九州大学学術情報リポジトリ
Kyushu University Institutional Repository

Design and Development of a Combined Cacao Bean Huller- Pulverizer Machine

May Rose B. Osoteo
Department of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University

John Cristian G. Badilla
Center for Resource Assessment, Analytics and Emerging Technologies (CReATE), Caraga State University

Dominic Ivan Tulin
Center for Resource Assessment, Analytics and Emerging Technologies (CReATE), Caraga State University

Art M. Dalman
Department of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University

https://doi.org/10.5109/7323350

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.786-791, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：
権利関係：Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International

KYUSHU UNIVERSITY

Design and Development of a Combined Cacao Bean Huller- Pulverizer Machine

May Rose B. Osoteo[1,2], John Cristian G. Badilla[2], Dominic Ivan Tulin[2], Art M. Dalman[1,2]
[1]Department of Agricultural and Biosystems Engineering, College of Engineering and Geosciences, Caraga State University, Butuan City 8600, Philippines
[2]Center for Resource Assessment, Analytics and Emerging Technologies (CReATE), Caraga State University, Ampayon, Butuan City 8600, Philippines
Corresponding author email: mrbosoteo@carsu.edu.ph

Abstract: *Cacao has a significant impact on the food industry. Approximately 6.5 million tons of cacao are produced every year. The study aims to design and fabricate a combined cacao bean huller-pulverizer where roasted cacao beans are processed to cacao powder. The machine was tested in terms of its capacity, efficiency, and fineness modulus. The result showed that the combined cacao bean huller-pulverizer has an average output capacity of 4.74 kg/hr and an average output efficiency of 46.8%. The cacao powder produced by the machine has a fineness modulus of 3.62. In contrast, the fineness modulus of the commercially available cacao powder was 4.33. The two different cacao powders showed a significant difference using an independent sample t-test. Based on the results, the overall performance of the combined cacao bean huller-pulverizer was fair. The financial feasibility of the machine was also evaluated, and a positive economic impact was observed.*

Keywords: Cacao, Cacao Powder, Huller, Pulverizer

1. INTRODUCTION

Cacao (*Theobroma cacao L.*), the cacao tree's seed, is used to produce cocoa, cocoa butter, and cocoa powder. Cacao is grown commercially in Western Africa and tropical Asia. Cacao is native to lowland rainforests of the Amazon and Orinoco River basins. The oval seeds have a sweet, sticky, white pulp covering that is about 2.5 cm long [1]. Cacao is economically important both for producing and consuming countries. It produces export revenues, income, and employment. Cacao is an important ingredient in many food industries [2]. Given its extensive applications and benefits within the Philippine market and agricultural sectors, the cocoa bean is regarded as one of the most widely consumed and highly sought-after commodities [3]. The location of the Philippines being conducive for cacao production and accessible to domestic and foreign trade heightened the interest of farmers and exporters to push for a much more competitive cacao industry that can compete with other cacao-growing nations [4].

However, de-hulling cacao beans is a laborious process that removes the hull from the nibs. Furthermore, pulverizing the cacao nibs into cacao powder has been a challenge since the existing machine used for pulverizing has low efficiency, leading to low production. Hence, the development of the Combined Cacao Bean Huller-Pulverizer is recognized. The study can help the cacao industry by providing a two-in-one machine that de-hulls and pulverizes cacao nibs into cacao powder. Also, this provides a much more efficient way of processing cacao nibs into cacao powder than traditional cacao powder processing. Furthermore, the study can benefit and contribute to the lives of cacao farmers.

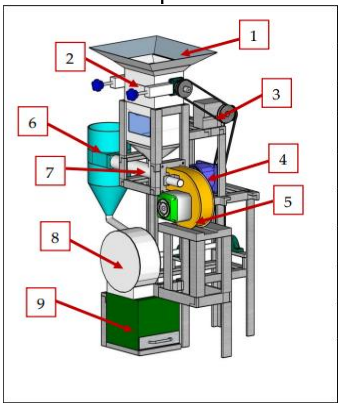
2. MATERIALS AND METHODS

2.1 Materials

Cacao beans, the primary component in this study, were bought in Langihan Public Market, Butuan City, in Agusan Del Norte, Philippines. Cacao beans were manually roasted for 30 minutes at a temperature of 250 Fahrenheit or 121 Celsius minimum heat [5].

2.2 Design of Combined Cacao Bean Huller and Pulverizer Machine

In the development of the Combined Cacao Bean Huller and Pulverizer Machine, various considerations were considered, such as its output capacity, hopper angle, crusher roller clearance, blower airflow rate, pulverizing chamber, and the fineness modulus of the commercially available cacao powder.



No.	Name of Parts
1	Hopper
2	Crushing Chamber
3	Reducer
4	Electric Motor
5	Blower
6	Cyclone Separator
7	Pipe
8	Pulverizing Chamber
9	Cacao Powder Collector

Fig. 1. Proposed Design of Combined Cacao Bean Huller-Pulverizer Machine.

The traditional cacao grinder equipment can grind cacao nibs with a capacity of 10 kilograms of nibs per hour, which is low. The hopper rear wall angle must be 60°, and the front wall must have an angle of 55° to have a smooth material flow [6]. The size of the cacao beans was considered when adjusting the space between the crusher rollers. The clearance space of the crushers is based on the average size of the cacao bean in terms of length, width, and height. The mean cacao bean length, width, and thickness were 22.5 mm, 12.86 mm, and 7.70 mm, respectively, for a moisture range between 5% and 24%

(wb) [7]. An adequate airflow rate must be considered to achieve the last step of the hulling phase. The separation process is achieved from the differences in density between the cacao nib and the cacao hull [8]. Based on the design considerations, the design was made, including the ideal materials.

2.3 Fabrication of the Machine

The development and evaluation of the Combined Cacao Bean Huller-Pulverizer machine was conducted in the Farm shop facility of the College of Engineering and Geosciences at Caraga State University. Adjustments were made during testing and evaluation which must be aligned with the design considerations.

2.4 Data Gathering and Performance Evaluation

This study has two experiments that were conducted in series. The first experiment evaluated the hulling performance in terms of its purity, hulling efficiency, blower loss, and cacao nibs' recovery index with respect to the optimization process. The first experiment was conducted to give the factors' best condition. The second experiment was a comparative analysis of the fineness modulus between the pulverized powder from the machine and commercially available cacao powder. The second experiment used the best combination from the first experiment to give the best result. The overall performance of the Combined Cacao Bean Huller-Pulverizer was evaluated for the general milling capacity, machine efficiency, hulling efficiency, and blower loss.

2.4.1 Evaluation of the Hulling Performance

The evaluation of the hulling performance of the combined Cacao bean huller-pulverizer was the first experiment related to its crusher clearance and airflow rate of the blower. The hulling performance was evaluated based on its purity, efficiency, blower loss, and cacao nibs' recovery index with different crusher clearance and blower airflow rates. The airflow rate of the blower was measured using a hot wire anemometer and is manually adjusted by widening or tightening the pipe's opening via a butterfly valve. On the other hand, the desired clearance of the crusher was attained using the adjusting knob by widening or tightening the opening of the crusher and is measured using a vernier caliper.

2.4.2 Evaluation of the Combined Cacao Bean Huller-Pulverizer Machine

After evaluating the hulling performance, the optimum combination of crusher clearance and the blower's airflow rate was determined. It was then used to evaluate a combined cacao bean huller-pulverizer to get the machine's overall performance. Machine output capacity and efficiency were determined using the formulas in Equation 1 and Equation 2. The fineness modulus was determined using the mechanical sieve and analytical balance. Microsoft Excel was used to compute the fineness modulus based on the data collected.

2.4.3 Experimental Set-up

The hulling performance of the machine was tested using three levels of crusher clearance and blower air velocity. The three levels for crusher clearance are 1 mm, 2 mm, and 3 mm, while the three levels for blower air velocity are 1.5 m/s, 2.0 m/s, and 2.4 m/s. The selected levels for the crusher clearance were based on the experiment done in designing the machine. The selected levels for the blower air velocity were based on the experiment done in designing the machine. Central Composite Design (CCD) was used to analyze complex systems of the variables' linear and nonlinear effects. The central composite design is an effective design in optimization since it generates a design with few experimental tests and provides accurate estimates. The experiment used thirteen treatments (5 center points and 8 non-center points).

The random treatment of crusher clearance and blower air velocity is shown in Table 1. It was used to determine the optimum crusher clearance and blower air velocity combination. Each treatment used 500 grams of roasted cacao beans. The evaluation of the hulling performance of the machine utilized some formulas from Philippine National Standards (PNS) for Agricultural Machinery-Cacao Huller- Methods of Test (PNS/BAFS/PAES 254:2018).

The fineness modulus was determined by comparing the commercially available cacao powder and the machine's cacao powder. Each treatment used 500 grams of roasted cacao beans.

2.5 Data Gathered

2.5.1 Determination of Machine Output Capacity

Machine output capacity is the ratio between the weight of cocoa powder to the overall operating time expressed in kilogram per hour (kg/hr).

$$OC_{MO} = \frac{Wp}{To} \quad \text{Eq. (1)}$$

Where:

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

2.5.2 Determination of Machine Output Efficiency

The ratio between the amount of cocoa powder produced from the amount of roasted cacao bean.

$$EEF_{MO} = \frac{Wo}{Wl} x100 \quad \text{Eq. (2)}$$

Where:

EFF_{MO} = machine output efficiency (%)
W_o = weight of cocoa powder (kg)
W_l = weight of roasted cacao nibs (kg)

2.5.3 Determination of Hulling Efficiency

Hulling efficiency is the weight of cacao nibs collected at the cacao nib's outlet over the weight of cacao nibs and un-hulled cacao beans expressed in percentage (%).

$$E_h = \frac{Wcn}{Wuh+cn} x100 \quad \text{Eq. (3)}$$

Where:

Eh = is the hulling efficiency (%)
W_{cn} = is the weight of cacao nibs collected at cacao nib's outlet/s (kg)
W_{uh} = the weight of un-hulled beans and cacao nibs at cacao nib's outlet/s (kg)

2.5.4 Determination of Blower Loss

Blower loss is the ratio of the weight of un-hulled roasted cacao beans and cacao nibs blown to the total weight of the input cacao nibs expressed in percentage (%). The amount of cacao nibs blown to the hull outlet during the operation.

$$B_l = \frac{Wb}{Icn} x100 \qquad \text{Eq. (4)}$$

Where:

Bl = blower loss (kg)
Wb = weight of blown cacao nibs (kg)
Icn = input cacao nibs (kg)

2.5.5 Cacao Nibs Recovery Index

The Cacao nibs recovery index is the ratio of the total weight of the roasted cacao nibs collected at the cacao nib outlet to the input cacao nibs. The cacao nibs used in the 34 determination of the cacao nib's recovery index are from the manual hulling of roasted cacao beans.

$$R_c = \frac{Wcn}{Wrc} x100 \qquad \text{Eq. (5)}$$

Where:

Rc = is the cacao nibs' recovery (%)
Wcn = is the weight of cacao nibs (g)
Wrc is the weight of dry cacao or roasted cacao beans (g)

2.5.6 Determination of Purity

Purity is the ratio of clean cacao nibs' weight to uncleaned cacao nibs expressed in percentage (%).

$$P = \frac{Wcn}{Th} x100 \qquad \text{Eq. (6)}$$

Where:

P = is the purity (%)
Wcn = is the weight of cacao nibs (g)
Wh = is the weight of hull/ testa (g)

2.5.7 Determination of Milling Capacity

Milling capacity is the quantity of roasted cacao nibs that the hammer mill can pulverize for a period. Milling capacity is expressed in kg/hr.

$$C_m = \frac{Wcp}{t} \qquad \text{Eq. (7)}$$

Where:

C_m = Milling Capacity
W_{cp} = Weight of cacao powder
t = Time

2.5.8 Determination of Milling Efficiency

Milling efficiency is the ratio between the weight of the cacao powder and the total weight of roasted cacao nibs. Milling efficiency is expressed in percentages.

$$E_m = \frac{Wcp}{Wcn} x100 \qquad \text{Eq. (8)}$$

Where:

Em = Milling Efficiency
W_{cp} = Weight of cacao powder
W_{cn} = Weight of cacao nibs

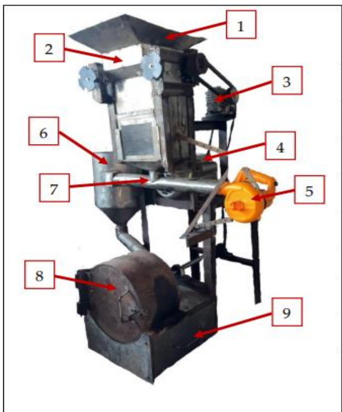
2.5.9 Fineness Modulus

The cocoa powder produced by the machine was compared to the commercially available cocoa powder to determine whether there were any differences in terms of fineness modulus. The cacao powder was tested three times with 100 grams per test. Mechanical sieve and analytical balance were used to determine the fineness modulus. The t-test was used to compare and determine the significant difference between the commercialized cacao powder and the Combined Cacao Bean Huller-Pulverizer's cacao powder.

3. RESULTS AND DISCUSSIONS

3.1 Machine Description and Working Principle

The Combined Cacao Bean Huller-Pulverizer machine consists of four main components: crusher, blower, cyclone separator, and hammer mill. The height of the machine is 1.42 meters. After passing through a hopper, the roasted cacao beans descended into a crusher that rotated at a speed of 29 rpm to be crushed. The crusher roller was made from a stainless rod attached to a stainless shafting and was powered by a 1-hp electric motor and a gearbox reducer (1:60). The crushed cacao beans went down to the hulling chamber where two baffle boards were present to aid the detachment of the cacao nibs from the hull. The cacao nibs and hull were blown by a blower with 1,400 rpm to the cyclone, where hulls were thrown away outside the cyclone while the cacao nibs flowed down to the pulverizer since cacao nibs have higher density than the hull. The cacao nibs were pulverized by the hammer mill powered by a 1-hp electric motor. The pulverized cacao nibs settled into the cabinet through a 2.5 mm screen.



No.	Name of Components
1	Hopper
2	Crushing Chamber
3	Reducer
4	Electric Motor
5	Blower
6	Cyclone Separator
7	Pipe
8	Pulverizing Chamber
9	Cacao Powder Collector

Fig. 2. Actual perspective view of the machine

3.2 Performance of the Huller

Table 1. Summary results of the different treatment combinations.

Trial #	Crusher Clearance (mm)	Blower Airflow (m/s)	Purity (%)	Hulling Efficiency (%)	Blower Loss (%)	Cacao Nibs Recovery Index (Decimal)
1	3	1.5	89.41	99.02	0.35	0.93
2	2	2.0	93.77	99.35	0.82	0.95
3	2	2.0	93.71	99.48	1.02	0.93
4	1	1.5	90.86	99.78	0.42	0.94
5	2	2.4	96.12	99.53	4.00	0.91
6	3	2.4	96.02	99.49	3.21	0.92
7	2	2.0	94.26	99.51	1.35	0.94
8	2	2.0	93.93	99.51	1.06	0.93
9	2	1.5	89.58	100.00	0.22	0.95
10	3	2.0	93.73	99.16	1.47	0.93
11	1	2.4	96.96	100.00	3.01	0.90
12	2	2.0	92.75	99.71	1.42	0.94
13	1	2.0	94.41	99.43	0.67	0.94

3.2.1 Purity

Based on the results from Table 3, the purity of the machine ranges from 89.41% to 96.96%. The highest purity was achieved by a 1 mm crusher clearance and 2.4 m/s blower airflow rate.

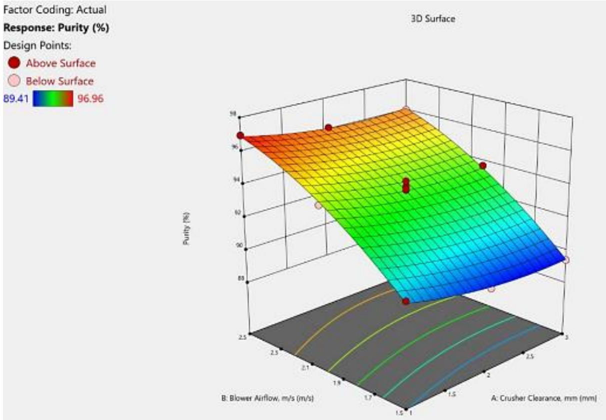


Fig. 3. Surface plot of Purity.

Surface regression model analysis and Analysis of variance (ANOVA) were used to determine the effect of the two factors. The quadratic model was used as it was found to be significant with a p-value of 0.0005 and supported by an insignificant lack of fit p-value of 0.9505, which states that the model was good in predicting the response. Furthermore, it was shown that the R^2 has a value of 0.9793, which meant that the two variables were just enough to predict the variability of the response. It was also shown in the ANOVA that the crusher clearance and the blower airflow rate showed a p-value of 0.0255 and 0.0001, respectively, which states that the two factors are significant ($p<0.05$), and the blower airflow rate provided a high impact in predicting the response.

3.2.2 Hulling Efficiency

Based on Table 3, the hulling efficiency of the machine ranges from 99.02% to 100%. The highest hulling efficiency was achieved twice by a crusher clearance of 2 mm with 1.5 m/s blower airflow and a 1 mm crusher clearance with 2.4 m/s airflow.

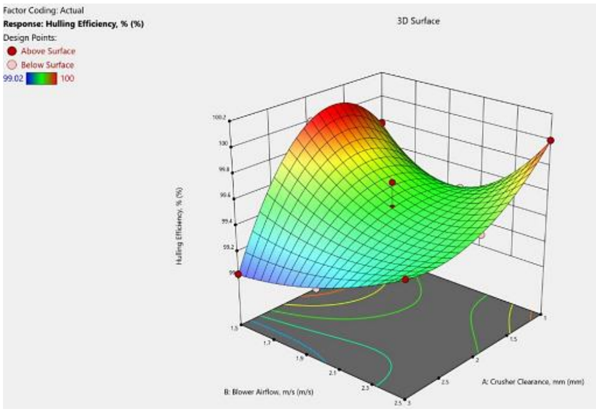


Fig. 4. Surface plot of Hulling Efficiency.

The surface regression model shows that the Quadratic model was most suited to predicting the percentage of hulling efficiency in relation to the two factors. An ANOVA for the quadratic model was used to test the significance of the model and other factors. The model showed an insignificant p-value of 0.1118 and was supported by an insignificant Lack of Fit value of 0.0697, which concluded that the model was reliable in predicting the response. Furthermore, the crusher clearance showed a significant p-value of 0.0235 and an insignificant p-value of the blower airflow rate of 0.6927. It also showed a 0.6607 value of the R^2, which interprets that the two variables were fair enough in predicting the variability of the response.

3.2.3 Blower Loss

Based on the results from Table 3, the blower loss of the machine ranges from 0.22% to 4%. The lowest blower loss was achieved by a 2 mm crusher clearance and 1.5 m/s blower airflow.

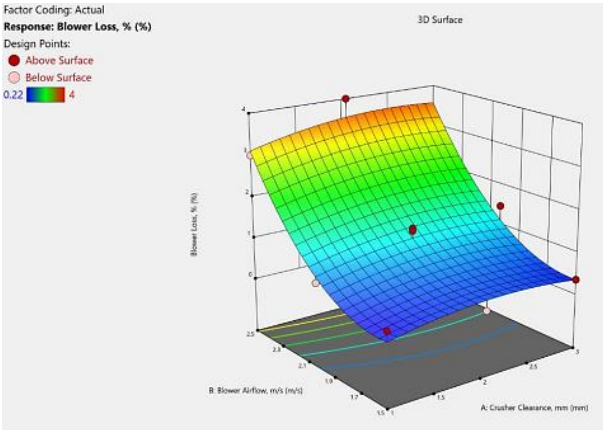


Fig. 5. Surface plot of Blower Loss.

Surface regression model analysis and Analysis of variance (ANOVA) were used to determine the effect of the crusher clearance and blower airflow rate. The quadratic model was used as it was found to be significant with a p-value of 0.0002 and supported by an insignificant lack of fit p-value of 0.1380, which states that the model was enough to predict the response. Moreover, an R^2 value of 0.95 concludes that the two variables were enough to predict the variability of the response. The crusher clearance shows an insignificant p-value of 0.3141 and a significant blower air flow rate with a p-value of 0.0001, which states that there is no significant impact in the response in either increasing or decreasing the crusher clearance along with the blower airflow rate.

3.2.4 Cacao Nibs Recovery Index

Based on the results from Table 3, the cacao nibs recovery index of the machine ranges from 0.90 to 0.95. The highest cacao nib's recovery index was achieved twice by a 2 mm crusher clearance with 2 m/s blower airflow and a 2 mm crusher clearance with 1.5 m/s blower airflow.

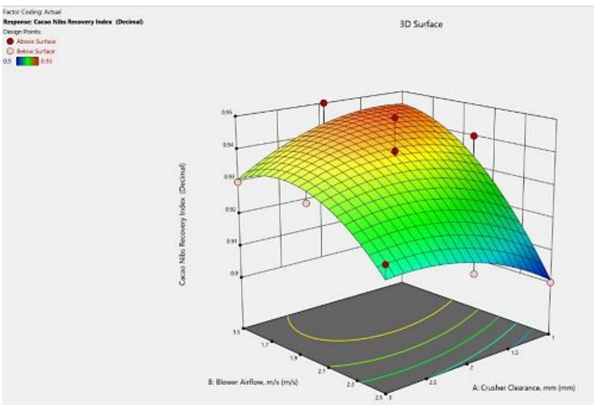


Fig 6. Surface plot of Cacao Nibs Recovery Index.

The quadratic model showed that it is the most suited to predicting the percentage of cacao nibs' recovery index among the other models. The Quadratic model showed a significant p-value of 0.0134, which was also supported by an insignificant lack of fit p-value of 0.5632. Therefore, the model was good in predicting the response.

3.2.5 Attaining Optimum Condition

A graphical method of contour plots for purity, hulling efficiency, blower loss, and cacao nibs' recovery index was utilized for selecting and determining for optimization. Figure 7 shows the overlay plot of purity, hulling efficiency, blower loss, and cacao nibs recovery index. The yellow region presented in the graph interprets the acceptance values of crusher clearance and blower air velocity during operation. Crusher clearance ranged from 1 to 2.25 mm and 2.75 to 3 mm and a blower air velocity rate ranged from 2.28 to 2.4 m/s is shown to be in the acceptance rating.

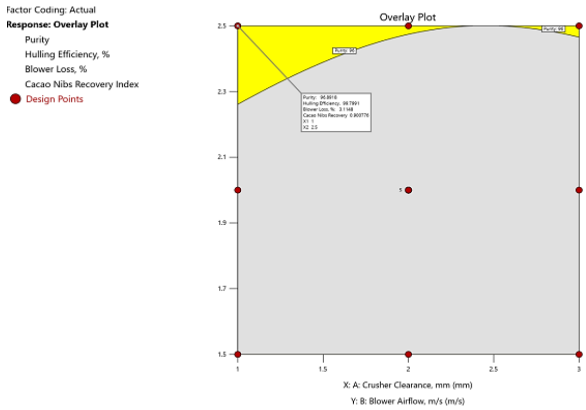


Fig. 7. Optimum process condition obtained by superimposing contour plots.

As presented in Figure 7, it can be shown that the machine setting of 1 mm crusher clearance and 2.4 m/s blower airflow velocity is the desired combination to achieve all the goals with the highest desirability of 0.465. Value for purity is 96.89%, hulling efficiency is 99.79%, blower loss percentage is 3.11%, and cacao nibs recovery index is 0.90. The 52 values of purity, hulling efficiency, and cacao nibs recovery index were then compared to the performance criteria for cacao huller from PNS/BAFS PAES 253:2018. Given the range of values in Table 4 as the optimization criteria, various solutions were given from the numerical optimization of the machine; the highest desirability was found to be 0.465.

Table 2. Criteria for optimization.

Name	Goal	Lower Limit	Upper Limit
Purity	Maximize	97	100
Hulling Efficiency	Maximize	98	100
Blower Loss	Maximize	0	10
Cacao Nibs Recovery Index	Maximize	0.85	1

3.2.6 Post Analysis

Post-analysis is essential to confirm the results obtained from the response predicted by the model. Table 5 shows the post-analysis summary of the optimum combination (1 mm crusher clearance and 2.4 m/s blower airflow rate) result comprising the response during the confirmation experiment and the predicted response by the model. The table shows that the observed mean achieved the interval set by the model. Furthermore, it states that the model was good at predicting the response.

Table 3. Post-analysis summary of optimum rate combination

Response	Predicted Mean	95% Pi Low	95% Pi High	Observed Mean	Data Mean
Purity	96.89	95.48	98.29	96.96	96.39
Hulling Efficiency	99.79	99.10	100.48	100	99.48
Blower Loss	3.11	2.00	4.22	3.01	2.9
Cacao Nibs Recovery Index	0.90	0.87	0.92	0.90	0.89

3.3 Performance of the Pulverizer

The pulverizer consists of a hammer mill and a perforated screen inside a corrugated pipe. The hammer mill has a concave clearance of 4 mm and a 1340.5 m/min tip speed. 3 trials were conducted to acquire the pulverizer's milling capacity and efficiency, where each trial used 500 grams of roasted cacao nibs.

Table 4. Performance of pulverizer summary result

Trial #	Pulverizer Output Capacity, kg/h	Pulverizer Output Efficiency %
1	4.2142	47.2
2	5.7619	48.4
3	5.4444	49
Mean	**5.1401**	**48.2**

As shown in Table 6, the pulverizer was tested in terms of output capacity and efficiency. The mean output capacity of the pulverizer was 5.1401, while the output efficiency of the pulverizer was 48.2%. Trial two achieved the highest output capacity and the fastest feeding and operation times among the three trials. The highest output efficiency was achieved by trial three, which produced the highest cacao powder, 0.245 grams. The different results in each trial may be due to several factors, such as the manual loading of the cacao nibs, their loading time, and the heat generated by the hammer mill.

3.4 Evaluation of Machine Performance

An experiment was conducted to evaluate the overall performance of the combined cacao bean huller-pulverizer machine with the acquired treatment combination. In Table 7, three (3) trials were conducted to provide results of the machine's output capacity, output efficiency, and the fineness modulus of the machine's product.

Table 5. Summary results of optimum performance after post-analysis.

Trial #	Machine Output Capacity, kg/h	Machine Output Efficiency, %	Fineness Modulus
1	4.22	45.0	3.60
2	5.35	49.6	3.60
3	4.53	45.8	3.67
Mean	**4.70**	**46.8**	**3.62**

As presented in Table 7, the highest machine output capacity and efficiency were achieved by Trial 2 with a value of 5.35 kg/h and 49.6%, respectively. The operation time of Trial 2 was 0.0463 hr, which was the fastest of the three trials. Furthermore, Trial 2 produced the highest cacao powder with 0.248 kg. However, the highest fineness modulus was achieved by Trial 3 with 3.67. The different results in each trial may be due to several factors, such as the loading time of cacao beans, the amount of blower loss, and the ability of the hammer mill to pulverize the cacao nibs.

3.4.1 Fineness Modulus of Cacao Powder

The fineness modulus of the cacao powder using the optimal treatment combination of the three (3) trials was numerically obtained using Microsoft Excel. Table 8 shows a mean value of the fineness modulus of the machine of 3.62.

Table 6. Summary results of fineness modulus.

Machine Type	Fineness Modulus
Combined Cacao Bean Huller-Pulverizer	3.62^a
Screw-Type Grinder	4.33^b

An independent sample t-test was performed to compare the cacao powder of the commercially available cacao powder from a Screw-Type Grinder and the cacao powder from the Combined Cacao Bean Huller-Pulverizer. Results showed a significant difference between the two (2) different cacao powder products at a 95% confidence level.

3.5 Financial Analysis

The machine's profitability, liquidity, and general financial health are determined through financial analysis. Determining the machine's financial viability involves analyzing its present and potential future performance.

The combined cacao huller-pulverizer has a capacity of 4.74 kg/hr, say 4.7 kg/hr, and was assumed to have a life span of four years. It was determined that the machine was financially feasible, with an NPV value of Php 341,516,58 and an IRR value of 123%. The machine’s BCR value is 0.99, which means the developed machine is considered cost-effective, and the Payback Period is 0.77.

4. CONCLUSION

The Combined Cacao Huller-Pulverizer Machine can continuously de-hull and pulverize roasted cacao beans into cacao powder with less human effort than the traditional process. On the other hand, the blower airflow rate plays a significant role in separating the cacao hull, as the blower airflow increases the value of the blower loss. The developed 3D models were good at predicting the response since the developed r-squared values have an adequate amount in predicting the variability of the response of the two sets of variables. However, the hulling efficiency model had a fair amount of r-squared value. 1 mm crusher clearance and 2.5 m/s blower airflow were the best combination in hulling performance since it has higher values of purity, blower loss, hulling efficiency, and cacao nibs’ recovery index compared to others. The financial feasibility of the machine showed that investing in the machine can bring a positive economic impact to the investor.

5. REFERENCES

[1] M. Christy and R. Cook, "cocoa bean," Britannica, 22 June 2024. [Online]. Available: https://www.britannica.com/topic/cocoa-bean. [Accessed 11 March 2024].

[2] S. K. Gayi and K. Tsowou, "Cocoa industry: Integrating small farmers into the global value chain," in *UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT*, 2016.

[3] M. Osoteo, L. Pajaron and A. Paque, "Development of Cacao Pod Crushing Machine," in *Proceeding of International Exchange and Innovation Conference on Engineering & Sciences (IEICES) 7*, Japan, 2021.

[4] D. o. Agriculture, "Philippine Cacao Industry Roadmap," 2022.

[5] M. Laiskonis, "Institute of Culinary Education," Ruling the Roast: Chocolate Craftsmanship, 28 January 2016. [Online]. Available: https://www.ice.edu/blog/ruling-roast-chocolate-craftsmanship. [Accessed 17 March 2024].

[6] K. Shahama, M. Anjaly, G. Rajesh, M. Sneha, P. Sanjay , A. Palakkeel, A. Narayanan, A. Suresh and J. Nasrin, "Development and Performance Evaluation of a Cocoa Bean Sheller cum Winnower," *International Journal of Environment and Climate Change*, vol. Volume 13, no. 4, pp. 56-63, 2023.

[7] A. Bart-Plange and E. Baryeh, "The physical properties of Category B cocoa beans," *Journal of Food Engineering*, vol. 60, no. 3, pp. 219-227, 2003.

[8] F. Ioannone, C. Di Mattia, M. De Gregorio, M. Sergi, M. Serafini and G. Saccheti, "Flavanols, proanthocyanidins and antioxidant activity changes during cocoa (Theobroma cacao L.) roasting as affected by temperature and time of processing," *Food Chemistry*, vol. 174, pp. 256-262, 2015.