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Improving the Performance Efficiency of the Cutting Drum in the Agricultural Waste Cutting Machine

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ONE of the most crucial mechanical operations for maximizing the use of agricultural waste is the cutting and chopping process. As consequently, a palm waste cutting machine was assessed and then developed to treat for treating processing defects and increase its working performance. The evaluation and development processes were mainly focused on the cutting tool of sharp angle (SA), the clearance (C) (between the shear rod and the cutting roller), the nature of the shear rod, and as well as the life span of the cutting knives. The productivity and cutting efficiency (ηc) of agricultural waste shredder machine (AWSM) increase to highly significant levels when the sharp edge of the knives is lowered to a 25-degree of SA. Additionally reducing the fuel consumption (FC) of cutting machines down to an appropriate level. The best machine productivity and ηc were attained, together with the lowest consumption of fuel, by reducing the C to a minimum of 1 mm. The optimum performance of AWSM was maintained by changing from a fixed to a moving shear rod and a 1 mm of C value. By using a double-edged sharpening instead of a single one, the cutting knives' lifespan was extended. Enhancing the cutting knife's material's mechanical and corrosion-resistant qualities allowed for better sharpening and longer life spans.

Keywords: Agricultural waste shredder, Palm waste, Cutting drum, Sharp angle of cutting knives, Clearance distance.

Introduction

The amount of agricultural waste that farmers produce has increased, as has the yearly buildup of such wastes without treatment. This can be attributed to the increased use of production elements and the associated horizontal and vertical development. Additionally, improper handling of these agricultural wastes poses a risk to the environment and wastes a significant amount of money. An estimated 35 million tons of agricultural waste are produced annually, of which 23 million tons are vegetarian wastes (used to make 4 million tons of organic fertilizer, 7 million tons of feed, and 12 million tons of unusable In addition to the approximately 12 million tons of animal waste generated annually, of which 3 million tones are used as organic fertilizer and 9 million tons are disposed of without being used. This means that each year, over 21 million tons of agricultural wastes (plant and animal) go unutilized and cause the agricultural environment's pollution. It becomes imperative to focus on recycling the agricultural wastes of crops, which account for a significant amount of garbage. It also becomes essential to activate the best methods for converting these wastes into economically valuable (Hassam, et al., (2014).

One of the most widely planted horticulture crops in the majority of Arab countries is the date palm (*Phoenix dactylifera L.*). It is regarded as a symbol of life in the Egyptian desert and has a major economic impact on human history (El-Salhy, et al., (2017). Egypt took the lead as the top producer of dates globally, accounting for approximately 18 % of the world's total production in 2021 (FAOSTAT, 2022). All of Egypt's cultivated areas contain date palm trees as well. To address the needs related to the future demographic expansion, a new policy for the development of the date palm industry must be devised. Additionally, it may thrive in adverse environmental conditions such as salt, drought, and severe weather (Daillo, H. (2005). Egypt has a vast distribution of date palms that extends from the far

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south to the far north and from the far east to the far west, according to Al-Wasfy and Mostafa (2008).

The first step to maximizing the use of agricultural waste is to develop agricultural waste shredders. The initial stage in obtaining fully usable materials from crop residues involves the mechanical treatment of these residues through size reduction, achieved by cutting or grinding them. However, the shredding process faces challenges such as low productivity, inefficiency, and increased fuel consumption (FC) of agricultural waste shredding machines (AWSM). These issues arise from a lack of identification of crucial factors that could enhance the performance of these machines, leading to a significant number of farmers refraining from purchasing them. This situation becomes more complicated as the quantities of agricultural waste increase annually (Abdelraouf et al., (2000); Abdelraouf and Abuarab (2012); Sabra et al., (2023); Abdelraouf and Fathy (2019); Eid and Negm (2019); Abdelraouf et al, (2021) and Abdelraouf and Ragab (2017). Shredding agricultural waste, particularly from palm plantations, is crucial for maximizing waste utilization, especially considering the expanding cultivated areas of palm trees in Egypt. Palm trees possess high resilience to drought and salinity, making them increasingly cultivated in response to water scarcity issues and their ability to thrive in such conditions (Okasha et al., (2013).

AWSM, used for cutting and chopping self-propelled agricultural waste, are equipped with a diesel engine for management and come in different types. These types include flail-type choppers with counterblades, flywheel cutterheads, and cylinder-type cutterheads. The second type, the flywheel cutterhead, is the most prevalent among Egyptian farmers due to its affordability, ease of installation and operation, and high cutting efficiency. However, it has a drawback as it leads to decreased machine productivity, reduced cutting efficiency, and increased fuel consumption (Suliman et al., (2004) and Suliman et al., (2008).

On a small farm, (Khader (1997) created a straightforward chopping technique employing field crop waste. He investigated the effects of the following variables on cutting length and efficiency: (a) chopping-drum speed; (b) the number of chopping-drum knives; and (c) the distance between stationary and spinning blades. Among the zwaste materials used were cotton, maize, bean, and rice straw. He concluded that the four moving blades might be used to make animal feed, silage, or compost based on the length of the trash being chopped. whereby the cutting length was affected by the C and drum speed. He investigated the impact of changing the number of knives and the speed of the cutter head for cutting some residual field crop. Additionally, he discovered that cutting length dropped as the number of blades and cutter head drum speed increased. The ideal working conditions were: (a) 1.5–3 cm animal feed, 1850 rpm drum speed, and 1 mm of C; (b) 3-6 cm silage, and 6–12 cm composting, 1250 rpm drum speed, and 5 mm of C. For rice straw, the ηc value at the suggested cutting length was 50%. An agricultural residue chopper was created by Younis et al., (2002) to increase productivity and make it more effective at chopping rice straw. To cut down on the amount of time needed for chopping and boost machine productivity, the original machine's development now includes a pre-cutting device. To assess its performance, they looked at the rotor speed, cutting-length %, and productivity. The output was 0.95 tonnes per hour, and at a rotor speed of 2000 rpm, the proportion of cutting wastes with a length of 1 to 9 cm reached 95%.

Lotfy (2003) was created and assessed a machine for cutting and tossing agricultural waste. The following parameters were used to evaluate the chopper's performance for three different types of crop residues (corn stalks, rice straw, and cotton): the number of cutting knives, the SA between them, varying feeding and cutting speeds, and varying clearances between rotating and fixed knives. By raising cutting clearance and feeding speed while lowering the number of cutter head knives and cutting speed, the cutting length was increased. After alteration, the machine's capacity was doubled, its length was lowered, and its operational costs were cut in half. Imbabi (2003) evaluated the effectiveness of a cutting device for crop waste. The results demonstrated that, at a rotation speed of the cutting knives of 1500 rpm, the highest values of both cut length and machine productivity were attained.

A fodder-bales cutter was designed, and its effectiveness was assessed by Al-Gezawe et al., 2016). The fodder bundle cutter's performance was assessed in terms of average and percentage cutting length, chopping effectiveness, needed power, energy requirements, and operational cost. Maximum machine productivity was 830.7 kg hr^{-1}, maximum necessary power 22.64 kW, maximum chopping efficiency 97.4%, and minimum average lengths of cut 1.54 cm were all recorded. When utilizing combination knives and hammers at a drum speed of 1040 rpm, the minimum operational cost values for wheat straw.

This study aims to evaluate the performance, develop, and identify the optimal engineering factors related to the performance of the effective parts of these machines in order to increase productivity and ηc, decrease FC, and shorten the number of maintenance times for AWSM, especially the growing palm plantations waste. By implementing the findings from this study, Egypt can improve its date palm agricultural waste management, contributing to sustainable development and economic growth in the country.

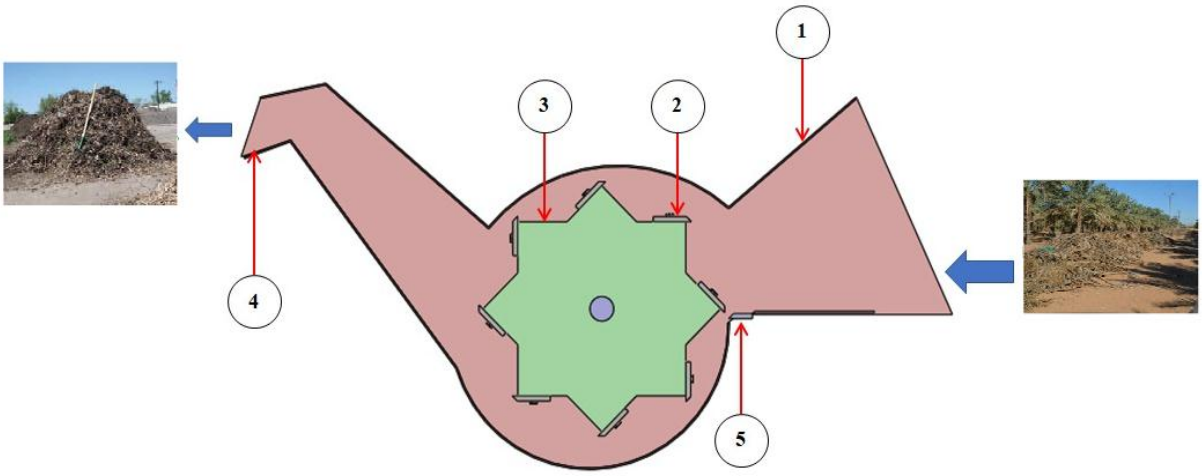
Materials and Methods:

One of the private farms in the Fayoum Governorate, Egypt served as the evaluation and development site for the agricultural waste cutting equipment.

More than one stage was conducted to improve the performance of the agricultural waste shredder under study: (1) Initial evaluation of AWSM before development, (2) Effect of some design factors on the performance of AWSM, (3) Improving the mechanical properties of the cutting knives materials, (4) Continuity of high performance palm AWSM by converting the fixed shear bar into a mobile one, (5) Increase the shelf life of cutting knives by rinsing both sides of knives instead of rinsing by one, (6) Impact of the development process on cost reduction.

Description of agricultural waste shredder machine (AWSM):

A diesel engine with 12 hp was needed to run the waste shredder A diesel engine with 12 horsepower was needed to run the waste shredder. The following are the shredding machine's specifications: **a)** Cutting drum: a cutting drum with a diameter of 45 cm and eight cutter knives. **b)** The knives and the countershear: The knives have the following measurements: 30 cm long, 8 cm wide, and 1 cm thick, with a 40° of SA edge. The countershear has the following measurements: 40 cm long, 5 cm wide, and 1 cm thick. **c)** The feeding tray measures 100 cm in length, 80 cm in near and front dimensions, and 40 cm in sidewall height. **d)** As illustrated in Figures 1 and 2, the feeding hole measures 40 cm in width by 10 cm in height.



[1:Input , 2:Cutting knives, 3:Cutting drum, 4:Output, 5:Fixed countershear]

Fig. 1. The use of the AWSM under study in cutting palm waste into compost.

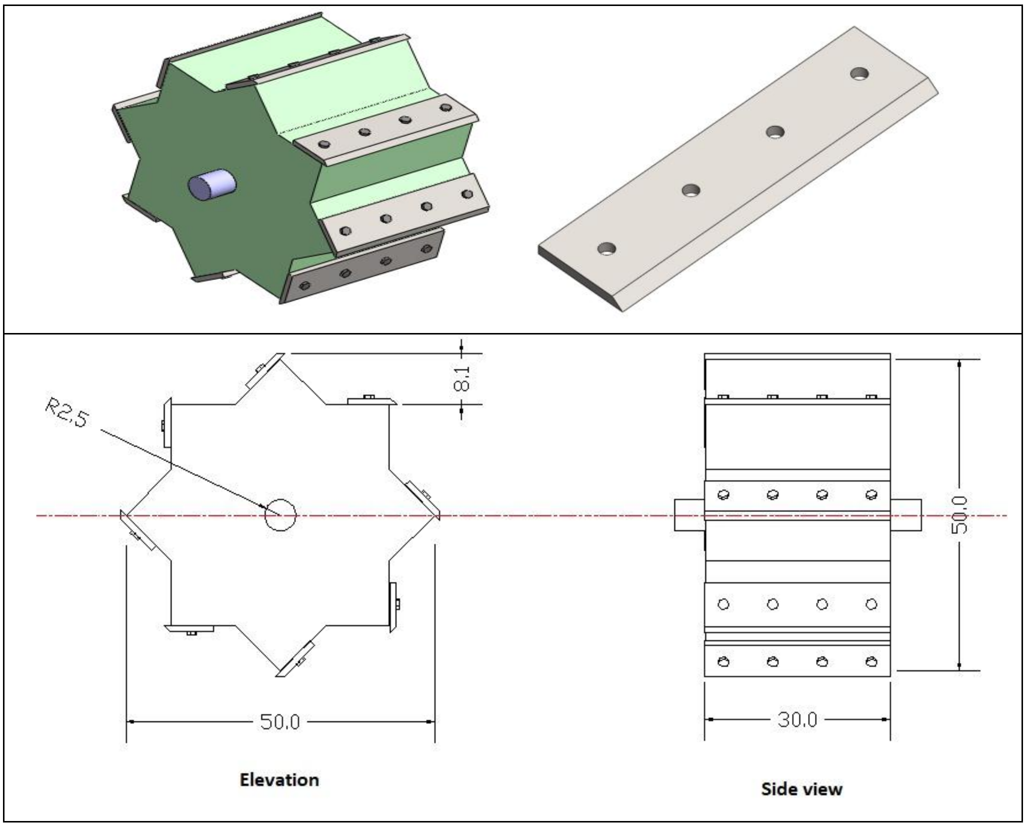


Fig. 2. Dimensional details of the cutting drum

Chemical, physical and mechanical characterization of palm waste

As each component of a palm frond (leaf) has a unique composition and traits, Fig. 3, depicts a picture of one. Date palm frond chemical composition and average weight percentage are shown in Table 1, and the full ranges of physical attributes are shown in Table 2. The mechanical characteristics of date palm fiber are displayed in Table 3. Date palm fiber's tensile strength and Young's modulus Table 4.

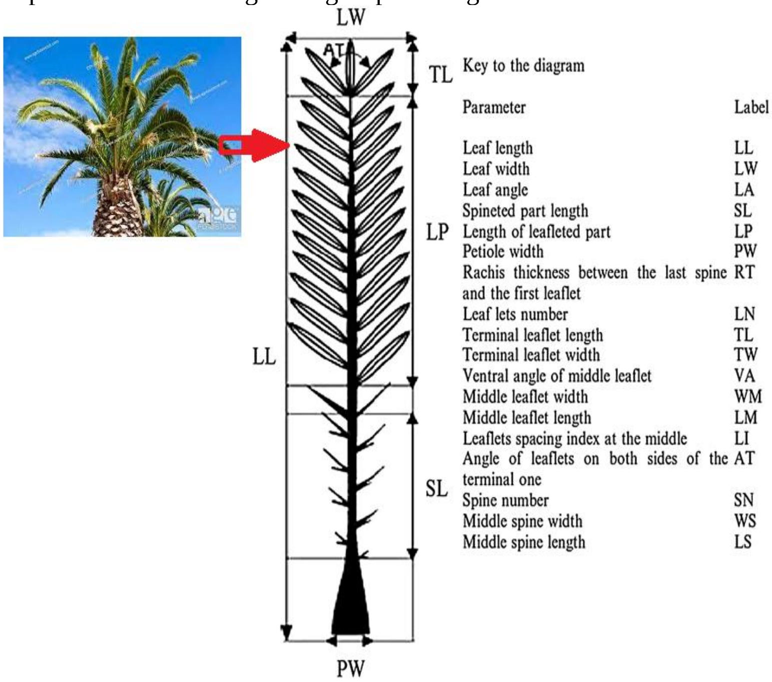


Fig. 3. Detailed morphological traits of date palm tree leaf

TABLE 1. Chemical components of date palm leaf, its leaflet and rachis portions.

Constituents	Cellulose, %	Hemicelluloses, %	Lignin, %	Ash, %	Extractive, %
Leaf	53.81	20.7	15.47	1.90	8.12
Rachis	38.16	28.07	22.73	5.76	5.28
Leaflet	40.23	12.81	32.22	10.44	4.35

TABLE 2. Physical properties of date palm fiber

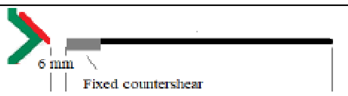
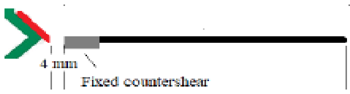
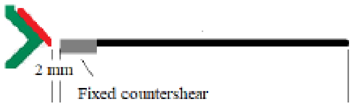
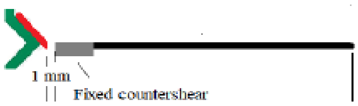
Density (g cm^{-3})	0.92 – 1.27
Length (mm)	25– 270
Diameter (µm)	120 – 1050
Specific modulus (approx.)	8
Elongation to break (%)	4 – 18
Thermal conductivity (W mK^{-1})	0.084

TABLE 3. Date palm fiber's tensile strength and Young's modulus.

Tensile strength (Mpa)	55 – 207
Young’s modulus (Gpa)	2.4 – 7.9

Table (4) represents Experimental design for a stage of development and dimensions of the cutting knives, fixed countershear, details of the SAs of the cutting knives, clearance between the fixed countershear and the cutting drum.

TABLE 4. Experimental design for a stage of development and dimensions of the cutting knives and fixed countershear.

SAs of the cutting knives	clearance between fixed countershear and cutting drum	
40°		**6 mm**
35°		**4 mm**
30°		**2 mm**
25°		**1 mm**

SA: Sharp angle

Evaluation parameters

Chemical analysis, microstructure and mechanical tests of cutting knives

The chemical analyses and microstructure of cutting knives samples were measured by a chemical analysis test set and an optical microscope (Olympus). Wear, tensile, and impact tests were carried out at the Central Metallurgical Research Development Institute (CMRDI), Cairo.

Machine production: A timer was used (every 15 minutes) to time the cutting operation in order to calculate the machine's productivity in Mg h^{-1}.

Cutting efficiency, ηc: An important factor to consider when assessing the effectiveness of the cutting process is the finished product's cutting length. Whereas the appropriate cutting length that can be used to create compost and forage is between 0 and 50 mm. Standard sieves with a cutting length of 0< Lc < 50 mm are used to separate a specific mass, from the chopped production into many weights. As a result, the ηc may be determined using the formula (1).

$$\eta c = \frac{S_a}{S_b} \times 100 \ldots\ldots\ldots\ldots (1)$$

Where: S_b is the weight of chopped production before segregation, g; S_a is the weight of the chopped production after segregation of cutting length 0< Lc < 50 mm, g.

Fuel consumption (FC): Before and after each test, the fuel tank was fully filled. Each test trial's amount of refuelling was measured using a graduated container. Equation (2) was used to compute the rate of FC.

$$FC, (lit\ h^{-1}) = \frac{fuel\ consumed, lit}{Time, h} \ldots\ldots\ldots\ldots (2)$$

Cost analysis:

The American Society of Agricultural and Biological Engineers (ASABE) Standards (ASABE Standards (2011) and Kay et al., (2020) were the sources for the engineering parameters employed in the analysis that follows.

$$Total\ costs = Ownership\ costs + \text{Operating costs} \ldots (3)$$

Where: Ownership costs: [annual depreciation expense, annual interest expense, taxes, insurance, and housing].

- Annual depreciation expense = (initial purchase cost – salvage value) / useful life
- Annual interest expense = (initial purchase cost + salvage value) / 2] × interest rate (0.05)
- Taxes, insurance, and housing (TIH) = (initial purchase cost + salvage value) / 2] × 0.015

Operating costs: [Repairs, fuel, lubrication, and labor]

Statistical Analysis

The statistical analysis of the data was carried out according to Gardner and Tremblay (2006). We calculated the values of least significant differences (L.S.D. at 5% level) in order to compare the means of the different treatments (Snedecor and Cochran (1982).

<u>Results and Discussion</u>

Initial evaluation of AWSM before development

The initial evaluation of AWSM for cutting palm waste has been carried out, and the mechanical properties of the cutting knives materials have been examined and tested. The dry waste of palm wastes were cut at a moisture content of 15%, and this is considered the worst conditions for the cutting process. The lower the moisture content of any residue, the greater the force required for cutting (Al-Awady et al., 2006 and Kepner et al., 1987)

The SA of the cutting knives was 40^{o} degrees, and the C distance between the fixed countershear and the cutting drum was 6 mm. The results of the performance evaluation of AWSM for cutting palm waste were as shown in Table (5). Chemical analysis of the raw material of the cutting knives was also carried out, and its mechanical properties were measured to determine the strength and durability of the raw material and whether the heat treatment was carried out in accordance with recognized international standards or not. Table (6) shows the results of the chemical analysis and the mechanical information that was done on the material of the cutting knives before development.

Through the results of the initial evaluation of the performance of the palm waste cutting machine in Tables (5, 6) it is clear that:

(1) Increasing of the machine production, ηc, and FC with increasing the cutting drum speed.

(2) Although the highest productivity of the machine was achieved at a speed of 1650 rpm, it was avoided to operate the machine at this speed due to the high vibration of the machine with this speed. It was recommended to operate the machine at a speed of 1550 rpm, which is the speed that

achieved the highest values of productivity and ηc

(3) The C distance between the fixed countershear and the cutting drum was 6 mm, and this is considered very large, as it was found through previous studies that the smaller the C distance, the higher the productivity of the machine, the higher the ηc, and the lower the FC. So, the C distance will be tested for less than what was measured from the initial evaluation of the machine, and this range is 4 mm, 2 mm, and 1 mm compared to the control treatment, which is 6 mm.

(4) The initial evaluation of the palm waste cutting machine was made at SA of 40 degrees for the

with no vibration of the machine.

cutting knives. The SA is considered large and not suitable for the process of cutting waste, as it was mentioned in the reference studies also that the smaller the SA, the better results it gave for the performance of the machine in terms of machine productivity, ηc, and FC, so it will be evaluated to a smaller extent for the SA in the next step, which is 35, 30 and 25 degrees compared to the SA of 40 degrees.

TABLE 5. Shredder performance for cutting palm wastes before development at 40^o knife-edge of SA and 6 mm C distance

Cutting drum speed, rpm	Machine production, Mg h^{-1}	ηc, %	FC
1250	0.25	24.7	6.5
1350	0.27	25.6	6.6
1450	0.30	29.2	7.0
1550	0.31	30.3	7.2
1650 (High vibration occurred in shredder)	0.35	31.9	7.5

ηc: Cutting efficiency; SA: Sharp angle; FC : FC Fuel consumption

Table (6) and (Fig. 4) show the results of the chemical composition, mechanical properties and microstructure of the as-received cutting knives material. The chemical composition of Table 5 shows that the current steel contains medium-carbon steel, which is also considered as heat-treatable steel. The microstructure of current heat-treatable steel contains a higher percentage of retained austenite (white cloud areas in Fig. 4) in a martensitic matrix. The presence of this phase within the microstructure will lead to its transformation into martensite during the work of the cutting tool, which leads to an expansion in the side matrix and micro-cracks inside the tools. Therefore, the current as-received cutting tool material shows relatively low hardness, impact, and elongation (Table 6). For these lower values of mechanical properties, it is very difficult to achieve the proper sharp edge cutting tool of SA values.

TABLE 6. Chemical composition and mechanical properties of the as-received cutting knives materials used in current study.

Chemical composition	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	V	Fe
	0.62	0.11	0.79	0.03	0.05	0.73	0.02	0.06	0.12	0.04	Rest
Mechanical properties	Hardness, HV			Impact, J		Tensile strength, kg mm^{-2}			Elongation, %		
	390 ± 10			8 ± 4		115 ±12			6.2 ±2		

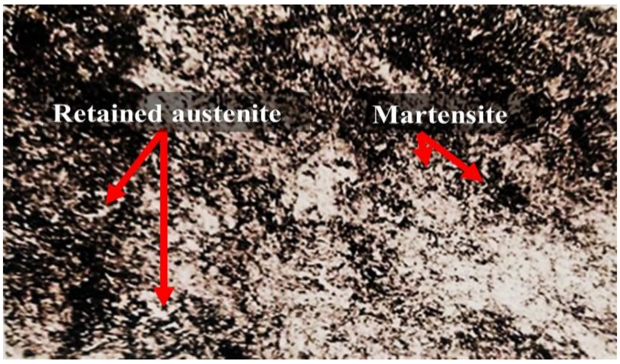


Fig. 4. The microstructure of as-received knives material. (X200)

Effect of some design factors on the performance of AWSM

Some major factors significantly affect the performance of AWSM. The SA of the cutting knives and the C distance between the moving cutting drum and the fixed counter shear are the most influential factors in the performance of the AWSM, including palm waste. (Fig. 5), Explains the steps to prepare new cutting knives with different bevel angles.

a). Determine where to sharpen your cutting knives **b). Sharpening of cutting knives** **c). Sharpening with multiple angles on one side**

Fig. 5. Steps to prepare new cutting knives with different bevel angles

Machine production

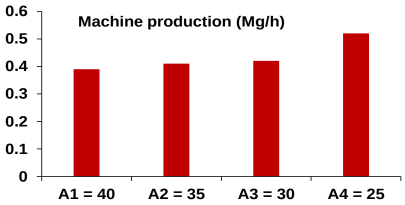
The productivity of AWSM was increased by decreasing the SA of cutting knives and decreasing the C between fixed shear bar and cutting roller. Where the highest production of the machine was when the SA of cutting knives was equal to 25 degrees, while it was less productive when it was 40 degrees. The cutting process is completed and the shredded residue comes out of the exit hole of AWSM. It was also observed that the highest productivity results were when the C distance between the fixed shear rod and the cutting roller was equal to 1 mm, while the lowest values were when the C distance was equal to 6 mm, and ensuring that the cutting process takes place from the first time and that the cut waste exits directly from the exit hole. Among the results of the interference for both factors, it was found that the highest values of machine productivity were achieved when the SA of cutting knives was equal to 25 degrees and the C distance was 1 mm (Figs. 6, 7, and Table 7).

Cutting efficiency (ηc): With the decrease in SA of cutting knives, the efficiency of cutting palm waste to the appropriate length for compost production increased. This was due to the ease of penetration of the small SA of the dry waste materials compared to the large SA, which led to the cutting process of the waste from the first time, and with a small length less than or equal to the length required to make compost. It has also been noted that with an increase in the C distance between the cutting roller and the fixed shear rod, the ηc values decrease, as the increase in the C distance value leads to the failure of the cutting process for the first time, which results in an increase in cutting lengths from the desired length for compost production. And with a review of the results of the interaction between the study factors, it was found that the highest ηc was achieved with an SA of 25 degrees for the sharp edge of the cutting knives with the lowest C distance, which is 1 mm (Figs. 6, 7, and Table 6).

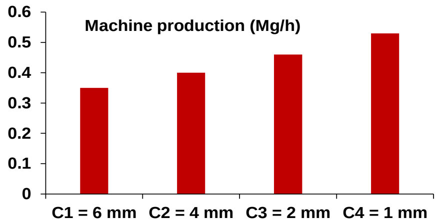
FC: The results in Figures (8, 9) and Table (7) showed that with a decrease in SA of cutting knives, the rate of FC decreased, and this also happened with a decrease in the C distance. This is probably due to the fact that the small cutting of SA did not require a large capacity for the cutting knives to penetrate the dry palm residues, which did not cause an increase in FC, and what helped in that was the small clearance between the shear rod and the cutting roller and the creation of tight cutting conditions.

Improving the mechanical properties of the cutting knives materials

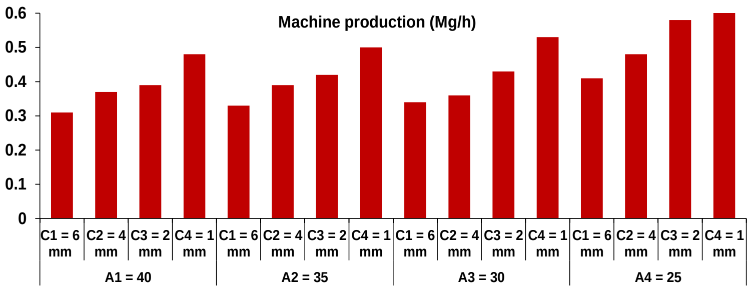
Although in the results mentioned above, the best SA for the cutting knives was determined with the most suitable C between the cutting roller and the fixed reed edge, some improvements will definitely increase the productivity and efficiency of the cutting process and will reduce the total costs. One of the most important and necessary improvements that are required to be done on the material of the cutting knives properly and according to standard specifications is material selection and or the heat treatment. Although a heat treatment that was performed on the current as-received material of the original cutting knives, but through the initial evaluation of microstructures and mechanical properties showed that it was badly needed to select more suitable materials and conduct a typical and standard heat treatment to improve the mechanical properties of these effective knives for the cutting process. Therefore, the proper heat treatment procedure and or a proper material selection to improve the current knives cutting tool should be our future challenge research work to improve the performances and increase the lifetime of such knives-cutting tools.



Effect of knife edge SA



Effect of clearance



Effect the interaction between knife edge SA and clearance

Fig. 6. Effect of knife edge SA and clearance between fixed countershear and the cutting drum on the machine production for palm AWSM. (C: Clearance between the shear rod and the cutting roller; ηc: Cutting Efficiency; AWSM: Agricultural Waste Shredder Machine; SA: Sharp angle; FC: Fuel consumption)

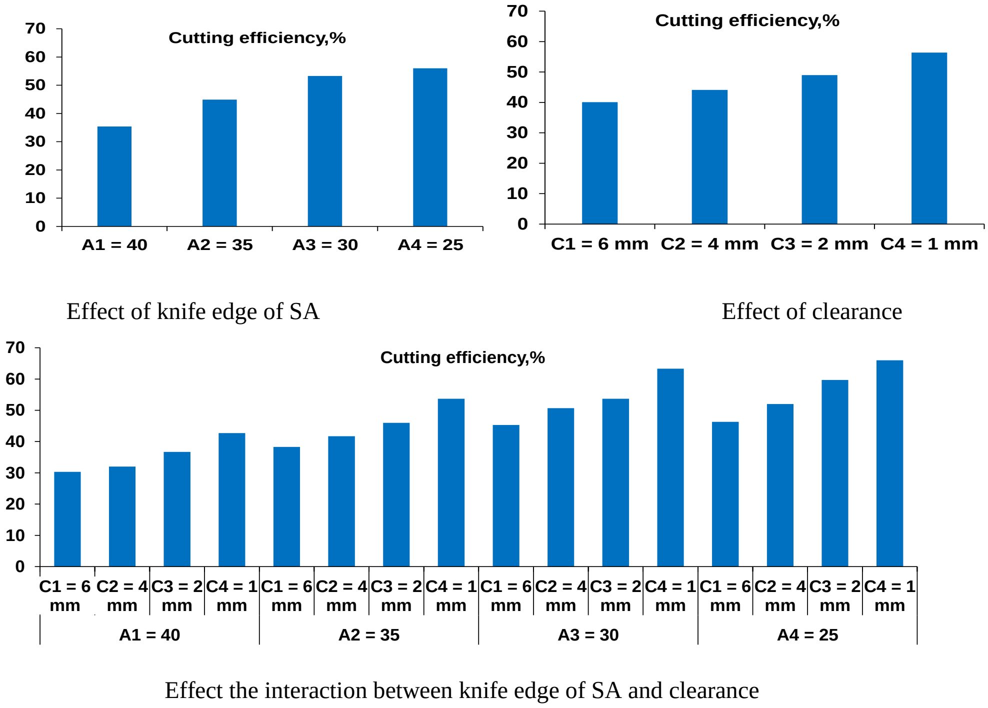


Fig. 7. Effect of knife edge SA and clearance between fixed countershear and the cutting drum on the ηc for palm AWSM. (C: Clearance between the shear rod and the cutting roller; ηc: Cutting Efficiency; AWSM: Agricultural Waste Shredder Machine; SA: Sharp angle; FC: Fuel consumption)

Fig. 8. Effect of knife edge of SA and C between fixed countershear and the cutting drum on the FC for palm AWSM. (C: Clearance between the shear rod and the cutting roller; ηc: Cutting Efficiency; AWSM: Agricultural Waste Shredder Machine; SA: Sharp angle; FC: Fuel consumption)

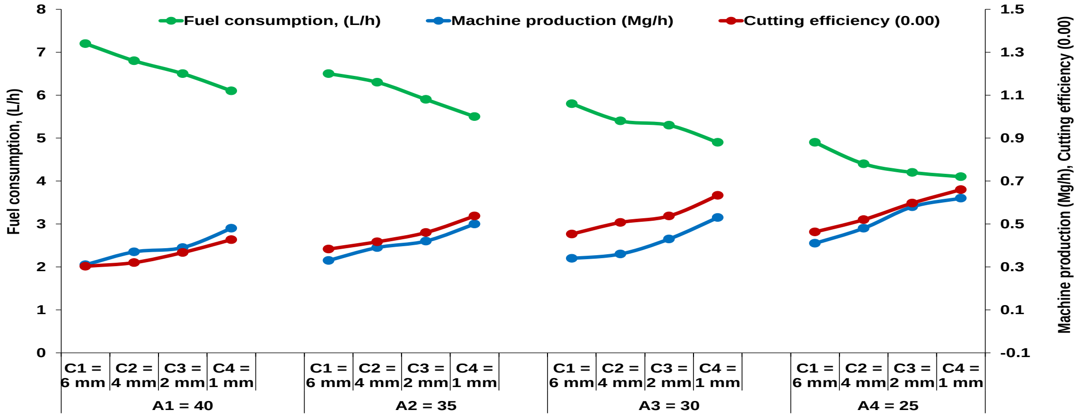


Fig. 9. Effect of knife edge angle (SA) and C between fixed countershear and the cutting drum on the machine production, ηc and FC for palm AWSM. (C: Clearance between the shear rod and the cutting roller; ηc: Cutting Efficiency; AWSM: Agricultural Waste Shredder Machine; SA: Sharp angle; FC: Fuel consumption)

Continuity of high performance palm AWSM by converting the fixed shear bar into a mobile one

After studying the effect of the C distance between the cutting roller and the fixed shear rod, the study concluded that by increasing the C distance, the different values expressing the performance of AWSM decreased significantly. With the fixed shear rod, the C will increase with the increase in the number of operating hours and the number of times the sharp edge of the cutting knives will be sharpened, which will lead to a decrease in the productivity of AWSM and efficiency of the cutting process in addition to an increase in the rate of FC. In order to avoid the aforementioned defects, the idea of converting the fixed shear rod into a movable shear rod was implemented, which had the possibility of adjusting and adjusting it to a lower value with each sharpening process of the sharp edge of the cutting knives, as shown in the results of Figs. (10, 11, 12, and 13).

TABLE 7. Effect of SA and C between fixed countershear and the cutting drum on the machine production, ηc and FC for palm waste cutting machine

Knife edge of SA	Clearance distance	Machine production	ηc, %	FC
SA1 = 40°		0.39	35.4	6.7
SA2 = 35°		0.41	44.9	6.1
SA3 = 30°		0.42	53.3	5.4
SA4 = 25°		0.52	56.0	4.4
LSD at 5%		0.01	1.2	0.1
	C1 = 6 mm	0.35	40.1	6.1
	C2 = 4 mm	0.40	44.1	5.7
	C3 = 2 mm	0.46	49.0	5.5
	C4 = 1 mm	0.53	56.4	5.1
LSD at 5%		0.01	1.5	0.4
SA1 = 40° (Control)	C1 = 6 mm (Con.)	0.31	30.3	7.2
	C2 = 4 mm	0.37	32.0	6.8
	C3 = 2 mm	0.39	36.7	6.5
	C4 = 1 mm	0.48	42.7	6.1
SA2 = 35°	C1 = 6 mm	0.33	38.3	6.5
	C2 = 4 mm	0.39	41.7	6.3

	C3 = 2 mm	0.42	46.0	5.9
	C4 = 1 mm	0.50	53.7	5.5
SA3 = 30^{o}	C1 = 6 mm	0.34	45.3	5.8
	C2 = 4 mm	0.36	50.7	5.4
	C3 = 2 mm	0.43	53.7	5.3
	C4 = 1 mm	0.53	63.3	4.9
SA4 = 25^{o}	C1 = 6 mm	0.41	46.3	4.9
	C2 = 4 mm	0.48	52.0	4.4
	C3 = 2 mm	0.58	59.7	4.2
	C4 = 1 mm	0.62	66.0	4.1
LSD at 5%		0.02	2.9	N.S.

C: Clearance between the shear rod and the cutting roller; ηc: Cutting Efficiency; AWSM: Agricultural Waste Shredder Machine; SA: Sharp angle; FC: Fuel consumption

Increase the shelf life of cutting knives by rinsing both sides of knives instead of rinsing by one

It was noticed through the initial evaluation of AWSM that the cutting knives installed on the cutting rollers are sharpened with a sharp edge on one side only, although they can be chamfered and sharpened on both sides, which will double their life span and reduce costs (Fig. 14).

Impact of the development process on cost reduction

Although the development process did not require additional costs, it made positive differences in reducing the total costs compared to the state of the machine before development.

The rinsing of the cutting knives from both sides instead of one side increased the shelf life, and thus increased the depreciation rate, and consequently reduced fixed costs. The variable costs decreased as a result of the effect of two factors, the first of which is the decrease in FC with the lowest bevel SA, which is 25 degrees, compared to 40 degrees before development.

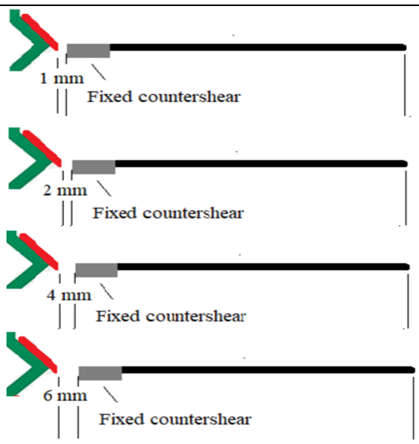
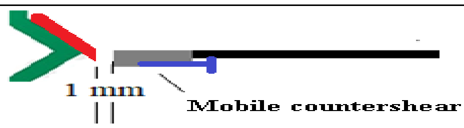
Fixed countershear	**Mobile countershear**
	
The clearance increases with the number of cutting blade edge sharpening, which will contribute to the gradual decrease in the performance of the cutting machine	The possibility of adjusting and moving the clearance distance to a minimum value after each process of sharpening the edge of the cutting knives, which will contribute to the stability of the high performance of the cutting machine

Fig. 10. The difference between fixed countershear and mobile countershear

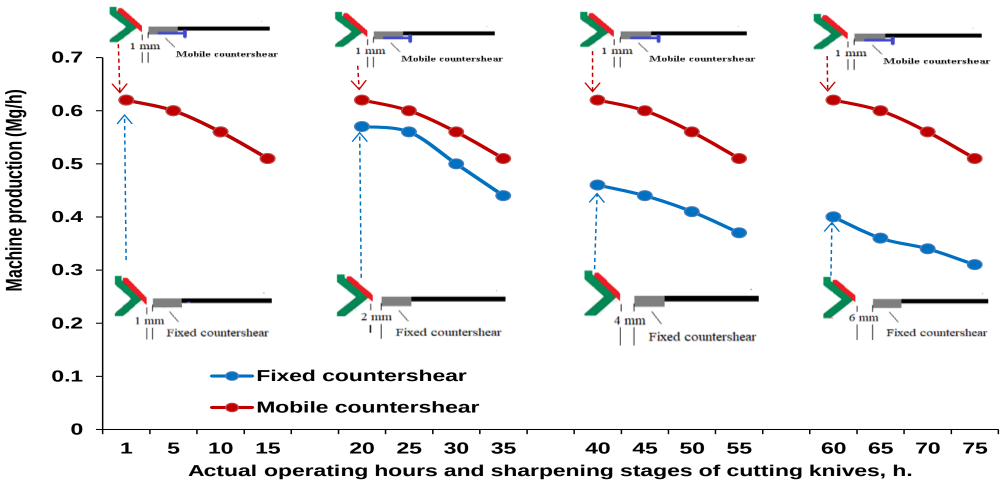


Fig.11. Effect of fixed countershear and mobile countershear on the machine production

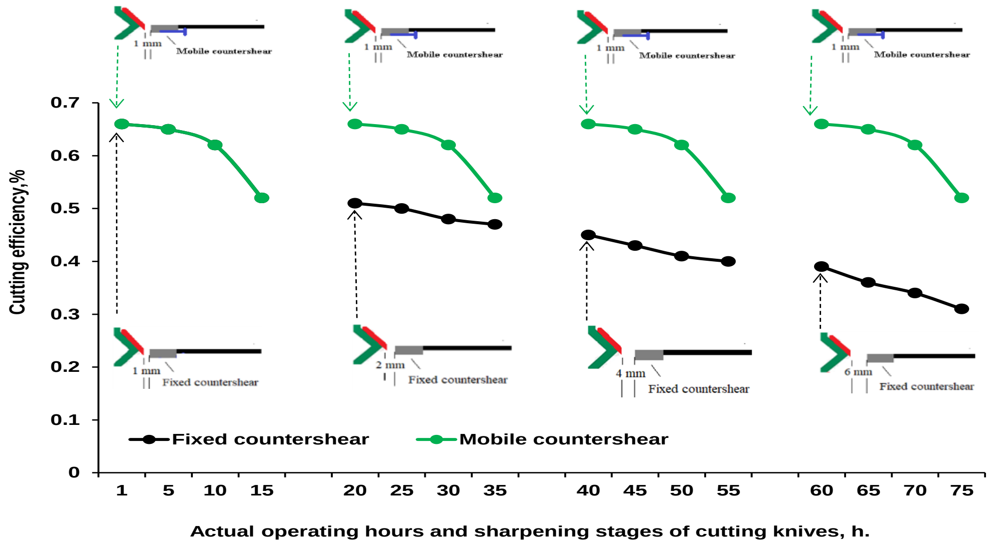


Fig. 12. Effect of fixed countershear and mobile countershear on the ηc

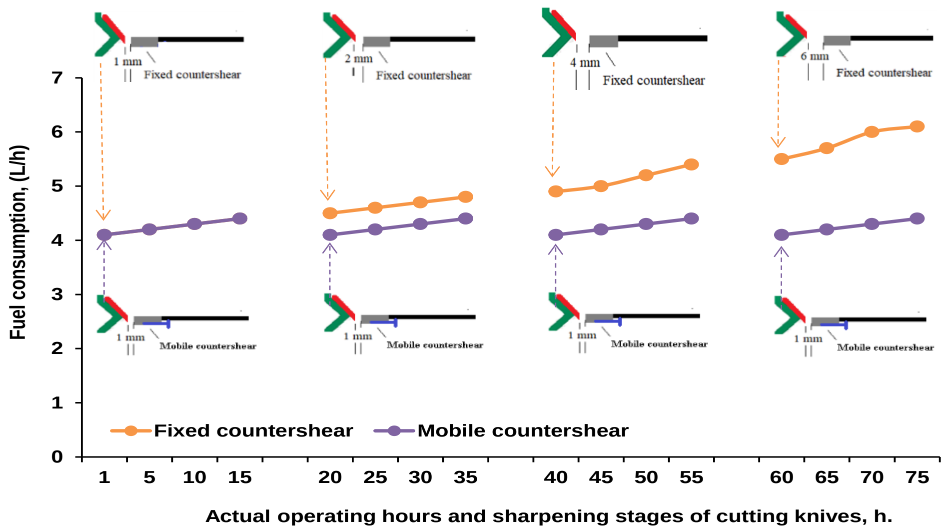
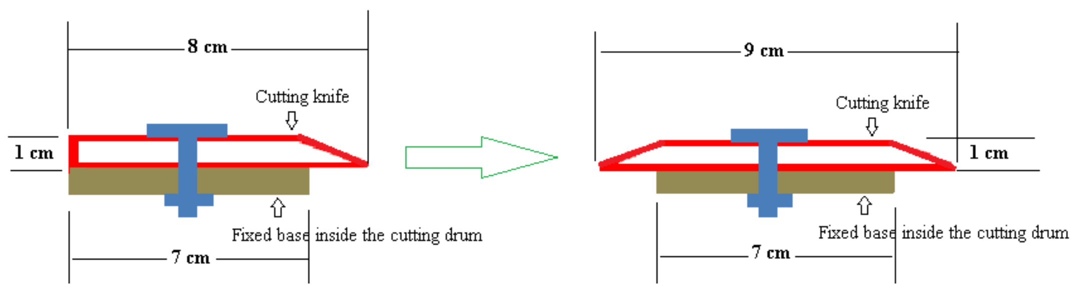


Fig. 13. Effect of fixed countershear and mobile countershear on the FC



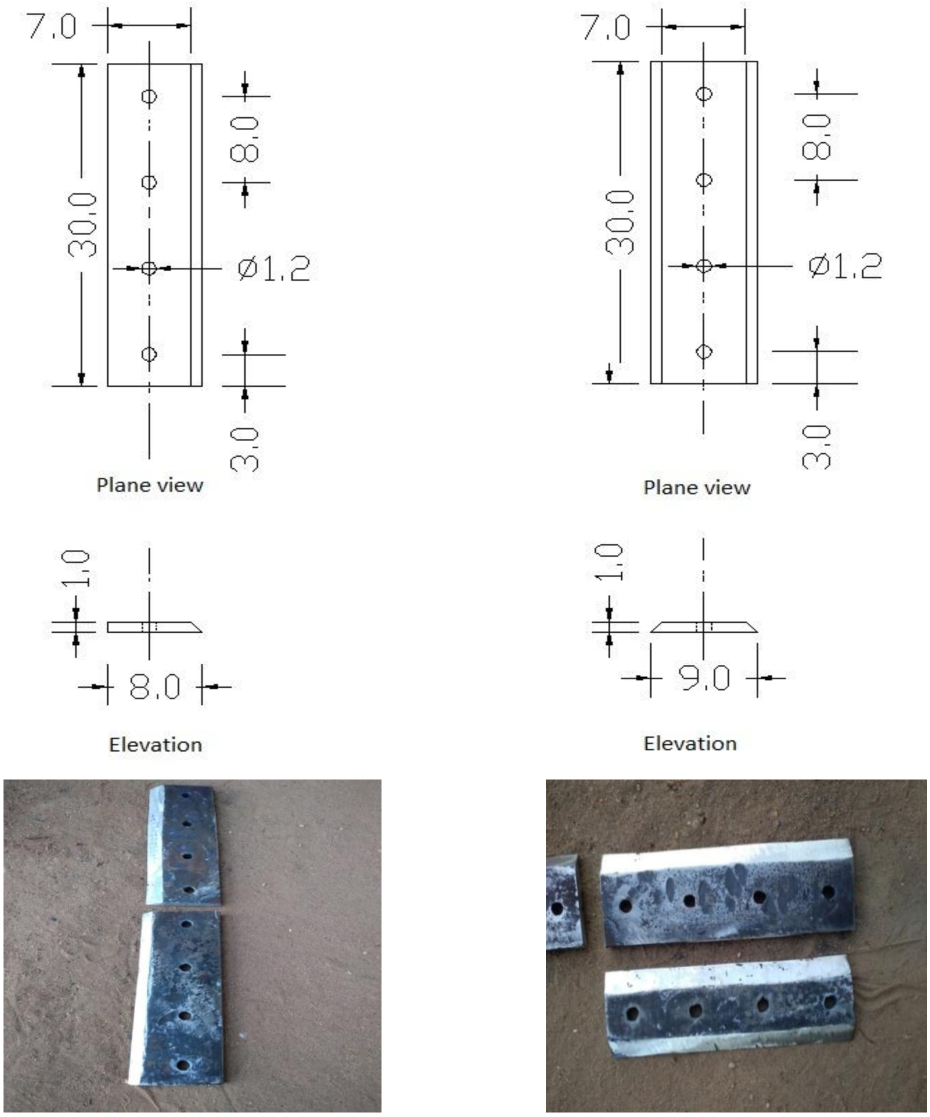


Fig. 14. Sharpen the sharp edge SA of the chopping knives on both sides

The fuel and maintenance costs decreased when relying on the movable shear rod as an economical alternative to the fixed shear rod. Maintaining the minimum C distance between the movable cutting knives and the shear rod has led to a decrease in FC, as all of the above are shown in Table (9).

In the end, there is a decrease in the total cost of the development state, which occurred more than 50% compared to the original knives and the state of the machine before the development.

TABLE 8. Impact of the development process on cost reduction

Shredder specification	Total costs		Before development	After development	Comment and notes
Knife edge SA	Ownership costs	Depreciation			
		Interest			
		TIH			
		Repairs			

	Operating costs	Fuel	40°	25°	Low FC with a smaller bevel SA due to the ease of cutting edge penetration of palm waste
		Lubrication			
		Labor			
C distance	Ownership costs	Depreciation			
		Interest			
		TIH			
	Operating costs	Repairs			
		Fuel	6 mm	1 mm	With the small C, there is no additional bending resistance of the palm waste, which requires more FC when there is a large C, as was the case with the machine before development.
		Lubrication			
		Labor			
Rinsing of the knives	Ownership costs	Depreciation	One side	Both sides	Increased life of double-sided beveled knives compared to single-sided beveled knives
		Interest			
		TIH			
	Operating costs	Repairs			
		Fuel			
		Lubrication			
		Labor			
Countershear shape	Ownership costs	Depreciation			
		Interest			
		TIH			
	Operating costs	Repairs	Fixed shear	Mobile shear	Lower FC and maintenance costs with a mobile shear compared to a fixed shear bar
		Fuel	Fixed shear	Mobile shear	
		Lubrication			
		Labor			

Clearance distance: C between fixed countershear and the cutting drum, TIH: Taxes, Insurance, and Housing

Conclusion

A machine for cutting palm waste was evaluated in order to develop it and treat its defects that reduce its performance. After the initial evaluation process and identification of the defects of the machine, the process of developing and improving the performance was carried out. The highest productivity of the cutting machine, the highest ηc of palm waste, and the lowest FC were achieved with a decrease in the SA of the cutting knives until it reached 25 degrees, which is The lowest SA was tested. The highest productivity of the cutting machine, the highest ηc of palm waste, and the lowest FC were achieved, with a decrease in the C distance between the shear rod and the cutting roller until it reached 1 mm, which is the lowest C distance tested. The highest values of machine performance were achieved when the sharp edge angle (SA) of the cutting knives was 25 degrees with a C of 1 mm. The fixed shear rod was converted into a movable shear rod to maintain the highest performance of the machine over time and adjust the C to the lowest value (1 mm) for each sharp edge operation of the cutting knives. The life span of the cutting knives is increased after sharpening the sharp edge on both sides instead of sharpening on one side only. Improving the mechanical and corrosion properties of cutting knives material were facilitated the optimum sharpening of cutting knives and increased their life span values.

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