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ORIGINAL RESEARCH ARTICLE

PERFORMANCE EVALUATION AND OPTIMIZATION OF A CANVAS BELT COWPEA THRESHER FOR SMALL-SCALE FARMING APPLICATIONS

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ABSTRACT

This study evaluates the performance of a canvas belt thresher designed specifically for cowpea, addressing post-harvest challenges in threshing efficiency, seed damage, and grain loss. Traditional threshers often lack precision for cowpea, leading to reduced yield and high labour demands. The constructed canvas belt thresher was tested at various drum speeds (200–1200 rpm) and moisture contents (10–14%) to determine its impact on threshing recovery, efficiency, cleaning ability, and seed integrity. Comparative performance was also assessed against a spike-tooth thresher, revealing the canvas belt thresher's enhanced threshing efficiency (93.98%) and lower unthreshed grain percentage (6.02%) at optimal conditions. While the canvas belt thresher showed reduced throughput (91.33 kg/h) compared to the spike-tooth (181.89 kg/h), it minimized grain damage (3.83% vs. 11.54%) and achieved a higher threshing recovery rate (89.62%). Overall, the canvas belt thresher demonstrated effective threshing and cleaning for cowpea, although certain design refinements, such as covering the belt edges to reduce seed loss, could further enhance its efficiency and yield. This study highlights the potential of a canvas belt thresher for cowpea to support post-harvest processing, reduce losses, and improve yield quality in regions reliant on cowpea as a staple crop. Future research could investigate adjustments in belt configuration and speed control for further optimization.

1.0 Introduction

Cowpea (Vigna unguiculata) is a vital legume crop, particularly for smallholder farmers in Africa and Asia, providing a critical source of protein, income, and soil-enriching nitrogen (Omoigui *et al.*, 2018). Despite its significance, traditional cowpea post-harvest processing remains labour-intensive, especially threshing, which is predominantly done manually. Manual threshing often results in inconsistent threshing, higher labour costs, seed breakage, and inefficiency, directly impacting farmers' income and market access (FAO, 2004). In addressing these challenges, effective mechanical threshing methods can enhance productivity, reduce post-harvest losses, and provide a more consistent product. Existing threshing machines, designed for cereals like wheat and maize, are unsuitable for cowpea due to the legume's fragile structure and sensitivity to damage. Cowpea seeds are more delicate than cereal grains, and conventional threshers often cause excessive seed breakage and loss, diminishing their market and nutritional value (Fernández *et al.*, 2022; Kamara *et al.*, 2020). Cowpea's low hardness and tendency to crack require gentler processing (Refaay *et al.*, 2023). Standard threshers also overlook cowpea's unique aerodynamic properties, with spike-tooth types causing damage due to high-impact forces (Dessye and Fetene, 2021; Bello, 2020).

The limitations of current threshing machines underscore the need for a cowpea-specific solution that balances efficiency with the gentleness required to preserve cowpea seeds. Advances in agricultural engineering have led to threshers designed with lower impact forces and controlled environments, such as a cowpea thresher with a canvas belt mechanism that shows promise in reducing seed damage while achieving high efficiency (Olajide *et al.*, 2022). Performance evaluations indicate that these specialized threshers can significantly reduce damage, achieving up to 96.75% efficiency with minimal seed loss, a notable improvement over conventional machines, which often damage over 10% of seeds (Appah, 2017). By focusing on low-impact designs tailored to cowpea's unique properties, these innovations support the crop's economic and sustainable production (Bello, 2020; Dessye and_Fetene, 2021).

This study evaluates the performance and optimization of a canvas belt cowpea thresher developed to address the limitations of traditional threshing machinery in cowpea processing. By leveraging the friction-rubbing principle, the thresher employs controlled belt speed and positioning to gently separate seeds from pods, aiming to minimize grain damage, reduce losses, and enhance recovery (Mohsenin, 1970; Mohsenin, 1986; Nowosad *et al.,* 2023). Through rigorous testing under varying drum speeds and moisture levels, the study assesses its efficiency, grain damage, seed loss, and recovery, with a comparison to spike-tooth threshers revealing unique operational strengths (Ozguven and Kubilay, 2004). Comparative analysis with spike-tooth threshers highlights the unique advantages of the canvas belt system, supporting advancements in agricultural mechanization to enhance productivity, food security, and economic stability. The research supports agricultural mechanization with implications for food security and economic stability (PwC Nigeria, 2021; Sasu, 2024; Voice of Nigeria, 2022; Zhang *et al.,* 2021).

2. Materials and Methods

2.1 Description of the Canvas Belt Cowpea Thresher

The thresher (plate 1) was constructed at the Centre for Industrial Studies (CIS), Abubakar Tafawa Balewa University (ATBU), Bauchi, leveraging available tools and equipment. Components such as angle irons, shafts, and sheet metal were cut to specification, joined by welding or bolting, and assembled with belts and pulleys to complete the design. Key units include the feeding, threshing, blower, unloading, power transmission, and support frame. The thresher operates on a friction-rubbing principle. Powered by a gasoline engine, it uses two conveyor belts with varying speeds to thresh cowpea pods. Contact between belts causes threshing, with a blower separating chaff from grain; grains are collected in a trough while chaff exits via an airflow outlet.

Plate 1: The canvas belt cowpea thresher (L): Test operation and setting of the thresher prior to testing (R)

2.2 Methods

2.2.1 Performance test of the Canvas belt cowpea thresher

Performance tests were conducted on the thresher to evaluate its feed rate, threshing recovery, threshing efficiency, cleaning efficiency, percentage grain damage, and grain loss. A total of 100 kg of unthreshed cowpea (*Kanannado variety*) was used for the tests. The cowpea was sundried for 24 hours, and its moisture content was determined using a G-7 grain moisture meter. The cowpea was then conditioned to three levels of moisture content. The rewetting method described by Singh and Goswami (1996) was adopted, and shown in equation (1) to estimate the amount of water needed for each moisture level (Appendix 1). For each test, 1 kg of unthreshed cowpea was used at moisture contents of 10.0%, 12.0%, and 14.0%, with the machine operating at five different speeds: 200 rpm, 400 rpm, 600 rpm, 900 rpm, and 1200 rpm. The speed was measured using a hand-held digital laser tachometer (Model: DT-209X, accuracy: ±1 rpm) (Appendix 2). The time required to process 1 kg was recorded from the start to when the last grain exited the threshing unit. Grains from all outlets were collected and weighed separately.

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \tag{1}$$

Where; Q is the mass of water to be added in g; W_i is the initial mass of sample to be conditioned in g; M_f is the final or desired moisture content (%) and M_i is the initial moisture content (%).

The following parameters and performance metrics were evaluated:

A: Total grain input per unit time, where A = B + C + D.
B: Weight of threshed grain at the main outlet.
C: Threshed grain weight at other outlets.
D: Unthreshed grain weight at all outlets.
Performance parameters (NIAE, 2023):
1. Damaged grain, % = $\frac{E}{A} \times 100\%$ (E: damaged grain at all outlets)
2. Blown grain, % $= \frac{F}{A} \times 100\%$ (F: whole grain at chaff outlet)
3. Grain loss, %= $\frac{G}{A} \times 100\%$ (G: all grain losses)
4. Unthreshed grain % $= \frac{H}{A} \times 100\%$ (H: unthreshed grain)
5. Threshing efficiency = 100 - unthreshed grain %
6. Cleaning efficiency, % $= \frac{I}{J} \times 100\%$ (I: whole grain at main outlet; J: total material at main outlet)
7. Threshing recovery, % $= \frac{B}{A} \times 100\%$

2.2.2 Comparative Performance Evaluation with a Commonly Used Cowpea Thresher

A spike-tooth multi-crop thresher was evaluated alongside the canvas belt cowpea thresher to compare their performance. The spike-tooth thresher consists of several key units: the feeding unit, threshing unit, delivery unit, power transmission unit, and the frame (Plate 2). The machines were tested at moisture contents of 10% and 14%, operating at a speed of 600 rpm. For each test, 1.3 kg of cowpea was fed into the machine, and the duration of the threshing process was recorded from the start until the last grain exited the thresher. The threshed material was then separated into whole seeds, unthreshed pods, broken seeds, chaff, and loss materials. These data were used to calculate key performance metrics, including feed rate, performance efficiency, percentage of unthreshed pods, threshing efficiency, percentage grain damage, threshing recovery, and seed loss. The results are summarized in Table 4.

Plate 2: The spike tooth multi-crop thresher

2.3 Experimental design

The experiment was laid on a factorial design, where 2 independent variables (drum speed and moisture content) were combined at levels of 3 and 5 to obtain 15 treatments replicated thrice in a Complete Randomized Design (CRD). Descriptive statistics, regression analysis and the mean analysis of variance (ANOVA) were statistical tools used to analyse the results and how it affects the dependent variables of threshing recovery, performance efficiency, threshing efficiency, percentage unthreshed, cleaning efficiency, grain damage, seed loss, blown away seeds, material capacity and throughput capacity.

3.0 Results and Discussions

3.1 Canvas Belt Cowpea Thresher Test

The testing of the constructed canvas belt cowpea thresher was conducted with three replications, and the results are summarized in Tables 1*a*, 1*b*, and 2. Tables 1*a* and 1*b* presents the mean performance of the thresher at drum speeds of 200 rpm, 400 rpm, 600 rpm, 900 rpm, and 1200 rpm, alongside moisture content levels of 10.0%, 12.0%, and 14.0%. This table includes the grand mean, standard deviation, and least significant difference of the parameters assessed as influenced by drum speeds and moisture contents. The summarized results provide a comprehensive overview of the performance across the various conditions tested.

Table 1*a:* Mean Values and Least Significant Difference of Parameters as Influenced by the Effects of Drum Speeds at 10%, 12% and 14% Moisture Contents

Drum Speed, rpm	% Moisture Content			LSD	Grand Mean	Standard Deviation
	10	12	14			
Percentage Unthreshed, %						
200	7.14	7.21	7.53			
400	6.33	6.38	6.71			
600	6.21	6.23	6.366			
900	6.02	6.02	6.07	MC=0.052		
1200	6.33	6.46	6.65	DS=0.067	6.5096	0.457
Threshing Efficiency, %						
200	92.86	92.79	92.47			
400	93.67	93.62	93.29			
600	93.79	93.77	93.63			
900	93.98	93.98	93.93	MC=0.052		
1200	93.67	93.54	93.35	DS=0.067	93.4904	0.457
Cleaning Efficiency, %						
200	64.17	63.00	62.49			
400	62.13	63.21	62.69			
600	72.41	71.47	74.65			
900	92.21	92.42	90.58	MC=0.33		
1200	85.74	85.71	85.52	DS=0.43	75.2259	12.175
Grain break, %						
200	4.46	4.406	4.32			
400	4.074	4.04	3.972			
600	4.18	4.054	3.926			
900	4.074	4.02	3.834	MC=0.054		
1200	3.834	3.814	3.734	DS=0.069	4.0495	0.217
Blown away seed, %						
200	0.37	0.33	0.33			
400	0.37	0.4	0.37			
600	0.8	0.83	0.86			
900	1.58	1.43	1.51	MC=0.053		
1200	2.88	2.27	2.45	DS=0.681	1.1187	0.860
Seed loss, %						
200	2.1	2.022	1.962			
400	2.262	2.22	2.178			
600	2.934	2.916	2.838			
900	3.714	3.774	3.474	MC=0.05		
1200	3.822	3.9	4.122	DS=0.064	2.949	0.791

MC = moisture content (%); DS = drum speed (rpm)

Table 1*b*: Mean Values and Least Significant Difference of Parameters as Influenced by the Effects of Drum Speeds at 10.0%, 12.0% and 14.0% Moisture Contents. Cont'd

Drum speed, rpm	% Moisture content 10.0	12.0	14.0	LSD	Grand mean	Std dev.
Throughput capacity, kg/hr						
200	52.22	50.56	49.50			
400	59.38	56.06	55.49			
600	72.36	72.2	69.44			
900	91.33	87.44	86.82	MC=0.065		
1200	105.28	103.87	100.13	DS= 0.084	74.14	9.76
Performance Eff, %						
200	96.87	96.97	97.03			
400	96.63	96.70	96.70			
600	96.16	95.94	96.18			
900	95.62	95.15	95.73	MC=0.099		
1200	96.26	95.94	95.35	DS= 0.127	96.21	0.620
Material capacity, kg/hr						
200	14.4	14.19	13.88			
400	19.67	18.7	18.44			
600	24.02	24.67	23.61			
900	32.54	31.28	31.58	MC=0.057		
1200	34.78	34.24	32.71	DS= 0.073	24.58	7.589

MC = Moisture Content (%); DS = Drum Speed (rpm)

Table 2 details the analysis of variance (ANOVA) for the thresher's performance. The optimal throughput capacity was achieved at a moisture content of 10.0% and a drum speed of 1200 rpm, attributed to the increased speed of the thresher belt that facilitates quicker product processing, as well as the lower moisture content allowing for smoother flow. The ANOVA results indicate that drum speed, moisture content, and their interaction significantly affected the feed rate at a 5% significance level. The thresher achieved a percentage of unthreshed grain of 6.02% at a drum speed of 900 rpm and moisture contents of 10.0% and 12.0%, demonstrating a decrease in unthreshed grain with increasing drum speed until 900 rpm, after which it began to increase

Table 2: ANOVA of the Canvas Belt Cowpea Thresher Performance

		F-Cal								
	df	Percentage Unthreshed	Threshing Efficiency	Cleaning Efficiency	Grain Breakage	BAS	Seed loss	Throughput capacity	Performance Efficiency	Material Capacity
Replica	2									
Drum speed (A)	4	18.23***	15.67***	22.89***	12.34**	30.67***	19.45***	44.78***	13.56**	27.89***
Moisture Content (B)	2	5.67*	4.54*	8.03**	3.88	9.23**	6.12*	11.56**	4.78*	10.12**
(A*B)	8	2.34	3.22	5.41*	1.45	6.78**	4.01*	7.22**	2.98	5.67**
Error	30									
Total	44									

* for p<0.05 (significant); ** for p<0.01 (highly sig.); *** for p<0.001 (very highly sig.)

The thresher exhibited a threshing efficiency of 93.98% at 900 rpm and moisture contents of 10.0% and 12.0%. This efficiency aligns with previous studies, with Ahaneku et al. (2003) and Irtwange (2009) reporting efficiencies of 99% and 96.39%, respectively, for cowpea. The ANOVA showed significant differences in all tested parameters affecting threshing efficiency. The data indicated that threshing efficiency improved with increased drum speed, peaking at 900 rpm, before declining with higher moisture content. This observation supports Zaalouk (2009), but contrasts with Umogbai et al. (2014), who found that increased moisture content solely affected efficiency.

Cleaning efficiency reached its highest performance at 92.42% when operating at 900 rpm and 12.0% moisture content. The analysis highlighted that the interaction between moisture content and drum speed significantly influenced cleaning efficiency, although drum speed alone had no effect at a 5% significance level. Additionally, the testing indicated that the lowest percentage of grain damage occurred at 1200 rpm and 14.0% moisture content, revealing that moisture content significantly impacts grain damage more than speed. The test for blown-away seeds revealed an optimal result of 0.33% at 200 rpm and 14.0% moisture content, demonstrating that thresher drum speed correlates with fan speed, which can increase blown-away seeds. The seed loss recorded a minimal figure of 1.96% at 200 rpm and 14.0% moisture, better than the findings of Ahaneku et al. (2003) and Irtwange (2009). Overall, the machine achieved an optimal threshing recovery of 89.62% at a drum speed of 900 rpm and moisture content of 10.0%, with the analysis of variance confirming significant effects of both parameters on recovery. More of the trend can be visualized in the Figure 1. The regression model and coefficient of determination for the thresher parameters, shown in Table 3, indicate high predictability for throughput capacity (R^2 = 99.14%) and less predictability for grain breakage (R^2 = 93.75%).

Table 3: Regression model showing the interaction between drum speed and moisture content on the threshing parameters

S/N	Parameter	Linear model	R^2
1	Percentage Unthreshed	0.0035*DS + 0.1535*MC + 5.9635	0.9789
2	Threshing Efficiency	-0.0011*DS - 0.0412*MC + 94.0385	0.9641
3	Cleaning Efficiency	0.0119*DS - 0.0462*MC + 62.0817	0.9563
4	Grain Breakage	-0.0007*DS - 0.0325*MC + 4.6705	0.9375
5	Blown away seed	0.0019*DS + 0.0003*MC + 0.0083	0.9876
6	Seed loss	0.0017*DS + 0.0281*MC + 1.6595	0.9721
7	Performance Efficiency	-0.0001*DS - 0.0286*MC + 96.8389	0.9234
8	Material Capacity	0.0135*DS - 0.1827*MC + 11.9485	0.9897
9	Throughput Capacity	0.0545*DS - 0.9595*MC + 49.6513	0.9914

DS = Drum speed (rpm); MC = Moisture content (%)

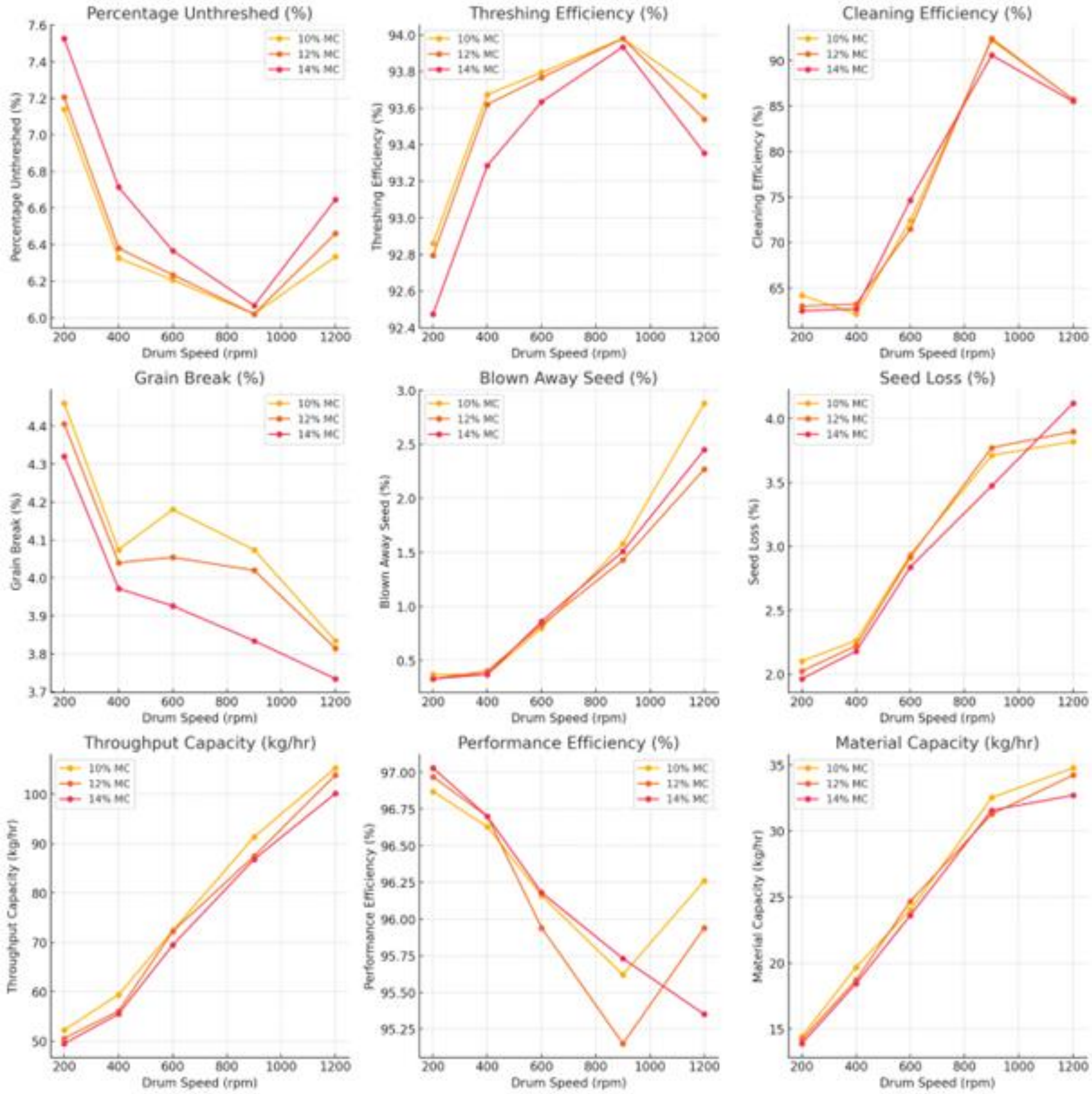

Figure 1. Canvas belt cowpea thresher parameter results at combine drum speed and moisture content settings for Percentage unthreshed (%), Threshing efficiency (%), Cleaning efficiency (%), Grain break (%), Blown away seed (%), Seed loss (%), Throughput capacity (kg/hr), Performance efficiency (%), and Material capacity (kg/hr).

3.2 Spike tooth multi-crop thresher test

Table 4 is the mean results of the canvas belt cowpea thresher performance at drum speed of 600rpm and moisture content levels of 10.0%, and 14.0%. It also comprises, the grand mean and the standard deviation of the parameters assessed as influenced by drum speeds and moisture contents. The results presented in Table 4 showed that whole seeds collected and the seed loss were not affected by change in moisture content. It further showed that there was a decrease in performance with respect to threshing efficiency, grain damage, threshing recovery, material capacity, performance efficiency and throughput capacity as moisture content increased from 10.0% to 14.0%. Meanwhile, the percentage unthreshed increased at increasing moisture content of the crop. The machines throughput capacity at 10.0% moisture content which was 181.89kg/hr is better compared to the 110.86kg/hr by Irtwange (2009). The machine has a performance efficiency of 98.46%, that is to say it is more effective when compared to the 81.21% performance efficiency by Ojo *et al.* (2010) at almost the same moisture content of cowpea tested.

Table 4: Mean values of spike-tooth multi-crop thresher performance parameters as influenced by levels of Moisture content at drum speed of 600rpm.

	% Moisture content			
Performance Parameter	**10.0**	**14.0**	**Grand Mean**	**SD**
Throughput capacity, kg/hr	181.89	177.05	179.47	1.56
Unthreshed, %	24.62	26.15	25.39	0.87
Threshing Efficiency, %	75.38	73.85	74.62	0.87
Grain damage, %	13.08	11.54	12.31	0.88
Seed loss, %	1.54	1.54	1.54	0
Threshing recovery, %	59.23	57.7	58.47	0.87
Material capacity, kg/hr	83.95	82.35	83.15	0.89
Performance Efficiency, %	98.46	97.69	98.08	0.62

3.3 Comparison of the Prototype Canvas Belt and the Spike-Tooth Thresher

The canvas belt cowpea thresher was compared with a spike-tooth multi-crop thresher, using the same engine power and cowpea variety, as shown in Tables 1 and 4. Tests used optimal settings: 600 rpm for the spike-tooth and 900 rpm for the canvas belt. The spike-tooth thresher achieved higher throughput (181.89 kg/h at 10% MC) than the canvas belt (91.33 kg/h). Increasing the speed beyond 900 rpm caused stability issues in the canvas belt. The canvas belt thresher showed a lower unthreshed percentage (6.02%) compared to 24.62% for the spike-tooth. Threshing efficiency was higher for the canvas belt (93.98%) than the spike-tooth (75.38%). Grain damage was 3.83% for the canvas belt and 11.54% for the spike-tooth at 14% MC. Seed loss was higher for the canvas belt (3.47% at 14% MC) than for the spike-tooth (1.54% at 10% MC). Threshing recovery differ, with 89.62% for the canvas belt and 59.23% for the spike-tooth, although wear and tear on the spike-tooth caused several openings. The spike-tooth showed better overall efficiency (98.46% vs. 95.73% for the canvas belt). However, improvements to the canvas belt, such as covering the sides to reduce seed spillage, could enhance performance. Additionally, the canvas belt's integrated cleaning mechanism, absent in the spike-tooth, makes its threshing process more complete.

4. Conclusion

The study evaluated the canvas belt cowpea thresher's performance and compared it with a spike-tooth thresher. The results indicate that the canvas belt thresher, with optimal performance at 900 rpm and 10% moisture content, achieved higher threshing efficiency (93.98%) and lower unthreshed percentage (6.02%) compared to the spike-tooth thresher. However, its throughput was lower, and seed loss was slightly higher at higher moisture levels. Suggested improvements to reduce seed spillage, combined with its effective cleaning mechanism, could enhance its suitability for smallholder cowpea farmers, offering a viable alternative to conventional methods.

Based on the findings, future studies should consider to:

1. Test alternative belt materials that are durable and friction-effective to enhance belt efficiency and lifespan.
2. Optimize belt design and speed by adjusting parameters such as speeds, widths, and textures to improve seed handling, reduce spillage, and increase throughput.
3. Enhance the blower airflow design to improve the separation of chaff and grain, particularly in higher moisture conditions.

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