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PERFORMANCE OF STRIPPER ELEMENT DESIGNS IN LABORATORY TESTING FOR STRIPPER HARVESTERS AT VARIOUS GRAIN MOISTURE LEVELS AND ROTOR SPEEDS

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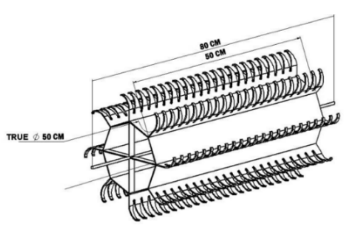


Abstract

The rice harvester machine (stripper) in Indonesia struggles with high grain losses and low cleanliness. This study examines factors such as comb design, rotor speed, and grain moisture levels contributing to these issues. Using a laboratory testing apparatus, the research evaluates different stripper element designs and rotor speeds at varying grain moisture levels. Data on collected and uncollected grains are categorized as unstripped, shattered, and scattered losses. The experimental design employs a factorial randomized block design with three replications, with percentage losses and cleanliness as dependent parameters and comb type, grain moisture content, and rotor speed as independent parameters. Analysis of variance assesses the significance of each parameter's influence and their interactions. Subsequent Duncan Multiple Range Tests at α 5% determine specific differences. ANOVA results show significant differences in losses among independent parameters and their interactions. Cleanliness observations also show significant differences among independent parameters. The best comb design is the curved comb type, with the lowest grain losses at 6.34% and highest cleanliness at 97.29%. Operating at a rotor speed of 1.41 m/s (54 rpm) with a grain moisture content of 12%, this design offers improved efficiency for rice harvesters in Indonesia.

Keywords: stripper, grain losses, cleanliness, peripheral speed, grain moisture

1.0 INTRODUCTION

Indonesia is one of the countries with the highest population density in the world. The population of Indonesia is approximately 275 million , ranking fourth after China with 1,426 million, India with 1,412 million, and the United States with 337 million as of 2022 [1]. The increase in population density in Indonesia significantly influences the consumption demand for rice. This implies that rice consumption needs in Indonesia are on the rise in line with its population density. The average annual growth rate in rice demand from 2008 to 2020 is 1.16%, with the demand reaching 4.66 million tons. Consequently, this results in a 4.32% annual decrease in the gap between rice production and consumption [2]. Various efforts can be made to address the high demand for rice consumption in Indonesia, one of which is by increasing the paddy harvest index [3]. However, enhancing the harvest index in paddy cultivation in areas with limited new agricultural land [4] and the widespread conversion of agricultural land to non-agricultural use [5], as seen in Indonesia, can be a challenging alternative solution to increasing rice production in the future.

Another significant challenge in increasing rice production in Indonesia arises from the handling of the harvesting process, which contributes significantly to losses. The largest percentage of losses in the postharvest stage of rice in Indonesia occurs during the harvesting process, accounting for 9.52%, followed by the threshing process at 4.78%, and milling at 2.19% [6]. The losses during harvesting should still be reducible using practical rice harvesting tools or machines. Best practices in harvesting are primarily achieved through two criteria: optimal harvest timing and the best utilization of available equipment for rice harvesting [7]. Optimal harvest timing for rice is related to maturity factors influenced by water content. Meanwhile, the effectiveness and production capacity influence the selection of tools and machines in rice harvesting. Some standard tools and machines used in other countries, such as Bangladesh, include the reaper, mini-combine, and combine harvester [8], which have also been chosen for rice harvesting in Indonesia.

Indonesia's standard and widely used rice harvesting machine is the stripper-type rice harvester [9]. The principle of the stripper machine is to extract rice grains from the plant without collecting straw [10]. The development of the stripper rice harvester began in 1989 when the International Rice Research Institute (IRRI) and Silsoe Research Institute, based on a joint initiative and support from the Overseas Development Administration in the UK, created a small walking stripper harvester suitable for small rice fields in Asia. IRRI's work focused on developing two walking stripper harvester systems to meet the labor-saving har- vesting technology needs in small rice fields. The first system is the Stripper Gatherer (SG) system, where the SG picker collects harvested rice into a detachable collection container. Threshing and cleaning are done in off-farm operations. The thresher/cleaner machine is a specially designed light axial flow unit that takes advantage of reduced straw quantity, length, and the high level of free grains in the harvested crop [11]. The second system is the Stripper Thresher (ST), where threshing and straw separation are done in the harvester machine, and only silent screening and cleaning are needed to produce clean grains [12].

A literature review indicates that despite numerous studies on strippers, their success has been somewhat limited [13]. Previous efforts to develop efficient seed stripping mechanisms failed mainly due to high breakage losses and poor performance on highly lodged crops [14]. Despite past failures, the stripping concept continues to attract the interest of researchers and harvest machine designers. The most promising striper system is undoubtedly the stripper header, developed at the Silsoe Research Institute, UK, and commercially produced by the British company Shelbourne [15]. The experience with strippers designed by IRRI in the Philippines offers promising opportunities to transform rice harvesting methods in Asia, a critical region for global rice cultivation. Crop management practices influence the acceptance of stripper technology in some areas. Further research is needed to optimize the potential of stripper principles fully [16].

Other factors that also play a role in determining the success of rice harvesting using a stripper machine include planting pattern factors. These planting pattern factors can influence rice yield loss, making it essential to understand them in depth for effective mitigation efforts. First, the uniformity of rice plants is crucial, as differences in height and maturity can lead to some plants being poorly harvested, resulting in wasted yield. This research focuses on testing several designs of the stripper machine's harvesting components, which are designed to adapt to plant variations, thereby improving harvesting efficiency. Second, the tilting of rice plants can disrupt the harvesting process, especially if the plants do not grow upright. Tilted plants are difficult for the harvesting components to reach, which can cause more grains to fall to the ground. By testing different harvesting components, this study is also relevant for finding a design that is more adaptive to field conditions, thereby reducing losses due to tilting. Third, unevenness during the planting process can create additional challenges. Plants that do not grow uniformly will result in certain areas being missed during harvesting. Through the analysis of several designs of harvesting components on the stripper machine, this research will evaluate the effectiveness of each in addressing this unevenness, with the aim of minimizing lost yield. Thus, understanding how to tackle these factors can be achieved through the analysis and testing of various designs of harvesting components for more efficient rice stripper machines. This research not only contributes to the understanding of how planting patterns affect yield but also offers technical innovations that can enhance harvesting efficiency, even when the planting patterns are not optimal.

Therefore, this research aims to analyze the performance of some recent designs on comb design of stripper rice harvesting machines and peripheral speeds of the rotor (stripper header) at various levels of grain moisture using laboratory testing apparatus. In this study, the factors affecting grain losses and cleanliness in rice harvester machines (strippers) in Indonesia are investigated, focusing on comb design, rotor speed, and grain moisture content. A laboratory testing apparatus is used to evaluate various stripper element designs and rotor speeds under different grain moisture levels. A factorial randomized block design with three replications is employed, categorizing data on collected and uncollected grains into unstripped, shattered, and scattered losses. Analysis of variance (ANOVA) is conducted to assess the significance of each parameter's influence and their interactions, followed by Duncan Multiple Range Tests at α 5% to identify specific differences. The significance of this research lies in the development of a deeper understanding of the factors influencing the efficiency of rice harvester machines. The practical implications of this study include improvements in the design and operational settings of the machines, which can reduce grain losses and enhance the cleanliness of harvested products. The application of these findings has the potential to provide economic benefits to local farmers, increase agricultural productivity, and contribute to food security in Indonesia. Furthermore, the research design opens opportunities for further investigations into the development of more effective and efficient harvesting technologies.

2.0 METHODOLOGY

2.1 Development of the Stripper Header Design for Paddy Stripper Machine

The stripper header designed for testing apparatus in the laboratory consists of an octagonal-shaped stripping rotor and eight stripping elements. The diameter of the stripping rotor in this header is 50 cm, with a length of 50 cm (Figure 1). Each corner of the stripping rotor has a bracket to secure eight stripping elements, each with dimensions of 50 cm in length and 5 cm in width. In this study, there are three types of stripping elements installed on the stripping rotor: the straight slender arrow type, the curved slender arrow type and the straight comb type. The stripping rotor and stripping elements are made of 2 mm thick iron plate material.

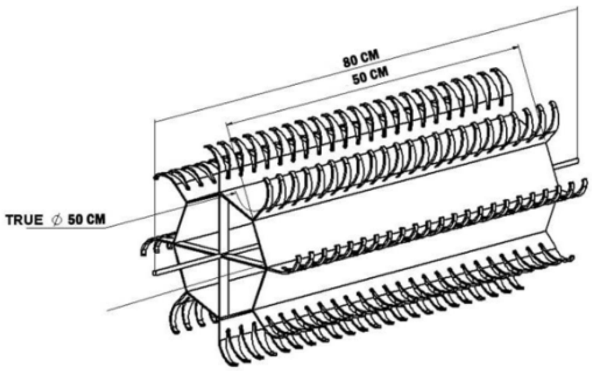


Figure 1 Stripping header

The stripper header also includes a shaft/axle used to connect the eight sides of the stripping rotor and support the rotational motion of the stripper header. A pulley is mounted on this shaft/axle to facilitate the rotational movement. The diameter of the shaft/axle in this stripper header is 1 inch, with a length of 80 cm. The stripper header is installed on a frame in the body of the testing apparatus, which can move forward due to the presence of assisting wheels connected to the track of the testing apparatus. The stripping rotor lifts and separates rice grains without cutting the straw [17]. The separated rice grains are directly conveyed to a storage container within the testing apparatus's body.

2.2 Testing Treatment Of Comb Design on The Stripper Header

The comb design used in this study consist of three types: 1) straight slender arrow type, 2) curved slender arrow type, and 3) straight comb type. The stripper element with the straight slender arrow type is common and has been widely used in rice harvester stripper machines in Indonesia. The stripper element with the straight slender arrow type, made of rubber material, has been previously studied in Konkan, India [18,19], and tested on the Ratnagiri-1 rice variety. The study's results explained that the stripper element with the straight slender arrow type resulted in an average loss of 6.39% of rice grains. The difference in this study compared to the previous one lies in the material used to form the stripper element, whereas in this study, the material used is a 2 mm thick iron plate.

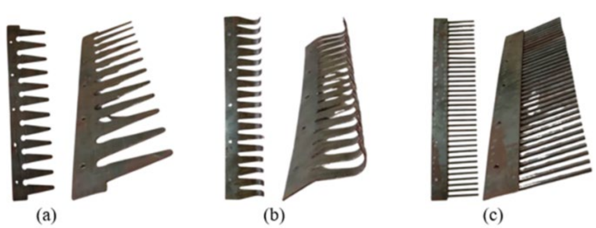
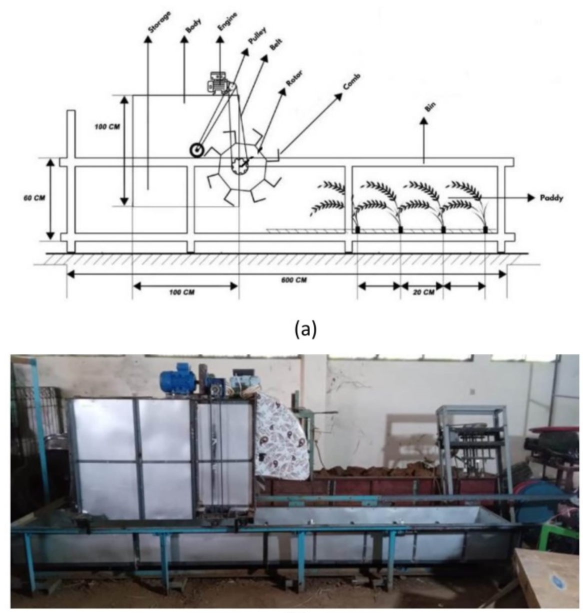


Figure 2 Stripping elements: (a) straight slender arrow type, (b) curved slender arrow type and (c) straight comb type

This study also introduces a new design of the stripper element with the curved slender arrow type, where the design of the stripper element in the straight slender arrow type was previously curved to reduce losses of scattered rice grains. The last design of the stripper element tested in this study is the stripper element with the straight comb type, which intends to reduce the level of rice grain losses due to breakage or shattered.

2.3 Testing Treatment of Comb Design on The Stripper Header

The developed testing apparatus (Figure 3) consists of two units: the harvesting unit and the grain collection and rice plant holding unit. The harvesting unit is responsible for driving the rotor/stripper header, which has dimensions of 150 cm in length, 60 cm in width, and 100 cm in height. Meanwhile, the grain collection and rice plant holding unit functioned to collect are using the route at entrance A compare with entrance B and entrance C. Since the entrance A is main entrance, this results is expected. For entrance B, there a less vehicles that used this route since the road that linking to the entrance is not main road compare to entrance A and entrance C. In entrance C, it indicate that there are a lot of bicycle that used this entrance since near the entrance, it has an area for student settlement scattered rice grains and serve as a holder for rice plants, with dimensions of 600 cm in length, width cm, and height of 60 cm. The harvesting unit and the grain collection and rice plant holding unit can move forward and backward as they have auxiliary wheels connected to a fixed frame track on the 3-meter-long testing apparatus.



(b)

Figure 3 Design in test apparatus (a), test apparatus (b)

The rotation of the stripper header moves in the opposite direction to the forward movement of the auxiliary wheels on the harvesting unit. The stripper header is powered by an AC electric motor with a maximum power specification of 1 hp and a speed of 1400 rpm, with an additional 1:10 gearbox. The transmission system driving the stripper header consists of pulleys and type A V-belts. The auxiliary wheels on the harvesting unit can move due to the power supplied by an AC electric motor with a power of 1 hp and a speed of 1400 rpm, along with an additional 1:60 gearbox. As a result, the speed of the stripper header's movement is 0.324 km/h.


(a) (b)
Figure 4 (a) The grain collection and rice plant holding unit, (b) Rice plants that are bound to the grain collection and rice plant holding unit

The grain collection and rice plant holding unit have five rows of components binding clusters of rice plants (Figure 4). The intra-row spacing is 20 cm, and the inter-row spacing is also 20 cm. These distances are adjusted according to Indonesia's most common rice planting patterns. The binding components on the grain collection and rice plant holding unit are made of straight strips of iron plate and curved iron plate strips, locked by a bolt and nut locking system.

2.4 Rice varieties

The Sintanur rice variety is quite popular among the Indonesian population due to its delightful taste and tender texture [20]. The Sintanur rice variety falls within the sinica/ japonica group. This plant has a lifespan of approximately 120 days, featuring a prolific number of productive tillers [21]. The Sintanur rice plant has an upright growth form, reaching a height of around [20][22]. The leaf position of Sintanur varies between upright and inclined, but the flag leaf is always upright. Its stem is categorized as moderately lodging-resistant. The grains skin of Sintanur are clean yellow in color, with a medium-sized and relatively stable shape in terms of shattering [23].

Table 1 Aparatus test

No	Particulars	Value
1	Variety	Sintanur
2	Crop height (cm)	120
3	Plant age (days)	115-125
4	Crop yield (ton/ha)	6
5	Moisture content at harvest (%)	14
6	Panicle lenght (cm)	20-25

Sintanur's production falls into the good category, amounting to 6 tons per hectare. Additionally, Sintanur exhibits resistance to brown planthopper biotypes 1 and 2, and susceptibility to brown planthopper biotype 3. Its resistance also extends to bacterial leaf blight strain III, with susceptibility to strains IV and VIII. Sintanur is well-suited for cultivation in lowland irrigated fields up to an elevation of 550 meters above sea level. The following characteristics of the Sintanur variety of are shown in Table 1.

2.5. Tested Observations Computed

The observations made in this study include grain losses and cleanliness. Observations of grain losses (%) are calculated by comparing the total sum of unstripped grain (g), shattered grain (g), and scattered grain (g) with the initial weight of the grain (g). Meanwhile, observations of cleanliness (%) are calculated by comparing the net weight (g) and gross weight (g) after the stripping process. The following are the equations used to calculate the grain loss parameter (equation 1) and cleanliness (equation 2) :

$$\text{Grain Loss } (\%)=\frac{W_1+W_2+W_3}{IW}\times 100 \quad (1)$$

$$\text{Cleanliness } (\%)=\frac{NW}{GW}\times 100 \quad (2)$$

Where, W1 is unstripped grain (g), W2 is shattered grain (g), W3 is scattered grain (g), IW is initial weight of the grain (g), NW is net weight of the grain (g) and GW is gross weight of the grain (g) after stripping process.

2.6. Experimental Design

The previous research [17] explained that the differences in the types of comb design, peripheral speed of the rotor, and forward speed of the stripper significantly influence grain losses and stripping efficiency. In this study, independent experiment parameters were conducted on three types of stripper element designs, three rotor peripheral speed levels, and three grain moisture content levels. The three types of comb design include the straight, slender arrow type, curved, slender arrow type, and straight comb type. The three levels of rotor peripheral speed are 1.41 m/s (54 rpm), 1.63 m/s (62 rpm), and 1.92 m/s (73 rpm). The three levels of seed moisture content are 20%, 16%, and 12%.

Table 2 Design of experiments (DoE)

Comb design		Grain moisture content (%)		Peripheral speed of rotor (m/s)		Rpm		Combinations
(A)		(B)		(C)		(D)		
1	Straight slender arrow	1	20	1	1.41	1	54	A1B1C1D1
		2	16	2	1.63	2	62	A1B2C2D2
		3	12	3	1.92	3	73	A1B3C3D3
2	Curved slender arrow	1	20	1	1.41	1	54	A2B1C1D1
		2	16	2	1.63	2	62	A2B2C2D2
		3	12	3	1.92	3	73	A2B3C3D3
3	Straight comb	1	20	1	1.41	1	54	A3B1C1D1
		2	16	2	1.63	2	62	A3B2C2D2
		3	12	3	1.92	3	73	A3B3C3D3

The dependent variables considered in this study are grain losses and cleanliness of the stripping process results. The testing was performed with three replications. The experimental design used in the research is a factorial randomized block design with the data analysis technique of ANOVA using IBM SPSS Statistics version 22.

Based on Table 2, this study was conducted with a combination of 9 experimental setups. The experimental combinations in this study were A1B1C1D1, A1B2C2D2, A1B3C3D3, A2B1C1D1, A2B2C2D2, A2B3C3D3, A3B1C1D1, A3B2C2D2, and A3B3C3D3. In this context, A, B, C, and D represent the independent variables, where A is the comb design, B is the moisture content (%), C is the peripheral speed of the rotor (m/s), and D is the rpm. The dependent variables in this study include grain losses (%) and cleanliness (%).

3.0 RESULTS AND DISCUSSION

3.1 Combine Effect Of Comb Design, Grain Moisture And Peripheral Speed Of The Rotor

Observations on the parameters of grain losses and cleanliness were conducted on three types of independent parameters, including comb design (straight slender arrow type, curved slender arrow type, and straight comb type), grain moisture (20%, 16%, and 12%), and peripheral speed of the rotor (1.41 m/s, 1.63 m/s, and 1.92 m/s). The parameters of comb design, grain moisture, and peripheral speed of the rotor each individually have a significant impact on grain losses. The same applies to the interaction between these three parameters, where the interaction of the three parameters also has a significant effect on grain losses.

Table 3 Analysis of variance for combine effect of comb design, grain moisture and peripheral speed of rotor on grain losses

Source	Degree of freedom	Mean square	F-value	P-value
Comb design (A)	2	6.267	428.076	0.000
Grain moisture (B)	2	1.270	86.726	0.000
Peripheral speed of rotor (C)	2	3.483	237.906	0.000
A*B*C	8	0.038	2.601	0.018
Error	54	0.015		
Corrected Total	80			

Significance at 5%

The ANOVA results in Table 3 explain that each parameter of comb design, grain moisture, the peripheral speed of the rotor, and the interaction of these three parameters have a P-value below 0.05. The interaction among these three variables can produce complex and unexpected effects. While each variable has a significant influence on the parameter of grain losses, the combination of comb design, grain moisture content, and peripheral speed of the rotor can significantly affect the parameter of grain losses. For example, at a certain grain moisture content, the type of comb design used may be more or less effective, depending on the peripheral speed of the rotor applied [19]. Factors such as the shape of the comb design can interact with the characteristics of grain moisture content and peripheral speed of the rotor to influence the extent to which grains can be harvested without experiencing losses [20]. In other words, these interactions can create optimal or suboptimal conditions that affect the level of grain losses.

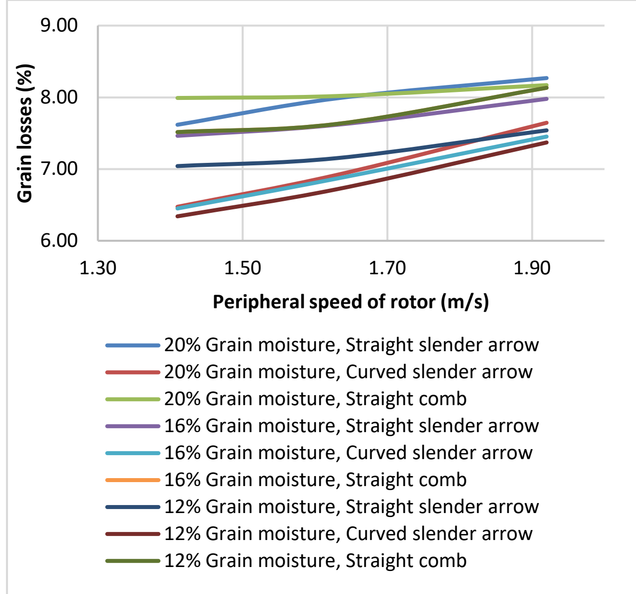


Figure 5 Effect of peripheral speed of rotor on grain losses with diferent grain moisture and comb design type

The optimal result for the lowest grain losses, 6.34%, is obtained with the curved slender arrow-type stripper element working on rice plants with a grain moisture level of 12% and a peripheral speed of the rotor of 1.41 m/s (54 rpm). At grain moisture levels of 14% and 20%, the curved slender arrow-type stripper element also produces optimal grain losses among other types of comb design, with results of 6.87% at a grain moisture level of 14% and a peripheral speed of the rotor of 1.63 m/s (62 rpm), as well as 6.92% at a grain moisture level of 20% and a peripheral speed of the rotor of 1.92 m/s (73 rpm). The results of the analysis of grain loss parameters can be seen in Figure 5.

The study of grain loss parameters differs from previous research [21], where the results of the earlier studies explained that grain losses decreased with an increase in the peripheral speed of the rotor. In contrast, this research produces an increase in grain losses with an increase in the peripheral speed of the rotor. The high grain losses observed in this study are attributed to factors that contribute to grain losses, such as unstripped grain, shattered grain, and scattered grain, which increase with the rise in the peripheral speed of the rotor.

The cleanliness parameter in this study is calculated based on the percentage of the net weight to the gross weight of the seeds after the stripping process. The net weight of the seeds is obtained by weighing the seeds after the sieving process, resulting in seeds without any impurities such as leaves, panicles, and stems that may be carried along after the stripping process [8]. Meanwhile, the gross weight is obtained by direct weighing (without sieving) of the collected seeds along with impurities such as leaves, panicles, and stems that are carried into the collection box of the harvesting unit after the stripping process [24]. Observations on cleanliness also show a significant effect based on the parameters of comb design, grain moisture, and peripheral speed of the rotor individually. Still, based on the interaction of these three parameters, it does not have a significant effect.

Table 4 Analysis of variance for combine effect of comb design, grain moisture and peripheral speed of rotor on cleanliness

Source	Degree of freedom	Mean square	F-Value	P-value
Comb design (A)	2	478.484	240.054	0.000
Grain moisture (B)	2	246.303	123.569	0.000
Peripheral speed of rotor (C)	2	336.252	168.696	0.000
A*B*C	8	1.384	0.694	0.695
Error	54	1.993		
Corrected Total	80			

Significance at 5%

The ANOVA results in Table 4 explain that each parameter of comb design, grain moisture, and peripheral speed of the rotor has a P-value below 0.05. Still, the interaction of these three parameters has a P-value above 0.05. The non-significant results in the interaction of the combination of the three variables—comb design, grain moisture content, and peripheral speed of the rotor—may be related to the nature of the cleanliness parameter itself. While each variable can individually affect the cleanliness level, the interaction among the three variables may not produce a sufficiently large effect to significantly impact the cleanliness parameter. For example, the comb design used may already be effective within the range of grain moisture content and peripheral speed of the rotor tested, meaning that changes in one variable do not result in significant additional impacts on cleanliness [24]. In other words, even though each factor has a significant influence on the cleanliness parameter, the combination of these three variables does not create a strong enough interaction to demonstrate a significant change in cleanliness.

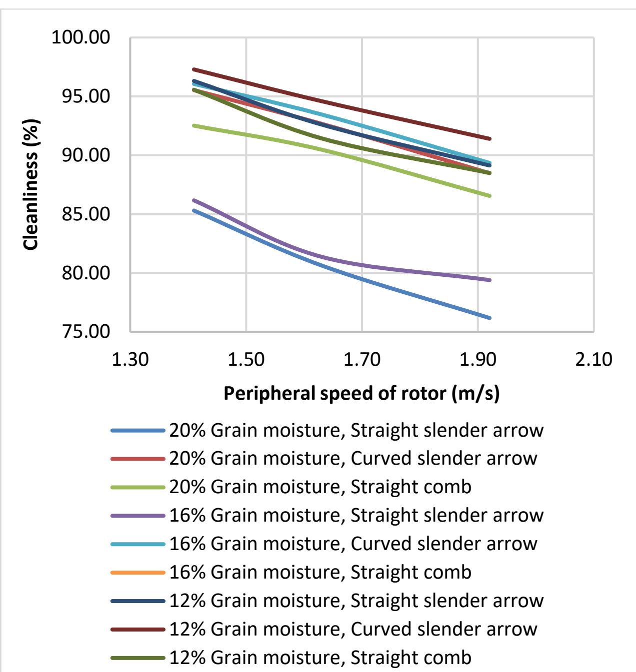


Figure 6 Analysis of variance for combine effect of comb design, grain moisture and peripheral speed of rotor on cleanliness

Additionally, the optimal conditions in the cleaning system may have already been achieved within the range of testing, so the interaction between the variables does not generate enough variation to significantly affect cleanliness results. Therefore, while each variable can make a significant individual contribution, their interactions do not yield the same changes in the cleanliness parameter.

The optimal result for the highest cleanliness, 97.29%, is obtained with the curved slender arrow-type stripper element working on rice plants with a grain moisture level of 12% and a peripheral speed of the rotor of 1.41 m/s (54 rpm). At grain moisture levels of 14% and 20%, the curved slender arrow-type stripper element also produces optimal cleanliness among other types of comb design, with results of 96.06 % at a grain moisture level of 14% and a peripheral speed of the rotor of 1.63 m/s (62 rpm), as well as 95.53% at a grain moisture level of 20% and a peripheral speed of the rotor of 1.92 m/s (73 rpm). The results of the analysis of cleanliness parameters can be seen in Figure 6.

3.2 Effect Of Striper Elements Design

The testing of three types of comb design (straight slender arrow, curved slender arrow, and straight comb) at each level of grain moisture and peripheral speed of the rotor resulted in the optimal lowest grain losses parameter for the curved slender arrow-type stripper element, with a mean value of 6.914%. The grain losses parameter generated by the curved slender arrow-type stripper element has the lowest result compared to the other two types of comb design. The grain losses for the two different kinds of comb design types, straight slender arrow, and straight comb, are 7.630% and 7.831%, respectively. Despite the similarity in the slender arrow-type comb design, a slight modification in the design, such as creating a curved slender arrow-type stripper element, can significantly influence the grain loss results. The curvature in the slender arrow type has the impact of reducing the scattered grain factor that occurs during the stripping process in this study.

Table 5 Effect of comb design on mean of grain losses

Treatment	Comb design		
	Straight slender arrow	Curved slender arrow	Straight comb
Grain losses (%)	7.630	6.914	7.831

Std. Error ± 0.023

The curved slender arrow-type stripper element in this study also produces the best mean cleanliness level, reaching 93.206%, when compared to the other two types of comb design, namely straight slender arrow with 85.241% and straight comb with 91.589%. The curvature effect on the slender arrow type of stripper element yields better grain-stripping results. This is evidenced by the collected results after the stripping process in the grain collection box of the harvesting unit, where the obtained grains have fewer impurities such as leaves, panicles, and stems that were cut by this stripper element unit. The stripper element with a straight comb type provides better grain-stripping results compared to the straight slender arrow type. The grain-stripping results by the straight comb type of stripper element minimize panicle and stem impurities, although there is still a significant amount of leaf impurities.

Table 6 Effect of comb design on mean of cleanliness

Treatment	Comb design		
	Straight slender arrow	Curved slender arrow	Straight comb
Cleanliness (%)	85.241	93.206	91.589

Std. Error ± 0.272

3.3 Effect Of Grain Moisture

Applying different levels of grain moisture treatment to test each type of stripper element with various levels of peripheral speed of the rotor resulted in the lowest mean grain losses at a grain moisture level of 12%. The grain losses at a grain moisture level of 12% were 7.242%, which is lower compared to the other two-grain moisture levels, precisely 7.456% at a grain moisture level of 16% and 7.676% at a grain moisture level of 20%. In this study, grain losses at a moisture level of 12% were dominated by the shattered grain factor, while the unstripped grain factor dominated grain losses at moisture levels of 20% and 16%. These results are similar to previous research which stated that higher grain moisture content can cause increased grain losses [25][26].

Table 7 Effect of peripheral speed of rotor on mean of grain losses

Treatment	Grain moisture		
	20%	16%	12%
Grain losses (%)	7.676	7.456	7.242

Std. Error ± 0.272

The effect of grain moisture also had a differential impact on the cleanliness parameter. The research results explain that a grain moisture level of 12% provides the best mean cleanliness result, reaching 93.399%. This result differs from the cleanliness at a grain moisture level of 20%, which is 87.598%, and a grain moisture level of 16%, which is 89.039%. As in previous research that explained the significant impact of moisture content on the cutting results of rice plant straw, it is evident in this study that lower moisture content has an additional effect on the strength of rice plant straw, especially rice stalk and rice leaf [23]. Rice plant straw at moisture levels above 12% in this study appears more brittle and prone to breakage compared to rice plant straw at a moisture level of 12%. Rice plant straw at a moisture level of 12% is more elastic and sufficiently resistant to cutting. This aligns with previous research results [9] that investigated the damage to rice stalks during the threshing process.

Table 8 Effect of grain moisture on mean of cleanliness

Treatment	Grain moisture		
	20%	16%	12%
Cleanliness (%)	87.598	89.039	93.399

Std. Error ± 0.272

3.4. Effect of peripheral speed of rotor

The effect of the peripheral speed of the rotor treatment on the grain loss parameter for each type of stripper element and grain moisture level in this study is clearly visible in Figure 5. The impact of the low peripheral speed of the rotor at 1.41 m/s (54 rpm) resulted in lower grain losses compared to higher peripheral speeds such as 1.63 m/s (62 rpm) and 1.92 m/s (73 rpm). The mean grain losses at a peripheral speed of the rotor of 1.41 m/s are 7.139%, while at a peripheral speed of 1.92 m/s, it is 7.847%, and at a peripheral speed of 1.63 m/s, it is 7.389%. These results explain that grain losses increase with an increase in the peripheral speed of the rotor. Previous research. [20] demonstrated that grain losses also increased from a rotor rotation speed of 850 rpm, resulting in 1.7% grain losses, which increased to 2.1% at a rotor rotation speed of 950 rpm.

Table 9 Effect of grain moisture on mean of grain losses

Treatment	Peripheral speed of rotor		
	1.92 m/s	1.63 m/s	1.41 m/s
Grain losses (%)	7.847	7.389	7.139

Std. Error ± 0.023

The effect of differences in the peripheral speed of the rotor also impacts the cleanliness parameter. The highest mean cleanliness of 93.556% was achieved at a rotor peripheral speed of 1.41 m/s, while a mean cleanliness level of 89.981% was obtained at a speed of 1.62 m/s. The lowest mean cleanliness of 86.499% was recorded at a rotor speed of 1.92 m/s. This indicates that as the peripheral speed of the rotor increases, the cleanliness level decreases. Previous research explains that higher rotor rotation speeds in the stripper machine can lead to a reduction in cleanliness

Table 10 Effect of grain moisture on mean of cleanliness

Treatment	Peripheral speed of rotor		
	1.92 m/s	1.63 m/s	1.41 m/s
Cleanliness (%)	86.499	89.981	93.556

Std. Error ± 0.023

4.0 CONCLUSION

The design of the stripper element for the stripper harvester can be tested on the developed laboratory apparatus using various treatments of comb design, peripheral speed of the rotor, and grain moisture. The optimal testing results, with the lowest observed grain loss parameter at 6.34% and the cleanliness parameter at 97.29%, were obtained from the stripper element with the curved slender arrow-type. The optimal testing results for the stripper element with the curved slender arrow type were achieved at a grain moisture level of 12% and a peripheral speed of the rotor of 1.41 m/s (54 rpm). As a recommendation for future research, it is essential to conduct field trials to test the optimal comb design and rotor speed under real conditions, as well as comparative studies on the performance of the curved comb design versus traditional designs in various regions of Indonesia.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Gerland, P. 2023. What's Beneath the Future: World Population Prospects. *Semaine Data-SHS*.

[2] Sutardi, Apriyana, Y., Rejekiningrum, P., Alifia, A. D., Ramadhani, F., Darwis, V., Setyowati, N., Setyono, D. E. D., Gunawan, & Malik, A. 2022. The transformation of rice crop technology in indonesia: Innovation and sustainable food security. *Agronomy*, *13*(1): 1.

[3] Anshori, A., Riyanto, D., & Widodo, S. 2021. The increase of rice cropping index supported by river dam irrigation in dry land. *IOP Conference Series: Earth and Environmental Science*, *653*(1): 12074.

[4] Ridwan, R., Effendi, N., Tanjung, F., & Asmawi, A. 2019. The Success and Failure of New Rice Fieldprint Program in Mentawai Island Regency. *International Journal on Advanced Science, Engineering and Information Technology*, *9*(6): 2055.

[5] Reynalda, T. H., & Shofwan, S. 2019. The Determinant of Farming Land Conversion into Non-Farming Land for Urbanization Development: A case of Malang regency, East Java. *1st International Conference on Economics, Business, Entrepreneurship, and Finance (ICEBEF 2018),* 703–707.

[6] Falatehan, A. F., Syaukat, Y., Hastuti, H., & Nasrullah, N. 2021. Paddy Loss and Its Implication to Fertilizer Subsidy in Indonesia. HAYATI Journal of Biosciences, 28(1): 73.

[7] Connor, M., Gummert, M., & Singleton, G. R. 2023. *Closing Rice Yield Gaps in Asia: Innovations, Scaling, and Policies for Environmentally Sustainable Lowland Rice Production*. Springer Nature.

[8] Hasan, M. K., Ali, M. R., Saha, C. K., & Alam, M. M. 2020. Sustainable Paddy Harvesting Solution for the Southern Delta of Bangladesh. 2020 *ASABE Annual International Virtual Meeting,* 1.

[9] Tang, Z., Zhang, B., Wang, B., Wang, M., Chen, H., & Li, Y. 2021. Breaking paths of rice stalks during threshing. *Biosystems Engineering*, 204: 346–357.

[10] Wang, J., Xu, C., Tian, L., Wang, J., & Tang, H. 2022. Study on the throwing mechanism and loss characteristics of three-dimensional disturbance comb. *Computers and Electronics in Agriculture,* 201, 107283.

[11] Kumari, S., Singh, K. P., & Nath, S. 2020. Design and development of multi-crop thresher for North-Western Himalayas.*Pantnagar Journal of Research*. 18(1): 46-52

[12] Yamin, M., Hamid, S., Ali, M. A., Bashir, S., Iqbal, M., & Ashraf, M. (2022). Performance optimization and knife dynamics of power tiller operated reaper during wheat harvesting. *Pakistan Journal of Agricultural Sciences*, 59(2).

[13] Tang, H., Xu, C., Zhao, J., & Wang, J. 2023. Formation and steady state characteristics of flow field effect in the header of a stripping prior to cutting combine harvester with CFD. C*omputers and Electronics in Agriculture*, 211: 107959.

[14] Rudoy, D., Egyan, M., Kulikova, N., & Chigvintsev, V. 2021. Review and analysis of technologies for harvesting perennial grain crops. *IOP Conference Series: Earth and Environmental Science,* 937(2): 22112.

[15] Tang, Z., Li, Y., Li, X., & Xu, T. 2019. Structural damage modes for rice stalks undergoing threshing. *Biosystems Engineering,* 186: 323–336.

[16] Bhanage, G. B., Shahare, P. U., Aware, V. V, Dhande, K. G., & Deshmukh, P. S. 2016. Laboratory testing of paddy stripping header mechanism. *Agriculture Update*, 11(2): 139–144.

[17] Fu, J., Ji, C., Liu, H., Wang, W., Zhang, G., Gao, Y., Zhou, Y., & Abdeen, M. A. 2022. Research progress and prospect of mechanized harvesting technology in the first season of ratoon rice. *Agriculture,* 12(5): 620.

[18] Liana, T., Susilawati, S., Lion, E., & Toni, H. 2023. Farmer's Preferences of Source Seed New Superior Varieties Character for Rice Seed Production. *BIO Web of Conferences,* 69: 4005.

[19] Hussain, A., Iqbal, A., Khan, Z. H., & Shah, F. 2020. Introductory Chapter: Recent advances in grain crops research*. Recent Advances in Grain Crops Research*, 1.

[20] Mahapatra, A. K., & Lan, Y. 2020. Structure, Composition, and Harvesting of Grains and Pulses. In *Handbook of Food Preservation.* 61–78. CRC Press.

[21] Liang, Z., & Wada, M. E. 2023. Development of cleaning systems for combine harvesters: A review. *Biosystems Engineering,* 236: 79–102.

[22] Zatmika, A., Mandang, T., Hermawan, W., Subrata, I. D. M., & Sutejo, A. 2023. Analisa Pengaruh Posisi Biji pada Malai Terhadap Gaya Perontokan Beberapa Varietas Padi. *Jurnal Ilmiah Rekayasa Pertanian Dan Biosistem*, 11(2): 292–302.

[23] Permana, I., Suryaman, M., Amilin, A., Zumani, D., & Mustofa, R. F. 2024. Application of Certified Superior Rice Seed Technology to Increase Organic Rice Production Farmer group in Cipatujah sub-district. *Jurnal Biologi Tropis,* 24(2): 17–25.

[24] Müller, A., Nunes, M. T., Maldaner, V., Coradi, P. C., de Moraes, R. S., Martens, S., Leal, A. F., Pereira, V. F., & Marin, C. K. 2022. Rice drying, storage and processing: effects of post-harvest operations on grain quality. *Rice Science*, *29*(1): 16–30.

[25] Chen, S., Ding, H., Tang, Z., Zhao, Y., Ding, Z., & Su, Z. 2022. Fluid Movement Law and Influencing Factors of Shredding on Rice Straw Briquetting Machines. *Agronomy, 12*(6): 1439.

[26] Riadi, M., Jayadi, M., Saragih, A. A., & Najamuddin, E. 2023. Response of vegetative phase growth of very early maturing rice plant to the application of liquid biosilica in paddy field. *IOP Conference Series: Earth and Environmental Science,* 1230(1): 12215.