Performance evaluation of a kenaf decorticator

Gabriel Ayodele Makanjuola[1] , Thomas Adedayo Ayorinde[2*],
Olabanjo Bankole Aluko[1], Oseni Kehinde Owolarafe[1], Lateef Ayodele Sanni[1]

(1. *Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria*;
2. *National Biotechnological Development Agency, Abuja*)

Abstract: The performance evaluation of an existing kenaf decorticator was carried out in this study. A field was planted with kenaf. It was maintained and monitored until the kenaf was 10 weeks old when the evaluation of the machine commenced. The kenaf decorticator was evaluated using different operation parameters, which included plant ages (10, 11 and 12 weeks after planting), kenaf stem sizes (0.0001-0.005 m, 0.005-0.015 m and 0.015-0.023 m) and decorticator speeds (8, 9 and 10 m s^{-1}) giving rise to a 3 by 3 factorial experiment. The result showed that the highest throughput value obtained was 612.26 kg h^{-1} when the machine was operated at 9 m s^{-1} using 0.015-0.023 m kenaf size harvested at 12 weeks after planting. The lowest percentage of kenaf fibre trapped in the machine was 10% which was obtained at week 12, when the machine operated at 9 m s^{-1} although ANOVA of fibre trapped showed that the operational parameters had no significant effect. The percentage waste collected decreased from 54% as the size range and speed reduced to 8 m s^{-1} while the percentage of fibre decorticated increased from 31% to 49% as the speed decreased to 8 m s^{-1}. The kenaf extraction efficiency increased from 74% to 91% as the size range increased. ANOVA showed that only size range had a significant effect on the efficiency of the machine. Duncan's multiple range test showed that 0.015-0.023 m had the highest mean of efficiency but maturity of stem and speed was statistically insignificant. The study concluded that the optimal operational parameters of the machine were 8 m s^{-1} with 0.015-0.023 m kenaf size and 12 week of kenaf maturity.

Keywords: kenaf, decortication, maturity, stem-size, machine-speed, performance

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1 Introduction

There is a continuous increase in the use of low-cost sacks for handling and storing agricultural products like cocoa, coffee, rice, bean, maize, and groundnut and so on. The textile industries also demand these sacks for packaging their products and textile industries are facing great pressure to reduce pollutant emissions. This drives textile manufacturers to seek new approaches to produce environmentally friendly products, such as recyclable and biodegradable textile materials. More attention has been drawn to agricultural products, wastes, and derivatives because of their renewability. In Nigeria, environmental degradation is increasing due to the increase in oil production (Energy Information Administration Nigeria, 2003) and felling of trees in forests. The need to develop a renewable resource that will provide raw materials in a sustainable manner has therefore led to the recent acceptance of kenaf as an industrial crop.

Kenaf (Hibiscus cannabinus L.) stems comprises of two important components: bast fibers in the bark, and core fibers in the center of the stems. The inner core fiber is about 60%-75%, which produces low quality pulp, and an outer bast fiber 25%-40%, which produces high quality pulp, in the stem. Kenaf fibers can be blended with synthetic fibers for making carpet. The fiber can also be used in making coarse bags, ropes, nets etc. Kenaf industrial applications include automobile, agriculture, construction, chemical process and packaging. Apparel fabrics and plastic/fiber composites from the fiber are its major end-use products. Other end use products include

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*** Corresponding author: Thomas Adedayo Ayorinde,** Bioresources Development Centre, National Biotechnology Development Agency, P.M.B 3524, Ogbomoso, Oyo state. Nigeria. Email: ayorindeadedayo@gmail.com. Tel: +23408132646687.

fiber board and particle board, oil and chemical absorbents, animal bedding, horticulture potting mix from the core, and livestock feed from the leaf (Dauda et al., 2012).

With the purpose of reducing import of these bags and save some foreign exchange, there is need to produce low cost bags from jute substitute plants grown in Nigeria. Kenaf and other similar substitute for jute were grown in commercial quantities in different parts of Nigeria. The fibre required for manufacturing these bags is obtained from the bark of kenaf and similar plants. This fibre can be extracted using three different methods: water retting of whole plant, chemical retting and mechanical fibre extraction. Water retting is possible only where large quantities of water are available at the time of harvest and chemical retting requires a lot of chemical. Due to the challenge of getting enough water (that can be used to ret the fibre in commercial quantity and the high cost of purchasing chemical for commercial retting), the need for the design of a mechanical device for the extraction of the kenaf fibre were arose. The first effort in the development of a kenaf decorticator in Nigeria took place many years ago in the Department of Agricultural Engineering of University of Ife (Makanjuola, 1976). The existing design was modified (courtesy of the Raw Material Research and Development Council of Nigeria) in 2010 to get the machine to a commercial status. The current version of the machine is to be evaluated for its performance. This study was undertaken to evaluate the performance of the machine.

2 Material and methods

2.1 Establishment of the kenaf plot

This experiment was carried out between June and October 2014 at the Teaching and Research Farm of the Obafemi Awolowo University, Ile-Ife, Nigeria. The kenaf plot was maintained and the plant growth was monitored till the plant was 10 weeks old when the experiment started.

2.2 Layout of the experimental plot

The dimension of the whole kenaf plot was determined using a measuring tape. The dimension of the land was found to be 43.7 m×30.5 m. The plot was divided into eight sub plots, which were scheduled for harvesting sequentially based on the maturity (i.e. 10^{th}, 11^{th}, and 12^{th} weeks).

2.3 Physical and mechanical properties of kenaf

The physical properties of kenaf stem variety V 36 revealed the maximum plant height recorded was 310 cm and the lowest was 150 cm. Maximum stem diameter was 30 mm and the smallest was 14 mm. The moisture contents determined ranged between 73%-75% (wet basis). The cutting characteristics of kenaf stems at three different moisture content levels of 35%, 55% and 72% revealed that the maximum cutting force and shearing energy were 1584.55 N and 8.75 J, respectively for 35% moisture content. While 694.86 N and 3.50 J were recorded for 72% moisture content. The Young's modulus ranged between 67.59 to 234.24 MPa (Dauda et al., 2014). These properties were considered in designing the kenaf decorticator.

2.4 Kenaf decorticator and decortication mechanism

The machine has a chute where the kenaf stem is fed into the machine. The stem passes through beaters which break the unwanted core material of the stem and push out the fibre and the unwanted core through the delivery plate. The fibre is separated from the unwanted broken core material manually. The beaters that brake the kenaf stem are of different sizes: small, medium and big beaters. The first set of beaters (the medium set) grips and pull the kenaf stem into the beating chamber of the machine. The small beater which is in the middle of the chamber has longer blade which is designed to ease the braking of very thick stems. The kenaf stem then gets to the final stage which has the large set of beaters which are responsible for the proper and final decortication of the stem. The three sets of beater are connected to a set of gear meshed together. Different views of the machine is shown in Figure 1-3. The material type and component of the kenaf decorticator is show in the explored view in Figure 2. The machine is driven by a 47 mm belt that is connected to a 2000 rpm diesel engine power unit with 9.48 kW maximum power.

2.5 Evaluation of Kenaf decorticator

The kenaf decorticator was firstly tested at the Agricultural and environmental engineering workshop after the machine has been coupled and tested on no load.

A small portion of the kenaf stems was harvested and tested on the machine. The diameter of each stem was firstly measured one after the other using a vernier caliper to determine the sizes of the kenaf stem before the stems were divided into different size ranges of (0.0001-0.005 m), (0.005-0.015 m) and (0.015-0.023 m). Each of the different size ranges of the kenaf stem was fed into the machine. The weight of each with different size range was measured to determine the weight of the kenaf stem before decortication. The weights of fibre collected and the kenaf core crushed were measured after the decortication.

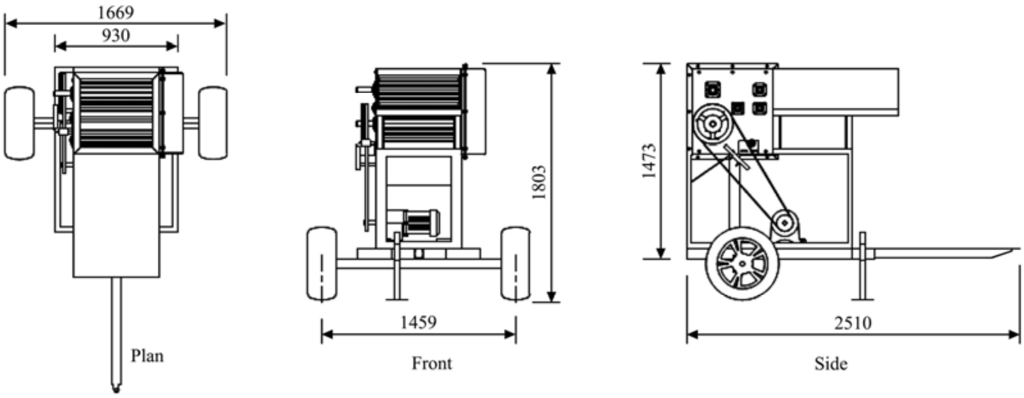
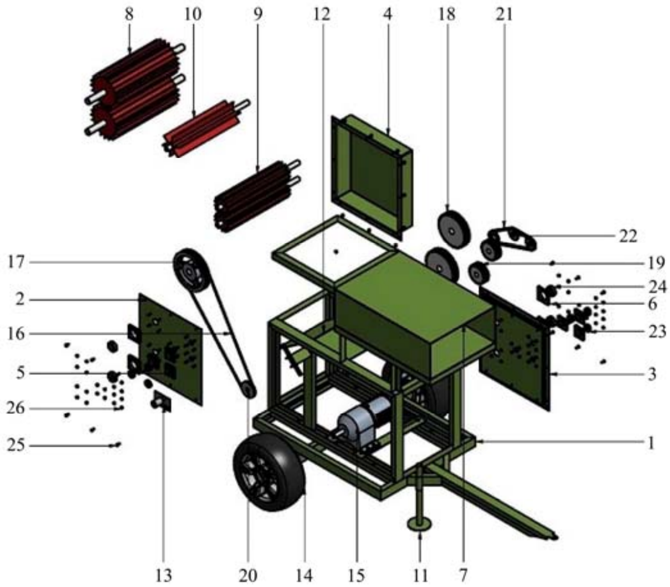


Figure 1 Plan, front and side views of the kenaf decorticator



Parts list			
S/N	Qty	Parts	Material
1	1	Frame	Mild steel
2	1	Side plate	Mild steel
3	1	Gearbox	Mild steel
4	1	Gearbox cover	Mild steel
5	6	Bearing housing 1	Mild steel
6	4	Bearing housing 2	Mild steel
7	1	Chute	Mild steel
8	2	Big beater	Mild steel
9	2	Medium beater	Mild steel
10	1	Small beater	Mild steel
11	1	Stand	Mild steel
12	1	Delivery plate	Mild steel
13	1	Idler	Mild steel
14	2	Wheel assembly	Composite
15	1	Gear motor	Composite
16	1	V-Belt	Rubber
17	1	Shaft pulley	Steel
18	2	Spur gear (big)	Steel
19	2	Spur gear (small)	Steel
20	1	Motor pulley	Steel
21	1	Roller chain	Steel
22	3	Roller chain sprocket	Steel
23	6	NSK 35 bearing	Steel
24	4	NSK 45 bearing	Steel
25	78	ISO 4018-M10 x 30	Steel
26	78	ISO 4033-M10	Steel

Figure 2 Exploded view of the kenaf decorticator

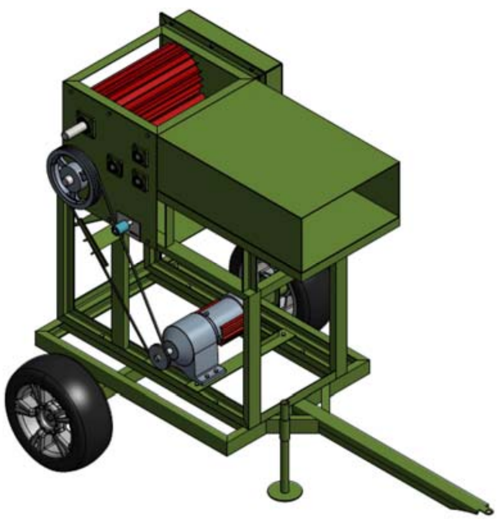


Figure 3 Isometric view of the kenaf decorticator

2.6 Procedure for evaluation and experimental design

Kenaf stems were cut from a particular plot at a particular week and divided into the three size ranges of 0.0001-0.005 m, 0.005-0.015 m and 0.015-0.023 m. The experimental samples were introduced to the machine at different rotational speeds. Each experiment was replicated twice. The following parameters were determined from the experiment.

2.6.1 Determination of throughput capacity of the machine

A weighted sample of kenaf stem was fed into the machine at different speeds, size ranges and maturity stages. The time taken to complete the decortication was recorded. The throughput capacity of the machine was calculated by using the formula below:

$$\text{Throughput capacity of the machine (kg h}^{-1}\text{)} = \frac{W_f}{T_t} \quad (1)$$

where, W_f = weight of fibre decorticated, kg; T_t = time taken to decorticated, h.

The throughput of the machine was determined at three different levels of speed, maturity and size.

2.6.2 Determination of percentage of kenaf fibre decorticated by the machine

A rope was tied on two poles in front of the machine such that the discharged fibre hanged on the rope as shown in Figure 4. The percentage was then calculated using the formula below:

$$\text{Fibre percentage} = \frac{W_f}{W_i} \times 100 \quad (2)$$

where, W_f = weight of fibre decorticated, kg; W_i = initial weight of fibre, kg.

Figure 4 The machine in operation

2.6.3 Determination of percentage of kenaf fibre trapped in the machine

The beater and chute of the machine was scraped to remove kenaf fibre trapped in the machine. The fibre collected was weighted and recorded. The percentage of fibre trapped is calculated using the formula below:

$$\text{\%age of fibre trapped} = \frac{W_t}{W_i} \times 100 \quad (3)$$

where, W_t = weight of fibre trapped, kg; W_i = initial weight of fibre, kg.

2.6.4 Determination of percentage of waste collected

The waste was packed, measured and recorded. The percentage of waste collected is calculated using the formula below:

$$\text{\%age of waste collected} = \frac{W_w}{W_i} \times 100 \quad (4)$$

where, W_w = weight of waste collected, kg; W_i = initial weight of fibre, kg.

2.6.5 Determination of kenaf extraction efficiency in percentage

A weighed sample of the plant was put through the machine. The decorticated bark kenaf were collected and shaken to remove any non-fibrous matter. The kenaf fibre were then weighed. All the woody and other non-fibrous part not removed by the machine were carefully picked with hands afterwards and the clean kenaf were reweighted (Goering et al., 1993). The ribbon extraction efficiency was calculated as follows:

$$\text{Kenaf extraction efficiency} = \frac{(W_1 - W_2)}{W_1 - W_3}, \% \times 100 \quad (5)$$

where, W_1 = weight of sample before decortication, kg; W_2 = weight of kenaf after decortication, kg; W_3 = weight of kenaf after all non-fibrous matter has been removed, kg.

The extraction efficiency of the machine was determined at the different combination of the operational parameters.

2.7 Statistical design

The experimental design conceived is a 3×3 factorial experiment, with three experimental factors namely the maturity of the kenaf, the speed of operation and the size (thickness) of the kenaf stem. The maturity stages of the kenaf considered for this experiment are 10th, 11th and 12th weeks. The speed levels considered are 8 m s^{-1}, 9 m s^{-1} and 10 m s^{-1} while the sizes are 0.0001-0.005 m, 0.005-0.015 m and 0.015-0.023 m. The experiment was replicated 3 times. Statistical analysis software 2002 was used for the analysis of variance at 0.05 significance level.

3 Results and discussion

3.1 Kenaf decorticator throughput capacity

Figure 5 showed the effect of processing parameters on the throughput capacity of the kenaf decorticator and Table 1 showed the analysis of variance of the kenaf decorticator throughput capacity. The figure 5 showed that the throughput of the kenaf decorticator increased as the maturity of kenaf increased. For example, at point 1, when the kenaf decorticator was tested at 8 m s^{-1} and with 0.0001-0.005 m size range, the throughput capacity increased from 192.87 kg h^{-1} at week 10 to 264.69 kg h^{-1} at week 11 and then increased further to 441.25 kg h^{-1} at week 12. This throughput value was higher than the throughput capacity of the groundnut decorticator, which was 153.5 kg pods h^{-1} (Kale et al., 2011) and that of a mango stone decorticator which was 250 kg h^{-1} (Jekayinfa and Durowoju, 2005). Table 1 showed that the throughput capacity of the kenaf decorticator were significantly different as the maturity stage increased. Duncan's Multiple Range Test for the throughput capacity of the kenaf decorticator presented on Table 2 showed that the mean of the throughput capacity increased as the maturity of plant increased. The result showed that the highest throughput value obtained was 612.26 kg h^{-1} when the machine was operated at 9 m s^{-1} using 0.015-0.023 m kenaf size harvested at 12 weeks after planting.

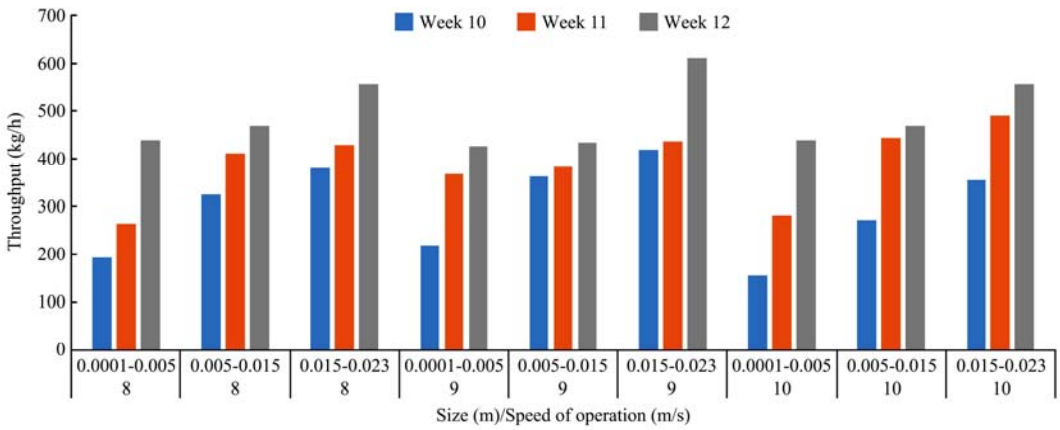


Figure 5 Effect of operational parameters on kenaf decorticator throughput

Table 1 ANOVA of kenaf decorticator throughput capacity

Source	DF	Type III SS	Mean Square	F Value	FCritical	Pr > F
MS	2	263393.0225	131696.5112	38.11	3.35	<0.0001
SO	2	14626.1056	7313.0528	2.12	3.35	0.1400
SR	2	198031.0452	99015.5226	28.65	3.35	<0.0001
MS*SO	4	18471.7302	4617.9325	1.34	2.73	0.2820
MS*SR	4	25574.8589	6393.7147	1.85	2.73	0.1483
SO*SR	4	4418.8424	1104.7106	0.32	2.73	0.8623
MS*SO*SR	8	32436.8168	4054.6021	1.17	2.31	0.3505
Error	27	93298.6722	3455.5064			
Corrected Total	53	650251.0936				

Note: MS=Maturity stage; SO=Speed of operation; SR=Size range.

Table 2 Duncan's multiple range test for the operation parameter of the kenaf decorticator in terms of performance indices

Source	Level	Tr	%D	%T	%W	%Eff
MS	Week 10	304.13^{c}	36.9032^{b}	17.729^{a}	45.368^{a}	88.758^{a}
	Week 11	394.02^{b}	36.5465^{b}	15.759^{a}	47.695^{a}	$88.123^{a\,b}$
	Week 12	475.13^{a}	43.1197^{a}	17.708^{a}	39.173^{b}	86.238^{b}
SO	8 m s^{-1}	389.87^{a}	41.7142^{a}	18.245^{a}	40.04^{c}	87.156^{a}
	9 m s^{-1}	411.84^{a}	39.0588^{b}	16.402^{a}	44.539^{b}	88.244^{a}
	10 m s^{-1}	371.58^{a}	35.7965^{c}	16.548^{a}	47.655^{a}	87.719^{a}
SR	0.0001-0.005	314.05^{c}	41.1222^{a}	17.051^{a}	41.827^{b}	85.159^{b}
	0.005-0.015	397.23^{b}	37.2332^{b}	18.437^{a}	$44.330^{a\,b}$	88.666^{a}
	0.015-0.023	462.00^{a}	38.2140^{b}	15.708^{a}	46.078^{a}	89.294^{a}

Note: Means with the same letter are not significantly different at $p<0.05$.

Performance indices: Tr = Throughput capacity of the kenaf decorticator; %D = Percentage of fibre decorticated; %T = Percentage of fibre trapped in the kenaf decorticator; %W = Percentage of waste collected from the kenaf decorticator; %Eff = Kenaf extraction of the kenaf decorticator.

It could be observed from Figure 5 that the speed of operation of the kenaf decorticator had effect on the throughput capacity of the kenaf decorticator. The throughput capacity when 0.015-0.023 m size was processed at speed of 8 m s^{-1} is 383.05 kg hr^{-1} at week 10, 430.48 kg hr^{-1} at week 11 and 558.55 kg hr^{-1} at week 12. The figure also showed that the throughput capacity was highest at 9 m s^{-1} but analysis of variance on Table 2 showed that the speed of operation did not have any significant effect on the throughput capacity of the kenaf decorticator.

The size range was also considered (Figure 5). It could be observed that the throughput capacity of the kenaf decorticator increased as the size range increased. The throughput capacity at 0.0001-0.005 m and kenaf decorticator speed of 8 m s^{-1} is 192.37 kg hr^{-1} at week 10. With 0.005-0.015 m size at 8 m s^{-1}, the throughput is 324.98 kg hr^{-1} at week 10 while it is 383.05 kg hr^{-1} for 0.015-0.023 m at the same speed and week. The trend of increase showed that the throughput capacity of the kenaf decorticator increased as the size range increased.

The analysis of variance in Table 1 showed that size range had a significant effect on the throughput capacity at 95% confidence interval. Duncan's multiple range test showed that the highest mean of throughput capacity was obtained when 0.015-0.023 m size stem was loaded in to the kenaf decorticator.

3.2 Fibre trapped by the kenaf decorticator

Figure 6 presented the effect of processing parameters on the percentage of fibre trapped in the kenaf decorticator while the analysis of variance was shown in Table 3. The focus in this section in terms of parameter is that the smaller the percentage of kenaf fibre trapped in the kenaf decorticator the better the performance of the kenaf decorticator. It could be observed that the range of the percentage of the fibre trapped in the kenaf decorticator was 10% to 24%. The figure did not show a consistent pattern of the result of fibre trapped in the kenaf decorticator, but a close look at the figure (especially category 4) showed that the lowest percentage of fibre trapped was obtained at week 12, 9 m s^{-1} and with 0.0001-0.005 m size range of kenaf. The analysis of variance on Table 3 also showed that none of the individual operation parameters and the combination of operation parameters had a significant effect on the percentage of fibre trapped at 95% confidence interval, which showed that the percentage of fiber trapped in the kenaf decorticator had no significant effect on the performance of the kenaf decorticator.

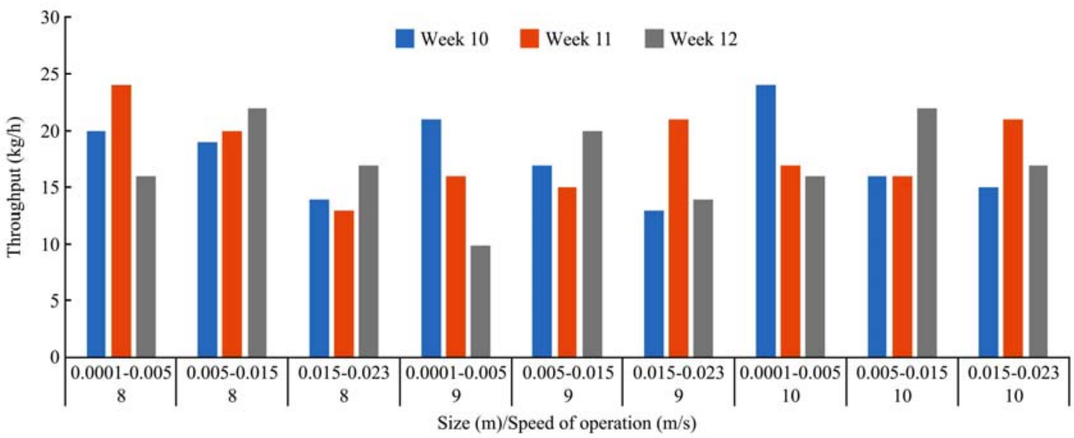


Figure 6 Effect of operational parameters on the fibre trapped by the kenaf decorticator

Table 3 ANOVA of the fibre trapped by the kenaf decorticator

Source	DF	Type III SS	Mean Square	F Value	F Critical	Pr > F
MS	2	46.0776480	23.0388240	1.13	3.35	0.3366
SO	2	37.7564751	18.8782375	0.93	3.35	0.4071
SR	2	67.0255323	33.5127661	1.65	3.35	0.2109
MS*SO	4	274.4782621	68.6195655	3.38	2.73	0.0230
MS*SR	4	274.4782621	68.6195655	3.38	2.73	0.0230
SO*SR	4	86.8259365	21.7064841	1.07	2.73	0.3913
MS*SO*SR	8	874.7528873	109.3441109	5.38	2.31	0.0004
Error	27	548.498060	20.314743			
Corrected Total	53	2260.908967				

3.3 Kenaf fibre decorticated

The effect of the three processing parameters on the percentage of kenaf fibre decorticated was shown in Figure 7. The figure showed that the highest percentage of fibre decorticated was obtained at 12 weeks after planting the kenaf stem. The chart showed that the percentage of fibre decorticated when 0.005-0.015 m size of kenaf was processed at kenaf decorticator speed of 8 m s^{-1} is 41% at week 10, 34% at week 11 and 43% at week 12. When 0.015-0.023 m size was processed at the same kenaf decorticator speed 43% was obtained at week 10, 36% at week 11 and 49% at week 12. This is the general trend of increase on the chart which showed that the percentage kenaf decorticated reached its highest value at week 12. Analysis of variance on Table 4 showed that maturity of the stem had a significant effect of the percentage of fibre decorticated. The Duncan's multiple range showed that the percentage of fibre decorticated at week 12 was statistically different from the percentage decorticated at week 10 and week 11. The highest mean of percentage fibre decorticated was obtained at week 12. This showed that the highest percentage kenaf fibre decorticated was 49%.

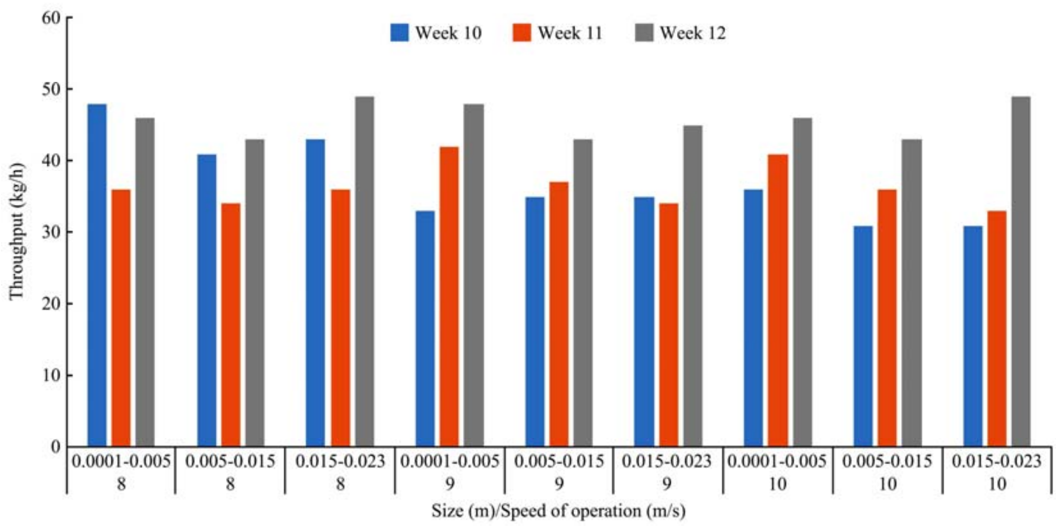


Figure 7 Effect of operational parameters on the kenaf fibre decorticated

Table 4 ANOVA of the kenaf fibre decorticated

Source	DF	Type III SS	Mean Square	F Value	F Critical	Pr > F
MS	2	491.8747608	245.9373804	38.39	3.35	<0.0001
SO	2	316.2744061	158.1372030	24.69	3.35	<0.0001
SR	2	147.2613614	73.6306807	11.49	3.35	0.0002
MS*SO	4	363.9518688	90.9879672	14.20	2.73	<0.0001
MS*SR	4	46.7023648	11.6755912	1.82	2.73	0.1536
SO*SR	4	27.7440392	6.9360098	1.08	2.73	0.3846
MS*SO*SR	8	83.8866818	10.4858352	1.64	2.31	0.1608
Error	27	172.957037	6.405816			
Corrected Total	53	1650.652520				

The Figure (Figure 7) also showed that the operating speed of the kenaf decorticator had effect on the percentage of fibre decorticated. With 0.015-0.023 m size of stem at week 10, 43% was decorticated at 8 m s^{-1}, 35% at 9 m s^{-1} and 31% at 10 m s^{-1}. This trend showed that the percentage of fibre decorticated decreased as the speed of operation increased. The highest percentage of kenaf decorticated was 49% which was lower than the percentage of threshing efficiency of a millet thresher which had an efficiency of 63.2% (Gbabo et al., 2013). Analysis of variance on Table 4 showed that speed of operation had a significant effect on the percentage of fibre decorticated. Duncan's multiple range test showed that speed had a different effect on the percentage of fibre decorticated and that the highest mean of percentage fibre decorticated was obtained when the kenaf decorticator was operation at 8 m s^{-1}. This showed that 8 m s^{-1} was the optimum speed to obtain the highest percentage of kenaf fibre during decortication.

3.4 Kenaf waste collected

The effect of processing parameter on the percentage of waste collected is shown in Figure 8. It was intended that the quantity of waste collected should be as small as possible. The chart showed that the percentage of waste collected reduces as the maturity of kenaf stem increases. At 0.005-0.015 m size of stem and kenaf decorticator speed of 8 m s^{-1} the percentage of waste collected at week 10 is 41%, it increased to 46% at week 11 and dropped to 35% at week 12. It showed that the percentage of waste collected at week 12 was lower than the percentage of waste collected at week 10 and 11. Analysis of variance on Table 5 showed that maturity stage had a significant effect on the percentage of waste collected from the kenaf decorticator. Duncan's multiple range test showed that the mean of percentage waste collected at week 12 was lower than mean of fibre collected at week 10 and 11. It showed that the kenaf decorticator performed best when kenaf stem was tested at week 12.

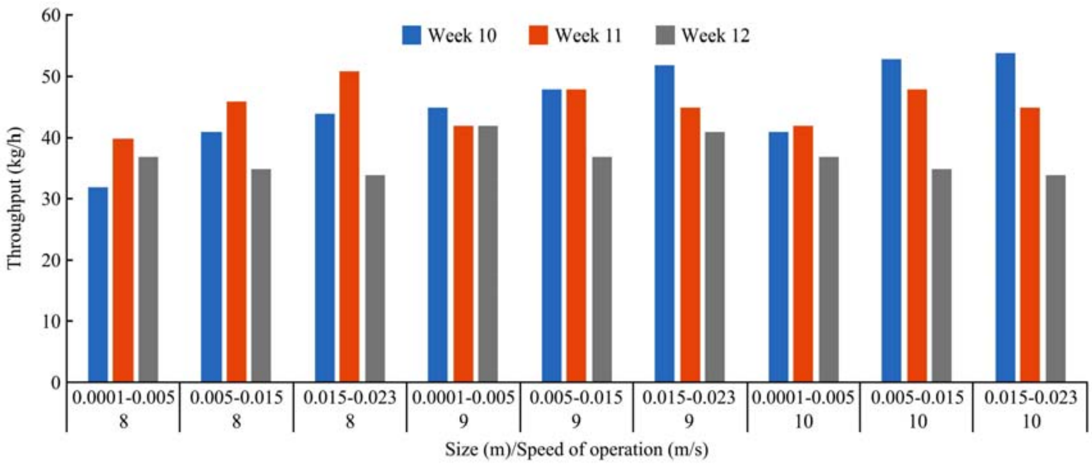


Figure 8 Effect of operational parameters on the kenaf waste collected

Table 5 ANOVA of kenaf waste collected

Source	DF	Type III SS	Mean Square	F Value	F Critical	Pr > F
MS	2	698.5406813	349.2703406	25.30	3.35	<0.0001
SO	2	527.4787139	263.7393569	19.10	3.35	<0.0001
SR	2	164.3484583	82.1742292	5.95	3.35	0.0072
MS*SO	4	171.5966537	42.8991634	3.11	2.73	0.0317
MS*SR	4	221.6944155	55.4236039	4.01	2.73	0.0111
SO*SR	4	22.8396428	5.7099107	0.41	2.73	0.7973
MS*SO*SR	8	733.7307561	91.7163445	6.64	2.31	<0.0001
Error	27	27	372.763563	13.806058		
Corrected Total	53	53	2912.992885			

The chart (Figure 8) also showed that the percentage waste collected from the kenaf decorticator at 8 m s^{-1} is lower than the percentage of waste collected when the kenaf decorticator was tested at the other speeds. When 0.005-0.015 m size of kenaf was processed at kenaf decorticator speed of 8 m s^{-1}, the percentage of waste collected at week 10 is 41%, at week 11 is 46% and at week 12 was 35%. The percentage waste collected increased slightly at 0.005-0.015 m size and 9 m s^{-1} which showed that 48% of waste was collected at week 10 and 11 and 37% was collected at week 12. With 0.005-0.015 m size at 10 m s^{-1} the waste collected at week 10 is 53%, 45% at week 11 and 35% at week 12. This showed that the kenaf decorticator would produce less waste when it was operated at 8 m s^{-1}. Analysis of variance in Table 5 showed that the speed of operation had a significant effect of the percentage of waste collected from the kenaf decorticator. Duncan's multiple range test showed that the mean of waste collected at 8 m s^{-1} was lower than the mean of waste collected at 9 and 10 m s^{-1}.

The chart showed that the effect of size range on the percentage of waste collected was very close. With 0.0001 – 0.005 m size of kenaf stem and at 9 m s^{-1} kenaf decorticator speed, 45% was collected at week 10 and

42% was collected at weeks 11 and 12. When 0.005-0.015 m size was processed at 9 m s^{-1} of kenaf decorticator speed, 48% was collected at weeks 10 and 11 while 37% was decorticated at week 12. Using 0.015-0.023 m size and at 9 m s^{-1}, 52% of fibre was decorticated at week 10, 45% at week 11 and 41% at week 12. The effect of size range on the percentage of waste collected was not clear on the chart because the inner core of the kenaf stem which constitutes the waste collected does not grow in proportion to the fibre of the kenaf stem. The analysis of variance in Table 5 showed that size range had a significant effect on the percentage of waste collected. Duncan's multiple range test showed that 0.0001-0.005 m size range had the lowest mean of percentage waste collected but the difference was minimal compared to other size range.

3.5 Kenaf decorticator extraction efficiency

The effect of processing conditions on the kenaf extraction efficiency of the kenaf decorticator was presented in Figure 9. The analysis of variance of the data was presented in Table 6. The kenaf extraction efficiency was the ability of the kenaf decorticator to produce a clean kenaf fibre. Therefore, the higher the efficiency the better the machine performance. The chart (Figure 9) showed that the values of the data were very close and the values ranged from 74% to 91% which showed that the extraction efficiency of the kenaf decorticator was very high. The 74%, which was the lowest value on this Table, was considerably higher than the cleaning efficiency of the millet thresher which is 62.7% (Gbabo et al., 2013).

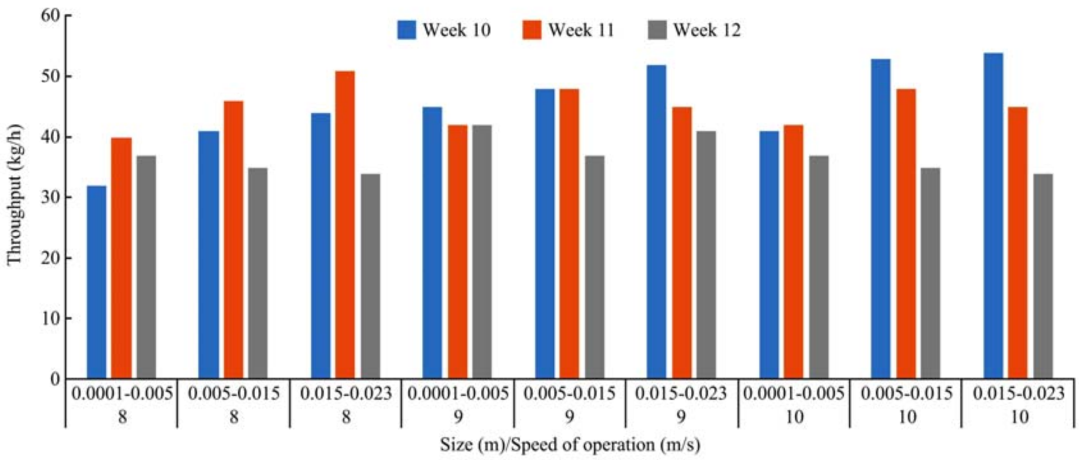


Figure 9 Effect of processing parameters on the kenaf extraction efficiency

Table 6 ANOVA for the kenaf decorticator extraction efficiency

Source	DF	Type III SS	Mean Square	F Value	FCritical	Pr > F
MS	2	61.8476934	30.9238467	3.19	3.35	0.0571
SO	2	10.6661375	5.3330687	0.55	3.35	0.5832
SR	2	178.8014782	89.4007391	9.22	3.35	0.0009
MS*SO	4	147.1806017	36.7951504	3.80	2.73	0.0142
MS*SR	4	45.1933112	11.2983278	1.17	2.73	0.3479
SO*SR	4	49.7339541	12.4334885	1.28	2.73	0.3014
MS*SO*SR	8	69.7720941	8.7215118	0.90	2.31	0.5306
Error	27	261.7347061	9.6938780			
Corrected Total	53	824.9299764				

Figure 9 showed that the extraction efficiency of the kenaf decorticator decreased as the maturity of kenaf stem increased. At 0.005-0.015 m size and speed of 8 m s^{-1}, the extraction efficiency of the kenaf decorticator was 91% at week 10, 89% at week 11 and 87% at week 12 and with 0.005-0.015 m size at 9 m s^{-1}, the extraction efficiency was 92% at week 10, 89% at week 11 and 86% at week 12. This is the general trend of the kenaf decorticator's extraction efficiency as the maturity of kenaf increases. Analysis of variance on Table 6 showed that there was no significant difference in the effect of maturity on the kenaf extraction efficiency. The Figure (Figure 9) did not show a consistent result pattern for the speed of operation, but a careful study of the figure showed that when 0.015-0.023 m size range was decorticated 8 m s^{-1}, 90% was obtained at week 10, 91% at week 11 and 89% at week 12, when the speed was 9 m s^{-1}, 84% was obtained at week 10, 92% at week 11 and 85% at week 12 and when the speed was 10 m s^{-1} 90% was obtained at week 10, 87% at week 11 and 74% at week 12. This showed that 8 m s^{-1} had slightly higher efficiency compared to 9 and 10 m s^{-1}. Analysis of variance on Table 6 showed that there was no significant difference in the effect of speed of operation on the mean of the kenaf decorticator's extraction efficiency. Duncan multiple range test showed that the means of 8, 9 and 10 m s^{-1} was not statistically different but result obtained in the percentage of kenaf decorticated and waste collected showed that more kenaf was decorticated at 8 m s^{-1} and less waste was collected at 8 m s^{-1} which showed that 8 m s^{-1} should be selected as the speed of operation of the kenaf decorticator because more kenaf would be produced and less waste would be collected at 8 m s^{-1}.

The effect of size range on the kenaf extraction efficiency in Figure 9 showed that the extraction efficiency increased as the diameter of kenaf stem increased. When 0.0001-0.005 m size was processed at kenaf decorticator speed of 8 m s^{-1}, the extraction efficiency at week 10 was 78% and increased to 85% at weeks 11 and 12 but with 0.005-0.015 m size and at same speed, the extraction efficiency was 91% at week 10; it dropped to 89% at week 11 and 87% at week 12. Using 0.015-0.023 m size with kenaf decorticator speed of 8 m s^{-1}, 90% was the extraction efficiency at week 10, increased slightly to 91% at week 11 and finally decreased to 89% week 12. Analysis of variance in Table 6 showed that size of the stem fed into the kenaf decorticator had a significant effect on the extraction efficiency of the kenaf decorticator. Duncan's multiple range test showed that 0.015-0.023 m size range of kenaf fibre had the highest mean of kenaf extraction efficiency, which was statistically the same as the mean obtained when 0.005-0.015 m was decorticated. This showed that the kenaf decorticator performed the best when 0.015-0.023 m and 0.005-0.015 m size range of kenaf stem was decorticated.

4 Conclusions

The following conclusions could be drawn from this research. The highest throughput value obtained was 612.26 kg h^{-1} when the machine was operated at 9 m s^{-1} using 0.015-0.023 m kenaf size harvested at 12 weeks after planting. The lowest percentage of kenaf fibre trapped in the machine was 10% which was obtained at week 12, when the machine operated at 9 m s^{-1} although ANOVA of fibre trapped showed that the operational parameters had no significant effect. The percentage waste collected decreased from 54% as the size range and speed reduced to 8 m s^{-1} while the percentage of fibre decorticated increased from 31% to 49% as the speed decreased to 8 m s^{-1}. The kenaf extraction efficiency increased from 74% to 91% as the size range increased. ANOVA showed that only size range has a significant effect on efficiency of the machine. Duncan's multiple range test showed that 0.015-0.023 m had the highest mean of efficiency but maturity of stem and speed was statistically insignificant. The study concluded that the optimal operational parameters of the machine were 8 m s^{-1} with 0.015-0.023 m kenaf size and 12 week of kenaf maturity.

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