Purity (P): It refers to the capacity of the machine to separate shelled kernels from the shells and other impurities.

$$P = \frac{\text{Weight of cleaned kernel}}{\text{Weight of uncleaned kernel}} \times 100 \quad (8)$$

Mechanically Damaged Kernel (D_k) : It refers to the damaged kernels during the shelling operation

$$D_k = \frac{\text{Weight of mechanically damaged kernel}}{\text{100 gram sample}} \quad (9)$$

Total Loss: It refers to the sum of the weight of blower loss, separation loss, unshelled loss, and scattering loss.

Blower loss is defined as the ratio of the weight of kernels blown by the sheller fan to the weight of the total kernel input of the sheller.

$$\text{Blower loss} = \frac{\text{Weight of blown kernel}}{W+L_T} \quad (10)$$

Separation loss is the ratio of the weight of kernels that come out of the shelling unit at the shell outlet, to the weight of the total kernel input of the sheller.

$$\text{Separation Loss} = \frac{\text{Weight of Separated Kernel}}{W+L_T} \quad (11)$$

Scattering loss is the ratio of the weight of kernels that fell out from the machine during shelling operation to the weight of the total kernel input of the sheller.

$$\text{Scattering Loss} = \frac{\text{Weight of scattered kernel}}{W+L_T} \quad (12)$$

Unshelled loss is the ratio of the weight of kernels that remained in the pods collected from all outlets, to the weight of the total kernel input of the sheller.

$$\text{Unshelled Loss} = \frac{\text{Weight of unsheled kernel}}{W+L_T} \quad (13)$$

Cost Analysis: The economic performance of the machine was evaluated based on annual cost, fixed costs, variable costs, unit operating cost, break-even cost, and payback period. Fixed costs include depreciation, interest on investment, property tax, insurance, and housing/shelter expenses. Variable costs include labor, repair, and maintenance per 100 hours of operation. On the other hand, the break-even cost and payback period indicate the point at which the total benefits offset the total costs.

RESULTS AND DISCUSSIONS

Machine Description

The fabricated machine has five (5) major components: the hopper, shelling, cleaning, transmission, and frame. The frame was designed in a garden cart-like structure to enhance mobility and facilitate easy transport of the machine. It is powered by a one (1) hp electric motor and connected to the shelling and cleaning assembly using a belt and pulley. It can be operated by at least one (1) operator (Photo 1).

Photo 1. Fabricated shelling cum grading machine
Source: Original.

Performance of the Machine

Analysis of the results after the evaluation of the machine showed that the sheller exhibited acceptable values of all the criteria for evaluation. Statistically, the mung bean pod moisture content significantly affects the machine's performance. The use of 12% MC pods resulted in a significantly higher input capacity, shelling capacity, and shelling efficiency, and significantly lower unshelled losses compared to 19% MC pods. On the other hand, 19% MC resulted in a significantly higher blower and separation efficiency and significantly lower blower and separation losses.

Moreover, the speed variations and the mung bean pod moisture content significantly affected the performance of mechanically damaged kernels. Based on the results, significantly lower mechanical damage kernels were observed when the combination of 500 rpm and 12% MC was used compared to other combinations.

Furthermore, the observed shelling recovery, scattering losses, and output purity of the sheller were not affected by the speed variations and mung bean pod moisture content levels (Table 1).

Table 4. Performance of the mung bean sheller cum cleaner using the best setting.

Machine Performance	600 rpm & 12% MC	600 rpm & 19% MC	500 rpm & 12% MC	500 rpm & 19% MC
Input Capacity, kg/hr	64.24	46.64	60.06	44.08
Shelling Capacity, kg/hr	30.99	20.27	28.37	18.76
Shelling Efficiency, %	97.83	96.22	97.49	94.16
Blower and Separation Efficiency, %	95.51	96.84	95.90	96.72
Shelling Recovery, %	91.01	91.60	91.95	89.45
Output Purity, %	98.35	98.59	97.55	98.27
Mechanically Damage Kernels, %	1.79	2.80	0.93	1.21
Blower and Separation Loss, %	5.29	2.98	3.94	3.04
Scattering Loss, %	1.53	1.63	1.60	1.66
Unshelled Loss	2.16	3.78	2.51	5.84

Source: Original.

The capacity of the machine is comparably lower than the developed machine of the Philippine Center for Postharvest Mechanization (PhilMech), which is powered by a 5 hp gasoline engine [7].

Compared with the small-scale mung bean sheller powered by a 1 hp electric motor developed by Gallegos et al., the machine's performance has no significant difference [6].

According to Abdimalik et al., recommended minimum performance of a sheller cum cleaning machine for grains in terms of efficiency, damage, and purity must be 99%, 2%, and 96%, respectively [10].

While the machine fell short with the minimum shelling efficiency, it exceeded the minimum performance in terms of purity and below the minimum damage. Still, the sheller performed well when pods with a higher speed of 600 rpm and a moisture content of 12% were used.

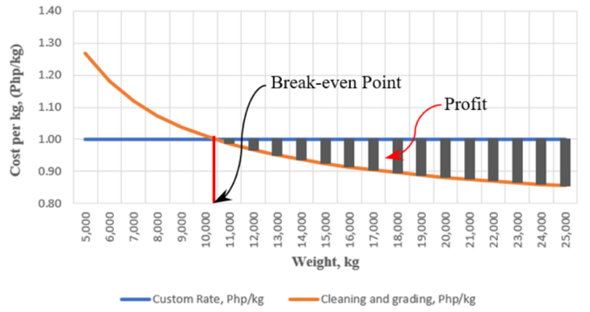

Fig. 6. Operating cost curve of the machine
Source: Original.

The cost of fabricating the machine was 14,674.70 Php. Operating the machine will cost 51.60 Php or 0.80 Php per kg.

The exchange rate between 1 Philippine Peso and 1 USD is 1 Php. = 0.017 USD.

As shown in Fig. 6, the machine will break even after operating a total input of 210 bags, assuming 50kg per bag.

Ownership of the machine must consider that the volume of harvest must exceeds the break-even weight to compensate for all the costs in one (1) year.

Farmer's associations can also prompt for group ownership. However, they must consider a custom rate of 1Php/kg to efficiently use the machine.

CONCLUSIONS

Based on the performance of the machine, the following conclusions were drawn:

- The fabricated mung bean shelling cum cleaning machine is operational and has met the design considerations;
- The best machine operational setting is 600 rpm and 12% moisture content on a wet basis;
- Although operational, further modifications to optimize the ergonomics and performance must be done;
- The ownership of the machine must be in a group. Individual ownership must be done if the volume of harvest of the area owned can exceed the break-even weight.

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