22 June 2021

Dear Prof. Dr. Giancarlo Cravotto

Editor-in-Chief: Processes

Submission of manuscript to Processes

It is my great pleasure to submit our paper entitled "**Design and performance of the coffee bean classifier**" to be considered for publication in your journal.

Urgency of this paper:
Currently some coffee production centers are still doing the classification manually, so it takes a very long time, a lot of manpower, and expensive operational costs. Therefore, this study aims to design and performance test of a coffee bean classifier that can speed up the coffee bean classification process.

This manuscript was sent to **Food Control** (Manuscript Number: FOODCONT-D-21-01427), but it was rejected for several reasons. The authors has fixed it to be sent to this journal of **Processes**.

As a corresponding author, we stated that:

1. That the work has not been published before
2. That it is not under consideration for publication elsewhere
3. That is publication has been approved by all co-author
4. That it is publication has been approved (tacitly or explicitly) by the responsible authorities where the work is carried out.

Please contact me if you need further information regarding the paper

Thank you in advance for your cooperation.
Sincerely,

The corresponding author:
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Design and performance test of the coffee bean classifier

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Abstract

Nowadays, some coffee production centers are still classification manually, so it requires a very long time, a lot of labor, and expensive operational costs. Therefore, the purpose of this research was to design and performance of the coffee bean classifier that can accelerate the process of classification beans. The classifier used consists of three main parts, namely the frame, driving force, and sieves. Research parameters include classifier work capacity, power, specific energy, classification distribution and effectiveness, and efficiency. The results showed that the best operating conditions of the coffee bean classifier was found at a rotational speed of 91.07 rpm and a 16° sieves angle with a classifier working capacity of 38.27 kg/h, the distribution of the seeds retained in the first sieve was 56.77 %, the second sieves was 28.12%, and the third sieves was 15.11%. The efficiency of using a classifier was found at a rotating speed of 91.07 rpm and a sieves angle of 16°. This classifier was simple in design, easy to operate, and can sort coffee beans into three classification, namely small, medium, and large.

Keyword: Classifier; Coffee beans; Efficiency; Specific energy; Sieves

1. Introduction

Coffee is a beverage that has a distinctive taste and aroma, so it is in demand by many people throughout the world [1] [2]. Coffee contains many bioactive compounds such as caffeine, chromogenic acid, and diterpenoid alcohol, which are beneficial to health [3] [4] [5]. Also, coffee contains macronutrients such as carbohydrates, proteins, fats, and micronutrients such as trigonelline and chromogenic acid as a source of natural antioxidants [6] [7] [8].

Many factors determine the quality and price of coffee [9] [10], one of which is the uniform size of the diameter of the beans [11] [12]. Uniformity of size not only makes the product more attractive to consumers but also can improve the quality of subsequent processing [13] [14]. The smallest seed size tends to burn excessively when roasting, while the largest tends to be undercooked which can affect the taste and aroma [15]. Therefore, before marketing the coffee beans must be graded to determine the classification based on the size of the diameter of the seeds and separate the broken, moldy, or germinated seeds [16] [17].

In general farmers, collectors, and retailers market coffee beans without classification because their time is limited to classification [18] [19]. According to Vogt [20], the process of classification coffee beans in several coffee production centers is still done manually, so it requires a very long time, a lot of labor, and expensive operational costs. The use of human labor for classification also has drawbacks, such as judgments that are subjective and inconsistent with the object being assessed [21] [22]. Coffee beans with a high degree of diameter difference require a long classification process [23] [24]. Adhikari et al. [25] also explained that coffee bean classifiers on the market were generally only used as the initial classification process, so that continued manual classification was still needed as the final stage of the classification process.

The coffee bean classifier, which has been widely circulating in the market today, is a type of sifter [26] [27]. This classifier is equipped with a blower to blow air. Classification containers are round, rectangular, or triangular [28]. The mechanism of movement of the classifier can be divided into three types, namely stationary, rotating, and vibrating [29]. A stationary type classifier is generally used to separate seeds with a diameter of 1.27-10.16 cm. The rotating type classifier has several sieves with different hole diameters. The vibrating type-classifier is mechanically driven from electrical energy to the frame, then proceeds to the sieves section [30] [31].

The effectiveness of a good working classifier is to produce a coffee bean size distribution that is close to the distribution obtained manually [32]. According to Chanpaka et al. [33], the effectiveness of classifiers tends to be lower at high capacities, so it is necessary to choose the rotation speed of the driving force and sifting angle to produce high work capacity and uniform quality of results.

Several researchers have previously implemented a coffee bean classifier using the principle of vibration to classify coffee beans [34] [35]. However, these classifiers are generally not ergonomic because the design does not fit the dimensions of the worker's body size. Therefore, it is necessary to research the design and performance testing of the coffee bean classifier. The purpose of this research is to develop designs and test the performance of coffee bean classifier that can accelerate the process of classification beans. The results of this study are expected to be used as information and operational guidelines for coffee processing to obtain optimal quality coffee classification.

2. Material and method

2.1. Material and Tools

The material used was dried Robusta coffee beans obtained from farmers in Tanjung, North Lombok Regency, West Nusa Tenggara Province. These skinless coffee beans have a moisture content between 12-15% and a diameter ranging from 4-8 mm. The equipment used was a modified flat-type coffee bean classifier (Figure 1), tachometer, and analytical scales.

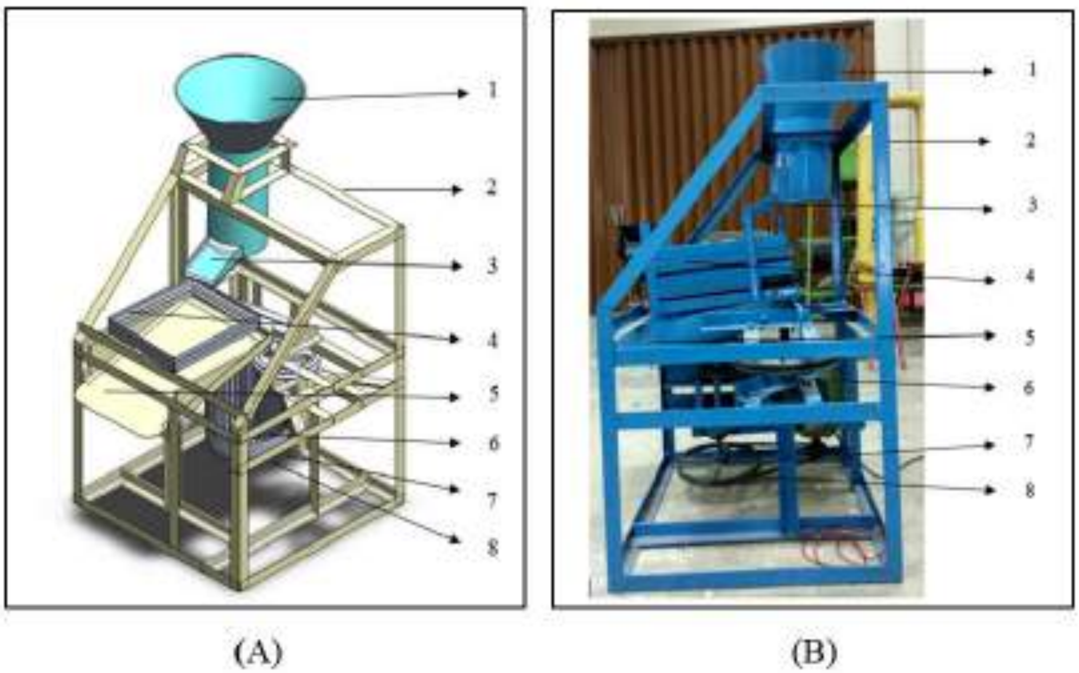

Figure 1. Design layout (A) and (B) beans coffee classifier.

Annotation:

1. Feed hopper
2. Frame
3. Output hopper
4. Classification chamber
5. Output

6. Electric motor drive
7. Pulley
8. V-belt

This classifier has three main parts, namely the frame, driving force, and sieves (Figure 1). The engine frame is made of angle iron with a size of 0.4 x 0.4 mm with a thickness of 0.04 mm. The frame has a height of 1300 mm, a length of 700 mm, a width of 290 mm, and a width of 700 mm below. Sieve units are rectangular with length, width, and thickness of each unit each were 440, 290, and 30 mm. The sieve wall is made of 30 mm thick wood, and each corner is connected with a 30 mm aluminum plate. The first, second, and third sieve each has a diameter of 7.5, 6.5, and 5.5 mm.

The driving force to vibrate the sieves component is a 1 HP electric motor. The power transmission system from the driving force to the classification engine shaft uses a pulley and V-belt system. The power transmission system from the pulley to the sieve shaft becomes vibration using a direct power transmission system.

2.2. Research Procedure

The study was conducted with two types of treatment variations, namely the rotational speed of the driving force and the sieves angle. The rotational speed of the driving force consists of 3 levels, namely 91.07, 65.88, and 31.41 rpm. Variations in the rotational speed of this driving power are generated by regulating the input power of the electric motor using a regulator. Meanwhile, the slope of the sieves angle consists of three levels, namely 10, 13, and 16°. The variation of the tilt angle was obtained by adjusting the position of the two ends of the sieve. Each treatment was repeated three times. For control, manually classification coffee beans.

2.3. Research Parameters

The parameters measured include classifier work capacity, power, specific energy, classification distribution, classification effectiveness, and classifier efficiency. There are two types of engine working capacity, namely theoretical and actual. The theoretical capacity was calculated by the equation:

$$Mc_T = 60\, V\, \rho\, n \qquad (1)$$

where, Mc_T = classifier capacity of theories (kg/h), V = volume classification (m^3), ρ = beans densities (kg/m^3), n = rotational speed of the driving force (rpm).

The actual capacity was calculated by the equation:

$$Mc_A = \frac{Ws}{t} \qquad (2)$$

where, Mc_A = classifier capacity of actual (kg/h), Ws = weight seeds (kg), and t = time (h).

Power was calculated by the equation:

$$P = \frac{2\pi\omega n}{60} \qquad (3)$$

where, P = Power (W), ω = torque moment (Nm), n = rotational speed of the driving force (rpm).

Classification specific energy consumption was calculated by the equation:

$$\text{GSEC} = \frac{P}{Mc_A} \qquad (4)$$

GSEC = Classification specific energy consumption (kJ/kg), P = Power (W), Mc_A = classifier capacity of actual (kg/h)

The distribution of classification results was calculated by the equation:

$$Dis = \frac{Gs}{Mt} \times 100\% \qquad (5)$$

where, Dis = classification distribution (%), Gs = classification siever (kg), Mt = total material (kg).

The effectiveness of classification was calculated by the equation:

$$E_{ff} = \frac{Mcg}{Mng} \quad (6)$$

where, E_{ff} = effectiveness (%), Mcg = classifier classification (kg), manual classification (kg).

The efficiency of the classifier was calculated by comparing theoretical capacity with actual capacity or with the equation:

$$\eta = \frac{Mc_T}{Mc_A} \quad (7)$$

where, η = classifier efficiency (%), Mc_T = classifier capacity of theories (kg/h), Mc_A = classifier capacity of actual (kg/h).

2.4. Data Analysis

The data were analyzed using regression equations to determine the relationship between the rotational speed of the driving force and the angle of sieves as independent variables on the working capacity of the classifier, power, specific energy, distribution of classification results, classification effectiveness, and classification efficiency as the dependent variable. The closeness of the relationship was indicated by the coefficient of determination (R^2). The higher the R^2 value means that there is a close relationship between the independent and dependent variables [36].

3. Result and discussion

3.1. Classifier Working Capacity

The results showed that coffee beans that fell from the hopper to the filter will be separated based on the diameter of the beans. The results of the actual capacity test showed that at a sifting angle of 10° obtained the classifier working capacity at a rotary speed of 91.07, 65.88, and 31.41 rpm each was 35.51, 26.62, and 22.55 kg/h (Figure 2). For a sifting angle of 13°, the classifier working capacity at the rotational speed of the driving force of 91.07; 65.88; and 31.41 rpm was 37.22, 28.21, and 23.45 kg/h, respectively. As for the sifting angle of 16°, the classifier working capacity at the rotational speed of the driving force of 91.07, 65.88, and 31.41 rpm was 38.27, 29.86, and 25.87 kg/h, respectively.

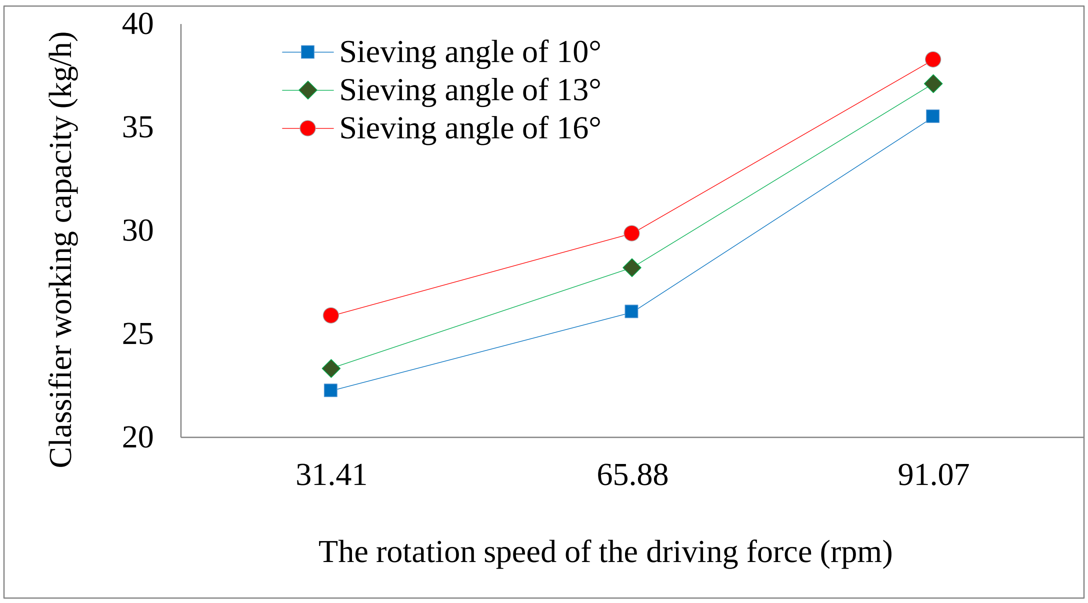

Figure 2. Relationship between the sifting angle and the rotational speed of the driving force on the classifier working capacity.

The linear regression equation of the relationship between the rotational speed of the driving force and the sifting angle of the classifier working capacity was shown in Table 1. The equation applies to the driving force rotation range between 31.41 to 91.07 rpm. Based on the consideration of the comfort level of the engine, then the maximum driving force rotation that can be used was 91.07 rpm.

Table 1. The linear regression equation of the relationship between the rotational speed of the driving force and the sieves angle of the classifier working capacity.

No.	Sieves angle	Linear regression equation	The correlation coefficient (R^2)
1	10°	y = 6.6235x + 14.693	0.9432
2	13°	y = 6.8885x + 15.783	0.9721
3	16°	y = 6.1985x + 18.939	0.9593

Notes: y = classifier capacity (kg/h) and x = the rotation speed of the driving force (rpm)

The classifier working capacity was largely determined by the rotational speed of the driving force and the sieves angle. The greater the rotational speed of the driving force and the sieves angle, the higher the classifier working capacity (Figure 2). Conversely, the smaller the rotational speed of the driving force and the sieves angle, the lower the classifier working capacity. This is thought to be due to the influence of the coffee bean slip style. A high slip force causes the seeds to slide down faster, so the chance to get into the sieves hole is also faster. This data is in line with the results of the study of Mofolasayo et al. [37] which reported that engine capacity is determined by the rotational speed of the driving force and the sieves angle. However, according to [38] that the use of sifting angles and the higher rotational speed of the driving force does not mean that the classifier provides work capacity with the best quality of the final product, but depends on the initial uniformity of the coffee beans to be graded.

3.2. Power

Power measurements are taken when there is a load using a clamp meter. The actual power at the rotational speed of the driving force 31.41 rpm was an average of 15 Watt, while the rotational speed of the driving force of 65.88 and 91.07 rpm are 17 and 20 Watt, respectively. This data shows that the higher the rotational speed of the driving force, the greater the classifier power. The same data has been reported by [39] that engine power at a rotational speed of 400 rpm has an average value of 87.5 Watts, while at a speed of 800 rpm the required power was 133.4 Watt.

Linear regression analysis obtained the equation of the relationship between the rotational speed of the driving force with power (y):

$$y = 6.48x + 15.267 \quad (8)$$

$R^2 = 0.9559$

The equation 8 only can be applied to the rotational speed of the driving force between 31.41-91.07 rpm. It showed that the higher the rotational speed of the driving force, the greater the power needed. A large classifier working capacity requires a high rotational speed of the driving force as well. The use of electrical energy can be greater with the higher rotational speed of the driving force. To follow the requirements of the International Energy Agency by using less energy input but getting the same quality [40], it is necessary to redesign this classifier.

3.3. Specific Energy Consumption

Specific energy consumption (SEC) was the energy needed to do coffee bean classification which can be calculated by dividing the power needed for the classification process by the actual capacity of the classifier. Based on the calculation results obtained specific energy classification of 135 kJ/kg. The SEC shows the level of efficiency and effectiveness of classification energy use based on inputs and outputs and its value is used to estimate energy consumption during the classification process.

Some researchers have also previously reported that SEC was a model of energy consumption from a certain perspective [41]. Because the SEC includes a mapping relationship between energy consumption during certain classification work processes, so its value can not only compare energy efficiency differences from the same machining process and different processing parameters but can also reflect energy intensity and productivity differences in different machining processes [42]. Therefore, even though some SEC models are not accurate enough and the relevant parameters are complex, the concept is easy to understand and calculate. Therefore according to [43] that the application is very general.

3.4. Distribution of Classification Results

The distribution of classification results in each siever was a comparison between the classification results in each siever and the total weight of the material being fed. The percentage of beans in each sifting was largely determined by the sieves angle and the rotational speed of the driving force (Figure 3). At the same sifting angle, the higher the rotational speed of the driving force, the less the numbers of beans are retained. This happens because the coffee beans are slipping more easily into the siever so that the number of beans that are retained was also getting smaller.

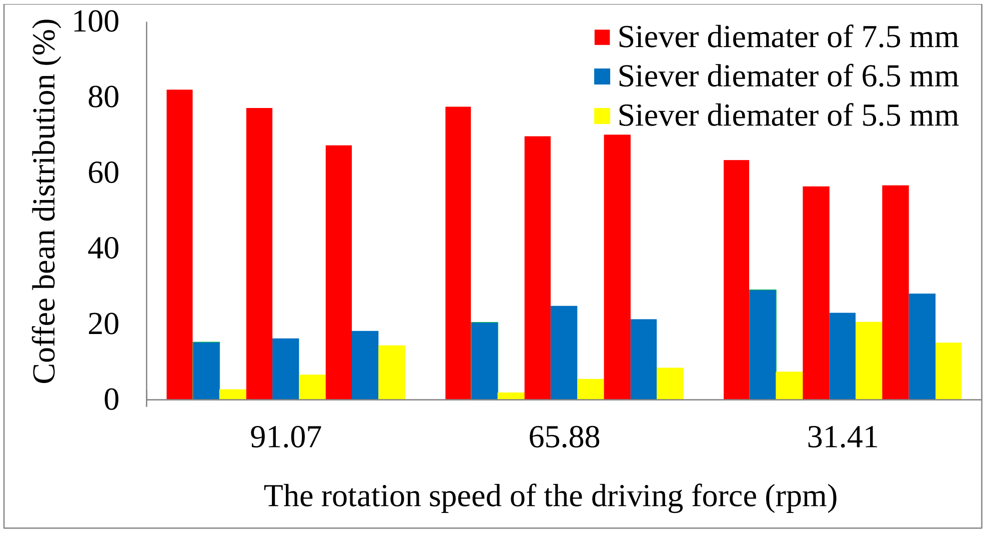

Figure 3. Distribution of retained coffee beans in each sieves unit.

The observations show that at a sieves angle of 10° and a rotational speed of driving force 31.41 rpm the number of beans held in the first sieve was 82.14%, while at a rotational speed of driving force 65.88 and 91.07 rpm the number of beans retained was 77.65% and 63.54%, respectively. The same trend occurs at the sieves angle of 13° and 16° (Figure 3). This result is in line with the research report by Gunathilake et al. [21] that the best classifier working conditions are those that give the smallest seed size distribution deviation compared to the seed size distribution obtained from manually graded beans.

3.5. Classification Electivity

3.5.1. The First Sieves

The first sieve is a retained collection of seeds with a diameter greater than 7.5 mm. The classification results show that the distribution of coffee beans retained in the first sieve with a rotational speed of 91.07 rpm and a sifting angle of 10° obtained 82.14% of coffee beans larger than 7.5 mm, whereas at the rotational speed of the driving force 65.88 and 31.41 rpm the percentages of coffee beans were 77.65% and 63.54%, respectively (Figure 4). This data shows that at the sifting angle of 10° and the rotational speed of the driving force of 91.07 rpm the percentage of the number of coffee beans that have a diameter smaller than the diameter of the 7.5 mm sieves hole is 17.86%. The higher the rotation speed of the driving force, the percentage of the number of coffee beans that have a diameter smaller than 7.5 mm is also greater. The same thing was also shown from the test results at the rotational speed of the driving force of 65.88 and 31.41 rpm was 15.21 and 2.65%, respectively.

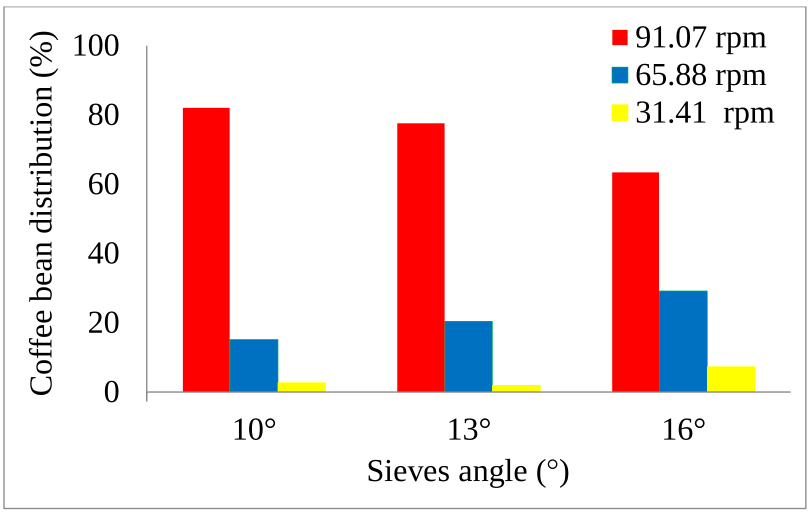

Figure 4. Distribution of coffee beans that pass through the first sieve.

3.5.2. The Second Sieves

The second sieve is a retained collection of beans with a diameter smaller than 7.5 and greater than 6.5 mm. The classification results show that the distribution of coffee beans retained in the second sieve at the rotation speed of the driving force of 91.07 rpm and 10° sieves angle was 77.14%, while at the rotation speed of the driving force of 65.88 and 31.41 rpm, 16.21% and 6.65%, respectively (Figure 5). This data shows that at a sieves angle of 10° and the rotation speed of the driving force of 91.07 rpm there are 22.86% of coffee beans, which have a diameter between

6.5 to 7.5 mm. The faster the rotation of the driving force, the percentage of coffee beans that have a smaller diameter of beans than 6.5 mm are also getting bigger. The same thing was also obtained from the test results on the rotation speed of the driving force of 65.88 and 31.41 rpm was 16.21% and 6.65%, respectively.

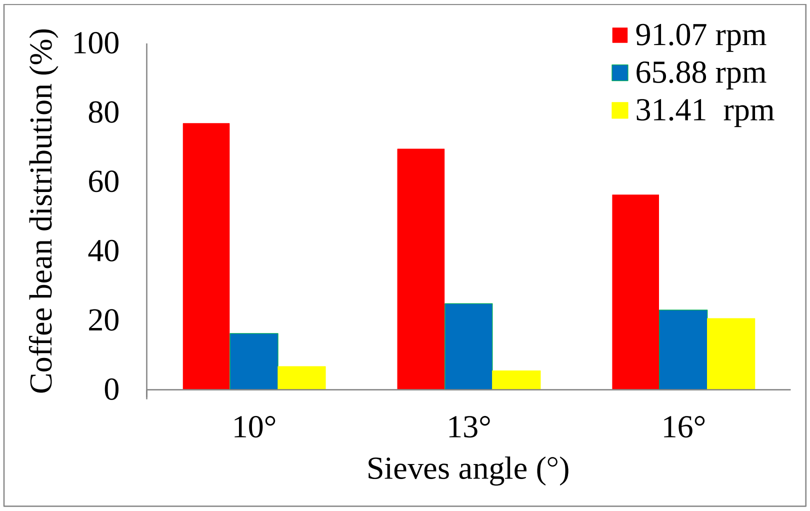

Figure 5. Distribution of coffee beans that pass through the second sieve.

3.5.3. The Third Sieves

The third sieve was a retained collection of beans with a diameter smaller than 5.5 mm. The classification results show that the distribution of coffee beans held in the third sieve at the rotation speed of the driving force of 91.07 rpm and 10° sieves angle was 67.34%, while at the rotation speed of the driving force of 65.88 and 31.41 rpm obtained 18.21% and 14.45%, respectively (Figure 6). This data shows that at a sieves angle of 10° and the rotation speed of the driving force of 91.07 rpm as much as 32.66% of coffee beans have a smaller bean diameter than the sieves hole diameter of 5.5 mm. The faster the rotation speed of the driving force, the percentage of coffee beans that have a bean diameter smaller than 5.5 mm is also getting bigger. Some previous research results also show the same trend data, as reported by [21] that the rotational speed of 15 rpm and the sieves angle of 3° to the horizontal axis of the cylinder produces the highest performance was 93.46%.

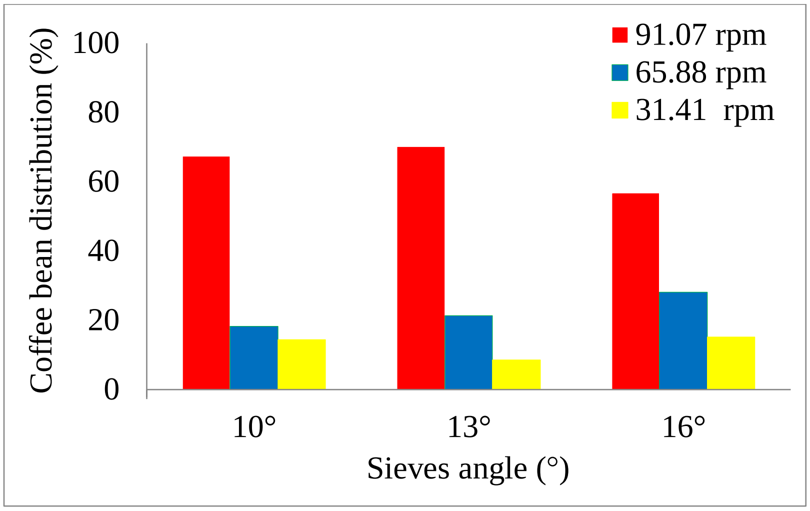

Figure 6. Distribution of coffee beans that pass the third sieve.

3.5.4. The Efficiency of Classification

The efficiency of classification are calculated by comparing the actual capacity of the engine with the theoretical capacity of the engine. The actual capacity of the classifier was the ability of the classifier to do classification within a certain time interval. Based on the calculation of the actual capacity of 16.5 kg/h and the theoretical capacity value of 18 kg/h, the efficiency of the classifier was 91.67%. This value indicates the efficiency of the classifier was already high, but still needs to be improved. To increase of the efficiency of classification, it needs to be increased by increasing the rotational speed of the driving force based on the Indonesian National Standard (INS).

The energy efficiency was the ratio between performance and energy input. The energy efficiency has a specific application definition for each different condition, but the most commonly used is a thermodynamic perspective that uses the ratio of product output and total energy input

[44]. Due to the complexity of the function of classifier tools, according to [41], the definition of energy efficiency was not clear so far and there are an amount of energy efficiency evaluation indicators that can be used for various classifier tools.

4. Conclusion

The working capacity of a classifier was largely determined by the rotational speed of the driving force and the sieves angle. The greater the rotational speed of the driving force and the sieves angle, the higher the working capacity of the engine. The best classification operating conditions was found at the rotational speed of the driving force of 91.07 rpm and a sieves angle of 16° with a classifier working capacity produced 38.27 kg/h. The distribution of beans held in the first, second, and third sieve was 56.77 each; 28.12; 15.11%, respectively. Efficiency using classifier was found at the rotational speed of the driving force of 91.07 rpm and a sieves angle of 16° was 91.67%. To produce high engine working capacity, a high-speed driving force was also needed. The power generated by the driving force increases with the increased rotation of the driving force. This classifier was feasible to be applied to improve the process of classifying coffee beans.

Acknowledgments

The authors gratefully acknowledge the Faculty of Food Technology and Agroindustries, the University of Mataram for all supporting facilities in this research.

Conflict of interest

No.

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Received: 22 June 2021
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Dear Prof. Dr. Giancarlo Cravotto

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I wish to submit a revised paper entitled “**Design and performance of the coffee bean classifier**” to be considered for publication in your journal.

Thank you to all reviewers for the advice given.
In principle, I agree with the suggestion, and we have improved this text based on the advice of the reviewers.

Thank you in advance for your cooperation.
Sincerely,

The corresponding author:
Dr. Ansar
Department of Agricultural Engineering, Faculty of Food Technology and Agroindustry, University of Mataram, Indonesia;
Email: ansar72@unram.ac.id.

Response to Reviewer 1 Comments

Point 1: The research paper is not appropriate, in this form, for publication. The explanation of the aim of the research, the research procedure, and the statistical approach is missed (for example, describe which parameter explains better the bean classifier, and the statistical difference for the different settings). There is a lack of scientific and critical comments on the results. The article in this form appears more like a technical report.

Response 1:
The research objectives have been well explained on page 2. Likewise, the research procedures have been explained on pages 3 and 4. The parameter that describes a good classification is equation (5). The research results have also been improved so that they are no longer similar to technical reports.

Response to Reviewer 2 Comments

1. The research experiment should be presented to a greater extent.
2. What number of samples were in the experiment, measurement time.
3. What standards were used, e.g. for moisture.
4. More information about the grain diameter - whether it is the maximum diameter, which dimension. The coffee bean does not have the shape of a ball.
5. I would suggest adding information about the physical properties of the tested grain.
6. Why was the grain quality, damage not also analyzed.
7. On the basis of what the research parameters were determined, the ranges, why only three speed levels and the slope of the sieves angle were investigated.
8. What were the grain densities.
9. The obtained results should be analyzed for variance, significance of differences, and standard deviation.
10. Are the regression coefficients statistically significant.
11. In Table 1, R^2 means the coefficient of determination, not the correlation coefficient.
12. Line 138. The sentence *the higher the R^2 value means that there is a close relationship between 138 the independent and dependent variables [36]* is a truism, it does not need to be quoted.
13. I would suggest extending the discussion of the results with more works by other authors.

Response:

1. An explanation has been added on page 3.
2. The number of samples in each experiment is 3 kg. Each experiment was repeated 3 times (page 40).
3. Humidity was not measured because the weather at the time of the study was very sunny.
4. The diameter of the coffee beans measured is the average diameter in an upright position based on the influence of the earth's gravity.
5. The physical properties of the grains tested are only the diameter of the seeds to determine the classification of the diameter
6. Damage to the seeds was not analyzed because during the classification process the seeds did not experience physical damage.
7. Three levels of velocities and sieve angle angles were investigated as these already represent the classification operation process.
8. Grain density has not been studied.
9. The results of the study have been analyzed using regression analysis to determine the relationship between the rotational speed of the driving force and the angle of the sieve as independent variables on the work capacity of the classifier, power, specific energy, distribution of classification results, classification effectiveness, and efficiency as dependent variable
10. The results show the coefficient of determination is close to one. This means that there is a statistically significant relationship.
11. Yes, that's right, the coefficient of determination (R^2), not the correlation coefficient. Have been revised on page 4.
12. Line 138 has been revised.
13. Some relevant research results have been added.

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Article

Design and performance test of the coffee bean classifier

Ansar [1,*)], Sukmawaty [1], Murad [1], Surya Abdul Muttalib [1], c [2], Abdurrahim [2]

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Abstract: Nowadays, some coffee production centers are still classification manually, so it requires a very long time, a lot of labor, and expensive operational costs. Therefore, the purpose of this research was to design and performance of the coffee bean classifier that can accelerate the process of classification beans. The classifier used consists of three main parts, namely the frame, driving force, and sieves. Research parameters include classifier work capacity, power, specific energy, classification distribution and effectiveness, and efficiency. The results showed that the best operating conditions of the coffee bean classifier was found at a rotational speed of 91.07 rpm and a 16° sieves angle with a classifier working capacity of 38.27 kg/h, the distribution of the seeds retained in the first sieve was 56.77 %, the second sieves was 28.12%, and the third sieves was 15.11%. The efficiency of using a classifier was found at a rotating speed of 91.07 rpm and a sieves angle of 16°. This classifier was simple in design, easy to operate, and can sort coffee beans into three classification, namely small, medium, and large.

Keywords: classifier; coffee beans; efficiency; specific energy; sieves

Citation: Lastname, F.; Lastname, F.; Lastname, F. Title. *Processes* **2021**, *9*, x. https://doi.org/10.3390/xxxxx

Academic Editor: Firstname Lastname

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1. Introduction

Coffee is a beverage that has a distinctive taste and aroma, so it is in demand by many people throughout the world [1,2]. Coffee contains many bioactive compounds such as caffeine, chromogenic acid, and diterpenoid alcohol, which are beneficial to health [3-5]. Also, coffee contains macronutrients such as carbohydrates, proteins, fats, and micronutrients such as trigonelline and chromogenic acid as a source of natural antioxidants [6-8].

Many factors determine the quality and price of coffee [9,10], one of which is the uniform size of the diameter of the beans [11,12]. Uniformity of size not only makes the product more attractive to consumers but also can improve the quality of subsequent processing [13,14]. The smallest seed size tends to burn excessively when roasting, while the largest tends to be undercooked which can affect the taste and aroma [15]. Therefore, before marketing the coffee beans must be graded to determine the classification based on the size of the diameter of the seeds and separate the broken, moldy, or germinated seeds [16,17].

In general farmers, collectors, and retailers market coffee beans without classification because their time is limited to classification [18,19]. According to Vogt [20], the process of classification coffee beans in several coffee production centers is still done manually, so it requires a very long time, a lot of labor, and expensive operational costs.

The use of human labor for classification also has drawbacks, such as judgments that are subjective and inconsistent with the object being assessed [21,22]. Coffee beans with a high degree of diameter difference require a long classification process [23,24]. Adhikari et al. [25] also explained that coffee bean classifiers on the market were generally only used as the initial classification process, so that continued manual classification was still needed as the final stage of the classification process.

The coffee bean classifier, which has been widely circulating in the market today, is a type of sifter [26,27]. This classifier is equipped with a blower to blow air. Classification containers are round, rectangular, or triangular [28]. The mechanism of movement of the classifier can be divided into three types, namely stationary, rotating, and vibrating [29]. A stationary type classifier is generally used to separate seeds with a diameter of 1.27-10.16 cm. The rotating type classifier has several sieves with different hole diameters. The vibrating type-classifier is mechanically driven from electrical energy to the frame, then proceeds to the sieves section [30,31].

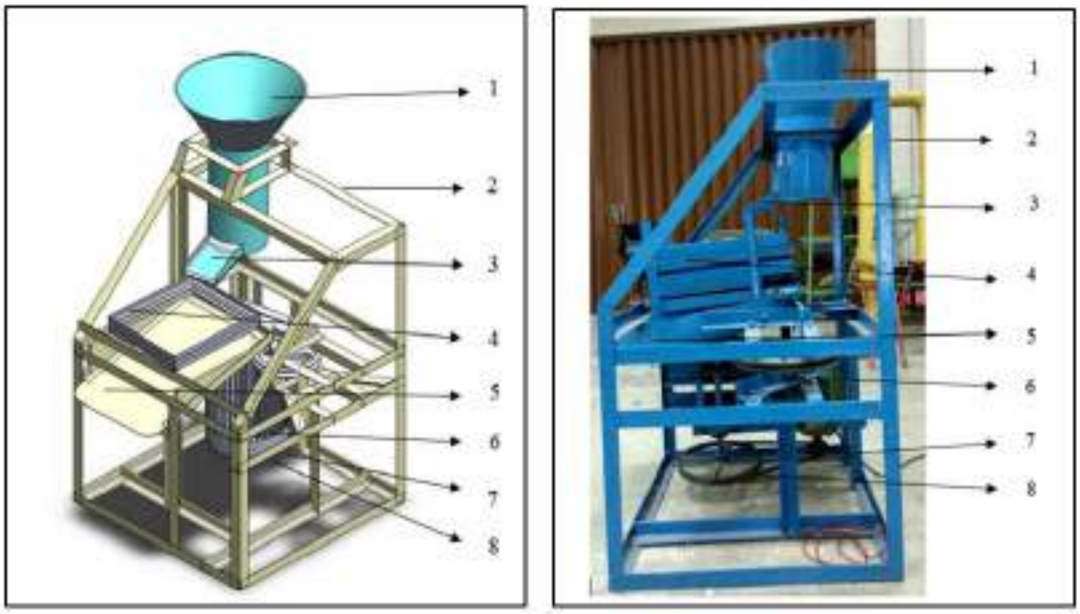
The effectiveness of a good working classifier is to produce a coffee bean size distribution that is close to the distribution obtained manually [32]. According to Chanpaka et al. [33], the effectiveness of classifiers tends to be lower at high capacities, so it is necessary to choose the rotation speed of the driving force and sifting angle to produce high work capacity and uniform quality of results.

Several researchers have previously implemented a coffee bean classifier using the principle of vibration to classify coffee beans [34,35]. However, these classifiers are generally not ergonomic because the design does not fit the dimensions of the worker's body size. Therefore, it is necessary to research the design and performance testing of the coffee bean classifier. The purpose of this research is to develop designs and test the performance of coffee bean classifier that can accelerate the process of classification beans. The results of this study are expected to be used as information and operational guidelines for coffee processing to obtain optimal quality coffee classification.

2. Materials and Methods

2.1. Material and Tools

The material used was dried Robusta coffee beans obtained from farmers in Tanjung, North Lombok Regency, West Nusa Tenggara Province. These skinless coffee beans have a moisture content between 12-15% and a diameter ranging from 4-8 mm. The equipment used was a modified flat-type coffee bean classifier (Figure 1), tachometer, and analytical scales.



(A) (B)

Figure 1. Design layout (A) and (B) beans coffee classifier.

Annotation:

1. Feed hopper
2. Frame
3. Output hopper
4. Classification chamber
5. Output
6. Electric motor drive
7. Pulley
8. V-belt

This classifier has three main parts, namely the frame, driving force, and sieves (Figure 1). The engine frame is made of angle iron with a size of 0.4 x 0.4 mm with a thickness of 0.04 mm. The frame has a height of 1300 mm, a length of 700 mm, a width of 290 mm, and a width of 700 mm below. Sieve units are rectangular with length, width, and thickness of each unit each were 440, 290, and 30 mm. The sieve wall is made of 30 mm thick wood, and each corner is connected with a 30 mm aluminum plate. The first, second, and third sieve each has a diameter of 7.5, 6.5, and 5.5 mm.

The driving force to vibrate the sieves component is a 1 HP electric motor. The power transmission system from the driving force to the classification engine shaft uses a pulley and V-belt system. The power transmission system from the pulley to the sieve shaft becomes vibration using a direct power transmission system.

2.2. Research Procedure

The study was conducted with two types of treatment variations, namely the rotational speed of the driving force and the sieves angle. The rotational speed of the driving force consists of 3 levels, namely 91.07, 65.88, and 31.41 rpm. Variations in the rotational speed of this driving power are generated by regulating the input power of the electric motor using a regulator. Meanwhile, the slope of the sieves angle consists of three levels, namely 10, 13, and 16°. The variation of the tilt angle was obtained by adjusting the position of the two ends of the sieve. Each treatment was repeated three times. For control, manually classification coffee beans.

2.3. Research Parameters

The parameters measured include classifier work capacity, power, specific energy, classification distribution, classification effectiveness, and classifier efficiency. There are two types of engine working capacity, namely theoretical and actual. The theoretical capacity was calculated by the equation:

$$Mc_T = 60\,V\,\rho\,n \qquad (1)$$

where, Mc_T = classifier capacity of theories (kg/h), V = volume classification (m^3), ϱ = beans densities (kg/m^3), n = rotational speed of the driving force (rpm).

The actual capacity was calculated by the equation:

$$Mc_A = \frac{Ws}{t} \qquad (2)$$

where, Mc_A = classifier capacity of actual (kg/h), Ws = weight seeds (kg), and t = time (h).

Power was calculated by the equation:

$$P = \frac{2\pi\omega n}{60} \qquad (3)$$

where, P = Power (W), ω = torque moment (Nm), n = rotational speed of the driving force (rpm).

Classification specific energy consumption was calculated by the equation:

$$\mathrm{GSEC} = \frac{P}{Mc_A} \qquad (4)$$

GSEC = Classification specific energy consumption (kJ/kg), P = Power (W), Mc_A = classifier capacity of actual (kg/h)

The distribution of classification results was calculated by the equation:

$$Dis = \frac{Gs}{Mt} \times 100\% \qquad (5)$$

where, Dis = classification distribution (%), Gs = classification siever (kg), Mt = total material (kg).

The effectiveness of classification was calculated by the equation:

$$E_{ff} = \frac{Mcg}{Mng} \qquad (6)$$

where, E_{ff} = effectiveness (%), Mcg = classifier classification (kg), manual classification (kg).

The efficiency of the classifier was calculated by comparing theoretical capacity with actual capacity or with the equation:

$$\eta = \frac{Mc_T}{Mc_A} \qquad (7)$$

where, η = classifier efficiency (%), Mc_T = classifier capacity of theories (kg/h), Mc_A = classifier capacity of actual (kg/h).

2.4. Data Analysis

The data were analyzed using regression equations to determine the relationship between the rotational speed of the driving force and the angle of sieves as independent variables on the working capacity of the classifier, power, specific energy, distribution of classification results, classification effectiveness, and classification efficiency as the dependent variable. The closeness of the relationship was indicated by the coefficient of determination (R^2). The higher the R^2 value means that there is a close relationship between the independent and dependent variables [36].

3. Results and Discussion

3.1. Classifier Working Capacity

The results showed that coffee beans that fell from the hopper to the filter will be separated based on the diameter of the beans. The results of the actual capacity test showed that at a sifting angle of 10° obtained the classifier working capacity at a rotary speed of 91.07, 65.88, and 31.41 rpm each was 35.51, 26.62, and 22.55 kg/h (Figure 2). For a sifting angle of 13°, the classifier working capacity at the rotational speed of the driving force of 91.07; 65.88; and 31.41 rpm was 37.22, 28.21, and 23.45 kg/h, respectively. As for the sifting angle of 16°, the classifier working capacity at the rotational speed of the driving force of 91.07, 65.88, and 31.41 rpm was 38.27, 29.86, and 25.87 kg/h, respectively.

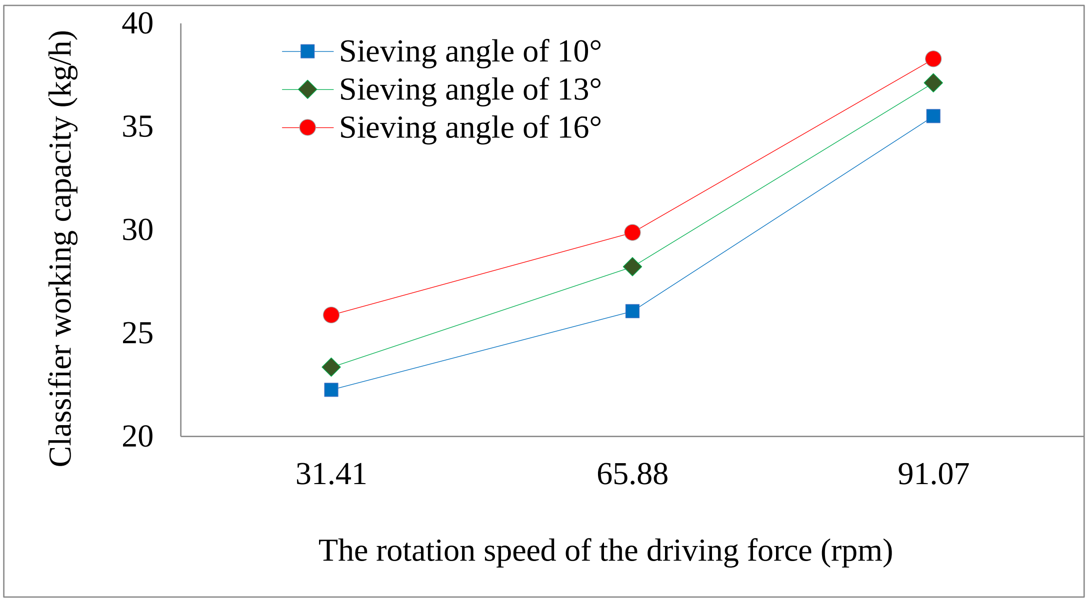


Figure 2. Relationship between the sifting angle and the rotational speed of the driving force on the classifier working capacity.

The linear regression equation of the relationship between the rotational speed of the driving force and the sifting angle of the classifier working capacity was shown in Table 1. The equation applies to the driving force rotation range between 31.41 to 91.07 rpm. Based on the consideration of the comfort level of the engine, then the maximum driving force rotation that can be used was 91.07 rpm.

Table 1. The linear regression equation of the relationship between the rotational speed of the driving force and the sieves angle of the classifier working capacity.

No.	Sieves angle	Linear regression equation	The correlation coefficient (R^2)
1	10°	y = 6.6235x + 14.693	0.9432
2	13°	y = 6.8885x + 15.783	0.9721
3	16°	y = 6.1985x + 18.939	0.9593

Notes: y = classifier capacity (kg/h) and x = the rotation speed of the driving force (rpm)

The classifier working capacity was largely determined by the rotational speed of the driving force and the sieves angle. The greater the rotational speed of the driving force and the sieves angle, the higher the classifier working capacity (Figure 2). Conversely, the smaller the rotational speed of the driving force and the sieves angle, the lower the classifier working capacity. This is thought to be due to the influence of the coffee bean slip style. A high slip force causes the seeds to slide down faster, so the chance to get into the sieves hole is also faster. This data is in line with the results of the study of Mofolasayo et al. [37] which reported that engine capacity is determined by the rotational speed of the driving force and the sieves angle. However, according to [38] that the use of sifting angles and the higher rotational speed of the driving force does not mean that the classifier provides work capacity with the best quality of the final product, but depends on the initial uniformity of the coffee beans to be graded.

3.2. Power

Power measurements are taken when there is a load using a clamp meter. The actual power at the rotational speed of the driving force 31.41 rpm was an average of 15 Watt, while the rotational speed of the driving force of 65.88 and 91.07 rpm are 17 and 20 Watt, respectively. This data shows that the higher the rotational speed of the driving force, the greater the classifier power. The same data has been reported by [39] that engine power at a rotational speed of 400 rpm has an average value of 87.5 Watts, while at a speed of 800 rpm the required power was 133.4 Watt.

Linear regression analysis obtained the equation of the relationship between the rotational speed of the driving force with power (y):

$$y = 6.48x + 15.267 \quad (8)$$

$R^2 = 0.9559$

The equation 8 only can be applied to the rotational speed of the driving force between 31.41-91.07 rpm. It showed that the higher the rotational speed of the driving force, the greater the power needed. A large classifier working capacity requires a high rotational speed of the driving force as well. The use of electrical energy can be greater with the higher rotational speed of the driving force. To follow the requirements of the International Energy Agency by using less energy input but getting the same quality [40], it is necessary to redesign this classifier.

3.3. Specific Energy Consumption

Specific energy consumption (SEC) was the energy needed to do coffee bean classification which can be calculated by dividing the power needed for the classification process by the actual capacity of the classifier. Based on the calculation results obtained specific energy classification of 135 kJ/kg. The SEC shows the level of efficiency and effectiveness of classification energy use based on inputs and outputs and its value is used to estimate energy consumption during the classification process.

Some researchers have also previously reported that SEC was a model of energy consumption from a certain perspective [41]. Because the SEC includes a mapping relationship between energy consumption during certain classification work processes, so its value can not only compare energy efficiency differences from the same machining process and different processing parameters but can also reflect energy intensity and productivity differences in different machining processes [42]. Therefore, even though some SEC models are not accurate enough and the relevant parameters are complex, the concept is easy to understand and calculate. Therefore according to [43] that the application is very general.

3.4. Distribution of Classification Results

The distribution of classification results in each siever was a comparison between the classification results in each siever and the total weight of the material being fed. The percentage of beans in each sifting was largely determined by the sieves angle and the rotational speed of the driving force (Figure 3). At the same sifting angle, the higher the rotational speed of the driving force, the less the numbers of beans are retained. This happens because the coffee beans are slipping more easily into the siever so that the number of beans that are retained was also getting smaller.

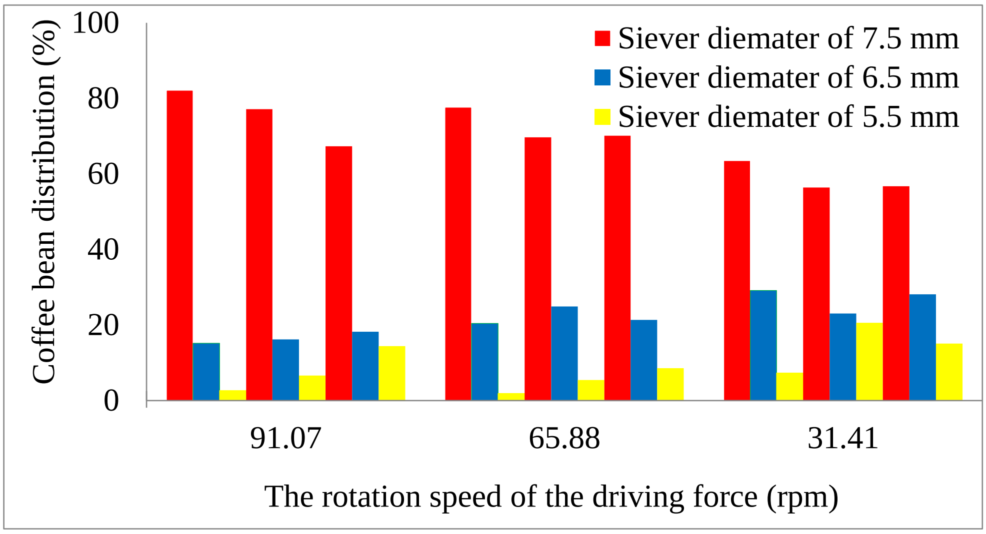


Figure 3. Distribution of retained coffee beans in each sieves unit.

The observations show that at a sieves angle of 10° and a rotational speed of driving force 31.41 rpm the number of beans held in the first sieve was 82.14%, while at a rotational speed of driving force 65.88 and 91.07 rpm the number of beans retained was 77.65% and 63.54%, respectively. The same trend occurs at the sieves angle of 13° and 16° (Figure 3). This result is in line with the research report by Gunathilake et al. [21] that the best classifier working conditions are those that give the smallest seed size distribution deviation compared to the seed size distribution obtained from manually graded beans.

3.5. Classification Electivity

3.5.1. The First Sieves

The first sieve is a retained collection of seeds with a diameter greater than 7.5 mm. The classification results show that the distribution of coffee beans retained in the first sieve with a rotational speed of 91.07 rpm and a sifting angle of 10° obtained 82.14% of coffee beans larger than 7.5 mm, whereas at the rotational speed of the driving force 65.88 and 31.41 rpm the percentages of coffee beans were 77.65% and 63.54%, respectively (Figure 4). This data shows that at the sifting angle of 10° and the rotational speed of the driving force of 91.07 rpm the percentage of the number of coffee beans that have a diameter smaller than the diameter of the 7.5 mm sieves hole is 17.86%. The higher the rotation speed of the driving force, the percentage of the number of coffee beans that have a diameter smaller than 7.5 mm is also greater. The same thing was also shown from the test results at the rotational speed of the driving force of 65.88 and 31.41 rpm was 15.21 and 2.65%, respectively.

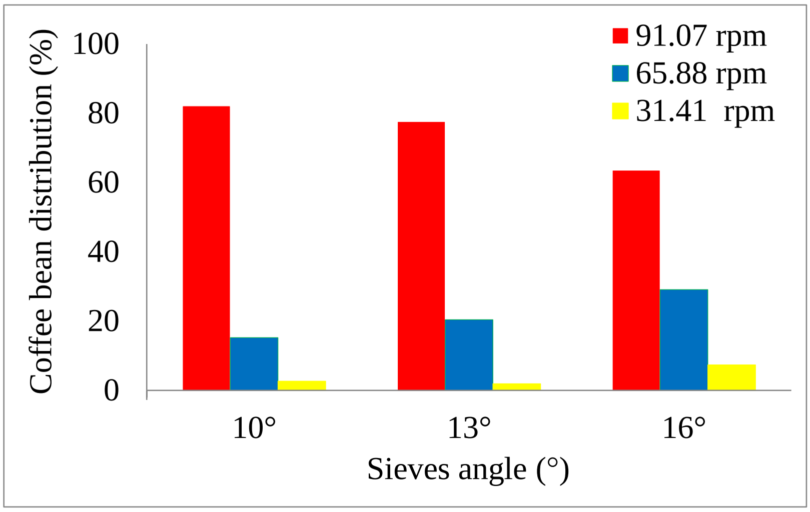


Figure 4. Distribution of coffee beans that pass through the first sieve.

3.5.2. The Second Sieves

The second sieve is a retained collection of beans with a diameter smaller than 7.5 and greater than 6.5 mm. The classification results show that the distribution of coffee beans retained in the second sieve at the rotation speed of the driving force of 91.07 rpm and 10° sieves angle was 77.14%, while at the rotation speed of the driving force of 65.88 and 31.41 rpm, 16.21% and 6.65%, respectively (Figure 5). This data shows that at a sieves angle of 10° and the rotation speed of the driving force of 91.07 rpm there are 22.86% of coffee beans, which have a diameter between 6.5 to 7.5 mm. The faster the rotation of the driving force, the percentage of coffee beans that have a smaller diameter of beans than 6.5 mm are also getting bigger. The same thing was also obtained from the test results on the rotation speed of the driving force of 65.88 and 31.41 rpm was 16.21% and 6.65%, respectively.

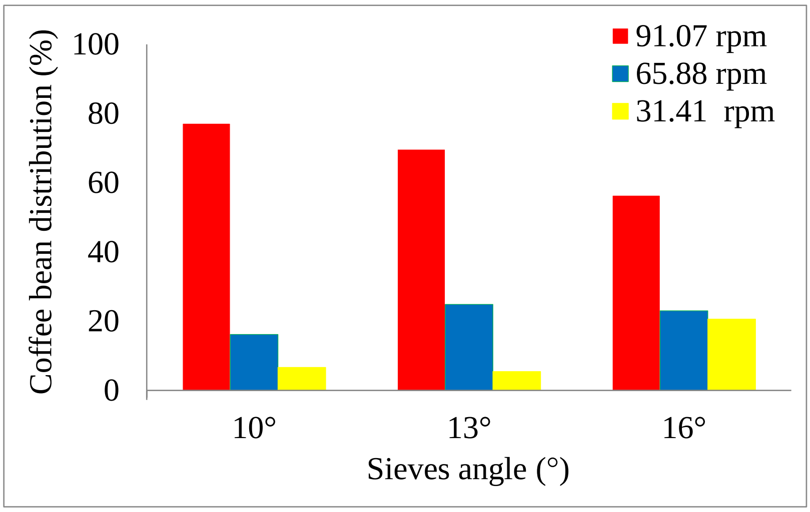


Figure 5. Distribution of coffee beans that pass through the second sieve.

3.5.3. The Third Sieves

The third sieve was a retained collection of beans with a diameter smaller than 5.5 mm. The classification results show that the distribution of coffee beans held in the third sieve at the rotation speed of the driving force of 91.07 rpm and 10° sieves angle was 67.34%, while at the rotation speed of the driving force of 65.88 and 31.41 rpm obtained 18.21% and 14.45%, respectively (Figure 6). This data shows that at a sieves angle of 10° and the rotation speed of the driving force of 91.07 rpm as much as 32.66% of coffee beans have a smaller bean diameter than the sieves hole diameter of 5.5 mm. The faster the rotation speed of the driving force, the percentage of coffee beans that have a bean diameter smaller than 5.5 mm is also getting bigger. Some previous research results also show the same trend data, as reported by [21] that the rotational speed of 15 rpm and the sieves angle of 3° to the horizontal axis of the cylinder produces the highest performance was 93.46%.

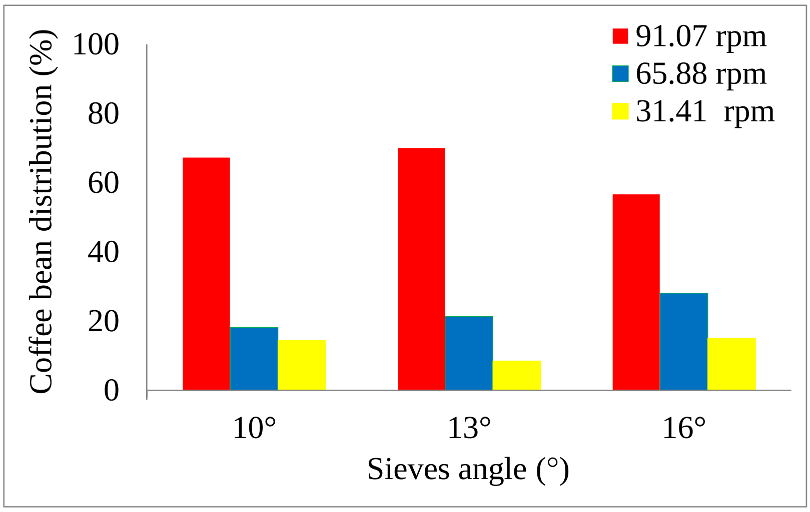


Figure 6. Distribution of coffee beans that pass the third sieve.

3.5.4. The Efficiency of Classification

The efficiency of classification are calculated by comparing the actual capacity of the engine with the theoretical capacity of the engine. The actual capacity of the classifier was the ability of the classifier to do classification within a certain time interval. Based on the calculation of the actual capacity of 16.5 kg/h and the theoretical capacity value of 18 kg/h, the efficiency of the classifier was 91.67%. This value indicates the efficiency of the classifier was already high, but still needs to be improved. To increase of the efficiency of classification, it needs to be increased by increasing the rotational speed of the driving force based on the Indonesian National Standard (INS).

The energy efficiency was the ratio between performance and energy input. The energy efficiency has a specific application definition for each different condition, but the most commonly used is a thermodynamic perspective that uses the ratio of product output and total energy input [44]. Due to the complexity of the function of classifier tools, according to [41], the definition of energy efficiency was not clear so far and there are an amount of energy efficiency evaluation indicators that can be used for various classifier tools.

4. Conclusions

The working capacity of a classifier was largely determined by the rotational speed of the driving force and the sieves angle. The greater the rotational speed of the driving force and the sieves angle, the higher the working capacity of the engine. The best classification operating conditions was found at the rotational speed of the driving force of 91.07 rpm and a sieves angle of 16° with a classifier working capacity produced 38.27 kg/h. The distribution of beans held in the first, second, and third sieve was 56.77 each; 28.12; 15.11%, respectively. Efficiency using classifier was found at the rotational speed of the driving force of 91.07 rpm and a sieves angle of 16° was 91.67%. To produce high engine working capacity, a high-speed driving force was also needed. The power generated by the driving force increases with the increased rotation of the driving force. This classifier was feasible to be applied to improve the process of classifying coffee beans.

Acknowledgments

The authors gratefully acknowledge the Faculty of Food Technology and Agroindustries, the University of Mataram for all supporting facilities in this research.

Conflict of interest

No.

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Article

Design and Performance Test of the Coffee Bean Classifier

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Abstract: Currently, some coffee production centers still perform classification manually, which requires a very long time, a lot of labor, and expensive operational costs. Therefore, the purpose of this research was to design and test the performance of a coffee bean classifier that can accelerate the process of classifying beans. The classifier used consisted of three main parts, namely the frame, the driving force, and sieves. The research parameters included classifier work capacity, power, specific energy, classification distribution and effectiveness, and efficiency. The results showed that the best operating conditions of the coffee bean classifier was a rotational speed of 91.07 rpm and a 16° sieve angle with a classifier working capacity of 38.27 kg/h: the distribution of the seeds retained in the first sieve was 56.77%, the second sieve was 28.12%, and the third sieve was 15.11%. The efficiency of using a classifier was found at a rotating speed of 91.07 rpm and a sieve angle of 16°. This classifier was simple in design, easy to operate, and can sort coffee beans into three classifications, namely small, medium, and large.

Keywords: classifier; coffee beans; efficiency; specific energy; sieves

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Citation: Ansar; Sukmawaty; Murad; Muttalib, S.A.; Putra, R.H.; Abdurrahim. Design and Performance Test of the Coffee Bean Classifier. *Processes* **2021**, *9*, 1462. https://doi.org/10.3390/pr9081462

Academic Editor: Arkadiusz Gola

Received: 22 June 2021
Accepted: 19 August 2021
Published: 21 August 2021

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1. Introduction

Coffee is a beverage that has a distinctive taste and aroma, so it is in demand by many people throughout the world [1,2]. Coffee contains many bioactive compounds such as caffeine, chromogenic acid, and diterpenoid alcohol, which are beneficial to health [3–5]. Additionally, coffee contains macronutrients such as carbohydrates, proteins, fats, and micronutrients, such as trigonelline and chromogenic acid, as a source of natural antioxidants [6–8].

Many factors determine the quality and price of coffee [9,10], one of which is the uniform size of the diameter of the beans [11,12]. Uniformity of size not only makes the product more attractive to consumers but can also improve the quality of subsequent processing [13,14]. The smallest seed size tends to burn excessively when roasting, while the largest tends to be undercooked which can affect the taste and aroma [15]. Therefore, before marketing, the coffee beans must be graded to determine the classification based on the size of the diameter of the seeds, and the broken, moldy, or germinated seeds must be separated [16,17].

In general, farmers, collectors, and retailers market coffee beans without classification because their time is limited for classification [18,19]. According to Vogt [20], the process of classification of coffee beans is still conducted manually in several coffee production centers, so it requires a very long time, a lot of labor, and expensive operational costs. The use of human labor for classification also has drawbacks, such as judgments that are subjective and inconsistent with the object being assessed [21,22]. Coffee beans with a high degree of diameter difference require a long classification process [23,24]. Adhikari et al. [25] also explained that coffee bean classifiers on the market were generally only used for the initial classification process, so that continued manual classification was still needed at the final stage of the classification process.

The coffee bean classifier, which has been widely circulating in the market today, is a type of sifter [26,27]. This classifier is equipped with a blower to blow air. Classification containers are round, rectangular, or triangular [28]. The mechanism of movement of the classifier can be divided into three types, namely stationary, rotating, and vibrating [29]. A stationary-type classifier is generally used to separate seeds with a diameter of 1.27–10.16 cm. The rotating type classifier has several sieves with different hole diameters. The vibrating-type classifier is mechanically driven from electrical energy to the frame, which then proceeds to the sieve section [30,31].

The effect of a well-working classifier is to produce a coffee bean size distribution that is close to the distribution obtained manually [32]. According to Chanpaka et al. [33], the effectiveness of classifiers tends to be lower at high capacities, so it is necessary to choose the rotation speed of the driving force, and the sifting angle, to produce high work capacity and uniform quality of results.

Several researchers have previously implemented a coffee bean classifier using the principle of vibration to classify coffee beans [34,35]. However, these classifiers are generally not ergonomic because the design does not fit the dimensions of the worker's body size. Therefore, it is necessary to research the design and performance testing of the coffee bean classifier. The purpose of this research is to develop designs and test the performance of a coffee bean classifier that can accelerate the process of classifying beans. The results of this study are expected to be used as information and operational guidelines for coffee processing to obtain optimal quality coffee classification.

2. Materials and Methods

2.1. Material and Tools

The material used was dried Robusta coffee beans obtained from farmers in Tanjung, North Lombok Regency, West Nusa Tenggara Province, Indonesia. These skinless coffee beans have a moisture content between 12 and 15% and a diameter ranging from 4 to 8 mm. The equipment used was a modified flat-type coffee bean classifier (Figure 1), tachometer, and analytical scales.

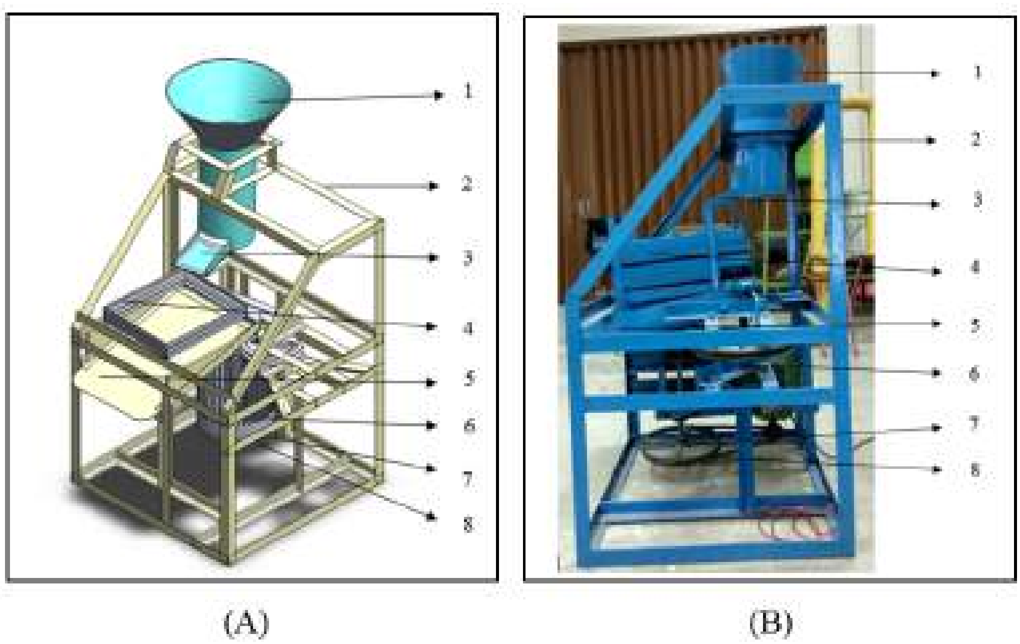

Figure 1. Design layout (**A**) and (**B**) beans coffee classifier.

Annotation:

1. Feed hopper
2. Frame
3. Output hopper
4. Classification chamber
5. Output
6. Electric motor drive
7. Pulley
8. V-belt

This classifier had three main parts, namely the frame, driving force, and sieves (Figure 1). The engine frame was made of angle iron with a size of 0.4 × 0.4 mm and a thickness of 0.04 mm. The frame had a height of 1300 mm, a length of 700 mm, a width of 290 mm, and a width of 700 mm below. The sieve units were rectangular with length, width, and thickness of each unit being 440, 290, and 30 mm, respectively. The sieve wall was made of 30 mm thick wood, and each corner was connected with a 30 mm aluminum plate. The first, second, and third sieve each had a diameter of 7.5, 6.5, and 5.5 mm, respectively.

The driving force to vibrate the sieves component was a 1 HP electric motor. The power transmission system from the driving force to the classification engine shaft used a pulley and V-belt system. The power transmission system from the pulley to the sieve shaft created vibration using a direct power transmission system.

2.2. Research Procedure

The study was conducted with two types of treatment variations, namely the rotational speed of the driving force and the sieve angle. The rotational speed of the driving force consists of 3 levels, namely 91.07, 65.88, and 31.41 rpm. Variations in the rotational speed of this driving power are generated by regulating the input power of the electric motor using a regulator. Meanwhile, the slope of the sieve angle consists of three levels, namely 10, 13, and 16°. The variation of the tilt angle was obtained by adjusting the position of the two ends of the sieve. Each treatment was repeated three times. For control, coffee beans were manually classified. The number of samples in each experiment was 3 kg. Each experiment was repeated 3 times. The diameter of the coffee beans measured was the average diameter in an upright position based on the influence of the earth's gravity.

2.3. Research Parameters

The parameters measured included classifier work capacity, power, specific energy, classification distribution, classification effectiveness, and classifier efficiency. There are two types of engine working capacity, namely theoretical and actual. The theoretical capacity was calculated by the equation:

$$Mc_T = 60\,V\,\rho\,n \tag{1}$$

where Mc_T = classifier capacity of theoretic (kg/h), V = volume classification (m^3), ρ = beans densities (kg/m^3), n = rotational speed of the driving force (rpm).

The actual capacity was calculated by the equation:

$$Mc_A = \frac{Ws}{t} \tag{2}$$

where Mc_A = classifier capacity of actual (kg/h), Ws = seeds weight (kg), and t = time (h).

Power was calculated by the equation:

$$P = \frac{2\pi\omega n}{60} \tag{3}$$

where P = Power (W), ω = torque moment (Nm), n = rotational speed of the driving force (rpm).

Classification specific energy consumption was calculated by the equation:

$$\text{GSEC} = \frac{P}{Mc_A} \quad (4)$$

where GSEC = Classification specific energy consumption (kJ/kg), P = Power (W), Mc_A = classifier capacity of actual (kg/h).

The distribution of classification results was calculated by the equation:

$$Dis = \frac{Gs}{Mt} \times 100\% \quad (5)$$

where Dis = classification distribution (%), Gs = classification sieve (kg), Mt = total material (kg).

The effectiveness of classification was calculated by the equation:

$$E_{ff} = \frac{Mcg}{Mng} \quad (6)$$

where E_{ff} = effectiveness (%), Mcg = classifier classification (kg), manual classification (kg).

The efficiency of the classifier was calculated by comparing theoretical capacity with actual capacity, or with the equation [36]:

$$\eta = \frac{Mc_T}{Mc_A} \quad (7)$$

where η = classifier efficiency (%), Mc_T = classifier capacity of theoretic (kg/h), Mc_A = classifier capacity of actual (kg/h).

2.4. Data Analysis

The data were analyzed using regression equations to determine the relationship between the rotational speed of the driving force and the angle of sieves as independent variables on the working capacity of the classifier; power, specific energy, distribution of classification results, classification effectiveness, and efficiency as the dependent variables. The closeness of the relationship was indicated by the coefficient of determination (R^2). A high R^2 value means that there is a close relationship between the independent and dependent variables.

3. Results and Discussion

3.1. Classifier Working Capacity

The results showed that coffee beans that fell from the hopper to the filter were separated based on the diameter of the beans. With a sifting angle of 10°, and with the classifier working capacity at rotary speeds of 91.07, 65.88, and 31.41 rpm, the results of the actual capacity test were 35.51, 26.62, and 22.55 kg/h, respectively (Figure 2). For a sifting angle of 13°, the classifier working capacity at the rotational speeds of the driving force of 91.07, 65.88, and 31.41 rpm gave results of 37.22, 28.21, and 23.45 kg/h, respectively. As for the sifting angle of 16°, and the classifier working capacity at the rotational speeds of the driving force of 91.07, 65.88, and 31.41 rpm, the results were 38.27, 29.86, and 25.87 kg/h, respectively.

The linear regression equation of the relationship between the rotational speed of the driving force and the sifting angle of the classifier working capacity is shown in Table 1. The equation applies to the driving force rotation range between 31.41 to 91.07 rpm. Based on the consideration of the comfort level of the engine, the maximum driving force rotation that could be used was 91.07 rpm.

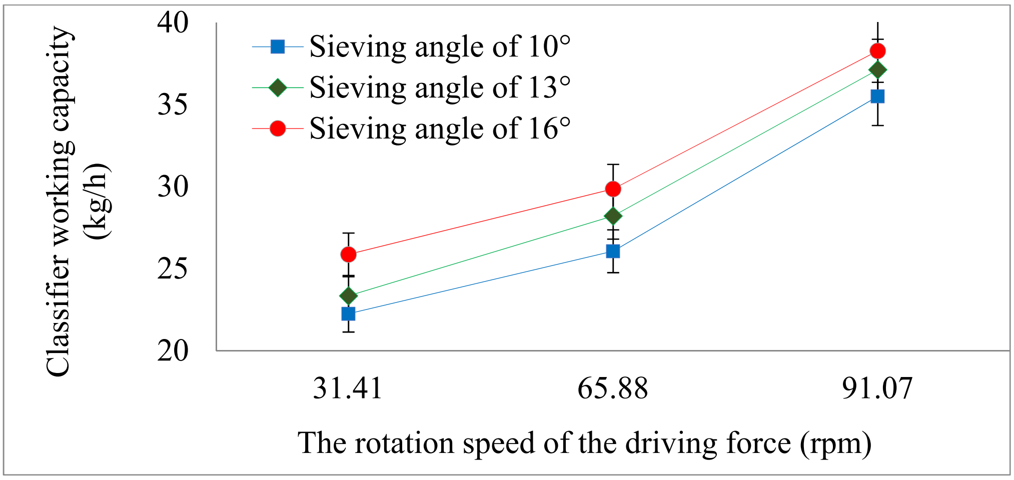

Figure 2. Relationship between the sifting angle and the rotational speed of the driving force on the classifier working capacity.

Table 1. The linear regression equation of the relationship between the rotational speed of the driving force and the sieve angle of the classifier working capacity.

No.	Sieve Angle	Linear Regression Equation	the Coefficient of Determination (R^2)
1	10°	y = 6.6235x + 14.693	0.9432
2	13°	y = 6.8885x + 15.783	0.9721
3	16°	y = 6.1985x + 18.939	0.9593

Notes: y = classifier capacity (kg/h) and x = the rotation speed of the driving force (rpm).

The classifier working capacity was largely determined by the rotational speed of the driving force and the sieve angle. The greater the sieve angle and rotational speed of the driving force, the higher the classifier working capacity (Figure 2). Conversely, the smaller the sieve angle and rotational speed of the driving force, the lower the classifier working capacity. This is thought to be due to the influence of the coffee bean slip style. A high slip force causes the seeds to slide down faster, so getting into the sieve hole is also faster. This data is in line with the results of the study by Mofolasayo et al. [37], which reported that engine capacity is determined by the rotational speed of the driving force and the sieve angle. However, according to Olukunle and Akinnuli [38], the use of sifting angles and higher rotational speed of the driving force does not mean that the classifier provides work capacity with the best quality of final product, but depends on the initial uniformity of the coffee beans to be graded.

3.2. Power

Power measurements are taken when there is a load, using a clamp meter. The actual power at the rotational speed of the driving force 31.41 rpm was an average of 15 Watts, while the rotational speed of the driving force of 65.88 and 91.07 rpm was 17 and 20 Watts, respectively. This data shows that the higher the rotational speed of the driving force, the greater the classifier power. The same data has been reported by Qian et al. [39]: that engine power at a rotational speed of 400 rpm has an average value of 87.5 Watts, while at a speed of 800 rpm the required power was 133.4 Watts.

Linear regression analysis obtained the equation of the relationship between the rotational speed of the driving force with power (y):

$$y = 6.48x + 15.267 \qquad R^2 = 0.9559 \tag{8}$$

The Equation (8) can only be applied to the rotational speed of the driving force between 31.41 and 91.07 rpm. It showed that the higher the rotational speed of the driving force, the greater the power needed. A large classifier working capacity requires a high rotational speed of the driving force as well. The use of electrical energy can be greater with the higher rotational speed of the driving force. To follow the requirements of the International Energy Agency by using less energy input but obtaining the same quality [40], it is necessary to redesign this classifier.

3.3. Specific Energy Consumption

Specific energy consumption (SEC) was the energy needed to do coffee bean classification which can be calculated by dividing the power needed for the classification process by the actual capacity of the classifier. Based on the calculation results obtained, the specific energy classification was 135 kJ/kg. The SEC shows the level of efficiency and effectiveness of classification energy use based on inputs and outputs, and its value is used to estimate energy consumption during the classification process.

Some researchers have also previously reported that SEC was a model of energy consumption from a certain perspective [41]. Because the SEC includes a mapping relationship between energy consumption during certain classification work processes, its value can not only compare energy efficiency differences from the same machining process and different processing parameters, but can also reflect energy intensity and productivity differences in different machining processes [42]. Therefore, even though some SEC models are not accurate enough and the relevant parameters are complex, the concept is easy to understand and calculate. Therefore, according to Ma et al. [43], the application is very general.

3.4. Distribution of Classification Results

The distribution of classification results in each sieve was a comparison between the classification results in each sieve and the total weight of the material being fed. The percentage of beans in each sifting was largely determined by the sieve angle and the rotational speed of the driving force (Figure 3). At the same sifting angle, the higher the rotational speed of the driving force, the fewer the number of beans retained. This happened because the coffee beans were slipping more easily into the sieve, so that the number of beans retained was also decreasing.

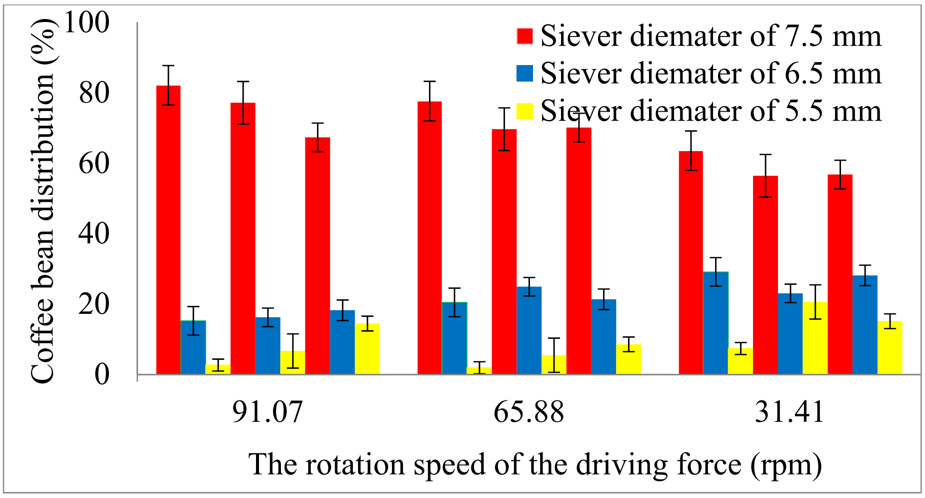

Figure 3. Distribution of retained coffee beans in each sieve unit.

The observations show that at a sieve angle of 10° and a rotational speed of driving force of 31.41 rpm, the number of beans held in the first sieve was 82.14%, while at a rotational speed of driving force of 65.88 and 91.07 rpm, the number of beans retained was 77.65% and 63.54%, respectively. The same trend occurred at the sieve angle of 13°

and 16° (Figure 3). This result is in line with the research report by Gunathilake et al. [21] that states that the best classifier working conditions are those that give the smallest seed size distribution deviation compared to the seed size distribution obtained from manually graded beans.

3.5. Classification Electivity

3.5.1. The First Sieve

The first sieve retained a collection of seeds with a diameter greater than 7.5 mm. The classification results show that the distribution of coffee beans retained in the first sieve, with a rotational speed of 91.07 rpm and a sifting angle of 10°, obtained 82.14% of coffee beans larger than 7.5 mm, whereas at the rotational speed of the driving force of 65.88 and 31.41 rpm, the percentages of coffee beans retained were 77.65% and 63.54%, respectively (Figure 4). This data shows that at the sifting angle of 10° and the rotational speed of the driving force of 91.07 rpm, the percentage of coffee beans that had a diameter smaller than the diameter of the 7.5 mm sieve hole was 17.86%. The higher the rotation speed of the driving force, the higher the percentage of the number of coffee beans with a diameter smaller than 7.5 mm. The same thing was also shown from the test results at the rotational speed of the driving force of 65.88 and 31.41 rpm: 15.21 and 2.65%, respectively.

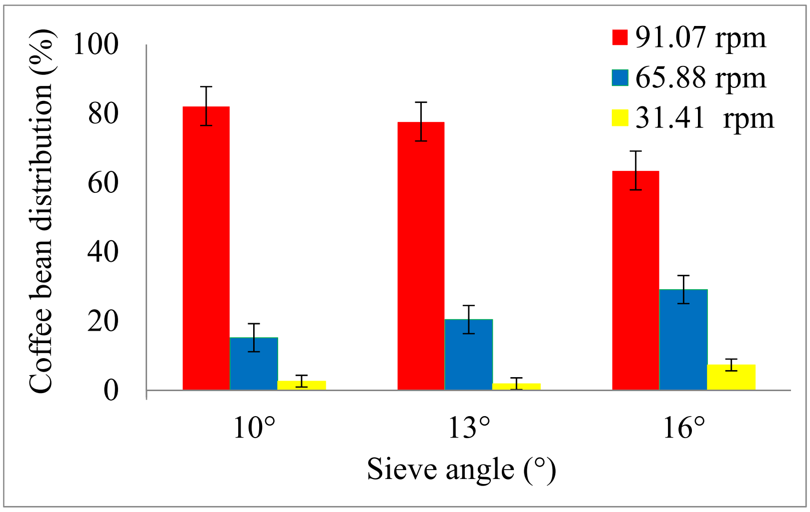

Figure 4. Distribution of coffee beans that pass through the first sieve.

3.5.2. The Second Sieve

The second sieve retained a collection of beans with a diameter smaller than 7.5 and greater than 6.5 mm. The classification results show that the distribution of coffee beans retained in the second sieve at the rotation speed of the driving force of 91.07 rpm and a sieve angle of 10° was 77.14%, while at the rotation speed of the driving force of 65.88 and 31.41 rpm, it was 16.21% and 6.65%, respectively (Figure 5). This data shows that at a sieve angle of 10° and a rotation speed of the driving force of 91.07 rpm, there were 22.86% of coffee beans with a diameter between 6.5 and 7.5 mm. The faster the rotation of the driving force, the higher the percentage of coffee beans with a diameter smaller than 6.5 mm. The same thing was also obtained from the test results on the rotation speed of the driving force of 65.88 and 31.41 rpm: 16.21% and 6.65%, respectively.

3.5.3. The Third Sieve

The third sieve retained a collection of beans with a diameter smaller than 5.5 mm. The classification results show that the distribution of coffee beans held in the third sieve at the rotation speed of the driving force of 91.07 rpm and a sieve angle of 10° was 67.34%, while at the rotation speed of the driving force of 65.88 and 31.41 rpm, it was 18.21% and 14.45%, respectively (Figure 6). This data shows that at a sieve angle of 10° and a rotation speed of the driving force of 91.07 rpm, as much as 32.66% of coffee beans had a smaller bean diameter than the sieve hole diameter of 5.5 mm. The faster the rotation speed of the driving force, the higher the percentage of coffee beans with a bean diameter smaller than 5.5 mm. Some previous research results also show the same trend data, as reported by Gunathilake et al. [21]: the rotational speed of 15 rpm and the sieve angle of 3° to the horizontal axis of the cylinder produces the highest performance of 93.46%.

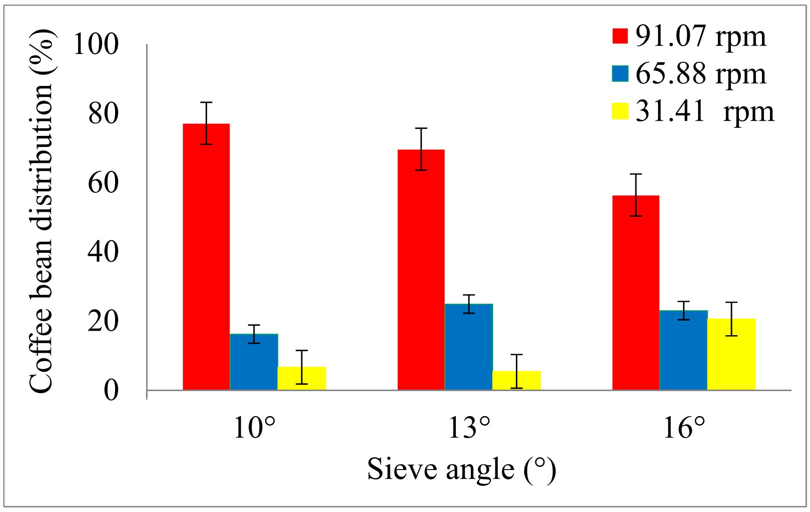

Figure 5. Distribution of coffee beans that pass through the second sieve.

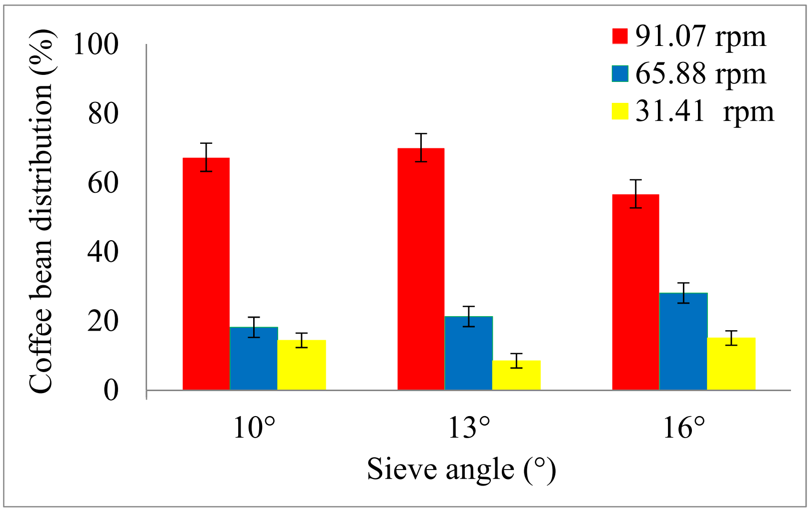

Figure 6. Distribution of coffee beans that pass the third sieve.

3.5.4. The Efficiency of Classification

The efficiency of classification was calculated by comparing the actual capacity of the engine with the theoretical capacity of the engine. The actual capacity of the classifier was the ability of the classifier to do classification within a certain time interval. Based on the calculation of the actual capacity of 16.5 kg/h and the theoretical capacity value of 18 kg/h, the efficiency of the classifier was 91.67%. This value indicates that the efficiency of the classifier was already high, but still needs to be improved. To increase the efficiency of classification, the rotational speed of the driving force needs to be increased based on the Indonesian National Standard (INS).

The energy efficiency was the ratio between performance and energy input. The energy efficiency has a specific application definition for each different condition, but the definition most commonly used is a thermodynamic perspective that uses the ratio of product output to total energy input [44]. Due to the complexity of the function of classifier tools, according to Zhou et al. [41], the definition of energy efficiency is not clear so far and there is an amount of energy efficiency evaluation indicators that can be used for various classifier tools.

4. Conclusions

The working capacity of a classifier was largely determined by the rotational speed of the driving force and the sieve angle. The greater the rotational speed of the driving force and the greater the sieve angle, the higher the working capacity of the engine. The best classification operating conditions was found at the rotational speed of the driving force of 91.07 rpm and a sieve angle of 16°, with a produced classifier working capacity of 38.27 kg/h. The distribution of beans held in the first, second, and third sieve was 56.77, 28.12, and 15.11%, respectively. Efficiency using the classifier was found at the rotational speed of the driving force of 91.07 rpm and a sieve angle of 16°; it was 91.67%. To produce high engine working capacity, a high-speed driving force was also needed. The power generated by the driving force increases with the increased rotation of the driving force. This classifier could feasibly be applied to improve the process of classifying coffee beans.

Author Contributions: Conceptualization, A. (Ansar). and S.; methodology, M.; software, R.H.P.; validation, S.A.M.; formal analysis, A. (Abdurrahim); investigation, R.H.P.; resources, A. (Abdurrahim); data curation, A. (Ansar); writing—original draft preparation, A. (Ansar); writing—review and editing, S.; visualization, M.; supervision, S.A.M.; project administration, R.H.P.; funding acquisition, A. (Ansar). All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: The authors gratefully acknowledge the Faculty of Food Technology and Agroindustry, University of Mataram for all supporting facilities in this research.

Conflicts of Interest: The authors declare no conflict of interest.

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