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Abstract: *Cocoa powder is in higher demand due to its application in numerous food products. To meet this demand, there is a need for efficient cocoa powder processing equipment. Hence, this research study seeks to develop a combined cacao bean huller-pulverizer machine for cocoa powder processing and evaluate its machine performance in terms of capacity and efficiency. A Central Composite Design (CCD) with a two-factor experiment was used to evaluate the performance of the developed machine. Results show that the average output capacity and efficiency of the developed combined cacao bean huller-pulverizer machine is about 5.56 kg/h and 83.37%, respectively. The machine was financially feasible based on the results of its financial analysis. Furthermore, the fineness modulus of the output product was compared to a commercialized cocoa powder, and it has no significant difference. This result indicates that the cocoa powder produced by the machine is acceptable.*

Keywords: Cocoa powder; Huller; Pulverizer; Central Composite Design; Fineness modulus

1. INTRODUCTION

Cacao (*Theobroma cacao L.*) is a member of the Malvaceae family, classified as a neotropical plant indigenous to the areas near and within the Amazonian lowland rainforests, currently supporting the livelihood of 40–50 million people in more than 50 countries [1]. It is highly considered as a commercially important plant species grown primarily for its beans. This is because cacao beans are composed of approximately 50% cocoa butter, a lipid that is the main ingredient for chocolates, cosmetics, and confectionery industries [2].

Products made from cocoa beans, which are the seeds of the cacao tree, include cocoa (liquor or powder) and cocoa butter (*Theobroma cacao L.*) [3]. While the chocolatiers focus on making confections, the cocoa processors make items like cocoa liquor, butter, and powder [4]. When the beans are processed at a much higher temperature, cocoa powder is produced. The cacao beans are roasted in addition to being fermented while cacao powder only involves fermentation. The taste of the chocolate is naturally acidic without any additional processing. The product is marketed as "natural cocoa" and is sifted and finely milled. Due to the added heating, there is a trade-off in that it could not have as many nutrients as cacao powder [5].

Hulling is an important process on cocoa powder production. The efficiency of a hulling facility directly affects the economy of a production line. Some words and expressions used to describe the process of separating the shell (hull) from its meat (nib) include winnowing, cracking, fanning, and hulling [6]. A clean separation of the two components is achieved by a process that is driven by economics, product integrity, and, in many nations, government regulation. Preventing the loss of the cocoa bean's precious nibs is crucial for ensuring optimal production.

In the Philippines, most cacao farmers are small landowners; hence, most of the processing operations are conducted manually, including separating cacao nibs from their husks. However, the manual methods of cacao processing, especially the hulling process, are laborious, making it less efficient. There are limited studies regarding the design of cacao hullers. However, cacao hullers that exist in the market are available. Due to the small production of cacao farmers, investing in the said technologies is quite expensive. A study by Hernando et al. [7] stated that the various factors, the impact-type cacao bean hulling machine with a combination of cracking and winnowing systems was successfully developed and constructed. Using a cyclone-type vacuum, the machine's impeller-type cracking chamber took the input material and transferred it to the aspirator. However, this machine only performs hulling operations, and the farmers still need to purchase a technology for pulverizing the cacao nibs. Thus, designing a hulling and pulverizing machine for cacao beans is highly sought-after to enhance the productivity of the cacao processors. This paper aims to design and fabricate a machine with a combination of cacao hulling and pulverizing processes that will help reduce time consumption and laborious production of cocoa powder.

2. MATERIALS AND METHODS

2.1 Machine Design

The design of the machine is the combination of cacao huller and cacao pulverizer. The machine has a hopper that directly transports the roasted cacao beans into the roller-type crusher with 26 degrees inclination [8]. After the cacao beans have been crushed, it will undergo separation or hulling. The attached vacuum will separate the hull from the cacao nibs, through the density difference of the two materials. The nibs will fall straight to the pulverizer following a pipe attached to it and to the hulling chamber. A fixed-type hammer mill is responsible for the pulverizing of cacao nibs. The mill consists of a four-blade hammer mill permanently attached to a rotating shaft. The housing of the mill which is the 12-inch diameter pipe is designed with corrugated upper portion in the inside. The lower part of the pipe was holed and fitted with a perforated steel sheet as the outlet part of the pulverized cacao with 3 mm hole size. An electric motor with 1hp power was used as the prime mover of the machine. Figure 1 shows the working design of the combined cacao bean dehuller-pulverizer and Figure 2 shows the close up view of the crushing element.

2.2 Performance Evaluation

The hulling performance of the machine was evaluated in relation to crusher clearance and the vacuum airflow rate. This evaluation will give the optimum operating condition of the machine with respect to the selected factors. The second experiment was conducted using the optimum combination of the first experiment, which is the comparative analysis between the fineness modulus from the developed machine and commercially available cocoa powder. A financial analysis was also conducted after the machine's experimental evaluation to determine the financial feasibility of the machine.

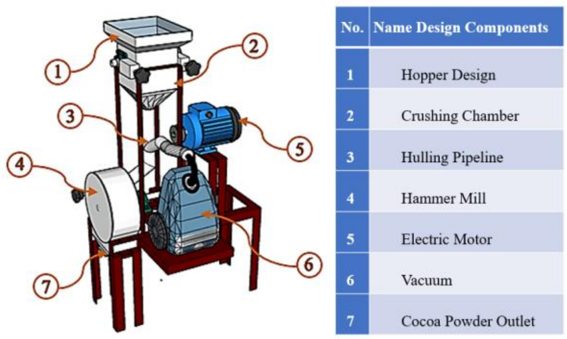


Fig. 1. Combined Cacao Bean Dehuller-Pulverizer.

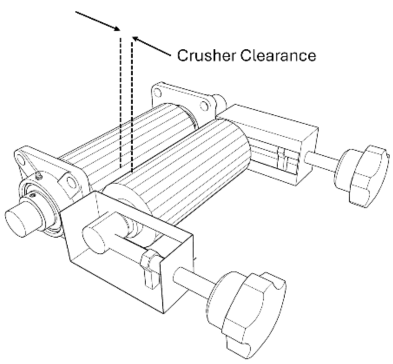


Fig. 2. Crushing Element.

2.3 Sample Preparation

Fermented and dried cacao beans were used in the evaluation of combined cacao huller-pulverizer machine. Figure 3 shows the dried cacao beans from the market of Langihan, Butuan City.

Fig. 3. Dried cacao beans

Samples are manually roasted for 35 min at 100 ºC maximum heat. For the evaluation of machine in relation to crusher clearance and the vacuum airflow rate, 13 runs and 500 g of manually roasted cacao beans each run was used. In the evaluation of the overall performance, 3 runs and 500 g of manually roasted cacao beans were used in every run.

2.4 Evaluation of Hulling Performance

The first experiment was the evaluation of the hulling performance of the machine in relation to its crusher clearance and vacuum airflow rate. The hulling performance was evaluated based on its purity, hulling efficiency, blower loss and cacao nibs' recovery index with respect to the combination of two (2) variables. Attaining the desired crusher clearance was done by rotating the adjuster knob which will direct the crusher to widen and tighten clearance and measuring the clearance using Vernier caliper. On the other hand, changing the opening of the vacuum to regulate the airflow rate and measuring the airflow rate using digital hot wire anemometer.

2.5 Evaluation of the combined cacao bean dehuller-pulverizer

After evaluating the hulling performance of the machine and identifying which combination of factors to be used in the combined cacao bean huller-pulverizer machine, the second experiment was the evaluation of its overall performance in terms of its machine output capacity, machine output efficiency and the determination of the fineness modulus of the cocoa powder which is the product of the machine. Machine output capacity and machine output efficiency were determined with formulas presented on Equation 5 and 6. Fineness modulus were determined with the mechanical sieve and analytical balance. The data gathered for the determination fineness modulus were calculated through Microsoft Excel.

2.6 Experimental Setup

The hulling performance of the machine was tested and subjected to three (3) levels of crusher clearance (1, 2 and 3 mm) and vacuum air velocity (1, 2 and 3 m/s). Each treatment utilized 500g of roasted cacao beans. The random treatment combination of crusher clearance and vacuum air velocity including the response is presented in Table 2. For the performance evaluation of the machine specifically on hulling performance, several formulas were utilized from Philippine National Standards (PNS) for Agricultural Machinery- Cacao Huller- Methods of Test (PNS/BAFS/PAES 254:2018) [9].

After the first experiment, the optimum combination of crusher clearance and vacuum airflow rate was determined. This optimum combination was used to determine the machine capacity and machine efficiency. Three (3) runs with 500 grams each run were used to conduct the second experiment. The fineness modulus of each run was determined for the comparative analysis between the fineness modulus of the cocoa powder from the combined huller-pulverizer machine and commercially available cocoa powder, which used a screw-type grinder. The determination of machine output capacity, machine output efficiency, and cocoa powder fineness modulus are presented in Table 3. Each run has 500g of roasted cacao beans fed in the machine.

2.7 Data Gathered

The following data were gathered in this experiment:

1. Weight of unhulled cacao beans
2. Weight of cacao nibs
3. Weight of hull
4. Weight of input roasted cacao beans
5. Total operating time

The following variables/parameters were determined:

1. Purity, %
2. Hulling Efficiency, %
3. Blower loss, %
4. Cacao nibs recovery, decimal
5. Machine output capacity, kg/h
6. Machine output efficiency, %
7. Fineness modulus

Table 1. Experiment treatment combination on the two (2) factor Central Composite Design (crusher clearance and vacuum airflow rate) with purity, hulling efficiency, blower loss and cacao nibs recovery index as responses

Run #	Crusher Clearance, mm	Vacuum Airflow Rate, m/s	Purity, %	Hulling Efficiency, %	Blower Loss, %	Cacao Nibs Recovery Index, Decimal
1	2	2	-	-	-	-
2	2	2	-	-	-	-
3	2	1	-	-	-	-
4	1	1	-	-	-	-
5	3	3	-	-	-	-
6	3	2	-	-	-	-
7	2	3	-	-	-	-
8	1	2	-	-	-	-
9	2	2	-	-	-	-
10	1	3	-	-	-	-
11	2	2	-	-	-	-
12	2	2	-	-	-	-
13	3	1	-	-	-	-

Table 2. Optimum combination (crusher clearance and vacuum airflow rate) with machine input capacity and machine output capacity, machine efficiency as responses

Run #	Machine Output Capacity, kg/h	Machine Output Efficiency, %	Fineness Modulus
1	-	-	-
2	-	-	-
3	-	-	-

2.7.1 Determination of Purity

Purity is the ratio of the weight of cacao nibs that are clean or hulled cacao to the weight of all uncleaned cacao nibs, and it is expressed in percentage (%). The formula for purity is presented in equation 1.

$$P = \frac{W_{cn}}{W_h} \text{ x } 100 \quad (1)$$

Where:
P = purity (%)
W_{cn} = weight of cacao nibs (kg)
W_h = Weight of hull/testa (kg)

2.7.2 Determination of Hulling Efficiency

Hulling efficiency is the weight of the cacao nibs collected at the cacao nib outlet/s divided by the weight of the cacao nibs and the weight of the unhulled cacao beans and it is expressed in percentage (%). The formula for hulling efficiency is presented in equation 2.

$$E_h = \frac{W_{cn}}{W_{ub+Cn}} \text{ x } 100 \quad (2)$$

Where:
E_h = hulling efficiency (%)
W_{cn} = weight of cacai nibs collected at cacao nibs outlet (kg)
W_{ub+cn} = weight of unhulled beans and cacao nibs at cacao nibs outlet (kg)

2.7.3 Determination of Blower Loss

Blower loss is the ratio of the weight of dry, unhulled, roasted cacao beans, and cacao nibs blown to the total weight of the input cacao nibs by the huller fan, and it is expressed in percentage (%). The input cacao nibs are from the manual hulling of roasted cacao beans. The weight of roasted cacao beans for manual hulling to be used is determined from each weight of vacuum output from each run. The formula for blower loss is presented in equation 3.

$$B_l = \frac{W_b}{I_{cn}} \text{ x } 100 \quad (3)$$

Where:
B_l = blower loss (%)
W_b = weight of blown cacao nibs (kg)
I_{cn} = input cacao nibs (kg)

2.7.4 Determination of Cacao Nibs Recovery Index

The cacao nibs recovery index is the ratio of the total weight of the cacao nibs gathered at the outlet to the input cacao nib weight and it is expressed in decimal. The input cacao nibs are from the manual hulling of roasted cacao beans. 500 g of roasted cacao beans was taken for manual hulling to equalize the weight of input roasted cacao beans from each run of the experiment. The weight of roasted cacao beans for manual hulling to be used is determined from each weight of vacuum output from each run. The formula for cacao nibs recovery index is presented in equation 4.

$$R_i = \frac{W_{cn}}{I_{cn}} \quad (4)$$

Where:
R_I = cacao nibs recovery index (decimal)
W_{cn} = weight of cacao nibs collected at cacao nib outlet (kg)
I_{cn} = input cacao nibs (kg)

2.7.5 Determination of Machine Output Capacity

$$OC_M = \frac{W_P}{T_o} \quad (5)$$

Where:
OC_{MO} = machine output capacity (kg/h)
W_p = total weight of cocoa powder (kg)
T_o = total opearating time (h)

2.7.6 Determination of Machine Output Efficiency

$$Eff_M = \frac{W_O}{W_I} \text{ x } 100 \quad (6)$$

Where:
Eff_{MO} = machine output efficiency (%)
W_O = weight of cocoa powder (kg)
W_I = weight of roasted cacao nibs (kg)

2.7.7 Comparison of Fineness Modulus

After the experiment with optimal treatment combination which used on the operation of the cacao bean huller-pulverizer machine, cocoa powder output in three runs were analyzed in terms of its fineness modulus and compared the result to the commercially available cocoa powder which used screw-type grinder. 100 g for each run output were taken to be subjected to get the fineness modulus. Mechanical sieve and analytical balance were used to determine the fineness modulus. A t-test was used to compare and to determine significance between the commercialized cocoa powder and cacao bean huller-pulverizer output. The comparison was done using IMB SPSS statistical software.

2.8 Statistical Analysis

The data gathered in the experiment was analyzed statistically following the Response Surface Methodology (RSM) method. The software used in the analysis was Design Expert v.13. An optimum combination of the factors was identified.
The parameters computed for the analysis were the following:

1. Purity
2. Hulling Efficiency
3. Blower Loss
4. Cacao nibs recovery index

A t-test analysis was conducted to analyze the data gathered during the experiment with optimal combination of the factors for the comparison of fineness modulus from the experiment to the fineness modulus of commercially available cocoa powder which used a screw-type grinder. The software used in the analysis was Statistical Tool for Agricultural Research (STAR) Software at P<0.05. Level of significance between two sets of samples from different cocoa powder products.

2.9 Financial Feasibility

For the evaluation of financial feasibility for combined cacao bean huller-pulverizer machine, the Net Present Value (NPV), Payback Period, Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period [10].

2.9.1 Net Present Value (NPV)

Net present value (NPV) is used to evaluate the present value of a series of future cash flows to the investment's initial cost. The product is profitable at the rate of interest set if the NPV is positive. It can be calculated or mathematically expressed by this equation.

$$NPV = -C_o + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_n}{(1+r)^T} \quad (7)$$

Where:
C_o = intial investment
C = cash flow
R = interest rate
T = time

2.9.2 Internal Rate of Return (IRR)

The internal rate of return (IRR) is the rate of return at which the present value of cash inflows and outflows are equal. The product is profitable at the rate of interest set if the IRR is positive. IRR is expressed as a percentage and can be calculated using this equation.

$$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_o \quad (8)$$

Where:
C_t = net cash inflow during the period *t*
C_o = total initial investment cost
IRR = the internal rate of return
T = the number of time period

2.9.3 Benefit-Cost Ratio (BCR)

The cost-benefit ratio evaluates a project's net benefit in relation to its net cost. A ratio greater than 1 indicates that the project's benefits outweigh its costs, whereas a ratio less than 1 indicates that the costs outweigh the benefits. It can be expressed mathematically by this equation.

$$BCR = \frac{\text{PV of benefit expected from the project}}{\text{PV of the cost of the project}} \quad (9)$$

2.9.4 Payback Period

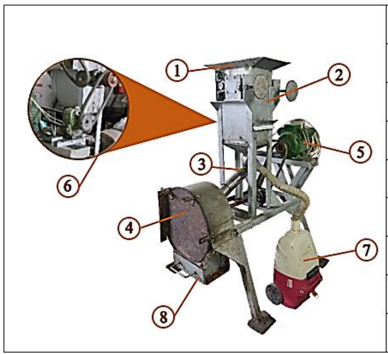
The time it takes for an investment to recover from the related cash flows. It can be calculated using this equation.

$$\text{Payback Period} = \frac{\text{Cost of project Investment}}{\text{Annaul Cash Inflows}} \quad (10)$$

3. RESULTS AND DISCUSSION

3.1 Machine Description

The combined cacao bean huller-pulverizer machine consisted of three main components: crusher, hulling chamber, and hammer mill. The desired measurement according to the designed dimensions was cut and fabricated to form the hopper for the crusher, crushing box, and drawer-type compartment. Each of those components had its subcomponents which were important for the whole machine system. Figure 4 shows the actual prototype of the fabricated combined cacao bean huller-pulverizer machine.



Name of Parts
1. Hopper
2. Crushing Chamber
3. Hulling Pipeline
4. Hammer Mill
5. Electric Motor
6. Gear Box
7. Vacuum
8. Cocoa Powder Outlet

Fig. 4. Actual perspective view of the machine.

3.2 Performance of the Huller

The performance of the huller was evaluated using a set of parameters: the crusher clearance and vacuum airflow rate. Crusher clearance with three (3) variations (1, 2, and 3 mm) and vacuum airflow rate with three (3) variations (1, 2 and 3 m/s) were evaluated based on its, purity, hulling efficiency, blower loss, and cacao nibs recovery index. The randomization and determination of different treatment combinations were identified using response surface methodology with central composite design.

3.2.1 Purity

The average purity of the nibs as presented in Table 4 ranges from 77.66% to 95.34%. In relation to purity, higher value would probably a product from the desired factor combination as purity percentage must close to 100%. The most acceptable purity was achieved with a factor combination of 2 mm crusher clearance and 3 m/s vacuum air velocity. A surface regression model analysis and Analysis of Variance (ANOVA) were conducted to determine the effect of the two factors in measure response. It shows that among several models, cubic model was found to be adequate for the prediction of the purity of the nibs which was given by the following equation:

$$\text{Purity} = 89.33 - 0.2550A + 8.84B + 0.3875AB + 1.74A^2 - 2.14B^2 - 3.32A^2B + 0.2825AB^2 \quad (11)$$

Where:
A = Crusher Clearance
B = Vacuum Air Velocity

In addition, the result presented a decent R^2 of about 0.8190 which meant that the two set of variables were just enough in predicting the variablity of the response. Analyzing the effect of individual factor, it was shown in the ANOVA that the vacuum air velocity showed that it can affect the purity significantly at 95% level of significance and the vacuum air velocity is the significant model for this case but the crusher clearance had no significant effect on the purity of the nibs. Such an effect can be obeserve by looking at the surface plot being developed in Figure 5. The model shows that either increasing or decreasing crusher clearance cannot predict the desired value for purity. On the other hand, the value of purity decreases when the vacuum air velocity also decreases. The increasing vacuum air velocity eventually resulted in a much acceptable purity.

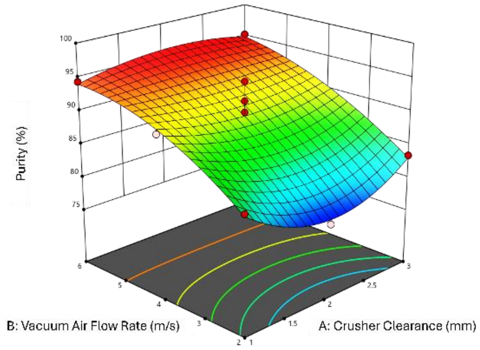


Fig. 5. Surface plot for purity.

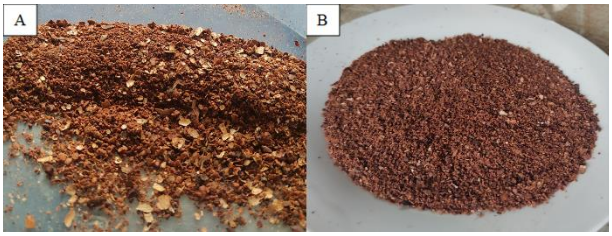


Fig. 6. Cocoa powder output at lowest and highest purity value, (A) 77.66% and (B) 95.34%.

As shown in Figure 6, the lowest purity value of 77.66% has a visible hull as it was included to the pulverizing process which should the nibs were pulverized. The figure also presented the cocoa powder with the highest purity percentage of 95.34%.

3.2.2 Hulling Efficiency

As can be gleared from Table 4, the average percentage of hulling efficiency ranged from 59.39% to 92.54%. It was determined by deviding the weight of unhulled beans and cacao nibs at cacao nibs outlet to the weight of cacao nibs collected at cacao nibs outlet. The highest percentage of hulling efficiency was attained at treatment combination of 2 mm crusher clearance and 2 m/s vacuum air velocity. The regression analysis shows that out of the several models, quadratic model (Eq. 12) was the most suited model in predicting the percentage of hulling efficiency by the machine in relation to crusher clearance and vacuum air velocity. In the surface plot (Fig. 7), it can primarily observed that a desired outcome for hulling efficiency was a result when the crusher clearance is set to 1 mm with the vacuum air velocity at 3 m/s. Figure 6 also shows the indirectly proportional relations between decreasing crusher clearance and increasing vacuum air velocity that resulted acceptable value of hulling efficiency. Thus, it means more broken beans as crusher clearance get tighten, the hulling efficiency increases. In contradiction, a study about motorized rice hulling machine had a different outcome as hulling efficiency increases as broken grain of rice percentage decreases [11].

$$\text{Hulling Efficiency} = 81.41 - 11.89A + 0.05000B + 5.32AB - 3.29A^2 + 3.40B^2 + 8.09A^2B + 3.71AB^2 \quad (12)$$

Where:
A = Crusher Clearance
B = Vacuum Air Velocity

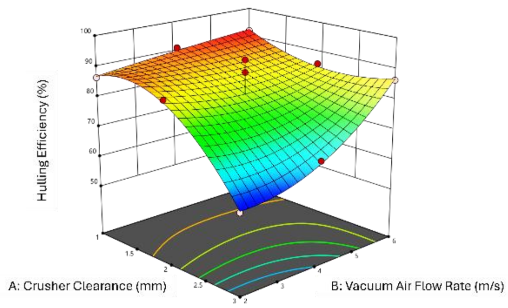


Fig. 7. Surface plot for hulling efficiency.

Additionally, further analysis showed that there is a significant interaction between the two independent variables to the percentage of hulling efficiency. It can be seen in the graph that setting a higher level of vacuum air velocity and decreasing the level of crusher clearance led to an increasing percentage of hulling efficiency. It was presented in the previous section that a higher level of vacuum air velocity accompanied by a lower level of crusher clearance eventually increased in the percentage of quality percentage of nibs since the vacuum can easily collect small piece of hull which is a result of tighter crusher clearance.

3.2.3 Blower Loss

Table 4 shows the average percentage of blower loss ranged from 25.45% to 76.52%. The desired blower loss of the machine must be as low as zero percent. In this case, the treatment combination with lowest blower loss percentage had to be the desired combination for operating the machine in terms of the blower loss percentage. The treatment combination with lowest percentage is set at 3 mm crusher clearance and 1 m/s vacuum air velocity.

The result in the regression shows that out of several models, quadratic model (Eq. 13) was the most suited model in predicting the percentage of blower loss by the machine in relation to crusher clearance and vacuum air velocity. An ANOVA for quadratic model was conducted to test the significance of the model and other factors. It appeared that the quadratic model was insignificant. It was then supported by a significant lack of fit test which concluded that the model was not reliable in predicting the response. It also has enough R^2 of about 0.5343 which meant that the two sets of variables were fair enough in predicting the variability of the response.

$$\text{Blower Loss} = 48.10 - 3.37A - 2.44B + 5.88AB - 15.22A^2 + 7.78B^2 \quad (13)$$

Where:
A = Crusher Clearance
B = Vacuum Air Velocity

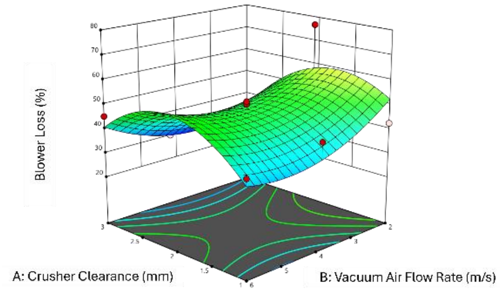


Fig. 8. Surface plot for blower loss.

A significant quadratic effect brought by the crusher clearance and vacuum air velocity was found. The quadratic effects of both crusher clearance and vacuum airflow rate are highly visible in the surface plot presented in Figure 8. It graphically shows that at any given crusher clearance and vacuum air velocity, the blower loss has both increasing and decreasing values (quadratic effect). It can also be seen in the surface plots that most blower loss percentage occurred at decreasing and increasing crusher clearance with increasing vacuum air velocity, primarily because of the stronger flow of air which can vacuums not just the hull but also the nibs that has greater density.

3.2.4 Cacao Nibs Recovery Index

The cacao nibs recovery index ranged from 0.56 to 0.97 as presented in Table 4. The highest cacao nibs recovery index occurs at treatment combination of 2 mm crusher clearance and 2 m/s vacuum air velocity. Surface regression analysis shows that cacao nibs recovery index can be predicted using cubic model (Eq. 14).

$$\text{Cacao Nibs Recovery Index} = 0.8086 - 0.1300A + 0.0750B + 0.0450AB - 0.0152A^2 + 0.0198B^2 + 0.0550A^2B + 0.0550AB^2 \quad (14)$$

Where:
A = Crusher Clearance
B = Vacuum Air Velocity

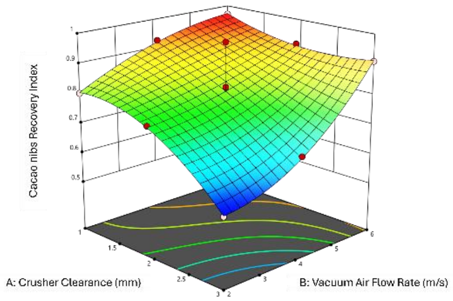


Fig. 9. Surface plot for cacao nibs recovery index.

The result in the ANOVA for cubic model shows a R^2 of 0.7598. The cubic effect is visible by looking at the surface plot being developed in Figure 9. The decreasing crusher clearance and increasing vacuum air velocity eventually resulted in a much acceptable cacao nibs recovery index value.

3.3 Optimum Condition

A graphical method for optimization was used in determining the optimum operating condition of the machine which used the contour plot for each response. The overlay plot for purity, hulling efficiency, blower loss and cacao nibs recovery index is shown in Figure 10. The yellow region in the figure is the acceptance rating of crusher clearance and vacuum air velocity best fit during operation. Based on the set criteria, the crusher clearance ranged from 1 mm to 1.15 mm and vacuum airflow rate ranged from 2 m/s to 3 m/s to satisfy the acceptance rating (optimum region).

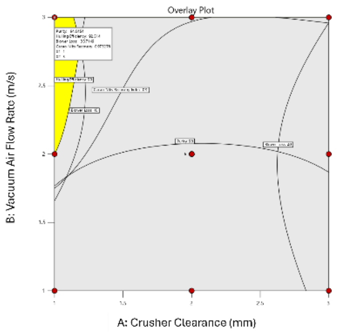


Fig. 10. Overlay plot of the optimum operating condition of the machine

3.4 Evaluation of Overall Machine Performance

Table 5 shows the results for three (3) runs with the machine set with the attained optimal treatment combination. In relation to the 1 mm crusher clearance and 3 m/s vacuum air velocity, machine output capacity, machine output efficiency and fineness modulus were observed and determined as the responses. The machine output capacity of the machine averaged 5.56 kg/h as presented in Table 5. Machine output efficiency was determined by dividing the weight of the input product which was the roasted cacao beans to the weight of output product which was the cocoa powder. Table 5 shows the machine output efficiency that has a mean of 83.37%.
The collected cocoa powder from the three (3) runs of the combined cacao bean huller-pulverizer which was set with the optimal treatment combination of 1 mm crusher clearance and 3 m/s vacuum air velocity were subjected to get the fineness modulus for each run. Microsoft Excel was used to numerically get the fineness modulus for each sample of cocoa powder. The averaged value of fineness modulus was 4.35 presented in Table 6.
An independent sample t-test was conducted to compare two (2) different cocoa powder product, one is a commercially available cocoa powder which used a screw-type grinder, and one is from the output of combined cacao bean huller-pulverizer machine. The result in the test showed that there is no significant difference between two (2) different cocoa powder products at 95% level of confidence.

Table 3. Summary results of the effect of the treatment combination in purity, hulling efficiency, blower loss and cacao nibs recovery index

Run #	Crusher Clearance, mm	Vacuum Airflow Rate, m/s	Purity, %	Hulling Efficiency, %	Blower Loss, %	Cacao Nibs Recovery Index, Decimal
1	2	2	89.89	65.91	39.05	0.68
2	2	2	83.86	80.92	46.13	0.78
3	2	1	77.66	85.69	76.62	0.76
4	1	1	84.12	86.39	42.41	0.80
5	3	3	95.22	86.31	45.18	0.91
6	3	2	90.13	67.17	33.43	0.67
7	2	3	95.35	85.79	46.06	0.91
8	1	2	90.64	90.94	43.26	0.93
9	2	2	88.26	88.47	51.27	0.82
10	1	3	94.39	92.03	38.63	0.97
11	2	2	91.56	77.27	50.19	0.78
12	2	2	94.46	92.54	42.86	0.97
13	3	1	83.40	59.39	25.45	0.56

Table 4. Post analysis summary at 1 mm crusher clearance and 3 m/s vacuum air velocity combination

Response	Predicted Mean	95% Pi Low	95% Pi High	Observed Mean
Purity	94.05	93.48	95.14	94.29
Hulling efficiency	92.51	89.84	94.41	92.15
Cacao nibs recovery index	0.97	0.94	0.98	0.96

Table 5. Summary of results for performance evaluation

Run #	Machine Output Capacity, kg/h	Machine Output Efficiency, %	Fineness Modulus
1	6.39	85.66	4.38
2	5.71	81.25	4.41
3	4.57	83.20	4.28
Mean	5.56	83.37	4.35

3.5 Financial Analysis

Financial analysis was conducted to analyze the financial impact of the developed machine. The capacity of the combined cacao bean huller-pulverizer machine is 5.56 kg/hr. The price of cacao powder was based on the market price. The results from the calculation indicate that the combined cacao bean huller-pulverized was financially feasible. Its BCR value, 2.04, higher than the required BCR of 1, which is acceptable for a developed machine. The newly invented combined cacao bean huller-pulverizer may produce a relatively high net present value (NPV) of revenue under constant price and production cost assumptions. Its value is Php 640,012.58 at a 12% discount rate. In addition, it is estimated that the investment cost can be recouped in around ten (10) months at a rate of return of 75.33%.

4. CONCLUSIONS

The machine can operate continuously from hulling to crushing with less human effort, according to the study's findings. The vacuum air velocity significantly [7]mpacts the recovery index for cacao nibs, hulling efficiency, and purity. Higher hulling efficiency, cacao nib recovery index, and purity percentages ultimately follow from higher vacuum air velocity. The crusher clearance significantly impacts the recovery index for cacao nibs, hulling efficiency, and purity. In the end, a better percentage of purity, hulling efficiency, and cacao nib recovery index are the outcomes of the lower crusher clearance. According to the optimization results, higher vacuum air velocity combined with lower crusher clearance is the machine's ideal operating condition. The financial feasibility study conducted shows that investing in the machine can bring a positive economic impact to the investor.

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