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RESEARCH ARTICLE

Design and performance evaluation of peg-tooth and rasp bar threshing units for Adlai (*Coix lacryma-jobi*)

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Abstract – Adlai (*Coix lacryma-jobi*) is a nutritionally valuable grain cultivated in parts of Mindanao, Philippines; however, its threshing process remains limited by the lack of crop-specific equipment. Farmers usually depend on paddy threshers that are designed for the physical features of paddy, not Adlai, and this may lead to a drop in threshing efficiency, low output capacity, and poor grain quality. This study aimed to design, fabricate, and evaluate two threshing cylinder configurations for Adlai: peg-tooth and rasp bar. The apparatus was operated in a 2×2×2 factorial experiment with 2 cylinder configurations, 2 feed rates of 30 and 60 kg/h, and 2 cylinder speeds of 750 and 1125 rpm with 6 replicates for each treatment combination. Performance was evaluated based on threshing efficiency, capacity, and grain damage. Results showed that the peg-tooth configuration generally produced higher threshing efficiency and threshing capacity than the rasp bar configuration under the tested conditions. The highest mean threshing capacity was obtained using the peg-tooth cylinder at 1125 rpm and 60 kg/h, with 91.20% threshing efficiency and 43.60 kg/h capacity. The highest average threshing efficiency of 94.26% was obtained using the peg-tooth cylinder at 1125 rpm and 30 kg/h. Generally, mean grain damage levels remained under 5% for all the mixes of treatments. Nevertheless, the performance variations noticed should be considered as the joint impact of cylinder configuration and clearance setting.

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1. Introduction

In 2010, the Philippine Bureau of Agricultural Research initiated studies on Adlai (*Coix lacryma-jobi* L.) as a possible alternative staple to rice and maize because of its good nutritional properties, such as relatively low glycaemic index and higher protein, fibre, and mineral content [1]-[2]. The development of Adlai-based products, such as cereals, gourmet food items, and herbal coffee mixes, has shown the crop's potential for food security and value-added processing [1], [3]. However, while interest in Adlai as a food crop has grown, the development of tailored machinery for its processing has remained limited. Threshing is one of the most important post-harvest operations, as it directly affects grain recovery, grain quality, processing time, and labour requirements. Reports on mechanical threshers for common cereals, such as rice and maize, have indicated threshing efficiencies of approximately 95%–99%, grain losses in the range of 1%–5%, and grain damage of approximately 2%–10% depending on the design of the machine and operating conditions [4]-[10]. However, these efficiencies are achieved primarily when the thresher is used on the crop for which it was designed. If the machine is used for another crop, the performance may decrease due to differences in grain size, husk attachment, hardness, moisture content, and threshing behaviour [5], [11]-[12]. Adlai has physical and mechanical properties that are different from those of rice and maize. It has relatively hard grains and is more firmly attached to the husk. It requires sufficient impact or rubbing action to separate the grain from the panicle [2], [13]. At the same time, the grains may crack, break, or crush as a result of excessive impact or friction. Under these conditions, the threshing of Adlai is more sensitive to the type of cylinder mechanism, cylinder speed, feed rate, and clearance setting. Hence, the thresher for Adlai should not be an adaptation of the traditional ones designed for other crops without performance evaluation. Among the commonly used threshing mechanisms, the peg-tooth cylinder mainly applies an impact force to detach grains from the crop material. It is widely used because of its simple construction, relatively low fabrication cost, and effectiveness in crops where stronger impact action is needed [4]-[5], [14]-[16]. Previous studies have shown that peg-tooth or spike-tooth mechanisms can perform effectively in crops such as soybean, cowpea, and sorghum, particularly when the grains require greater detaching force [14], [16]-[21]. On the other hand, the rasp bar cylinder works mainly through rubbing action. This mechanism may reduce direct impact on the grain and may help minimise grain damage, although it can also result in lower threshing efficiency when the grain attachment is relatively strong [5], [8], [22]-[23].

Several studies have emphasised that threshing performance is influenced by design and operating parameters, such as cylinder speed, spike construction, and feed rate [20], [22], [24]-[26]. One of the benefits of increasing the cylinder speed is that it can enhance threshing efficiency and capacity, as the crop experiences a greater impact or rubbing action. However, higher speed may also increase grain damage if the applied force becomes excessive [8], [25]. This trade-off shows that threshing performance is crop-specific and must be optimised based on the crop's physical and mechanical properties. Although threshing machines are available for major crops, limited engineering data are available on the threshing behaviour of Adlai. In particular, there is still a lack of systematic evaluation comparing different threshing cylinder configurations for this crop. This gap is important because the direct use of conventional paddy or maize threshers may not provide the best balance between threshing efficiency, output capacity, and grain quality for Adlai. Moreover, without a crop-specific performance evaluation, it is difficult to identify which threshing configuration is more suitable

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for future design improvements [27]. This study aimed to design, fabricate, and evaluate two threshing cylinder configurations for Adlai, namely a peg-tooth and a rasp bar. The fabricated threshing units were tested under controlled operating conditions using two feed rates and two cylinder speeds. The performance was evaluated as threshing efficiency, capacity, and grain damage. The two configurations used different concave clearance settings; therefore, performance differences were interpreted as the combined effect of cylinder configuration and clearance setting rather than cylinder type.

2. Materials and Methods

2.1 Experimental Design

The experimental design used in this study is shown in Figure 1. The experiment was a 2×2×2 factorial design with three fixed factors: cylinder configuration, feed rate, and cylinder speed. Cylinder configuration had two levels: peg-tooth and rasp bar. Feed rate had two levels: 30 kg/h and 60 kg/h, while cylinder speed had two levels: 750 rpm and 1125 rpm. Each treatment combination was replicated six times, resulting in 48 experimental observations. The eight treatment combinations and their codes are listed in Table 1. The response variables were threshing efficiency, threshing capacity, and threshing damage. The factorial design was selected to determine not only the individual effects of cylinder configuration, feed rate, and speed, but also their two-way and three-way interaction effects on threshing performance. The peg-tooth and rasp bar cylinder assemblies differed not only in threshing element geometry but also in concave clearance. The peg-tooth assembly used a 10 mm concave clearance, whereas the rasp bar assembly used a 17 mm concave clearance. Therefore, the cylinder configuration in this study represents the combined effect of the threshing element type and its corresponding clearance setting. Concave clearance was not independently varied; thus, performance differences should not be attributed solely to cylinder geometry. This limitation was considered in the interpretation of the results.

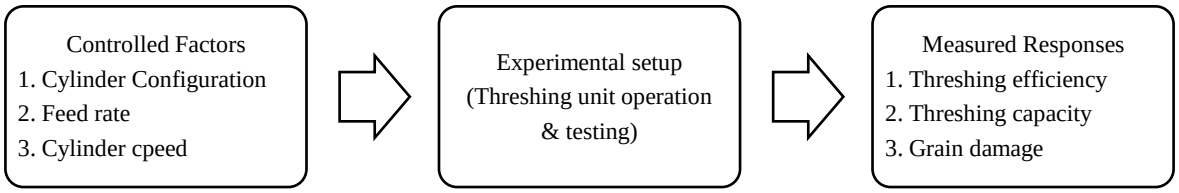


Figure 1. Experimental design of the Adlai threshing unit performance evaluation

2.2 Materials and Sources

Matured and harvested Adlai crops were acquired from the Malagos farm in Davao City, Kinabuhi Organic Food and Agriventures, Inc. The crop samples were used for the actual performance evaluation of the fabricated threshing unit. The main instruments used during testing were a digital tachometer for measuring cylinder speed, a digital weighing scale with 0.01 g precision for weighing the threshed, unthreshed, and damaged grain mass, and a stopwatch for recording the threshing time. The threshing machine was constructed from local materials that were highly rated in terms of strength, rigidity, cost, availability, and suitability for agricultural machinery. The main parts were made in accordance with the Philippine Agricultural Engineering Standards for mechanical threshers and agricultural machine elements [28].

2.3 Machine Design Procedure

2.3.1 Design considerations

The design of the Adlai threshing unit was based on the physical characteristics of Adlai grains, the desired feed rate, the chosen cylinder speed, the type of threshing mechanism, and the required machine capacity. Adlai grains are relatively small and hard, and they are approximately 4–8 mm long and 3–6 mm wide [2], [13]. These characteristics influence the required threshing action and cylinder configuration. Adlai is fairly tightly husked, and it takes considerable mechanical force to remove the grains from the ear. Excessive impact or rubbing, however, can damage the grains. Thus, we considered a pair of threshing mechanisms. The peg-tooth design primarily uses impact force, while the rasp bar design primarily uses rubbing and stripping actions [5], [8], [22]-[23]. These configurations were compared under controlled operating conditions. The cylinder speeds (750 rpm and 1125 rpm) were selected based on the operating range of the machine, the results of the preliminary trial operation, and the literature, which states that cylinder speed is a major factor influencing threshing efficiency, threshing capacity, and grain damage [4]-[5], [8], [12], [25]-[26]. A lower cylinder speed was chosen to represent a less aggressive threshing condition, and a higher cylinder speed was chosen to study the effect of increased impact or rubbing. Similarly, the feed rates of 30 kg/h and 60 kg/h were selected to represent low and moderate feeding conditions suitable for small-scale Adlai threshing operations.

2.3.2 Design of a threshing machine

The threshing machine comprised a feed chute, threshing cylinder, concave, frame, blower, discharge outlet, power transmission system, and prime mover. The effective diameter and length of the cylinder were 300 mm and 900 mm, respectively, and the ratio of the diameter to the length of the cylinder was 1:3. This ratio was selected to allow for an adequate threshing surface while maintaining a compact machine configuration, which is appropriate for small-scale operations [29]-[32]. The peripheral speed of the threshing cylinder was calculated from the relationship between the cylinder diameter, peripheral speed, and rotational speed, as expressed in Eq. (1).

$$v = \frac{\pi D_c N_c}{60} \quad (1)$$

where v is the cylinder peripheral speed, m/s; D_c is the effective cylinder diameter (m) and N_c is the cylinder rotational speed (rpm). Eq. (1) was used to estimate the threshing intensity produced by the selected cylinder speeds.

2.3.3 Force requirement

The total force required for threshing was estimated from the drum impact force and frictional resistance during the crop movement through the threshing chamber. The total force is expressed as follows: (2).

$$F_t = F_d + F_r \quad (2)$$

where F_t is the total threshing force (N); F_d is the drum impact force (N); and F_r is the frictional force (N).
The drum impact force was estimated from the crop mass flow rate and exit velocity of the threshed grain as follows:

$$F_d = Qv_e \quad (3)$$

where Q is the mass feed rate (kg/s); and v_e is the exit velocity of the threshed material (m/s).
The exit velocity of the threshed material was assumed to be proportional to the cylinder peripheral speed as follows:

$$v_e = av \quad (4)$$

where a is the velocity coefficient, dimensionless; and v is the cylinder peripheral speed (m/s). In this study, a value of $a = 0.8$ was used for the design calculation [29], [31], [32].
The frictional force was estimated as a fraction of the total threshing force:

$$F_r = fF_t \quad (5)$$

where f is the friction coefficient, dimensionless. For design estimation, the coefficient of friction was selected based on the type of threshing contact. A value of $f = 0.75$ was used for the peg-tooth configuration, while $f = 0.7$ was used for the rasp bar configuration [31], [32].
Substituting Eq. (5) into Eq. (2) yields the following intermediate expression:

$$F_t = F_d + fF_t \quad (6)$$

Eq. (6) was rearranged to isolate the total threshing force:

$$F_t = \frac{F_d}{1 - f} \quad (7)$$

Substituting the impact force expression from Eq. (3) into Eq. (7) gives:

$$F_t = \frac{Qv_e}{1 - f} \quad (8)$$

Finally, substituting the exit velocity relationship from Eq. (4) into Eq. (8) yields the design equation for estimating the total threshing force:

$$F_t = \frac{Qav}{1 - f} \quad (9)$$

Eq. (9) was used to estimate the theoretical minimum threshing force required by the threshing cylinder under selected operating conditions.

2.3.4 Power requirement

The theoretical power required by the threshing cylinder was determined from the product of the total threshing force and cylinder peripheral speed as follows:

$$P_t = F_t v \quad (10)$$

where P_t is the theoretical threshing power (W); F_t is the total threshing force (N); and v is the cylinder peripheral speed (m/s).
To account for mechanical losses, bearing friction, air resistance, transmission losses, vibration, and non-uniform crop feeding, a service factor was applied as follows:

$$P_d = S_f P_t \quad (11)$$

where P_d is the design power (W); S_f is the service factor, dimensionless. A service factor was used to ensure that the selected prime mover could accommodate operational fluctuations during threshing.

2.3.5 Sample calculation for power requirement

To demonstrate the application of the design equations, a sample calculation was performed for the peg-tooth configuration operating at a feed rate of 60 kg/h and a cylinder speed of 1125 rpm. The following values were used.

$D_c = 0.3$ m; $N_c = 1125$ rpm; $Q = 60\,\frac{\text{kg}}{\text{h}} = 0.0167$ kg/s; $a = 0.80$, $f = 0.75$

Using Eq. (1), the cylinder peripheral speed was calculated as follows:

$$v = \frac{\pi D_c N_c}{60} = \frac{\pi(0.3)(1125)}{60} = 17.67 \text{ m/s}$$

Using Eq. (4), the exit velocity of the threshed material was calculated as

$$v_e = av = 0.8(17.67) = 14.14 \text{ m/s}$$

Using Eq. (3), the drum impact force was calculated as follows:

$$F_d = Qv_e = 0.0167(14.14) = 0.236 \text{ N}$$

Using Eq. (7), the total threshing force was calculated as follows:

$$F_t = \frac{F_d}{1-f} = \frac{0.236}{1-0.75} = 0.944 \text{ N}$$

Using Eq. (10), the theoretical threshing power was calculated as follows:

$$P_t = F_t v = 0.944(17.67) = 16.68 \text{ W}$$

This is the theoretical minimum power required for crop impact and frictional resistance in the threshing cylinder. In reality, more power is required to overcome power losses due to bearing friction, belt transmission, air resistance, vibration, and uneven crop feeding. Therefore, a prime mover with a sufficient margin over the theoretical minimum power was chosen to ensure that the machine operated constantly during field tests [10], [29]-[32].

2.4 Standard Operating Procedure

Before each test run, the machine was inspected to ensure that the threshing cylinder, concave, belt drive, blower, and discharge outlet were properly installed and aligned. The desired cylinder speed was set and verified using a digital tachometer. The Adlai crop sample was weighed according to the required feed rate before being introduced into the feeding chute. To operate the machine, freshly harvested Adlai was passed into the threshing chamber by the feeding chute. After passing through the threshing cylinder and concave assembly, the crop was separated into grains by either impact, rubbing, or stripping actions, which were decided by the cylinder design. Grains and small crop pieces that were detached came out through the concave gaps, whereas longer stalks were blown out through the straw outlet. Finally, the collected threshed grains from the grain outlet were weighed and assessed. The threshed grain mass, unthreshed grain mass, damaged grain mass, and threshing time were recorded for each trial. The same procedure was repeated for all treatment combinations.

2.5 Machine Performance Evaluation

The performance of the Adlai threshing unit was evaluated using threshing efficiency, threshing capacity, and grain damage.

2.5.1 Threshing efficiency

Threshing efficiency was calculated as the ratio of the threshed grain mass to the total grain mass entering the thresher:

$$\eta_t = \frac{m_t}{m_t + m_u} \times 100\% \tag{12}$$

where η_t is the threshing efficiency (%); m_t is the mass of threshed grain (kg); and m_u is the mass of unthreshed grain (kg).

2.5.2 Threshing capacity

Threshing capacity was calculated as the mass of threshed grain produced per unit of time:

$$C_t = \frac{m_t}{t} \times 3600 \tag{13}$$

where C_t is the threshing capacity (kg/h); m_t is the mass of threshed grain (kg); and t is the threshing time (s). The factor 3600 was used to convert seconds to hours.

2.5.3 Grain damage

Damaged grains were determined based on their weight using a classification technique. After each trial, the threshed grain sample was examined, and the damaged grains were sorted manually. Damaged grains consisted of grains that were

obviously cracked, broken, crushed, or reduced to less than approximately three-fourths of their original size. The separated damaged grains were weighed on a digital scale of 0.01 g accuracy. Grain damage was calculated as:

$$D = \frac{m_d}{m_t} \times 100\% \tag{14}$$

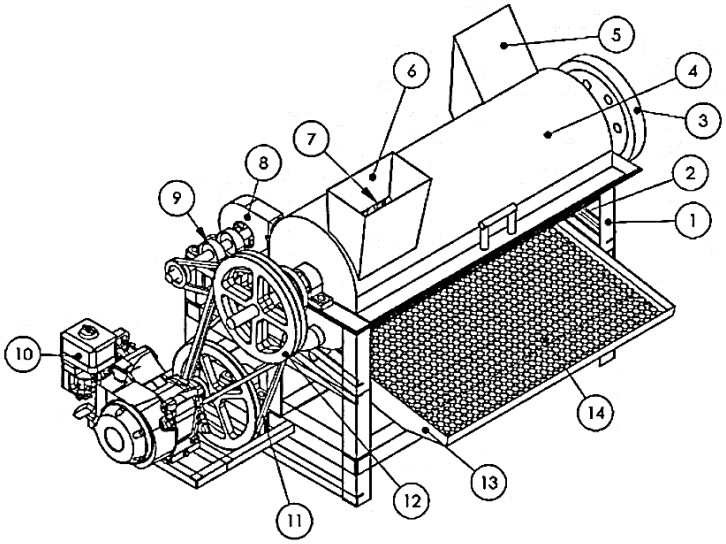
where D is the grain damage (%); m_d is the mass of damaged grain (kg); and m_t is the mass of threshed grain (kg).

This method provides a quantitative weight-based measure of grain damage rather than relying only on visual observation. Visual classification was used only to identify damaged grains, while the final damage percentage was based on the measured grain mass.

3. Results and Discussion

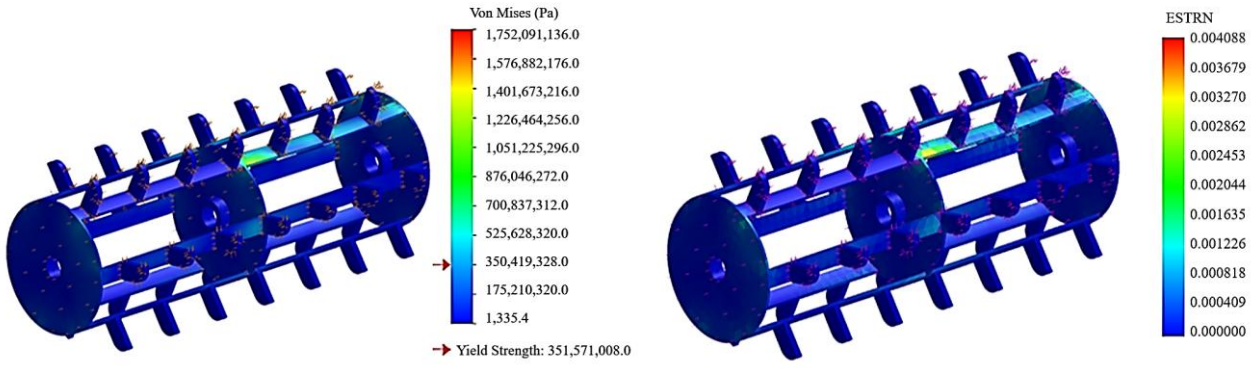
3.1 Machine Design and Simulation Results

The main components of the fabricated Adlai threshing machine are shown in Figure 2. The labelled two-dimensional wireframe provided an overview of the arrangement of these components and served as a guide during fabrication. Static structural simulations were conducted using SolidWorks to examine the stress and strain responses of the peg-tooth and rasp bar cylinder assemblies under the assumed loading conditions. The purpose of the simulation was to provide preliminary structural verification of the threshing cylinder assemblies before actual fabrication and testing. The analysis considered the material properties of mild steel, with a yield strength of 351.5 MPa. The applied load represented the expected crop load acting on the cylinder during the threshing operation. The simulation of the peg-tooth cylinder (Figure 3) revealed that the generated stress was below the yield strength of the chosen material, indicating that the cylinder was capable of handling the assumed static load condition. There was a slight stress concentration locally near the midpoint of the cylinder, which seems to be related to the crop load distribution and the shaft support condition. The developed strain results indicated very little deformation, with a strain of only 0.002862 mm/mm. Therefore, the peg-tooth layout was quite stiff for the given static load.



No.	*Description*
1	Frame
2	Concave
3	Flywheel
4	Cylinder Cover
5	Exhaust Cylinder
6	Feeding Chute
7	Threshing Cylinder
8	Blower
9	Pillow Block/ Bearings
10	Prime Mover
11	V-belts
12	Pulleys
13	Reciprocating Sieve
14	Perforated Metal for Sieving

Figure 2. Two-dimensional wireframe drawing of the Adlai threshing machine

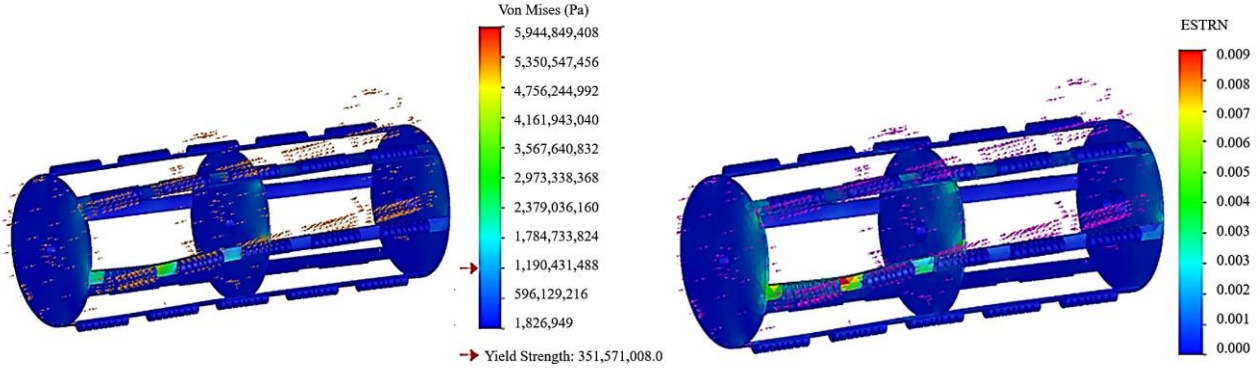


(a) (b)

Figure 3. Static stress (a) and strain (b) simulation results of the peg-tooth cylinder

The rasp bar cylinder (Figure 4) also showed stress values below the yield strength of mild steel. However, compared with the peg-tooth configuration, the rasp bar assembly exhibited a greater tendency to deform under the same assumed

loading condition. This behaviour may be attributed to the difference in geometry and load distribution between the two cylinder assemblies. Because the rasp bar elements are arranged differently from the peg-tooth elements, the cylinder may experience a different stress distribution under crop resistance during operation.

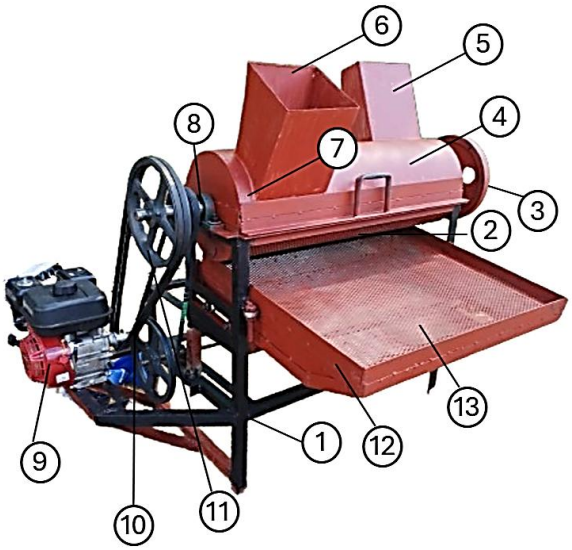


(a) (b)

Figure 4. Static stress (a) and strain (b) simulation results of the rasp bar cylinder

3.2 Machine Fabrication

The fabricated Adlai threshing machine is illustrated in Figure 5. The frame was made of mild-steel members to provide rigidity and stability during operation. Most structural components were welded to prevent loosening due to vibration during threshing. The threshing cylinders were mounted on the shaft using a hub-and-key arrangement to ensure proper alignment and power transmission. A 5.6 kW (7.5 hp) gasoline engine was used as the prime mover, and power was transmitted to the threshing cylinder through a V belt and pulley system. The operating speed was adjusted within the range of 750–1125 rpm.



No.	*Description*
1	Frame
2	Concave
3	Flywheel
4	Cylinder Cover
5	Exhaust Cylinder
6	Feeding Chute
7	Threshing Cylinder
8	Pillow Block/ Bearings
9	Prime Mover
10	V-belts
11	Pulleys
12	Reciprocating Sieve
13	Perforated Metal for Sieving

Figure 5. Fabricated Adlai threshing machine

Table 1. Treatment combination reference

Treatment Code	Cylinder Configuration	Feed rate (kg/h)	Cylinder speed (rpm)
P-60-750	Peg-tooth	60	750
P-60-1125	Peg-tooth	60	1125
P-30-750	Peg-tooth	30	750
P-30-1125	Peg-tooth	30	1125
R-60-750	Rasp bar	60	750
R-60-1125	Rasp bar	60	1125
R-30-750	Rasp bar	30	750
R-30-1125	Rasp bar	30	1125

3.3 Performance Evaluation of the Threshing Cylinders

The performance of the two-cylinder configurations was evaluated using two feed rates and two cylinder speeds. The study followed a 2×2×2 factorial design, with cylinder configuration, feed rate, and cylinder speed as controlled factors. Each treatment combination was replicated six times. The response variables were threshing efficiency, threshing capacity, and grain damage. Significantly, the peg-tooth and rasp bar setups were also operating at different concave clearances, which is a factor that cannot be overlooked. A 10 mm clearance was used for the peg-tooth assembly, whereas a 17 mm clearance was used for the rasp bar assembly. Hence, the cylinder configuration in this study is simply a shorthand for the combined effect of a cylinder element's geometry and its clearance setting. Because the concave clearance was not varied as a separate factor, the observed performance differences should not be attributed solely to the cylinder type. Presented in Table 2 are the mean values for all groups regarding threshing efficiency, capacity, and damage. It was observed that peg-tooth groups exhibited higher threshing efficiencies and capacities compared with rasp bar groups under varying operating conditions. Nevertheless, both cylinders maintained threshing damage below 5% across various operating conditions.

Table 2. Mean values for the response variables

Treatment Code	Mean Values		
	Threshing Efficiency (%)	Threshing Capacity (kg/h)	Threshing Damage (%)
P-60-750	72.57 ± 0.74	33.91 ± 1.48	2.581 ± 0.26
P-60-1125	91.20 ± 1.54	43.60 ± 2.87	4.435 ± 0.57
P-30-750	80.05 ± 2.17	21.73 ± 1.09	2.280 ± 0.45
P-30-1125	94.26 ± 2.54	27.43 ± 1.11	2.665 ± 0.74
R-60-750	63.62 ± 2.22	19.78 ± 1.39	1.654 ± 0.38
R-60-1125	72.30 ± 1.88	27.09 ± 2.04	2.289 ± 0.58
R-30-750	73.10 ± 2.55	16.79 ± 1.04	1.626 ± 0.73
R-30-1125	76.82 ± 3.66	22.46 ± 1.38	2.263 ± 0.43

Note: Values are presented as mean ± standard deviation with n = 6

Table 3. Factorial ANOVA results for threshing efficiency, threshing capacity, and threshing damage

Response Variables	Source of Variation	Sum of Squares	df	F-value	p-value	Interpretation
Threshing Efficiency (%)	Cylinder Configuration	2046.894	1	387.578	<0.001	Significant
	Feed Rate	451.843	1	85.556	<0.001	Significant
	Speed	1535.559	1	290.757	<0.001	Significant
	Cylinder Configuration × Feed rate	9.057	1	1.715	0.198	Not Significant
	Cylinder Configuration × Speed	313.601	1	59.380	<0.001	Significant
	Feed rate × Speed	66.012	1	12.499	<0.001	Significant
	Cylinder Configuration × Feed Rate × Speed	0.217	1	0.041	0.840	Not Significant
	Error	211.250	40	-	-	-
Threshing Capacity (kg/h)	Cylinder Configuration	1234.139	1	450.712	<0.001	Significant
	Feed Rate	970.083	1	354.551	<0.001	Significant
	Speed	603.572	1	220.427	<0.001	Significant
	Cylinder Configuration × Feed rate	322.248	1	117.686	<0.001	Significant
	Cylinder Configuration × Speed	4.410	1	1.611	0.212	Not Significant
	Feed rate × Speed	23.674	1	8.646	0.005	Significant
	Cylinder Configuration × Feed Rate × Speed	4.160	1	1.519	0.225	Not Significant
	Error	109.528	40	-	-	-
Threshing Damage (%)	Cylinder Configuration	12.786	1	43.884	<0.001	Significant
	Feed Rate	3.387	1	11.623	<0.001	Significant
	Speed	9.245	1	31.731	<0.001	Significant
	Cylinder Configuration × Feed rate	3.052	1	10.475	0.002	Significant
	Cylinder Configuration × Speed	0.703	1	2.412	0.128	Not Significant
	Feed rate × Speed	1.613	1	5.537	0.024	Significant
	Cylinder Configuration × Feed Rate × Speed	1.620	1	5.560	0.023	Significant
	Error	11.655	40	-	-	-

3.4 Effect on Threshing Efficiency

The peg-tooth configuration operating at 30 kg/h and 1125 rpm yielded the highest mean threshing efficiency (94.26 %), whereas the rasp bar configuration achieved only 76.82% under the same conditions. Factorial ANOVA (Table 3) showed

that cylinder configuration, feed rate, and speed had a significant effect on threshing efficiency. An increase in speed led to an improvement in efficiency because it increased the impact or rubbing action applied to the crop. The peg-tooth configuration showed a higher response at higher speeds, probably because of its impact feature, which was more effective for Adlai grains with a stronger husk attachment. Usually, a 30 kg/h feed rate resulted in higher efficiency than a 60 kg/h feed rate because the lower feed rate allowed for better contact between the crop and the threshing elements [4]-[5], [8], [12], [25]-[26].

3.5 Effect on Threshing Capacity

The highest mean threshing capacity was recorded for the peg-tooth configuration at 60 kg/h and 1125 rpm, at 43.60 kg/h. Threshing capacity was significantly influenced by cylinder configuration, feed rate and speed. Capacity has a direct relationship with the amount of crop material entering the threshing chamber per unit of time, which was increased using a higher feed rate, and speed provided better grain detachment and therefore material flow into the threshing tray. The higher capacity was attributed to its impact action that slashed grains quicker, causing it to produce a higher capacity than the rasp bar configuration. However, this result should be interpreted as the effect of the full cylinder assembly rather than only cylinder geometry because the two configurations had different concave clearances [5], [8], [22]-[23].

3.6 Effect on Grain Damage

The rasp bar configuration generally produced less grain damage than the peg-tooth configuration because its rubbing and stripping actions reduced the direct impact on the grains. The highest mean grain damage was observed for the peg-tooth configuration at 60 kg/h and 1125 rpm, with 4.43%. This suggests that the higher speed and feed rate increased mechanical severity through greater grain-to-metal and grain-to-grain contact. Although mean damage remained below 5% for all treatments, the results show a trade-off: the peg-tooth configuration improved efficiency and capacity but increased damage under more aggressive conditions, while the rasp bar configuration reduced damage but produced lower efficiency and capacity [5], [7]-[8], [10], [23].

3.7 Factorial ANOVA Results

The factorial ANOVA results for the threshing efficiency, capacity, and damage are presented in Table 3. A 2×2×2 factorial ANOVA was used to identify the main and interaction effects of cylinder configuration, feed rate, and cylinder speed.

3.8 Overall Performance Interpretation

The overall threshing efficiency and capacity of the peg-tooth configuration were higher than those of the rasp bar configuration under the test conditions. This result may be associated with the peg-tooth components delivering a stronger impact action that was more effective in detaching the Adlai grains. However, this more aggressive threshing action also increased grain damage, especially under higher-speed and higher-feed-rate conditions [5], [8], [14], [23], [25]. The rasp bar configuration contributed to lower threshing efficiency and capacity but generally caused less grain damage. This suggests that the rasp bar mechanism could be less aggressive and more favourable when grain quality is preferred over output capacity. However, the lower efficiency of the Adlai threshing means that further optimisation of the rasp bar geometry, concave clearance, or speed may be needed [8], [22], [23]. The results confirm the importance of matching the threshing mechanism and operating parameters with the physical characteristics of the crop [5], [8], [11], [12], [23], [32]. For Adlai, which has a relatively firm husk attachment, sufficient impact or rubbing action is required to achieve effective separation. However, excessive mechanical action can increase damage.

4. Conclusions

This study designed, fabricated, and evaluated two threshing cylinder configurations for Adlai, namely, a peg-tooth configuration with 10 mm concave clearance and a rasp bar configuration with 17 mm concave clearance. The machine was tested using two feed rates, 30 kg/h and 60 kg/h, and two-cylinder speeds, 750 and 1125 rpm, under a 2 × 2 × 2 factorial experimental design. Based on the results, the peg-tooth configuration generally produced higher threshing efficiency and capacity than the rasp bar configuration. The highest mean threshing efficiency was obtained from the peg-tooth configuration at 30 kg/h and 1125 rpm, with a value of 94.26%. The highest mean threshing capacity was obtained from the peg-tooth configuration at 60 kg/h and 1125 rpm, with a value of 43.60 kg/h. However, this same condition also produced the highest mean grain damage of 4.43%. The rasp bar configuration produced lower threshing efficiency and capacity but generally resulted in lower grain damage. The factorial ANOVA showed that cylinder configuration, feed rate, and cylinder speed significantly affected threshing efficiency, threshing capacity, and grain damage. Several interaction effects were also significant, indicating that the performance of the machine was influenced by the combined effects of the operating parameters rather than by one factor alone.

The results show that if the goal is to at least maximise threshing efficiency and capacity, the peg-tooth arrangement would be more appropriate; however, if grain damage is a lesser concern, the rasp bar arrangement could be considered. However, because the two configurations used different concave clearances, the observed performance differences should be interpreted as the combined effect of cylinder element geometry and concave clearance. Therefore, the study did not isolate the independent effect of cylinder type alone. The study also identified limitations in the cleaning system, as fragmented leaves and stalks were observed at the grain outlet. This may have affected the accuracy of the weight-based performance measurements. Future work should improve the cleaning and separation system, measure and control crop

moisture content during testing, and independently evaluate the effects of concave clearance, cylinder speed, feed rate, and cylinder geometry. Additional dynamic, fatigue, and vibration analyses are also recommended to supplement the preliminary static simulation results.

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M. B. Espinosa: Conceptualisation; Methodology; Data curation; Writing – original draft
K. C. Lustria: Methodology; Formal analysis; Visualisation; Writing – review & revise
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C. P. Genobiagon Jr.: Conceptualisation; Supervision; Writing – review & revise

Availability of Data and Materials
The datasets generated and/or analysed in the current study are available from the corresponding author upon reasonable request.

Ethics Statement
This study did not involve human participants or animal subjects. Therefore, ethical approval was not required.

Generative Artificial Intelligence Disclosure
The authors claim that artificially intelligent-assisted technologies, such as generative AI, were not used to generate content, ideas, or theories. We have used AI to enhance readability and refine the language. This was done with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

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