Original Research Article

Small-Scale Demucilager Machine for Arabica Coffee (*Coffea arabica*)

ABSTRACT

Natural fermentation is the conventional method in the Philippines to remove coffee mucilage. It is the soaking in water the depulped coffee cherries for 24-48 hours. However, this process is time and water-consuming, laborious, and causing weight loss to the beans. The study aimed to design and fabricate a small-scale demucilager machine for Arabica coffee and evaluate its performance to eliminate natural fermentation. The designed and manufactured device has 918 mm x 622 mm x 1,113 mm dimension, consisting of six major components: hopper, demucilaging cylinders, water supply system, output chute, power transmission system, and frame. It is a horizontal continuous demucilaging machine operated by abrasion of the parchment coffee between the demucilaging cylinders' walls while being conveyed from the hopper side to the output chute side. The study results showed that at 1.23m/s peripheral speed and 0o inclination, the machine has 37.87 kg/hr capacity, 79.0% efficiency, 4.87% parchment coffee damage, 96.96% product recovery, 41.54 W-hr electrical energy consumption, and 0.22 L/kg water consumption. The machine's use showed reduced processing time from 12-24 hours to 2.64 hours, human resources from 4 to 2 operators, and water used for removing mucilage from 0.87-1.60 L/kg to 0.22 L/kg. Lastly, the demucilaging machine is acceptable to coffee growers and cooperatives to reduce the processing time, human resources, and water used for removing mucilage. It is economically feasible to the local coffee industry with a payback period of 2.49 years and a break-even weight of 11,517.00 kg/yr at a custom rate of 1.75 Php/kg.

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Keywords: demucilager; coffee processing; mucilage removal; natural fermentation

1. INTRODUCTION

Coffee production is time-consuming and laborious work. After harvesting, the ripe coffee cherries will undergo a series of operations to produce ground coffee ready for brewing. These operations need different machinery for easy accomplishment; however, most of the activities are manually accomplished since available machinery are usually manufactured abroad and intended for large-scale plantations. Many small-scale coffee growers in the country are shifting from coffee production to other types of crops such as bananas due to this nature of coffee processing [4].

Natural fermentation is the common practice in the country for removing coffee mucilage. This is performed by soaking the beans and letting microbial organisms and enzymes do the biological degradation and later to facilitate the removal by washing. It is done in batches, time and water consuming and causing weight loss compared to demucilager [3]. These disadvantages, however, are usually disregarded by the farmers since there are no other means of demucilaging the beans.

Several demucilager machines are available in other countries designed mostly for large-scale processing, but not in the Philippines. Hence, this study was conceived to produce an alternative solution for the removal of mucilage without fermentation.

The study's general objective was to design, fabricate, and evaluate a small-scale demucilager machine for Arabica coffee. Specifically, the study aimed to:

1. establish the design requirements of a small scale demucilager machine;
2. design and fabricate a demucilager machine for Arabica coffee suitable for the local coffee growing condition;
3. evaluate the performance of the machine in terms of the capacity, efficiency of removing mucilage, product recovery, damaged parchment coffee and electrical power consumption;
4. conduct a field demonstration of the machine to compare it with the conventional removal of coffee mucilage and asses its acceptability; and,
5. perform a simple cost analysis of the machine.

2. METHODOLOGY

2.1 Conceptualization of the Study

The study was conceptualized based on the local coffee industry's problems resulting from the survey conducted among the major coffee growers and cooperatives in the Benguet province (Atok, La Trinidad, Tuba, and Tublay).

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The demucilager machine for Arabica coffee was designed for small-scale coffee producers. The machine's designed capacity had a minimum of 15 kg/hr based on the lowest fresh parchment coffee processed by the cooperatives and growers. Other requirements considered in the design of the device include 1) machine capable of removing coffee mucilage with a minimum efficiency of 72% based on the washer peeler [5] with similar principle of operation; 2) machine with maximum mechanical damage to the beans of less than 5%, based on the percent damage of demuclager machine by Dagwat and Marquez [2].

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The machine was designed so that the depulped cherries fed from the hopper were conveyed to the demucilaging cylinder through the water supply system provided at the hopper. The demucilaging cylinder has two parts, the rotating inside cylinder and the stationary outside cylinder. The twined polyethylene rope on the inside demucilaging cylinder then conveys the beans through the cylinders' gaps. During the conveyance, the polyethylene rope's abrasive surface removes the bean's mucilage by turning between the stationary and the rotating demucilaging cylinders. While the parchment coffee beans are conveyed inside the demucilaging cylinder, the water dripping from the water supply system lubricates, washes, and removes the beans' mucilage. The demucilaged coffee beans were then collected at the output chute. The wastewater collected in the tub placed below the demucilaging cylinders was recirculated in the machine using a water pump.

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2.2 Design of the Major Components

The maximum weight was determined using the volume of the clearance between the outer and inner demucilaging cylinder computed in Equation 1:

$$V = \frac{\pi}{4}\left(Do^2 - Di^2\right)\times(L) \qquad (1)$$

where:

V - volume, m^3
D_o - diameter of outer rope cylinder, 0.1524 m
D_i - diameter of inner rope cylinder, 0.127 m
L - length of the cylinder, 0.762 m

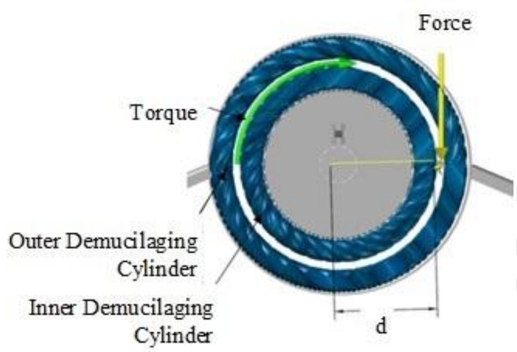

Figure 1. Diagram of the forces acting on the cylinder

The computed volume of 0.00425 m^3 was multiplied by the bulk density of fresh parchment coffee (846 kg/m^3) to obtain the maximum weight of 3.60 kg (Equation 2),

$$m = V^*\rho_b \quad (2)$$

where:
m - mass, kg
V -volume, m^3
ρ_b -bulk density, kg/m^3

The computed force acting on the shaft of the demucilaging cylinder caused by the parchment coffee weight is 35.32 N (Figure 1). The factor of safety of 4 was used, obtaining the total force of 141.28 N. The torque applied to the shaft is 9.89 N.m (Equation 4).

$$F = m \times g \quad (3)$$

$$T_s = F \times d \quad (4)$$

where:
F - force, N
m - mass, kg
g - acceleration due to gravity, (9.81 m/s^2)
T_s - torque applied to the shaft, N.m
d - distance of the force to the shaft, 0.07 m

The rotational speed of the machine used in the design is 360 rpm based on preliminary tests. The angular velocity and the power needed in the shaft are 37.70 rad/s and 372.85 Watts, respectively (Equations 5 and 6).

$$\omega = \frac{2\pi \times N}{60} \quad (5)$$

$$P_s = T_s \times \omega \quad (6)$$

where:
ω - angular velocity, rad/s
N - rotational speed, rpm
T_s - torque applied to the shaft
P_s - power requirement of the shaft, Watts

The torque and power required to drive the pulley computed were 4.98 N.m and 187.75 Watts (Equations 7 and 8), respectively, based on the 254 mm diameter pulley with 4 kg mass.

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$$T_p = w_p \times r_p \quad (7)$$

$$P_p = T_p \times \omega \quad (8)$$

where:
P_p - power required to drive the pulley, Watts
T_p - torque required to drive the pulley, N.m
w_p - weight of the pulley, N
r_p - radius of the pulley, m

Considering the selected water pump (25 W) with 1.2 m head and the power loss during transmission due to creeping and sleeping of the belt up to 5% of the power generated from the motor [1], the total power requirement is 613.63 Watts (0.82 hp). Hence, a 746 Watts (1 hp) electric motor was used.

The torque computed applied to the device is 19.79 N.m, and the diameter of the shaft is 18.08 mm (Equation 9 and 10), considering a tolerance of 20% [1]. For safety in the working operation of the device, the selected shaft diameter is 25.4 mm.

$$T = \frac{P}{\omega} \quad (9)$$

$$\sigma = \frac{16T}{\pi d^3} \quad (10)$$

where:
σ - allowable stress, Pa
T - torque, N.m
d - diameter of the shaft, m

The selected shaft diameter can withstand the maximum allowable twist for shaft with 0.25^{o} (Equation 11 and 12).

$$J = \frac{\pi d^4}{32} \quad (11)$$

$$\theta = \frac{TL}{JG} \times \frac{180}{\pi} \quad (12)$$

where:

θ - allowable stress twist, ^{o}
T - torque, N.m
L - length of shaft, 0.762 m
J - polar moment of inertia, m^4
G - modulus of rigidity, Pa

The machine's conceptualized design is shown in Figure 2 based on the computed dimension of the different major components of the machine.

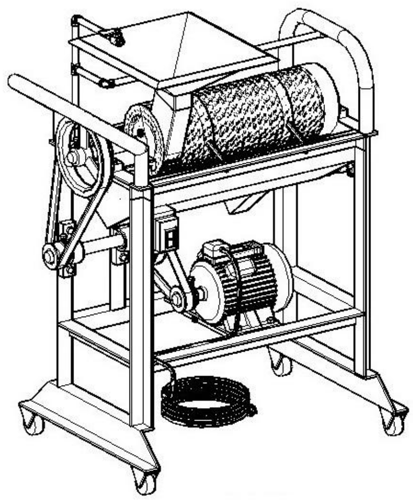

Figure 2. Conceptualized design of the demucilager machine

2.3 Simple Cost Analysis

A simple cost analysis was conducted to determine the financial viability of the coffee demucilager machine. The financial viability indicators used were the Break-Even Point (BEP), Payback Period (PBP), and Benefit-Cost Ratio (B/C Ratio) of operating the machine.

3. RESULTS AND DISCUSSION

3.1 Survey on Local Coffee Growers and Cooperatives

A survey was conducted on four identified cooperatives in the province of Benguet (Atok, La Trinidad, Tuba, and Tublay) and seven individual coffee growers. Based on the results, the minimum capacity of the machine recommended for the community is 15 kg/hr to process the lowest volume of fresh parchment coffee (60% of cherries) being produced (25-50 kg coffee cherries).

Processing coffee cherries (pulping-drying) requires 2-5 laborers. All surveyed cooperative and individual coffee growers use natural fermentation for up to 12-48 hours (Figure 3) with 0.87-1.60 L/kg water consumption. When asked if the respondents wanted to buy a demucilager machine in the market, three cooperatives and six individual growers surveyed wanted to avail if they could afford it.

Figure 3. Conventional removal of mucilage

3.2 Description of the Machine

Comment [A10]: this section needs to be inserted in Materials and Methods.

The fabricated demucilaging device's design is a continuous type machine (Figure 4) with an overall dimension of 918.2 mm x 622.4 mm x 1,113.2 mm. It has six major parts: hopper, demucilaging cylinder, water supply system, output chute, frame, and power transmission system. The device removes the mucilage adhering to newly depulped parchment coffee by

Figure 4. Fabricated demucilaging machine

abrasion between the rotating inner demucilaging cylinder and the stationary outer demucilaging cylinder. The rotating cylinder's outside surface, and the stationary cylinder's inside surface were twined with 14 mm polyethylene rope, thus providing abrasive property.

All parts of the device that comes in contact with the product and water are made of stainless materials. Other parts were coated with paint to resist corrosion.

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3.3 Performance Evaluation of the Demucilager Machine

3.3.1 Machine Capacity

The machine's capacity shows that the peripheral speed of the demucilaging cylinder had a significant effect at a 5% level of significance. The capacities of 33.96 kg/hr and 39.86 kg/hr at peripheral speeds of 0.9 m/s and 1.53 m/s, respectively, significantly varies. The mean capacity of 37.91 kg/hr at 1.23 m/s peripheral speed, on the other hand, had no significant difference on either capacities of 33.96 kg/hr and 39.86 kg/hr. With this, it is recommended to operate the device at the peripheral speed of either 1.23 m/s or 1.53 m/s at any inclination.

Comment [A12]: in Methodology, no statistical analysis has been described. But, here, significant effect was explained. How come?

Comment [A13]: This sentence needs to be rewritten.

3.3.2 Machine Efficiency

The machine's efficiency is significantly affected by the interaction of the two factors – peripheral speed and inclination of the device with 79.0% at 1.23 m/s peripheral speed and 0^o inclination significantly different from all other treatment means except to 0.92 m/s and 0^o with 74.0%. With the mean efficiency analysis, it is recommended to operate the device at the peripheral speed of 1.23 m/s and 0^o inclination to optimize the machine providing the highest efficiency.

Comment [A14]: This sentence has grammatical error. Rewrite it.

3.3.3 Product Recovery

Further, the interaction of the factors on the product recovery of the machine is significantly different. The highest product recovery of 97.11% at 1.53 m/s peripheral speed and 0^o inclination significantly varies to the lowest product recovery (90.07%) at 1.53 m/s peripheral speed and 10^o inclination but it does not significantly vary to the product recovery of 1.23 m/s pheripheral speed and 0^o inclination (96.96%).

Comment [A15]: This sentence must be rewritten.

3.3.4 Damaged Parchment Coffee and Electrical Power Consumption

The parchment coffee damage caused by the machine and the electrical power consumption as affected by the peripheral speed of the demucilaging cylinder and the machine's inclination were not significantly affected by the factors. The mechanical damage and the power consumption of the machine is 4.87% and 41.54 W-hr, respectively. Lastly, water consumption using the recommended inclination of 0^o is 0.22 L/kg.

Comment [A16]: This sentence must be rewritten.

3.3.5 Comparison between the Conventional Mucilage Removal and the Demucilager Machine

Visitation, interview, and survey to the coffee cooperatives and growers before the study's conduct was done to gather information on Arabica coffee's wet processing. Another survey was done on the observers during the final test and the field demonstration of the device. The comparison between the conventional mucilage removal and the demucilager machine is presented in Table 1.

Table 1. Comparison of fermentation and the mechanical demucilager

ITEM	FERMENTATION & WASHING	DEMUCILAGER
Duration of processing, hr	12-24	2.64

Average no. of manpower	4	2
Average water consumption, L/kg	0.87-1.60	0.22

3.3.6 Simple Cost Analysis on the Use of the Device

The cost of fabrication of the device is ₱30,823.74 with a machine capacity of 37.87 kg/hr based on the optimum efficiency. The calculated break-even point (BEP), payback period (PBP), and benefit-cost ratio (BCR) were summarized in Table 2. Processing parchment coffee with a custom rate of at least ₱1.75/kg could create an income opportunity, and investments can be recovered at 2.49 years.

Table 2. Summary of simple cost analysis on the use of the device

PARAMETER	CUSTOM RATE, ₱/kg		
	1.75	2.00	2.25
BEP, kg/yr	11,517.00	8,505.00	6,742.00
Payback Period, yr	2.49	1.57	1.14
Benefit-Cost Ratio	0.62	1.16	1.78

4. CONCLUSION

In the conclusion of the study,
1. The machine capacity established for the design was at least 15 kg/hr to cater to the fresh parchment coffee produced by individual coffee growers and cooperatives. The device's efficiency must be at least 72% based on the washer peeler with a similar operation principle. Parchment coffee damage caused by the machine must not be more than 5%.

2. A horizontal continuous demucilaging machine with an overall dimension of 918 mm x 622 mm x 1,113 mm was designed and fabricated. It performs demucilaging by abrasion of the parchment coffee between the outside surface of the rotating demucilaging cylinder and the inside surface of the stationary demucilaging cylinder while being conveyed from the hopper side to the output chute side.

3. The device is recommended to be operated at the peripheral speed of 1.23 m/s and 0o inclination based on the machine's highest efficiency affected by the interaction of the peripheral speed and inclination with 79.0%. The capacity of the machine is 37.87 kg/hr, product recovery is 96.96%, mechanical damage is 4.87%, the power consumption of the machine is 41.54 W-hr, and the water consumption is 0.22 L/kg.

4. Field demonstrations and surveys showed that it is acceptable to local individual coffee farmers and coffee cooperatives to reduce manpower, time consumed in processing coffee, and water consumption.

5. The simple cost analysis of the device's use revealed that it is financially viable with the custom rate of ₱1.75/kg, providing an annual net income of ₱12,400, Benefit-Cost Ratio of 0.62, and a payback period of 2.49 years. Using a higher custom rate would provide lesser break-even weight and a shorter payback period for the machine while increasing the annual net income with the same operating cost per year.

Comment [A17]: This section cannot be considered as an item for conclusion.

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