Optimization of the Number of Cylinder Blades in Coffee Pulper Machine: Finite Element Analysis and Simple Additive Weighting Methods

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ABSTRACT

The increasing interest in coffee in all circles means that coffee production and quality must always increase due to consumer demands. One way to maintain the quality of coffee beans is by breaking them down using a huller machine. This research aims to improve the optimization of coffee machines by modifying the cylinder blades of huller machines with variations of 3, 4, 5, and 7 cylinder blades in terms of static loading design and quality and production capacity of coffee bean breaking. The experiment was carried out using 400 rpm and breaking 10kg of dry coffee cherries every time the sample was taken. The research results show that the best sample collection is the variation of 3 cylindrical blades with the maximum stress and lowest deformation values of 6.67 MPa and 0.000737 mm. In terms of production quality, it shows that the best sampling was the three cylindrical blade variations with 50% whole and good coffee beans. In terms of production capacity, the most significant capacity was the seven cylindrical blade variations with a value of 294.11 kg/hour. Sampling from the four most optimal variations uses the SAW (Sample Additive Weighting) method. The most optimal result from the 4 test criteria, the variation of 3 cylindrical blades is the best because it has the highest score with a value of 0.9754.

Keywords: *ANSYS, coffee huller machine, finite element method, huller machine blades, production capacity, production quality*

I. Introduction

Indonesia ranked as the fourth largest coffee producer in the world in 2024, after Brazil, Vietnam, and Colombia [1]. Coffee is one of the plantation products that is highly favoured by both young and old. The expansion of coffee plantation areas in Indonesia also increased significantly between 1980 and 2016. The area of coffee plantations in 1980 was 707,464 hectares, while in 2016, it increased to 1,233,294 hectares, an increase of 74.33% with a growth rate of 1.61% [2]. As coffee becomes more popular among various groups, the readiness of technology must be balanced with the continuously increasing production. Especially in the post-harvest technology sector, there must be readiness to handle the overflowing harvest each year, thus requiring appropriate technology to help the production rate keep pace with consumer demand.

Indonesia ranked as the fourth largest coffee producer in the world in 2002, following Brazil, Colombia, and Vietnam. Coffee is one of the plantation products that is highly favored by both young and old [1]. The expansion of coffee plantation areas in Indonesia increased significantly between 1980 and 2016. The area of coffee plantations in 1980 was

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707,464 hectares, while in 2016, it increased to 1,233,294 hectares, representing a growth rate of 1.61% [2]. As coffee becomes more popular among various groups, the readiness of technology must keep pace with the continuously increasing production. Especially in the post-harvest technology sector, there must be readiness to handle the overflowing harvest each year, thus requiring appropriate technology to help the production rate keep up with consumer demand.

There are two methods of coffee bean peeling: dry peeling (huller) and wet peeling (pulper) [3]. In the dry method, coffee cherries are first dried and then sun-dried. After that, the coffee is ready to be peeled using a coffee peeling machine (huller). One of the most important components of the coffee peeling machine is the cylinder blades [4]. The peeling cylinder typically has four blades that function to peel the coffee beans [5].

This research focuses on optimizing the number of cylindrical blades in a machine used in the village of Panduman, which originally used four blades, by exploring variations with 3, 4, 5, and 7 blades. Previous studies have identified that using 3, 5, and 7 blades can impact quality and productivity [6], leading to the identification of three optimal blade configurations. In this study, a comparative analysis was conducted on the machine using these different blade quantities. Load analysis tests were performed to observe total deformation and von Mises stress. Additionally, an experimental study assessed the peeling results for the four-blade variation at a machine speed of 400 rpm. The Simple Additive Weighting (SAW) method was then used to determine the best blade variation based on the test results.

II. Material and Methods

1. Materials

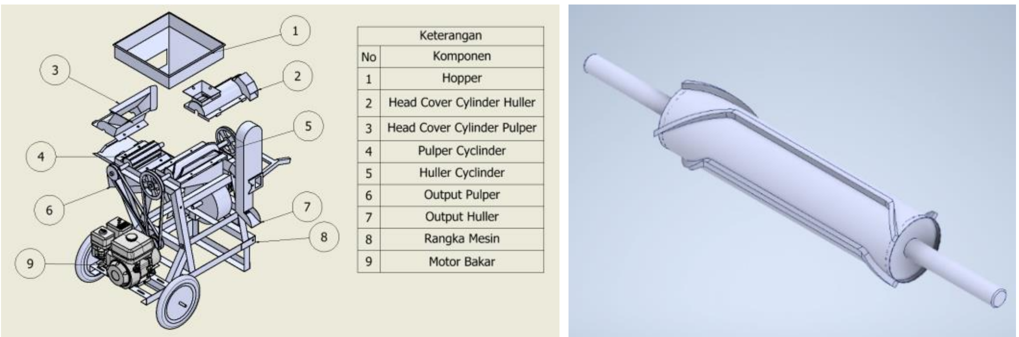
Mild steel is used for the cylindrical blades. It also known as low-carbon steel, is a type of carbon steel with a low carbon content [7]. There are various grades of mild steel with different levels, but all have a carbon content of no more than 0.25% and no less than 0.05%. This carbon content is added to enhance properties such as corrosion resistance, wear resistance, and tensile strength. Mild steel is easy to form and soft, making it easier to work with in manufacturing processes [8].

2. CAD Design Modeling

The researcher created an initial sketch and determined the dimensions of the object to be redesigned, based on the actual dimensions of the coffee huller machine. This machine serves two functions as part of the Panduman Village Community Service Grant [3]. The design was then developed using the Autodesk Inventor application [9], as shown in Figure 1.

2. Static Structural Simulation

This research utilizes a structural static simulation model, determining technical data based on mild steel material [10], [11] as specified for a dual-function coffee machine. The study involves meshing the geometry, identifying fixed supports, applying loading forces [12], [13], and producing data on the meshing shapes of the coffee peeling cylinders with 3, 4, and 5 blades. It includes the results of stress and total deformation simulations. These outcomes are then analyzed and compared based on the number of blades: 3, 4, 5, and 7.



(a) (b)

Fig. 1. (a) Double functions coffee peeling machine (b) coffee huller cylinder blade

3. Test the Quality of Coffee Peeling (Experimental)

This research focuses on selecting Arabica coffee beans for processing using the dry coffee hulling method [14]. The beans are dried for three days until their water content reaches 11.40%-11.60%, below the SNI maximum of 12.5%. The criteria for evaluating the coffee peeling results include whether the beans are fully peeled and the production capacity of the coffee machine. The machine operates at a speed of 400 rpm, with variations of 3, 4, 5, and 7 cylinder blades, processing 10 kg of coffee beans. Each variation was tested once, and the results were recorded by category. Analysis and comparisons were also made with previous research.

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III. Results and Discussions

1. Meshing

The meshing simulation used measuring 2.5 mm produces elements with a rate level of meshing skewness quality in the very good category because the average meshing value produced is 0.4. A meshing value of 0.4 falls within the "very good" category, which ranges from 0.25 to 0.5 (Figure 2). Meshing with variety of blade numbers is presented in Figure 3 followed by mesh number and nodes in Table 1.

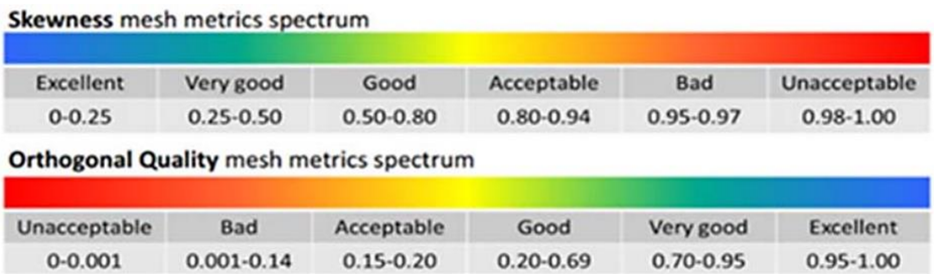
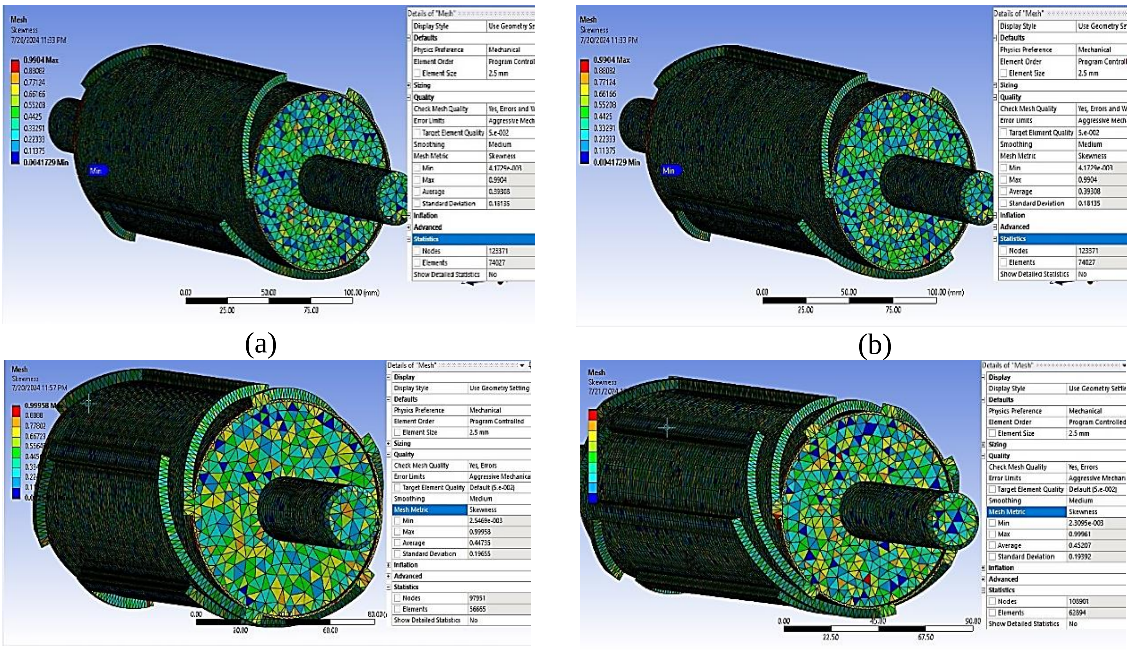


Fig. 2. Meshing quality category level



(a) (b) (c) (d)

Fig. 3. Meshing: (a) 3 Cylindrical blades; (b) 4 Cylindrical blades; (c) 5 Cylindrical blades; (d) 7 Cylindrical blades.

Table 1. Meshing

Geometry	Number of Node/element	Element size (mm)	Average mesh ration skewness quality
3 Cylindrical blades	123.371 / 74.027	2.5 mm	0.39
4 Cylindrical blades	92.173 / 53.255	2.5 mm	0.44
5 Cylindrical blades	97.951 / 56.665	2.5 mm	0.44
7 Cylindrical blades	108.901 / 62.894	2.5 mm	0.45

In meshing analysis, skewness is a critical factor that indicates the quality of the mesh elements. Skewness measures how equilateral (or equiangular) the elements are. A skewness value of 0 represents a perfect element, while values closer to 1 indicate poor quality [16]. A skewness value of 0.4 is considered "very good" because it ensures that the elements are relatively equilateral, which is crucial for accurate finite element analysis (FEA) [17]. High-quality mesh elements minimize numerical errors and improve the convergence of the simulation. This is because well-shaped elements lead to better interpolation of the field variables (such as stress and strain), resulting in more accurate simulation results [18]. Therefore, achieving an average skewness value of 0.4 positively impacts the overall simulation accuracy, as it ensures that the mesh elements are well-shaped and the numerical errors are minimized. This allows for reliable and precise analysis of the coffee pulper machine's performance with different numbers of cylindrical blades.

2. Stress Maximum

Figure 4 illustrates the maximum stress observed in coffee peeling machines with different configurations of cylindrical blades: (a) 3 cylindrical blades, (b) 4 cylindrical blades, (c) 5 cylindrical blades, and (d) 7 cylindrical blades. By taking samples from these 4 variations, we can compare the data derived from the maximum stress values.

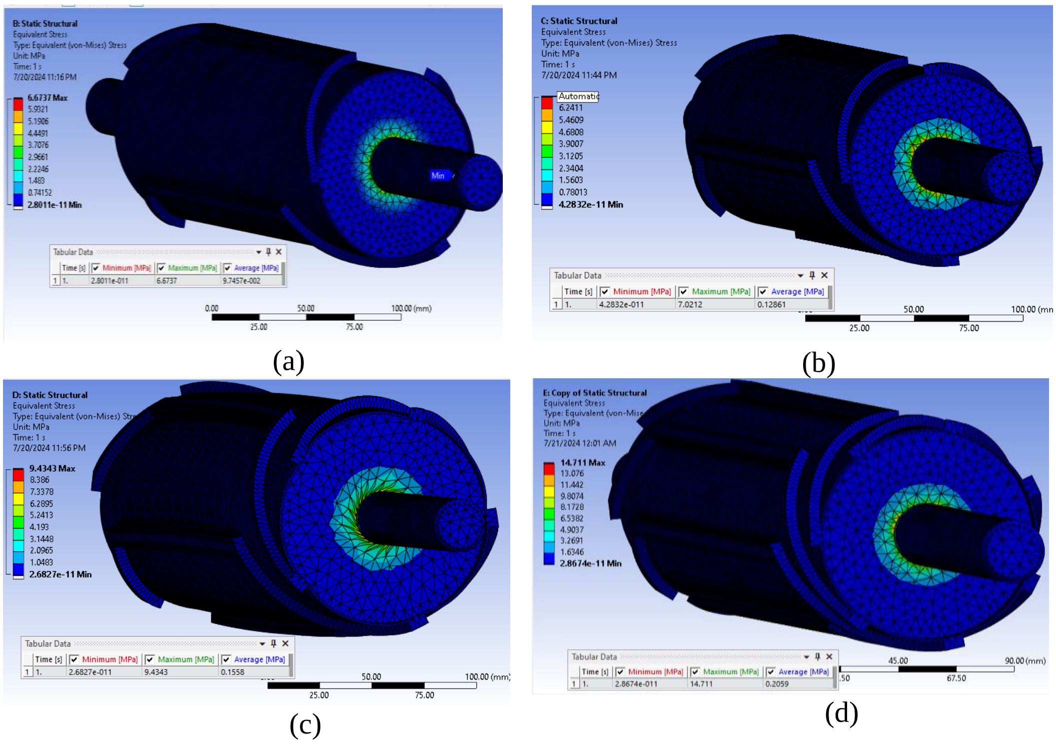


Fig. 4. Maximum stress (a) 3 Cylindrical blades; (b) 4 Cylindrical blades; (c) 5 Cylindrical blades; (d) 7 Cylindrical blades

Taking samples from 4 variations, namely 3, 4, 5, and 7 cylindrical blades of coffee peeling machines, can be compared from several data that have been taken from the maximum voltage value.

Figure 5 shows the graph of the effect of blade variations on maximum stress during the single coffee peeling process. None of the variations reached the maximum stress limit of 125 MPa for mild steel.

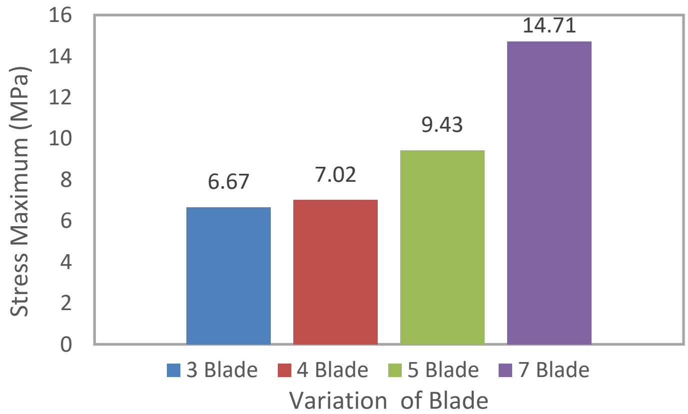


Fig. 5. Graph of the effect of blade variations on maximum stress

In the single coffee peeling process, none of the variations reached the maximum stress limit of 125 MPa for mild steel. From the sample data, we observed that the 7-blade variation had the highest contact area, resulting in the highest pressure of 14.71 MPa. Conversely, the 3-blade variation had the lowest maximum stress value of 6.67 MPa. Thus,

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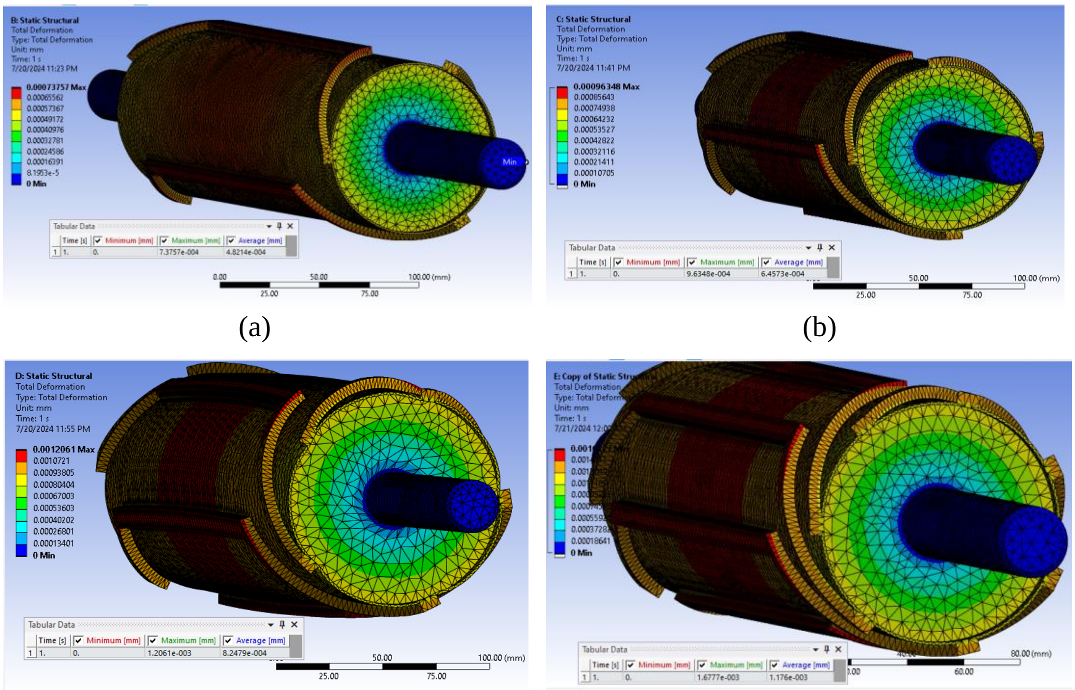
minimal contact appears to be more advantageous as it results in a lower distribution of maximum stress values.

3. Total Deformation

The total deformation data from the samples of 4 variations of the cylindrical huller blades show that the largest deformation occurs with the 7-blade variation, which has the most contact during coffee peeling, resulting in a maximum deformation of 0.00167 mm for a single coffee bean cracking process. Conversely, the best and smallest total deformation is observed with the 3-blade variation, with a total deformation of 0.000737 mm for a single uniform coffee bean cracking process, as shown in Figure 6.



(a) (b) (c) (d)

Fig. 6. Maximum Stress (a) 3 Cylindrical blades; (b) 4 Cylindrical blades; (c) 5 Cylindrical blades; (d) 7 Cylindrical blades

The total deformation data from the four variations of cylindrical huller blades show that the largest deformation occurs with the 7-blade variation (Figure 7), which has the most contact during the coffee peeling process, resulting in a maximum deformation of 0.00167 mm for a single coffee bean. Conversely, the smallest total deformation is observed with the 3-blade variation, with a total deformation of 0.000737 mm for a single coffee bean.

When considering the trade-offs between higher productivity and reduced peeling quality, it is important to balance these two factors to achieve optimal performance. In a real-world setting, higher productivity typically means processing a larger volume of coffee beans in a shorter time, which can improve overall efficiency and meet production targets. However, increased productivity may come at the cost of reduced peeling quality, resulting in greater coffee waste and lower-quality beans that do not meet industry standards [16].

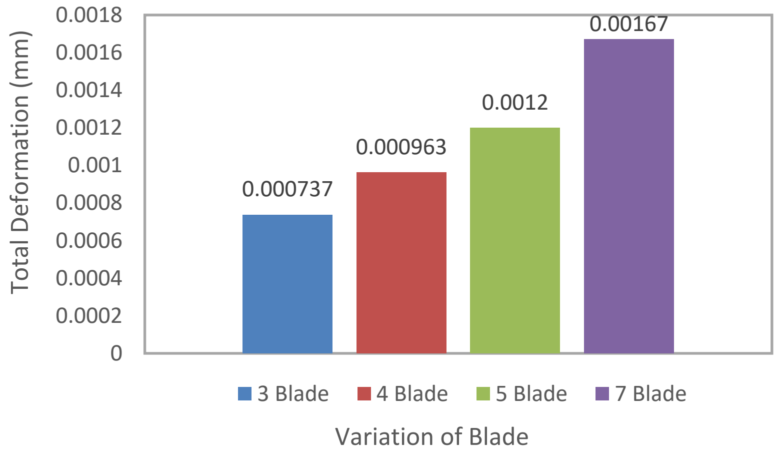


Fig. 7. Graph of the effect of blades variations on total deformation

To mitigate these trade-offs, coffee producers must carefully evaluate the performance of their huller machines and consider the following strategies:

Adjusting Operating Parameters: Fine-tuning the operating parameters of the huller machine, such as blade speed and pressure, can help achieve a balance between productivity and peeling quality. By optimizing these parameters, producers can enhance the peeling precision while maintaining acceptable productivity levels [17].

Regular Maintenance and Upkeep: Implementing a robust maintenance management system ensures that the huller machine operates at peak performance. Regular inspections, timely blade replacements, and addressing wear and tear can help maintain peeling quality and extend the machine's lifespan [18].

Investing in Advanced Technologies: Adopting advanced technologies, such as improved blade designs and materials, can enhance the machine's performance. These innovations can reduce stress and deformation, leading to better peeling quality and higher productivity [16].

Training and Skill Development: Providing training to operators on best practices and efficient machine operation can help them make informed decisions and adjustments to optimize both productivity and peeling quality [17].

In summary, the practical implications of the stress and deformation findings underscore the importance of maintaining a balance between productivity and peeling quality. By implementing effective strategies and investing in advanced technologies, coffee producers can optimize their huller machines' performance, ensuring consistent high-quality output and minimizing operational costs.

4. Value of Quality and Productivity of Coffee Peeling

In terms of coffee peeling efficiency, the data indicates a consistent trend (see Table 2). The uniform peeling of 10 kg of dry Arabica coffee beans reveals that the highest quality of peeling is achieved with the 3-blade variation, which has a peeling percentage of 50% [19]. This is followed by the 4-blade variation at 45%, the 5-blade variation at 44%, and the 7-blade variation at 40%. This suggests that increased contact between the coffee beans and blades results in decreased peeling quality, causing more damage and less effective peeling [20].

Table 2. Coffee peeling test results

Cylindrical blades	Cylinder rotation (rpm)	Peeling time (hr:min:sec:m.sec)	Coffee weight		Peeling results	
			before peeling (kg)	after peeling (kg)	quality (%)	productivity (kg/hour)
3	400	0:02:22.00	10	5	50	270.27
4	400	0:02:15.08	10	4.5	45	279.32
5	400	0:02:34.00	10	4.4	44	256.41
7	400	0:02:05.45	10	4	40	294.11

As illustrated in Figure 8, the graph of the effect of variation on the quality of coffee peeling further supports these findings. The 3-blade variation demonstrates the highest peeling quality, followed by the 4-blade, 5-blade, and 7-blade variations. This trend suggests that increased blade contact with the coffee beans leads to a higher likelihood of damage and reduced peeling quality [6].

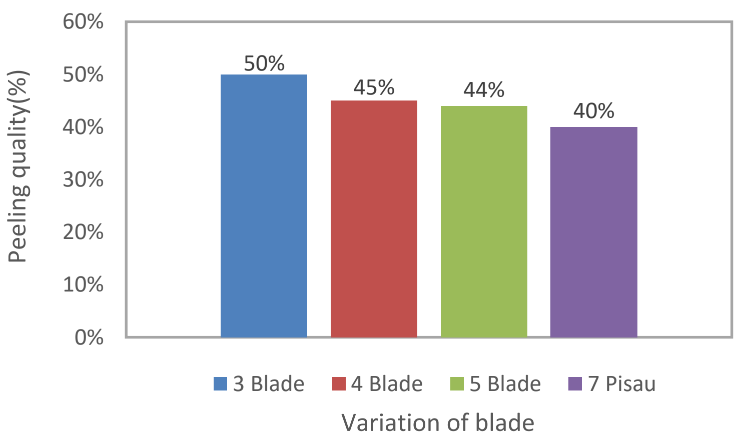


Fig. 8. Graph of the effect of variation on the quality of coffee peeling

The effectiveness of coffee bean crushing production capacity varies with different cylindrical blade configurations. As shown in Figure 9, the 3-blade variation has a production capacity of 270.27 kg/hour, the 4-blade variation has a capacity of 279.32 kg/hour, the 5-blade variation has a capacity of 256.41 kg/hour, and the 7-blade variation has a capacity of 294.11 kg/hour [6]. The number of cylindrical blades significantly affects the coffee huller machine's production capacity. From the sampling of Arabica coffee peeling, it can be concluded that as the number of blades increases, so does the applied pressure. Excessive pressure during peeling can lead to poor peeling quality due to the excessive force applied to the coffee beans.

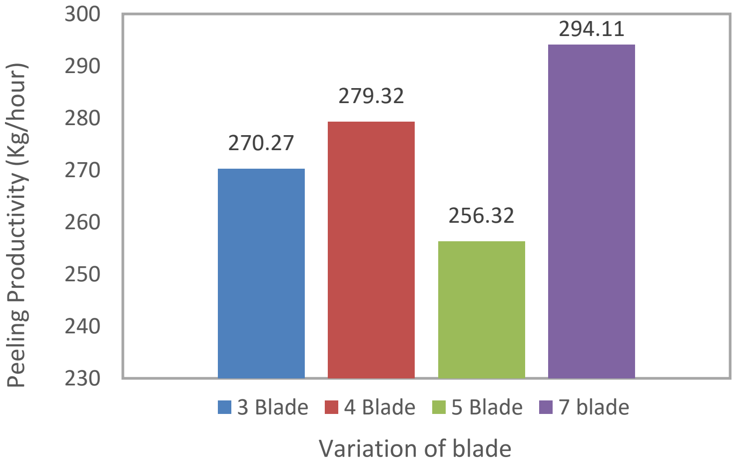


Fig. 9. Graph of the effect of blade variation on production capacity

5. *Optimization of variations in the number of cylindrical blades*

Tests have been conducted on four types of knives, evaluating four criteria: total deformation, maximum stress, peeling quality, and peeling productivity. The SAW (Simple Additive Weighting) method was used to determine the most optimal results from these tests. The weightings and criteria for the four knife blade variations were determined based on the test results, as shown in Table 3.

Table 3. Determination of criteria and weighting

Parameters	Total deformation (min)	Stress maximum (min)	Peeling quality (max)	Peeling productivity (max)
Weight	10%	20%	40%	30%
3 cylindrical blades	0.000737	6.67	94.33	270.27
4 cylindrical blades	0.000963	7.02	90	279.32
5 cylindrical blades	0.0012	9.43	80	256.41
7 cylindrical blades	0.0016	14.71	75.47	294.11
divider	0.000737	6.67	94.33	294.11

The highest weight is assigned to the peeling quality, as poor peeling quality leads to greater losses in the peeling process, with more coffee being wasted and failing to meet the standards. The weight assigned to each criterion was carefully chosen based on its impact on the overall performance of the coffee pulper machine:

Peeling Quality (40%): This criterion is given the highest weight because maintaining high peeling quality is crucial to minimize coffee waste and ensure that the beans meet the required standards. Poor peeling quality results in greater losses and inefficiency in the peeling process.

Peeling Productivity (30%): Productivity is also important as it directly affects the throughput and efficiency of the machine. High productivity ensures that a large volume of coffee beans can be processed in a shorter time, improving overall efficiency.

Maximum Stress (20%): This criterion measures the mechanical stress experienced by the blades during operation. Lower stress values indicate better durability and longevity of the blades, reducing maintenance and replacement costs.

Total Deformation (10%): Total deformation is given the lowest weight as it has a relatively smaller impact on the overall performance compared to the other criteria. However, it is still important to minimize deformation to maintain the structural integrity of the blades.

The results of decision-making using the additive weighing sampling method for the four variations in the number of cylindrical blades indicate that the most optimal alternative is the 3-blade variation, with the highest total score of 0.9754. The 4-blade, 5-blade, and 7-blade variations have sequential scores of 0.9312, 0.8033, and 0.7547, respectively.

The importance of maintaining peeling quality is influenced by stress and deformation in the coffee peeling machine. Ensuring optimal peeling precision and minimizing waste often requires balancing productivity with bean quality. In real-world operations, operators are frequently faced with trade-offs between achieving high productivity and maintaining peeling quality, which may sometimes require additional manual sorting processes. Therefore, companies must select the right machines and technologies and implement efficient maintenance management to ensure optimal machine performance and maintain peeling quality.

This study has some limitations, particularly in the sample selection, as only one trial could be conducted due to the limited availability of coffee beans during the research. Future research should consider repeating the experiments multiple times to ensure more valid results. The total scores of the 4 variations using the SAW method are presented in Table 4.

Table 4. Total score of 4 variations using the SAW method

Variation in the number of blades	Total score
3 cylindrical blades	0.1+0.2+0.4+0.2754 = 0.9754
4 cylindrical blades	0.0765+0.19+0.38+0.2847 = 0.9312
5 cylindrical blades	0.0614+0.1414+0.3392+0.2613 = 0.8033
7 cylindrical blades	0.0441+0.0906+0.32+0.3 = 0.7547

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IV. Conclusions

From the analysis of deformation and maximum stress on four variations of cylindrical blades, it was found that the three-blade variation provided the best peeling results due to minimal contact and low stress, achieving the highest score in the SAW method (0.9754). Although the seven-blade variation had the highest production capacity (294.11 kg/hour), it did not perform well in terms of coffee bean quality. This indicates that the three-blade variation is superior in minimizing bean waste and offering low maintenance costs with minimal risk of damage, owing to its precise blade configuration and high-quality performance.

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