Technical Performance and Economic Potential of the Locally Developed Pulping Machine For Dried Coffee Cherries

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ABSTRACT
This study evaluated a locally fabricated drum-type coffee pulping machine designed for dried Robusta cherries in Luna, Apayao, Philippines. The machine's performance was tested at four drum speeds (701–1100 rpm) using a Completely Randomized Design. Results showed optimal performance at 901–1000 rpm (T2), achieving 92.60% pulping recovery, 97.34% efficiency, and 41.55 kg/hr input capacity, with minimal losses. Economic analysis revealed a payback period of 212 days, a benefit-cost ratio of 1.1, and a 170.28% return on investment, confirming viability. Recommendations include operational optimizations and noise reduction modifications.

Keywords: Dried Coffee Cherries, Coffee Parchment, Robusta, Drum type

THE PROBLEM AND ITS BACKGROUND

Introduction

Agricultural activities have caused a rapid increase in the volume of agricultural waste and much of which remains underutilized. Coffee, known for its rich aroma and unique flavor, originates from its fruit known as coffee cherries, which are processed by first removing the outermost layer of the cherry, known as the coffee pulp. This coffee pulp is the primary by-product of coffee cherries from coffee processing and as stated by Pandey et al. (2000) it constitutes approximately 40-50% of the cherry's total weight, making it a significant source of biomass.

One of the current banner programs under the Department of Agriculture (DA) is the High Value Crop Development Program (HVCDP), one of its objectives is to promote organic farming for high-value crops. Converting agricultural waste from the coffee processing into organic farming materials greatly supports this initiative. Coffee farmers in Apayao province, part of Cordillera Administrative Region (CAR) primarily cultivate Robusta varieties, which are harvested from May to July and November to January. They harvest cherries for home consumption and leave the rest as waste. Accordingly, many coffee growers in each municipality also sell their cherries directly to individual market vendors who often buy them at low prices (PLGU-OAS, 2022) this is aligned with the Regional Integrated Research, Development, Extension Agenda and Program – Cordillera Administrative Region (RIRDEAP-CAR) coffee production agenda, which identifies low coffee productivity as a key challenge.To address this, specific technologies related to different coffee-growing elevations and the needs of specific coffee varieties should be developed. Introducing an appropriate prototype technology for primary post-harvest processing, such as depulping, could help mitigate this issue by enabling the coffee farmers to process their own coffee cherries, adding value to their produce and increasing their income. To ensure the long-term sustainability and productivity of the coffee sector, extension services and capacity-building initiatives should be implemented to train farmers on the proper use and maintenance of such machines.

Thus, this study aims to develop a locally-fabricated coffee pulper designed to process dried pulp which could serve as a readily available source for composting and provide coffee farmers with an additional value-added product. The development of this coffee pulping machine addresses the shared needs of local coffee farmers, including increasing profitability and production levels by enabling them to own a coffee pulping machine, thereby contributing to the overall sustainability of agriculture in the area.

Objective of the Study

The general objective of the study is to develop and evaluate a coffee pulping machine. Specifically, the study aims to:

1. design and fabricate a coffee pulping machine;
2. determine the optimal pulping operational condition of the machine;
3. evaluate the machine's performance in terms of its pulping capacity, pulping efficiency, pulping recovery, total losses and energy consumption; and
4. assess its economic viability.

Conceptual Framework of the Study

In light of the aforementioned related literature and studies, a coffee pulping machine can be designed and developed for Apayao coffee farmers to use after the harvest season. In designing and developing the new coffee pulper, the following inputs were considered: 1) the problems and needs in designing a coffee pulper; 2) the variety of coffee cherries to be used in the performance evaluation; and 3) the desired performance of the prototype to be developed. This can be achieved by following strategies that assess both the technical and economic characteristics to produce a newly developed coffee pulper that is efficient and economically feasible.

The research paradigm of the study is shown in Figure 4, highlighting the input-process-output approach, which is essential in designing, developing, and evaluating a coffee pulping machine.

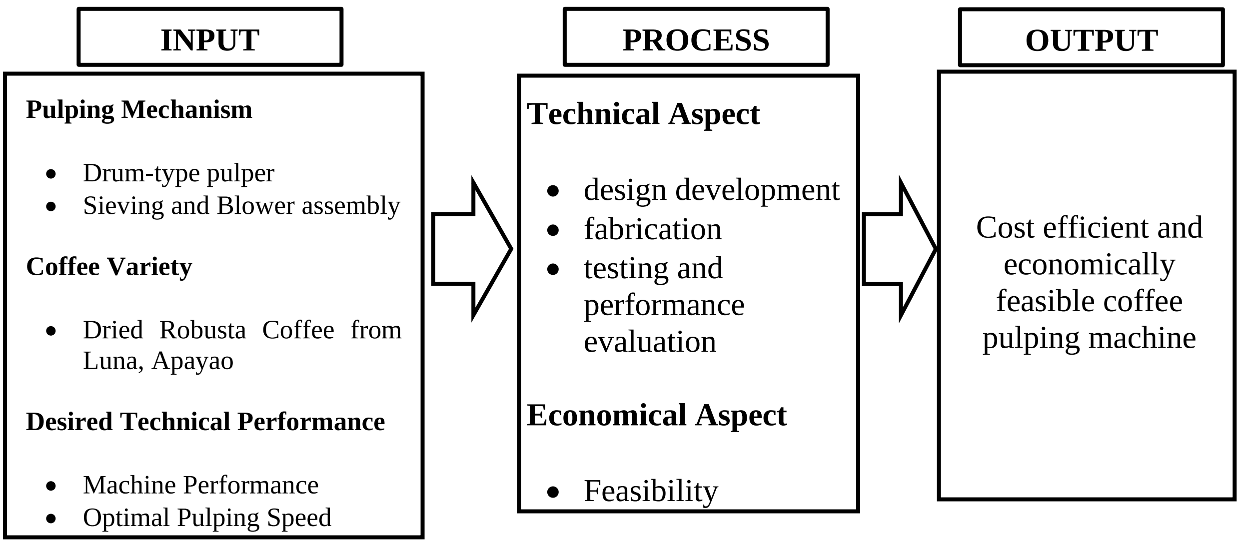


Figure 4. Research paradigm of the study.

MATERIALS AND METHODS

Materials

The materials and equipment presented in Tables 2 and 3 were used to fabricate the prototype of the developed coffee pulping machine. Table 4 presents the instruments used for testing and evaluation, all of which were calibrated to ensure accuracy in collecting the required data on the machine's overall performance.

Table 2. List of Fabrication Equipment needed in the study.

Equipment	Purpose
Arc Welding Machine	Use to weld the metal components together using welding rod
Lathe Machine	Used to reshaped desired metal pieces
Oxyacetylene Welding	Used to cut metal with controlled heat
Drill Press Machine	Used to drill holes
Grinder	Used for smoothening surfaces and removing excess material.
Cut off Machine	Used to cut metal to specified dimensions
Sheet Bender	Used for rounding and bending stainless sheets and G.I. sheets
Hammer	Used for reshaping the desired shape of the metal sheets
wrenches and ratchet & sockets	Used for tightening and loosening bolts and nuts
PPE (welding gloves and grinding mask)	Used for personal protection during welding and grinding operations
L square/tape measure/vernier caliper	Used for measuring desired dimensions

Table 3. List of Fabrication Materials needed in the study.

Material	Purpose
Angular Bars	Used for the frame assembly
Stainless steel sheet	Used for all components in contact with the coffee cherries and parchment

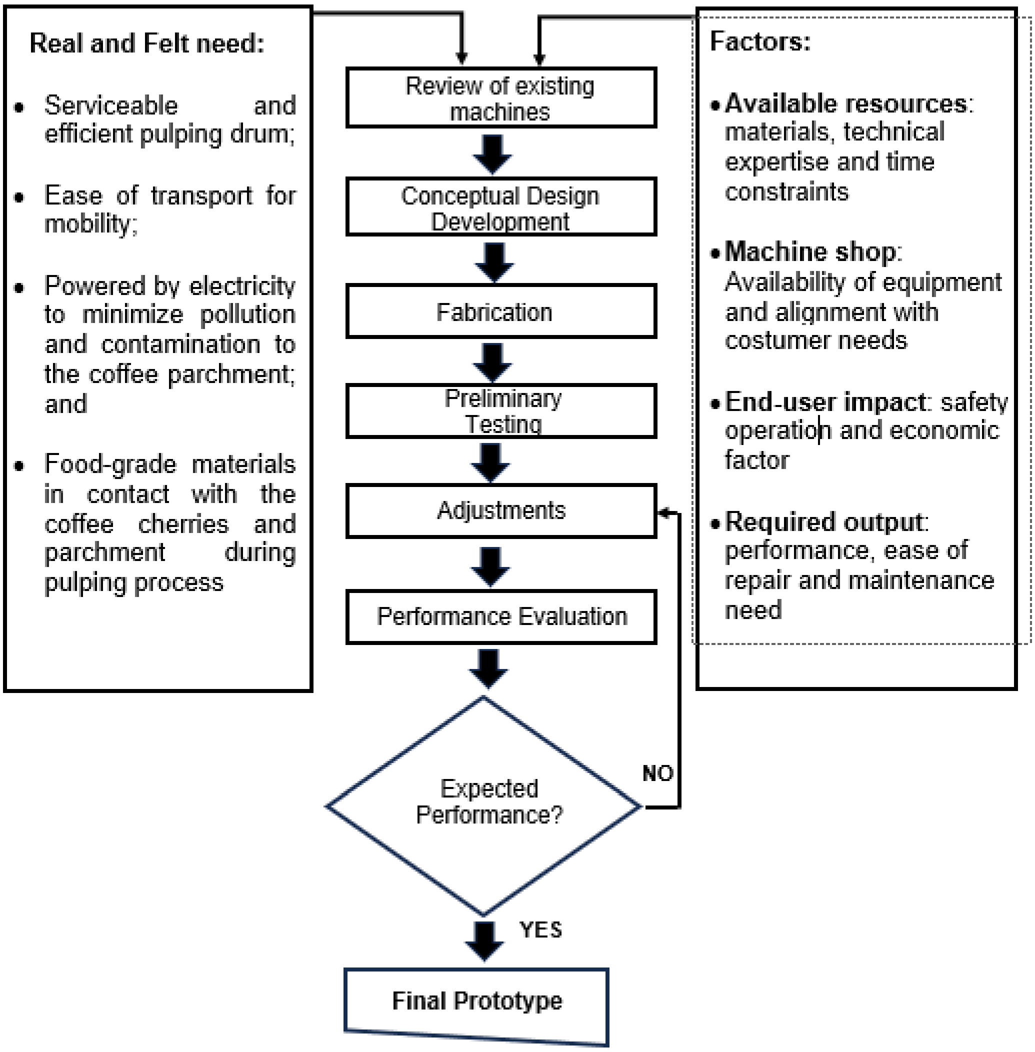
Stainless steel perforated sheet	Used for the sieve assembly in separating the parchment and dried pulp
CR Shaft	Used as shafting of the pulping drum and the sieving mechanism
Bolts and Nuts (stainless and high tensile)	Used as bulbs of the pulping drum(stainless) and hold other machine components (high tensile)
Steel plate	Used for the circular disks in the pulping drum
Pillow blocks	Holds the shafts
Pulleys and belts	Transmits power required from the electric motor to the shafts
Electric motor	Prime mover of the machine
Industrial blower	Used as one part of the sieving mechanism

Table 4. List of instruments needed in the evaluation of the study.

Instrument	Purpose
Non-contact tachometer	Measures the angular speed of the pulping drum of the machine in each treatment replication
Digital timer	Measures the operating time of the machine in each treatment replication
Weighing scale	Measures the weight of the sample materials before and after of each replication
Noise level meter	Measure the noise level produce by the machine during operation.
Digital camera	Used for photo documentation
Recording notes and pen	Used for data recording and labeling

Methodology

The study was conducted based on the following major activities and strategies as shown in the Figure 5



Conceptual Design Development of the Machine

The design of the developed coffee pulper was created using Autodesk Inventor as shown in Figure 6. The machine's components include frame assembly, hopper, feed roll, cover plate, pulping chamber assembly, sifter assembly and blower, caster wheels, main outlet and pulp outlet.

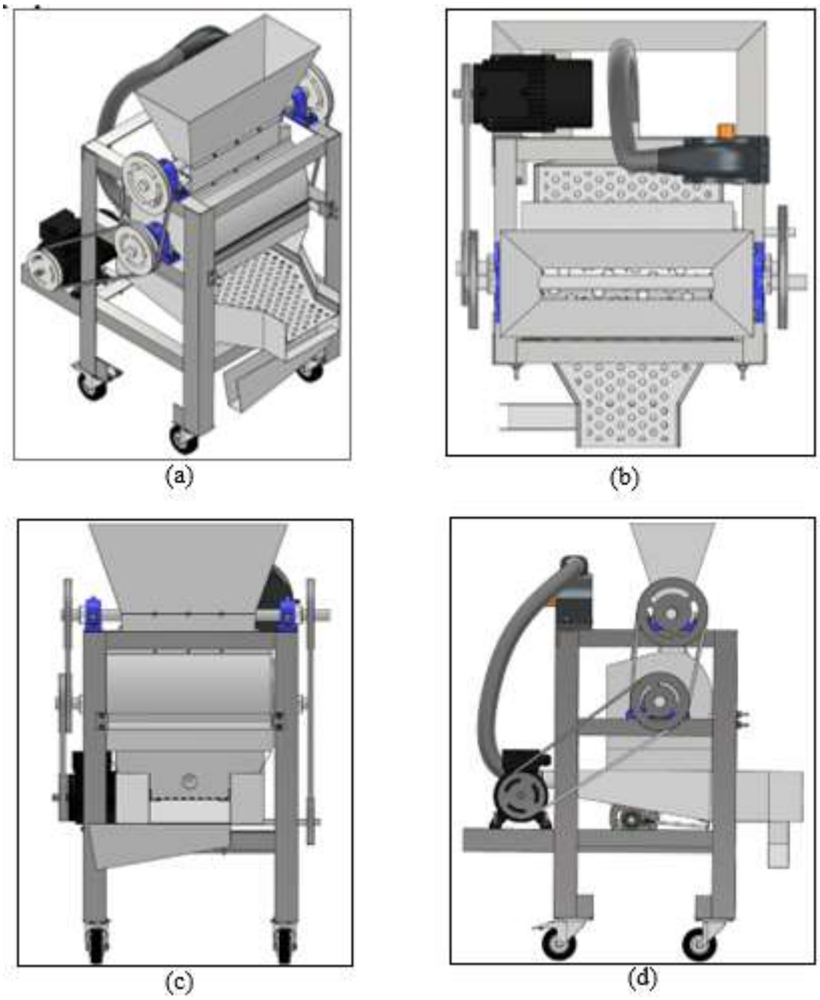


Figure 6. Machine Drawing from different perspective (a) isometric view (b) top view, (c) front view, (d) side view

Working Principle of the Developed Coffee Pulping Machine

The developed coffee pulping machine is driven by an electric motor. Coffee cherries are fed through the hopper and move into the pulping chamber by gravity, after being guided by the feed roll. The pulper operates on the principle of impact and rubbing, where bolts on the rotating pulping drum interact with the cover plate to detach the pulp from the coffee parchment. As the drum rotates against the cover plate, the impact force shears the skin, followed by a squeezing action that rubs the cherries between the two components. The increasing friction, due to the narrowing pulping clearance, effectively separates the pulp from the parchment coffee. Both the parchment and separated pulp then pass through the sieving assembly. The coffee parchment passes through a perforated metal sheet into its receiving tray, while the pulp is blown away by the blower (Figure 7).

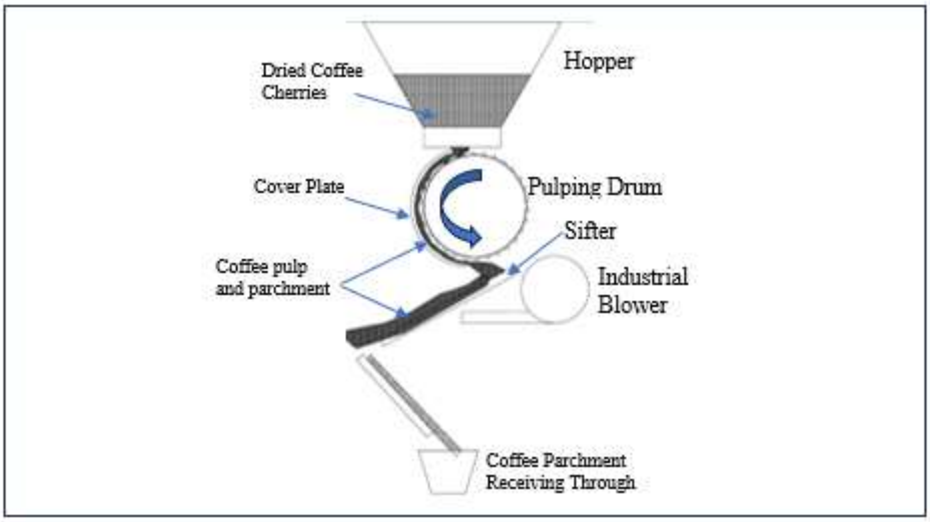


Figure 7. Schematic Diagram of the Developed Coffee Pulping Machine

Design Specification of Parts

The appropriate dimensions and types of materials used in the fabrication of the coffee pulping machine were computed using the following equations.

Drum Shaft Design

The drum assembly is connected to the shaft and is acted on by the weight of the drum and is subjected to shearing, bending and torsional stresses. Its diameter is determined using Equation 1 (Khurmi and Gupta, 2005):

$$D^3 = \frac{16}{\pi \, x \, \tau} \sqrt{((K_m M_m)^2 + (K_t M_t)^2)} \qquad \text{Equation 1}$$

where: τ = allowable shear stress for bending and torsion;
K_m = combined shock and fatigue factor applied to bending;
K_t = combined shock and fatigue factor applied to torsion;
M_m = maximum bending moment; and
M_t = torsional moment, $= \frac{P \, x \, 60}{2\pi N}$

V-belt and Pulley Design

V-belt is a machine element used to transmit motion and power to shaft with center distances. Using equation 2, given from PAES 301:2000, the appropriate design formula is:

$$L = 2C + \frac{\pi}{2}(D + d) + \frac{(D+d)}{4C} \qquad \text{Equation 2}$$

where: L = nominal pitch length of the belt, in
C = the center-to-center-distance between the two pulleys, in
D = the pitch diameter of the large pulley, in; and
d = the pitch diameter of the small pulley, in

Pulley is a wheel with one or more grooved rims used to transmit motion and power by means of one or more V-belt. The diameter and the rated speed of the electric motor is determined, and speed of the pulping drum is depended on each treatment. From this given, the desired size of pulley to attach in the pulping drum can be computed using equation 3:

$D_2 = \frac{(D_1)(N_1)}{N_2}$ Equation 3

where: D_2 = Diameter of the pulping drum's pulley, in;
D_1 = Diameter of the motor's pulley, in;
N_1 = Rated speed of the electric motor, rpm; and
N_2 = Desired speed of the pulping drum's pulley, rpm

Hopper Design

Ozigbo and Murphy (2015), states that in order to prevent tunneling and arching during material discharge, the walls of the hopper should exceed the natural angle of repose of the stored material by at least 10°. The volume formula of a pyramid frustum shape is outlined in Equations 4 as per Mayanja et al. (2018):

$$V = (\frac{h}{3})x(A_1 + A_2 + \sqrt{(A_1 x A_2)})$$ Equation 4

where: h - height of the hopper, cm
A_1 – bottom area of the frustrum, cm^2
A_2 – top area of the frustrum, cm^2

Size Determination of Electric Motor

The power required to operate the pulping machine consists of power required to drive the shaft and the attached drum (P_1), feed roll (P_2) , sieve assembly (P_3) and power required to pulp the coffee cherries (P_4). Computation for P_1, P_2, P_3 and P_4 can be computed using equation 5 given from the study of Ozigbo and Murphy (2015):

$$P_{1,2,3} = F\ x\ r\ x\ \omega$$ Equation 5

where: F = is the force weight of shaft and the drum, P_1 , feed roll assembly for P_2, force weight of the sieve assembly and pulleys, P_3 , Newton (N)
ω = angular velocity of each of the respective component, m/s

From the study of Ismael et.al. (2014), the design of the machine considered a pulping force F= 20N to pulp the dried coffee cherries, thus the computation formula for P_4 is by equation 6:

$$P_4 = \ Fx\ v$$ Equation 6

where: F = pulping force, N
V = velocity of the rotating drum, $\frac{m}{s}$

Fabrication of the Developed Coffee Pulping Machine

This step involved the fabrication of the prototype based on the technical drawings provided in Appendix D. Fabrication was carried out at Baddo Auto Repair Shop in Barangay San Francisco, Luna, Apayao, using tools and equipment commonly found in local machine shops. All components used in the prototype were locally available and relatively low in cost. Additionally, pre-testing of the prototype was conducted at the fabrication site to make necessary adjustments and ensure it met the desired performance output.

Testing and Performance Evaluation

The performance parameters such as pulping capacity, pulping recovery, pulping efficiency, energy consumption rate, total losses, percentage of unpulped loss, percentage of separation loss, and percentage of scattering loss were evaluated at different pulping speeds. For each treatment, one (1) kilogram of dried coffee cherries was used per replication, and each replication required reloading the initial load. The total operating time per replication was measured from the initial loading of the one-kilogram coffee cherries to the completion of the second reloading. The noise emitted by the machine was measured based on the procedure specified in PNS/BAFS 401:2024: Coffee Pulper – Method of Test.

Input Capacity of the Machine

Input capacity is the amount of coffee cherries that the machine can process per unit of time and can be calculated using Equation 7:

$$IC_m = \frac{M_{cc}}{T} \qquad \text{Equation 7}$$

Where: IC_m - Input capacity of the machine, $\frac{kg}{hr}$

M_{cc} - Mass of the coffee cherries fed in the hopper, kg

T - time taken from the machine to complete pulping, hr.

Output Capacity of the Machine

Output capacity is the rate at which the machine can produce coffee parchment per unit of time and can be calculated using Equation 8:

$$OC_m = \frac{M_T}{T} \qquad \text{Equation 8}$$

Where: OC_m - Output capacity of the machine, $\frac{kg}{hr}$

M_T - Total mass of the coffee parchment collected, kg

Pulping Recovery

Pulping recovery is the ratio of the mass of parchment coffee collected at the main outlet to the total mass of coffee cherries input to the machine, computed using equation 9:

$$P_R = \frac{M_{mo}}{M_c} x\ 100 \qquad \text{Equation 9}$$

Where: P_R - Pulping recovery, %

M_c - Mass of the coffee parchment collected at main outlet, kg

Pulping Efficiency of the Machine

Pulping efficiency is the ratio of the total mass of parchment coffee collected at all outlets to the total mass of parchment coffee collected at main outlet and total losses, computed using Equation 10:

$$\varepsilon = \frac{M_T + L_{SE} + L_{SC}}{M_C + L_T} \qquad \text{Equation 10}$$

Where: ε - pulping efficiency, %

L_{SE} - mass of the separation losses, kg

L_{SC} - mass of the scattered losses, kg

L_T - mass of the total losses, kg

Electric Consumption Rate

This is the amount of electricity consumed by the prime mover of the machine per unit time of operation expressed in kilowatt-hour, can be computed using equation 11:

ECR = V x I x T Equation 11

Where: ECR – Electric consumption rate, kWh

V – Rated voltage of the prime mover, volts

I - Electric current, amp.

Total Losses

Total losses is the sum of the mass collected from the separation losses, unpulped losses, and scattering losses, can be computed using equation 12:

$$L_T = L_{SE} + L_{UP} + L_{SC} \qquad \text{Equation 12}$$

where: L_{UP} - mass of the collected unpulped losses, g

Percentage of unpulped loss

The percentage of unpulped loss ($\%L_{UP}$) is the ratio of the total mass of unpulped coffee cherries collected at all outlets to the sum of the total mass of parchment coffee at main outlet and the total losses, expressed in percentage and can be computed using equation 13:

$$\%L_{UP} = \frac{L_{up}}{M_c + L_T} \text{ x } 100 \qquad \text{Equation 13}$$

Percentage of separation loss

The percentage of separation loss ($\%L_{SC}$) is the ratio of the total mass of the parchment coffee that is separated at the pulp outlet of the machine to the sum of the total mass of parchment coffee at main outlet and the total losses, expressed in percentage and can be computed using equation 14:

$$\%L_{SE} = \frac{L_{SC}}{M_c + L_T} \text{ x } 100 \qquad \text{Equation 14}$$

Percentage of scattering losses

The percentage of separation loss ($\%L_{SC}$) is the ratio of the total mass of scattered coffee parchment to the sum of the total mass of parchment coffee at main outlet and the total losses, expressed in percentage and can be computed using equation 15:

$$L_{SC} = \frac{L_{SC}}{M_c + L_T} \text{ x } 100 \qquad \text{Equation 15}$$

Statistical Analysis

The data were analyzed using Statistical Tool for Agricultural Research (STAR)2.0.1, developed by the International Rice Research Institute (IRRI). The four (4) varying pulping drum speeds were used and assessed using ANOVA single factorial Completely Randomized Design (CRD) followed by pairwise mean comparisons employing Least Significant Difference (LSD) at a 5% level of significance. The treatments used for the performance evaluation of the machine were achieved by varying the diameter of the pulley attached to the shaft of the pulping drum.

T_1R_3	T_3R_2	T_3R_1
T_2R_2	T_4R_1	T_4R_2
T_4R_3	T_2R_1	T_2R_3
T_1R_2	T_3R_3	T_1R_1

Treatments

T_1 = 1001-1100 rpm
T_2 = 901-1000 rpm
T_3 = 801-900 rpm
T_4 = 701-800 rpm

Economic Benefits from the New Coffee Pulping Machine

The economics of using the developed coffee pulping machine were determined through a simple cost analysis, based on valid assumptions. According to PNS/BAFS 400:2024: Coffee Pulper – Specifications, stainless steel grade 304 should be used for components in direct contact with the parchment and coffee cherries. These include the hopper, feed roll, pulping drum assembly, cover plate, and sieve assembly. However, the prototype was fabricated using locally available materials. The cost of replacing prototype components in contact with the coffee cherries and parchment with stainless steel were considered to estimate the potential benefit of the new developed coffee pulping machine.

The benefit-cost ratio (BCR) analysis was used to evaluate the feasibility of the coffee pulping machine. The benefit-cost ratio was computed using equation 16:

$$BCR = \frac{Annual\ Benefit}{Annual\ Cost} \quad \text{Equation 16}$$

Furthermore, the Return on Investment (ROI) analysis was used to determine the profit from an initial investment as a percentage of the amount invested:

$$ROI\ (\%) = \frac{\text{Annual Generated Income}}{\text{Cost of Machine}} \times 100 \quad \text{Equation 17}$$

Also, the Payback Period analysis was used to determine the period of time required to recover the return on the capital investment of the machine. It was computed as:

$$\text{Payback Period (year)} = \frac{\text{Cost of Machine}}{\text{Annual Generated Income}} \quad \text{Equation 18}$$

Lastly, the Break-Even Point were analyzed to assess the needed unit sales to cover the fixed and variable cost annually. It was analyzed using the equation 19:

$$BEP\ \left(\frac{kg}{yr}\right) = \frac{Fixed\ Cost + Variable\ Cost}{Selling\ Price - Unit\ price} \quad \text{Equation 19}$$

RESULTS AND DISCUSSION

The Developed Coffee Pulping Machine

The developed coffee pulping machine (Plate 3) was designed for pulping dried coffee cherries. It mechanically separates the dried pulp (husk) from the coffee parchment, and the separated pulp can potentially be used as a source of organic fertilizer. This machine also replaces the labor-intensive manual pulping method, offering a more efficient and less physically demanding alternative. It was specifically designed for optimal functionality while minimizing space requirements, with dimensions of 85 cm in length, 70 cm in width, and 98 cm in height.

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Plate 3a. Actual View 1

Plate 3b. Actual View 2

Plate 3. The Developed Coffee Pulping Machine.

General Observations

During pre-testing of the prototype, the shaft speed of the pulping drum was transmitted from the electric motor using a pulley and belt. Initially, the drum rotated at a low RPM, which resulted in an unresponsive separation of the pulp and parchment coffee. By adjusting the pulley combination and using a smaller pulley for the pulping drum, a higher pulping speed was achieved and generated greater shearing stress in the pulping mechanism. However, more unpulped coffee cherries were collected at the main outlet, requiring them to be reloaded. The output after reloading resulted in more reliable performance.

The dried coffee cherries used in the test were directly sourced from the seller, and their moisture content was not determined. However, due to its hard texture and since it was sun-dried after its harvest as a common practice in the community, this was considered the baseline condition before undergoing depulping.

During the conduct of performance evaluation of the machine, it was operated by one operator, which is responsible for switching the machine on and off, feeding the coffee cherries into the hopper, and managed the collection of the coffee parchment at the main outlet. Moreover, the noise level of the machine was measured at a distance of 50 mm from the operators' ear. It was observed that the machine produced averagely 97 decibels (dBA), which did not conform to the recommended noise level for coffee pulpers based on the Philippine National Standards/ Bureau of Agriculture and Fisheries Standard (PNS/BAFS). The excessive noise was due to the sound generated by the industrial blower.

Discussion of Results

Input Capacity

Table 5 shows the summary of input capacity at different pulping speeds, with a grand mean of 39.21 kg/hr. Based on the results of the Analysis of Variance (ANOVA), the input capacity at T1 was significantly higher than at T2 and T3, while the input capacity at T4 was significantly lower than all other treatments. This indicates that the input capacity of the machine increases with higher pulping speeds. These findings are consistent with the study of Mussa et al. (2023), which demonstrated that increasing drum speed leads to higher input capacity, suggesting that higher operational speeds can enhance throughput in pulping processes.

Table 5. Input Capacity (kg/hr.) of the Pulping Machine at different Pulping Speeds

Treatment	Replication			Treatment Total	Treatment Mean
	I	II	III		
T1	48.65	52.17	50.70	151.53	50.51 [a]
T2	42.35	40.45	41.86	124.66	41.55 [b]
T3	36.36	36.74	37.50	110.60	36.87 [c]
T4	28.57	27.27	27.91	83.75	27.92 [d]
Grand Total				470.54	
Grand Mean					39.21

Note: Means with the same superscript were not significantly different from each other

Table 5a. Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-values		
				Computed	Tabular	
					5%	1%
Treatment	3	798.559	266.1863	218.71**	4.05	7.59
Error	8	9.7366	1.2171			
Total	11	808.2956				

CV (%) = 2.81 ** - Significant at 1%

$LSD_{1\%} = 3.02$

Output Capacity

The output capacities of the machine at different pulping speeds are presented in Table 6, with a grand mean of 39.21 kg/h. Analysis of Variance (Table 6a) revealed a highly significant effect of pulping speed on output capacity (F = 276.95). The Least Significant Difference (LSD 1% = 2.803) test confirmed that all treatment means were significantly different from one another. These results indicate that as pulping speed increases, the machine's output capacity also increases. This relationship occur because output capacity is a function with respect to the duration of operation. Furthermore, these findings align with the study of Singh et al. (2020), which showed that higher rotor speeds resulted in greater output capacity due to increased material flow per unit of time.

Table 6. Output Capacity (kg/hr.) of the Machine at different Pulping Speeds

Treatment	Replication			Treatment Total	Treatment Mean
	I	II	III		
T1	45.58	48.63	46.80	141.01	47.00 [a]
T2	39.90	38.55	40.14	118.59	39.53 [b]
T3	32.69	32.73	33.68	99.10	33.03 [c]
T4	24.77	22.99	23.78	71.54	23.85 [d]
Grand Total				430.23	
Grand Mean					35.85

Note: Means with the same superscript were not significantly different from each other

Table 6a. Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-values		
				Computed	Tabular	
					5%	1%
Treatment	3	868.885	289.962	276.95**	4.05	7.59
Error	8	8.376	1.047			
Total	11	878.261				

CV (%) = 2.85% ** - Significant at 1%

LSD $_{1\%}$ =2.803

Pulping Recovery

The percentages of pulping recovery at varying pulping speeds are summarized in Table 7, with a grand mean of 88.01%. The results indicate that pulping recovery significantly differed across treatments, as revealed by the Analysis of Variance in Table 7a. Comparison of treatment means shows that the highest pulping recovery (92.60%) was observed in T2, which was significantly higher than 90.47% in T1, 87.10% in T3, and 81.87% in T4. These results suggest that T2 provided optimal conditions for pulping recovery, whereas a decline in recovery was evident at both lower (T3, T4) and higher (T1) pulping speeds. This variation may be attributed to the excessive vibration of the machine at T1 and insufficient shearing force between the coffee cherries and the pulping mechanism at the lower pulping speeds of T3 and T4. Table 7. Pulping Recovery (%) of the Machine at different Pulping Speeds.

Table 7. Pulping Recovery (%) of the Machine at different Pulping Speeds.

Treatment	Replication			Treatment Total	Treatment Mean
	I	II	III		
T1	91.20	90.50	89.70	271.40	90.47 [b]
T2	91.70	92.50	93.60	277.80	92.60 [a]
T3	87.60	86.60	87.10	261.30	87.10 [c]
T4	82.70	81.30	81.60	245.60	81.87 [d]
Grand Total				1056.10	
Grand Mean					88.01

Note: Means with the same superscript were not significantly different from each other

Table 7a. Analysis of Variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-values		
				Computed	Tabular	
					5%	1%
Treatment	3	197.016	65.672	115.89**	4.05	7.59
Error	8	4.533	0.567			
Total	11	201.549				

CV (%) = 0.855% ** - Significant at 1%

LSD $_{1\%}$ =2.062

Pulping Efficiency

Table 8 presents the pulping efficiencies of the machine at different pulping speeds, with a grand mean of 96.52%. The results show that the pulping efficiencies of T1, T2, and T3 did not differ significantly from each other, but all were significantly higher than that of T4. The Analysis of Variance (ANOVA) in Table 8a indicates that pulping speed had a highly significant effect on pulping efficiency. The Least Significant Difference (LSD) test at the 1% significance level confirmed that T4 had a significantly lower pulping efficiency compared to the other treatments. The results revealed that increasing pulping speed generally leads to higher pulping efficiency, as observed in the significantly lower efficiency at the lowest speed (T4).

Table 8. Pulping Efficiency (%) of the Machine at different Pulping Speeds

Treatment	Replication			Treatment Total	Treatment Mean
	I	II	III		
T1	97.22	97.80	97.38	292.40	97.47 [a]
T2	97.52	97.15	97.37	292.03	97.34 [a]
T3	97.09	96.63	96.35	290.08	96.69 [a]
T4	94.72	94.28	94.74	283.74	94.58 [b]
Grand Total				1158.24	
Grand Mean					96.52

Note: Means with the same superscript were not significantly different from each other

Table 8a. Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-values		
				Computed	Tabular	
					5%	1%
Treatment	3	16.099	5.367	64.74**	4.05	7.59
Error	8	0.663	0.083			
Total	11	16.762				

CV (%) = 0.855% ** - Significant at 1%

LSD $_{1\%}$ =2.062

Energy Consumption Rate

The energy consumption rates of the machine at different pulping speeds are summarized in Table 9, with a grand mean of 0.0263 kWh. The results indicate that as the rotational speed of the pulping drum increases, the energy consumption rate generally decreases. Treatments T1 (1001–1100 rpm) and T2 (901–1000 rpm) recorded the lowest mean energy consumptions at 0.0193 kWh and 0.0235 kWh, respectively. In contrast, T3 (801–900 rpm) and T4 (701–800 rpm) exhibited higher energy consumption rates at 0.0268 kWh and 0.0356 kWh, respectively. It is evident that the means of T1 and T2 were not significantly different, while T3 and T4 differed significantly from each other and from T1 and T2. These results show that lower pulping speeds require more energy due to longer operating times.

Table 9. Energy Consumption Rate (kWh) of the Machine at different Pulping Speeds

Treatment	Replication			Treatment	Treatment
	I	II	III	Total	Mean
T1	0.0199	0.0187	0.0192	0.0578	0.0193 [d]
T2	0.0229	0.0242	0.0234	0.0704	0.0235 [c]
T3	0.0275	0.0267	0.0263	0.0805	0.0268 [b]
T4	0.0364	0.0364	0.0359	0.1069	0.0356 [a]
Grand Total					0.3156
Grand Mean					0.0263

Note: Means with the same superscript were not significantly different from each other

Table 9a. Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-values		
				Computed	Tabular	
					5%	1%
Treatment	3	0.0004	0.0001	291.11**	4.05	7.59
Error	8	0.0000	0.0000			
Total	11	0.0004				

CV (%) = 2.69% ** - Significant at 1%

$LSD_{1\%} = 0.0019$

Total Losses

Table 10 presents the total losses incurred by the machine at different pulping speeds. The ANOVA results shown in Table 10a reveal a highly significant difference among treatments, as indicated by the computed F-value of 30.83, which is considerably higher than the tabular F-values at both the 5% (4.05) and 1% (7.59) significance levels. The mean total losses per treatment indicate that the highest loss occurred in T4, which was significantly greater than the losses observed in T1 to T3. These findings suggest that operating the pulping machine at lower speeds (T4) results in significantly higher total losses, likely due to an increased number of unpulped cherries, causing more beans to be discarded along with the pulp.

Table 10. Total Losses (gram) of the Machine at different Pulping Speeds

Treatment	Replication			Treatment Total	Treatment Mean
	I	II	III		
T1	59	49	56	164	54.67 ^{b}
T2	50	56	52	158	52.67 ^{b}
T3	53	54	61	168	56.00 ^{b}
T4	82	79	77	238	79.33 ^{a}
Grand Total				728	
Grand Mean					60.67

Note: Means with the same superscript were not significantly different from each other

Table 10a. Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-values		
				Computed	Tabular	
					5%	1%
Treatment	3	1410.667	470.222	30.83**	4.05	7.59
Error	8	122.00	15.250			
Total	11	1532.667				

CV (%) = 6.44% ** - Significant at 1%

$LSD_{1\%} = 10.699$

Unpulped Losses

The computed percentage of unpulped loss of the machine at different pulping speeds is presented in Table 11. The ANOVA results shown in Table 12a indicate a highly significant effect of pulping speed on unpulped loss, with T4 exhibiting the highest unpulped loss at 5.42%, which is significantly greater than the losses observed in T1 (2.54%), T2 (2.66%), and T3 (3.40%). These findings suggest that operating the pulping machine at lower speeds, as in T4, leads to a higher percentage of unpulped coffee. This is likely due to the lower shearing force between the pulping drum and cover plate in relation to the coffee cherries. These results are also consistent with the study by Mussa et al. (2023) on their modified double-disc coffee pulpers, which found unpulped losses ranging from 1.87% to 4.43% at increased pulping speeds.

Table 11. Unpulped Loss (%) of the Machine at different Pulping Speeds

Treatment	Replication			Treatment Total	Treatment Mean
	I	II	III		
T1	2.78	2.20	2.62	7.61	2.54 ^{c}
T2	2.48	2.85	2.63	7.97	2.66 ^{bc}
T3	2.91	3.65	3.65	10.20	3.40 ^{b}
T4	5.28	5.72	5.26	16.26	5.42 ^{a}
Grand Total				42.04	
Grand Mean					3.50

Note: Means with the same superscript were not significantly different from each other

Table 11a. Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-values		
				Computed	Tabular	
					5%	1%
Treatment	3	16.023	5.341	57.04**	4.05	7.59
Error	8	0.749	0.094			
Total	11	16.772				

CV (%) = 8.74% ** - Significant at 1 %

LSD $_{1\%}$ =0.838

Separation Loss

Table 12 presents the separation loss of the machine at different pulping speeds. Comparison among treatments from the ANOVA (Table 12a) showed no significant difference in mean separation loss among T1 (1.35%), T2 (1.46%), and T3 (1.73%). However, T4 (2.15%) exhibited a significantly higher separation loss compared to the other treatments. This means that operating the machine at the lowest pulping speed (701–800 rpm) resulted in greater separation loss compared to higher speeds. Generally, higher pulping speeds, such as those in T1 and T2, were more effective in minimizing separation loss. These results align with the findings of Martinez et al. (2015), who reported that optimizing rotational speed in agricultural processing equipment significantly improves separation efficiency and reduces material loss.

Table 12. Separation Loss (%) of the Machine at different Pulping Speeds

Treatment	Replication			Treatment Total	Treatment Mean
	I	II	III		
T1	1.44	1.36	1.26	4.06	1.35 ^{b}
T2	1.45	1.53	1.42	4.39	1.46 ^{b}
T3	1.72	1.52	1.93	5.18	1.73 ^{b}
T4	2.09	2.02	2.35	6.46	2.15 ^{a}
Grand Total				20.09	
Grand Mean					1.67

Note: Means with the same superscript were not significantly different from each other

Table 12a. Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-values		
				Computed	Tabular	
					5%	1%
Treatment	3	1.135	0.378	17.90**	4.05	7.59
Error	8	0.169	0.021			
Total	11	1.304				

CV (%) = 8.68% ** - Significant at 1%

LSD $_{1\%}$ =0.398

Scattering Losses

Table 13 presents the scattering loss percentages observed in a coffee pulping machine operating at different pulping speeds. The ANOVA from Table 14a indicates a highly significant effect of pulping speed on scattering loss, confirming that variations in pulping speed substantially influence the scattering loss during operation. Mean comparisons reveal that T1 exhibited the highest scattering loss at 1.81%, which is significantly greater than the losses observed in T3 at 1.01%. T2 and T4 both had scattering losses of 1.26%, which were not significantly different from each other but differed from T1 and T3. This is conformed from the research result on modified double-disc coffee pulpers of Mussa et al (2023) which stated that the higher machine speeds can attributed to excessive vibrations.

Table 13. Scattering Loss (%) of the Machine at different Pulping Speeds

Treatment	Replication			Treatment	Treatment
	I	II	III	Total	Mean
T1	1.85	1.57	1.99	5.42	1.81 [a]
T2	1.24	1.33	1.22	3.78	1.26 [ab]
T3	1.08	0.98	0.97	3.02	1.01 [b]
T4	1.65	1.12	1.01	3.78	1.26 [ab]
Grand Total				16.00	
Grand Mean					1.33

Note: Means with the same superscript were not significantly different from each other

Table 13a. Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-values		
				Computed	Tabular	
					5%	1%
Treatment	3	1.025	0.342	8.01**	4.05	7.59
Error	8	0.341	0.043			
Total	11	1.366				

CV (%) = 15.49% ** - Significant at 1 %

$LSD_{1\%} = 0.566$

The results presented in Table 14 summarize the overall effects of pulping speed on the coffee pulping machine's performance parameters. Higher pulping speeds (T1 and T2) significantly improved input and output capacities, pulping recovery, and pulping efficiency, while reducing total losses, percentage of unpulped losses, percentage of separation losses, and energy consumption rates. T1 recorded the highest input (50.51 kg/hr) and output capacities (47.00 kg/hr), affirming that increasing the pulping speed improves capacities. However, T1, also resulted in the highest scattering loss of 1.81%, this was possibly cause due to the excessive machine vibrations. In contrast, the lowest pulping speed (T4) consistently exhibited the poorest performance, with the lowest capacities, highest total losses and percentage of unpulped losses, and highest energy consumption. Highest pulping recovery was attained at T2 (92.60%), this indicates an optimal balance between speed and pulping efficiency without excessive vibration.

Table 14. Summary Table of the Coffee Pulping Machine's Performance

Performance Parameter	Treatments			
	T1 (1001-1100 rpm)	**T2 (901-1000 rpm)**	**T3 (801-900 rpm)**	**T4 (701-800 rpm)**
Input Capacity (kg/h)	50.51[a]	41.55 [b]	36.87[c]	27.92[d]
Outnput Capacity (kg/h)	47.00[a]	39.53[b]	33.03[c]	23.85[d]
Pulping Recovery (%)	90.47[b]	92.60[a]	87.10[c]	81.87[d]
Pulping Efficiency (%)	97.47[a]	97.34 [a]	96.64 [a]	94.58[b]
Energy Consumption Rate (kWh)	0.0193[d]	0.0235[c]	0.0268[b]	0.0356[a]
Total Losses (g)	54.67[b]	52.66[b]	56.00[b]	79.33[a]
Unpulped Loss (%)	2.54[c]	2.66[bc]	3.40[b]	5.42[a]
Separation Loss (%)	1.35[b]	1.46[b]	1.73[b]	2.15[a]
Scattering Loss (%)	1.81[a]	1.26[ab]	1.01[b]	1.26[ab]

Note: Means with the same superscript were not significantly different from each other.

Economic Benefit from the Coffee Pulping Machine

To assess the economic benefits of owning a coffee pulping machine, the cost of the coffee parchment (green coffee bean) that is produced by the machine was estimated by applying a 15% profit margin from the actual cost of the dried robusta coffee cherries. The computations and cost analysis of using a coffee pulping machine were based on the actual performance data and economics of farm machines. The investment cost of the developed coffee pulping machine was based on the latest and local market values. The machine was assumed to operate for 400 hours annually, corresponding to 4 hours a day and a 25 days per month. The operational period was estimated at 3 months per harvest season annually in Apayao, excluding Sundays and holidays. The remaining months of the year were allocated for machine maintenance and other activities related to the depulping process and the machine was required to be operated by one operator.

As presented in Table 15, the total cost of the machine was ₱ 75, 000.00 with an annual fixed cost of ₱ 14,775, annual variable cost of ₱ 47, 868 and, operating cost of ₱ 2,346,000. the annual benefit of ₱ 2,538,000, and an annual net income of ₱ 129,357 with a payback period of 212 days this indicates that the investment cost can be recovered after 212 days of operation.

The benefit-cost ratio (BCR) was calculated at 1.1 and the return on investment of the machine was 170.28%, this shows that by owning the developed coffee pulping machine is economically viable having a greater than 1 of BCR which confirms that the investment is profitable. The minimum production required annually to cover all costs and avoid losses was based on the computed Break-Even Point (BEP) of 3,133 kg of coffee parchment per year.

Table 15. Economic benefit of using the Coffee Pulping Machine

Parameters	
A. Investment Cost (Cost of the Machine)	₱75,000.00

B. Annual Cost	₱2,410,293.00
a. Fixed Cost	₱14,775.00
Depreciation	₱6,750.00
Interest of Investment	₱5,775.00
Tax & Ins.	₱2250.00
b. Variable Cost	₱47,868.00
Cost of Electricity	₱12,867.96
Labor Cost	₱20,0000.00
Repair and Maintenance	₱15,000.00.00
c. Operating Cost	₱2,346,000.00
C. Annual Benefits	₱2,538,000.00
D. Annual Net Income	₱127,707.00
E. Benefit-Cost Ratio	1.1
F. Return on Investment (%)	170.28
G. Payback Period (days)	212
H. Break-Even Point (kg/year)	3,133

SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

Most coffee farmers in Apayao harvest coffee cherries primarily for home consumption, leaving the rest to go to waste. Many coffee growers across the municipalities also sell their cherries directly to individual market vendors, who often purchase them at low prices. To address this issue, the study was conducted with the aim of designing, fabricating, and evaluating the performance and economic viability of a locally developed coffee pulping machine intended for dried Robusta coffee cherries. The developed machine, featuring a drum-type pulper driven by an electric motor and equipped with a sieving mechanism, was fabricated using locally available materials. It was tested and evaluated in Luna, Apayao, from August 2024 to January 2025.

Four levels of pulping speeds (1001–1100, 901–1000, 801–900, and 701–800 rpm) were used, and the experimental design applied was a Completely Randomized Design (CRD) with three replications. The performance of the machine was evaluated based on pulping capacity, pulping efficiency, pulping recovery, energy consumption rate, total losses, and loss percentages (unpulped, scattering, and separation). Results revealed that pulping capacity, recovery, and efficiency increased with higher pulping speeds, while total losses, percentage losses, and energy consumption increased at lower pulping speeds. Furthermore, T2 (901–1000 rpm) maintained high pulping efficiency with relatively low energy consumption, whereas T1 (1001–1100 rpm) resulted in higher scattering losses due to excessive machine vibrations.

The analysis of the economic benefits of owning the coffee pulping machine revealed a Benefit-Cost Ratio (BCR) of 1.1, a Return on Investment (ROI) of 170.28%, a payback period of 212 days, and a break-even point of 3,133 kg per year, confirming the machine's economic feasibility.

Conclusion

In the light of the summarized findings, the following conclusions are drawn:

- The design of the locally developed coffee pulping machine powered by electric motor, drum-type

pulping mechanism, and incorporated with sifter and industrial blower is effective and functional for processing dried robusta coffee cherries.
- The machine performed acceptable performance across all treatments where T2 (901-1000 rpm) being the most favorable operating condition, significantly influenced the performance of the machine by yielding the highest pulping recovery and efficiency.
- Pulping efficiency improved with increasing speed but too much speed like T1(1000-1100 rpm) caused more scattering losses due to vibration.
- The machine was economically viable and feasible with higher return on investment, lesser payback period and low break-even volume.

Recommendations

Based on the results of the study, the following are recommended:

For operation,
- To achieve the best pulping performance and optimal energy use, operate the machine at a drum speed of 901–1000 rpm (T2).
- Use ear muffs by the operator, to comply with national noise standards and improve operator comfort.
- Operate the machine at the highest speed setting (T1) only when maximum output is prioritized and cherry input is uniform, but be cautious of increased scattering losses due to vibration.

For further study,
- Evaluate the machine using coffee cherries with known moisture content for better control and validation of results.
- Test the machine across different Robusta varieties or elevation-based harvests to assess adaptability.
- Integrate automation component such as feed regulators or digital speed control.
- Evaluate the effects of varying drum, sieve hole sizes and wind velocity of the blower on pulping efficiency and recovery, especially when processing uneven cherry sizes.

For modification,
- Add a protective noise-dampening enclosure for the blower system.
- Redesign the hopper for better flow of uneven-sized cherries and reduced loading effort.

Redesign the sieving mechanism to minimize vibrations at higher speeds and enhance pulping consistency.

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