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

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ABSTRACT

Natural fermentation is time- and water-consuming, laborious, and causes weight loss in the coffee beans. It is the conventional method to remove coffee mucilage in the Philippines that can take up to 48 hours. This study aimed to develop a small-scale demucilager machine and evaluate its demucilaging capacity, demucilaging efficiency, product recovery, damaged parchment coffee, and electrical power consumption. It also aimed to compare the use of the demucilaging machine and the natural fermentation in terms of processing time, human labor, and water consumption. The developed demucilaging machine is a continuously-fed horizontal machine that separates mucilage from the parchment coffee by abrasion. It consisted of the following components: the hopper, which receives the freshly depupled parchment coffee: the demucilaging cylinders, which separate the mucilage to the parchment coffee: the water supply system that delivers water to the hopper and the demucilaging cylinders: the output chute, that discharges the parchment coffee: the power transmission system, transmit power from the electric motor to the machine: and, the frame, that holds other components in place. Evaluation results showed that the machine has a 37.87 kg/hr capacity, 79.0% demucilaging efficiency, 4.87% parchment coffee damage, 96.96% product recovery, and 41.54 W-hr electrical energy consumption at 1.23m/s peripheral speed and 0^{o} inclination. It also reduced processing time from 12-24 hours using natural fermentation to 2.64 hours using the machine. Human labor was also reduced from 4 in natural fermentation to 2 operators using the machine. Water consumption from natural fermentation to machine use is 0.87-1.60 L/kg to 0.22 L/kg, respectively. Lastly, the use of the machine is economically feasible at a custom rate of 1.75 Php/kg with a break-even weight of 11,517.00 kg/yr. The payback period of the machine is 2.49 years with a benefit-cost ratio of 0.62.

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

1. INTRODUCTION

Coffee processing requires a lot of time and labor. Harvested ripe coffee cherries undergo a series of processing operations to produce ground coffee ready for brewing. However, most operations are manually accomplished since available machinery in the market is usually manufactured abroad and intended for large-scale plantations. This nature of coffee processing leads to many small-scale coffee growers shifting from coffee production to other crops [1].

Natural fermentation is the conventional practice for removing coffee mucilage in the country. This is performed by soaking the coffee beans in the water for the microbial organisms and enzymes to degrade the mucilage adhering to the parchment coffee. This process requires a lot of time and water. It also causes weight loss to the beans as soluble solids are diffused in the water [2]. These disadvantages, however, are usually disregarded in coffee processing because no alternative method is available to the farmers.

Several demucilager machines are available in other countries designed primarily for large-scale coffee processing, such as those developed by Ariza et al. [3] and Oliveros et al.[4], but not in the Philippines. Thus, this study was conceptualized to create an alternative solution for removing coffee mucilage, skipping the fermentation process.

Generally, the study aimed to develop and evaluate the performance of a small-scale demucilager machine for Arabica coffee. It specifically aimed to establish the design requirements of the conceptualized small-scale demucilager machine. Additionally, it aimed to design and fabricate a demucilager machine based on the established design requirements and evaluate its performance in terms of the machine capacity, efficiency, product recovery, damaged parchment coffee, and electrical power consumption. Lastly, to conduct a field demonstration of the machine to compare it with the conventional removal of coffee mucilage and conduct a simple cost analysis on the use of the machine.

2. METHODOLOGY

2.1 Conceptualization of the Study

This study was conceptualized based on the survey result conducted among the local coffee growers and four major coffee cooperatives in the Benguet province. It is to address the concern of lacking coffee processing machinery from small-scale farms with an average farm size of one to two hectares [1].

The conceptualized and designed demucilager machine was intended for small-scale coffee processors and farmers. Based on the surveys conducted, it was designed to have a minimum capacity of 15 kg/hr. The demucilaging efficiency is to have at least 72% based on a machine with the same principle of operation [5]. Less than 5% of mechanical damage to the beans was also considered based on the previously developed demucilager machine [6].

The machine was designed to convey the freshly depulped parchment coffee from the hopper to the demucilaging cylinders. The inner demucilaging cylinder (the rotating cylinder) and the outer demucilaging cylinder (the stationary cylinder) twined with polyethylene rope remove the bean's mucilage through the cylinder's gap while turning and conveying it to the output chute. Simultaneously, the water dripping from the water supply system at the hopper and above the cylinders lubricates, removes the beans' mucilage, and washes it away. The collection of the demucilaged coffee beans is at the output chute. The water is recirculated to the machine using a water pump placed in the tub below the demucilaging cylinders.

2.2 Design of the Major Components

The maximum volume of parchment coffee the machine can hold was determined using the clearance volume of the gap between the outer demucilaging cylinder and the inner demucilaging cylinder (Equation 1).

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

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

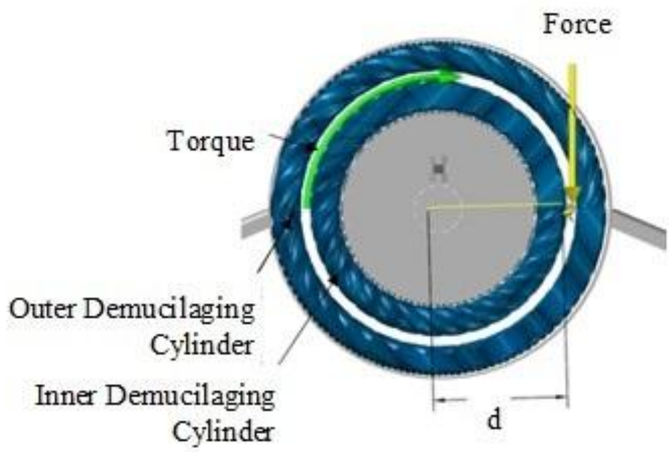

Figure 1. Diagram of the forces acting on the cylinder

The bulk density of fresh parchment coffee (846 kg/m^3) [7] was multiplied by the computed volume of 0.00425 m^3, determining that the maximum weight of parchment coffee inside the demucilaging cylinder's gap is 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 applied to the demucilaging cylinder's shaft due to the parchment coffee's weight is 35.32 N (Figure 1). For a factor of safety of 4 for the steel shaft [8], the total force applied to the shaft is 141.28 N. Thus, 9.89 N.m is the torque acting on the shaft (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

Based on preliminary tests, the rotational speed of the machine is 360 rpm. Hence, the shaft's angular velocity and power 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

For the 254 mm diameter pulley with 4 kg mass used in the design, the torque requirement is 4.98 N.m. (Equations 7) . Hence, the power needed to drive the pulley was 187.75 Watts (Equations 8).

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

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

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

With a power loss because of creeping and slipping of the belt of up to 5% [9], the total power requirement is 613.63 Watts (0.82 hp). With the available electric motor sizes in the market, the selected prime mover is 746 Watts (1 hp) electric motor.

Using the selected electric motor power, the torque acting on the machine is 19.79 N.m. (Equation 9). Using a tolerance of 20% [9], the required diameter of the shaft to be used in the machine is computed to be 18.08 mm (Equation 10). Therefore, a 25.4 mm shaft diameter is selected based on the available shaft diameter in the market and for safety in the working operation of the machine.

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

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

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

Confirming that the selected shaft diameter can withstand failure, the computed allowable twist for the selected shaft is 0.25^o (Equations 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 the shaft, 0.762 m

J - polar moment of inertia, m^4
G - modulus of rigidity, Pa

The conceptualized design of the machine is shown in Figure 2 based on the design calculation of the dimensions of the different major components.

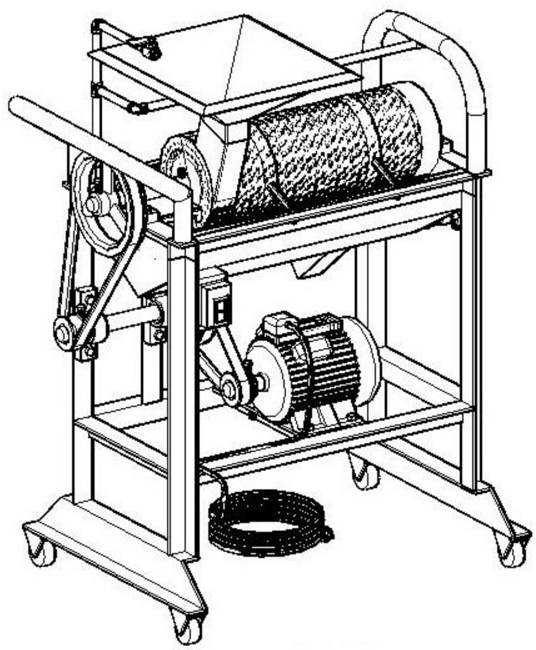

Figure 2. Conceptualized design of the demucilager machine

2.3 Description of the Machine

The developed machine is a horizontal continuous-fed demucilaging machine (Figure 3) with an overall dimension of 918.2 mm x 622.4 mm x 1,113.2 mm. It consists of the hopper, the demucilaging cylinder, the water supply system, the output chute, the frame, and the power transmission system. The machine removes the coffee mucilage adhering to beans by abrasion. The twined 14 mm polyethylene rope on the inside rotating cylinder and on the stationary outside cylinder provides abrasive property. Stainless material was used for all parts of the machine that were in contact with the parchment coffee and water. The frame was coated with epoxy paint to resist corrosion.

Figure 3. Fabricated demucilaging machine

2.4 Statistical Analysis

Factors considered in the evaluation of the study were the peripheral speed of the demucilaging cylinder with three levels (Factor A - 0.92 m/s, 1.23 m/s, and 1.53 m/s) and the inclination of the machine with three levels (Factor B - 0^o, 5^o, and 10^o). Each treatment combination has three replications. The Factorial in Completely Randomized Design (CRD) was the statistical tool used to analyze the effect of factors on the capacity, efficiency, product recovery, damaged parchment coffee, and electrical energy consumption. The Least Significant Difference (LSD) was used for the posthoc analysis at a 5% significance level.

2.5 Simple Cost Analysis

The coffee demucilager machine's financial viability was analyzed using indicators, namely the Break-Even Point (BEP), annual net income, the Payback Period (PBP), and the Benefit-Cost Ratio (B/C Ratio).

3. RESULTS AND DISCUSSION

3.1 Survey on Local Coffee Growers and Cooperatives

A survey conducted on four identified cooperatives in the province of Benguet and seven individual coffee growers resulted that the minimum design capacity of the machine recommended for the local community is 15 kg/hr. The human labor requirement in coffee processing is 2-5 laborers. Natural fermentation is used by all surveyed respondents ranging from 12-48 hours (Figure 4) with 0.87-1.60 L/kg water consumption. Three cooperatives and six individual growers surveyed are interested in a coffee demucilaging machine.

Figure 4. Conventional removal of mucilage

3.2 Performance Evaluation of the Demucilager Machine

3.2.1 Machine Capacity

The machine's capacity evaluation results show that the demucilaging cylinder's peripheral speed was significantly affected at a 5% significance level. The capacity significantly varies at peripheral speeds of 0.9 m/s and 1.53 m/s, with 33.96 kg/hr and 39.86 kg/hr, respectively. No significant difference was observed in the mean capacity of 37.91 kg/hr at 1.23 m/s peripheral speed compared to either 33.96 kg/hr or 39.86 kg/hr capacities. This result recommends operating the device at the peripheral speed of either 1.23 m/s or 1.53 m/s on any machine inclination.

3.2.2 Machine Efficiency

The interaction of the factors significantly affected the demucilaging efficiency of the machine. The treatment of 1.23 m/s peripheral speed at 0^o inclination with 79.0% demucilaging efficiency is significantly different from all other treatment means except for 0.92 m/s and 0^o with 74.0% efficiency. Hence, the machine is recommended to operate at the peripheral speed of 1.23 m/s and 0^o inclination providing the highest efficiency.

3.2.3 Product Recovery

The interaction of factors on the product recovery of the machine significantly varies. The highest product recovery of 97.11% at the treatment of 1.53 m/s peripheral speed and 0^o inclination varies significantly from the lowest product recovery (90.07%) at the treatment of 1.53 m/s peripheral speed and 10^o inclination. However, the treatment of 1.53 m/s peripheral speed and 0^o inclination does not significantly vary the product recovery of the treatment 1.23 m/s peripheral speed and 0^o inclination (96.96%).

3.2.4 Damaged Parchment Coffee and Electrical Power Consumption

The machine's parchment coffee damage and the electrical power consumption were not significantly affected by factors considered in the study. The mechanical parchment coffee damage of the machine is 4.87%. The machine's power consumption is 41.54 W-hr.

3.2.5 Comparison between the Conventional Mucilage Removal and the Demucilager Machine

Before the study, a visit, interview, and survey were conducted on coffee cooperatives and growers. Another survey was done during the field demonstration of the machine. Table 1 compares the conventional mucilage removal and the use of the demucilager machine on the duration, human labor, and water consumption.

Table 1. Comparison of conventional mucilage removal and the demucilager machine

ITEM	CONVENTIONAL MUCILAGE REMOVAL	DEMUCILAGER MACHINE
Duration of processing, hr	12-24	2.64
Average no. of human labor	4	2
Average water consumption, L/kg	0.87-1.60	0.22

3.2.6 Simple Cost Analysis on the Use of the Machine

The machine's investment cost is ₱30,823.74. With a custom rate of ₱1.75/kg, the investment cost can be recovered at a break-even point (BEP) of 11,517.00 kg/yr with a payback period (PBP) of 2.49 years. The use of the machine could create an income opportunity because it has a benefit-cost ratio (BCR) of 0.62 with an annual net income of ₱12,400.

4. CONCLUSION

Before the design of the machine was created, essential design requirements were established based on the survey conducted and literature review. The capacity used in the design of the machine was at least 15 kg/hr, the efficiency was at least 72%, and the mechanical parchment coffee damage must not be more than 5%.

Additionally, the evaluation result showed that the machine has an efficiency of 79.0% and 37.87 kg/hr capacity at a peripheral speed of 1.23 m/s and 0^o inclination. It has a product recovery of 96.96%, mechanical damage of 4.87%, power consumption of 41.54 W-hr, and water consumption of 0.22 L/kg.

Moreover, the field demonstrations showed that the demucilager machine is acceptable to local farmers and cooperatives to reduce human labor, processing time, and water consumption.

Lastly, the simple cost analysis showed that the machine is economically viable at a custom rate of ₱1.75/kg. The machine's use with a Benefit-Cost Ratio of 0.62 could provide an income opportunity to the coffee farmer with an annual net income of ₱12,400 and a payback period of 2.49 years.

DISCLAIMER

“Some part of this manuscript was previously presented and published in the following conference.

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