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Determination of Some Engineering Properties of Siwi Palm Fronds for designing a Leaflets Separation Machine

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A PROTOTYPE design for a palm leaflets separation machine was proposed based on the most important measured engineering properties of Siwi palm fronds. Three commercial date palm plantations randomly were selected in Assiut Governorate and the cities of Dakhla and Kharga in the New Valley Governorate. The palm plantations are called: 1. Al-Sharif farm in the Assiut Valley, New Assiut City; 2. Al-Ashwal farm in Al-Kharga city and 3. Al-Hindao farm in the Al-Dakhla city. Cultivars in the three farms were Siwi (Saidi). Field measurements were carried out during November and December 2021 and 2022 seasons. The results showed that the mass of individual fronds ranged from 2.2 to 3.27 kg with a mean value ± SD was 2.76 ± 0.23 kg. The mass of individual midrib ranged from 1.6 to 2.4 kg with a mean value of 2 ± 0.18 kg. The percentage of leaflets and midribs ranged from 25.91 to 27.52 and 72.73 to 73.39 % and the mean values were 27.49 ± 0.65 and 72.51 ± 0.18 %, respectively. Cutting force at the blade sharp 15° ranged from 191.3 to 284.35 kg, while cutting force at the blade angle 45° ranged from 328.27 to 492.6 kg. The cutting force increased by increasing the blade sharpening angle at all positions of midribs.

Keywords: Mechanical processing, Pruning products, Leaflets separating, Siwi palm, Separator.

Introduction

1

The Noble Qur'anic verses indicate the high status of palm trees among the rest of the trees that were mentioned more than once in the Noble Qur'anic verses. The date palm has been honored in the heavenly books and the Prophetic hadiths. It is a blessed tree. Man has worked to cultivate it since ancient times. It is the basic food for desert dwellers. Therefore, attention must be paid to serving and preserving it and conducting many research studies to strengthen the industries based on it **(Ahmed et al., 2024)**. Perhaps one of the most important goals of sustainable development for developing countries is to enhance the utilization of renewable energy sources in all sectors in general and the agricultural sector in particular **(Elkaoud et al., 2024)**. Egypt occupies first place in the world in date production, with a productivity of up to one million seven hundred thousand tons annually, as Egypt is the first in date production in the world, equivalent to about 18% of global production, and it is distributed in Siwa, the Bahariya Oasis, the New Valley, and Aswan, because Egypt It has a wealth of palm trees

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estimated at 15 million fruitful palm trees, in addition to the largest date farm in the world, which was established on an area of 40 thousand acres and includes 2.5 million palm trees, making Egypt one of the first countries in the world to produce and export of dates in the world **(Adm et al., 2023)**. The date palm is the source of a wide range of products and services, including many necessities of life. The primary product of the date palm is fruit, which is rich in protein, vitamins, and mineral salts. All secondary palm products resulting from annual pruning have essential uses for the cultivator. **Bekheet and El-Sharabasy, (2015)** reported that the western part of Egypt, from the Nile to the Libyan frontier, is occupied by a vast desert plateau. It is cut, from the southeast to northwest, by a succession of depressions called the New Valley. In this valley, various oases are located that are, namely, from north to south: Siwa, Bahariya, Farafra, Dakla, Kharga, and Fayoum. The Siwi cultivar is considered one of the most important and most numerous date palm cultivars grown in Egypt. The total number of productive Siwi cultivar date palms is estimated at 1,822,419 female trees. **Sharabasy and Ghazzawy, (2022)** indicated that the date palm has a value of great importance, which makes it one of the most critical major economic crops, as it has many uses that vary between food and industry, as the industrial processes based on this crop vary, starting from the exploitation of the fruits in various manufacturing processes and through the exploitation of the seeds are used to make coffee, also use the palm stalk in the work of the ceiling, and cellulose is extracted from the leaves, leaves have particular importance in making shades and roofs. **Jonoobi et al., (2019)** said that date palm leaves are important natural sources of fibers where that can be used as an input for many industrial applications in almost all fields date palm fronds are abundant, renewable, and environmentally friendly, as they are considered agricultural waste that is often burned or discarded. Utilizing date palm leaves can provide economic and environmental benefits by converting this waste into value-added products. **Zaid and De Wet (2002a)** mention that palm trees are a type of evergreen plant belonging to the Arecaceae family. Its scientific name is Phoenix dactylifera L. It is a large palm tree, 15 to 30 m high, with a cylindrical stipe (often called trunks or stems) these stems are covered with fibers and mesh, bearing a crown of leaves (fronds). The leaves are 4 to 6 m long, pinnate, divided into leaflets, and inserted on the stipe through a large petiole. The leaflets are lanceolate, with sharp tips and induplicate (V-shaped) folding, the basal leaflets being reduced to spines. The axes (midrib) of date palm leaves are 3-6 m in length depending upon age and variety. The midrib is broad at its base but rapidly narrows towards the apex of the leaf. The leaflets are 15-100 cm in length and 1–6 cm in width, depending upon age and variety, and number between 120 and 240 per frond. **Latibari et al. (1996)** estimated the different parts of a date palm tree branch and their approximate weight as shown in Table (1).

Table 1. Different parts of a date palm tree branch (Latibari *et al.*, 1996).

Parts	Weight (Kg.)	% of the total branch weight	% of total residues from each tree
Midrib	5.4	30	15.88
Rachis	7.8	43.33	22.94
Leaflet	4.8	26.67	14.12
Total	18	100	53

Depending on the variety, age of a palm, and environmental conditions, the leaves of a date palm are 3 to 6 m long (4 m average) and have a normal life of 3 to 7 years. The palm leaf is divided into three regions: the petiole, the spinal region that transitions into the blade region that is held by a geometrically shaped midrib. Angular leaflets are distributed in the blade region (Fig. 1). The number of leaves produced annually varies from 10 to 26 and a mature palm may have from 100 to 125 leaves. Each leaf is formed with about 150 leaflets; the leaflets are 30 cm long and 2 cm wide. Leaf structure is variety and environment-dependent, but usually, the whole length of a frond has the following proportions: the distance from the fib*er* at the base of the frond to the base of the spine-leaflets is about 28 % of the whole frond; the spine-leaflets occupy about 4 %; the leaflets occupy about 62 %; and the terminal leaflets occupy about 6 %. **(Zaid and de Wet 2002)**.

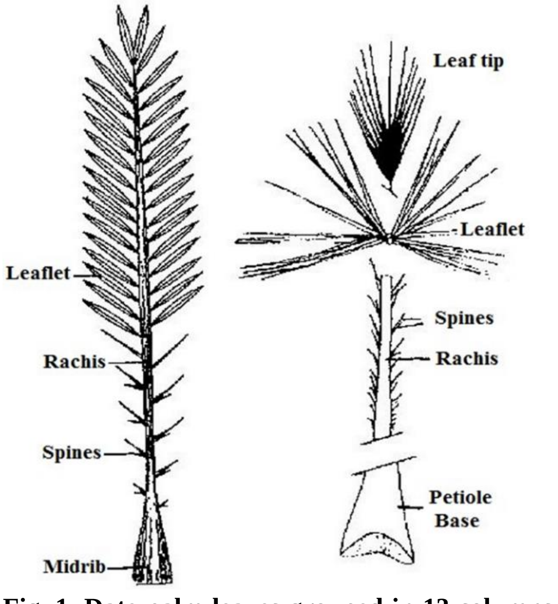

Fig. 1. Date palm leaves grouped in 13 columns, spiraling to the right or the left according to Zaid and de Wet (2002).

A date palm annually produces approximately 20 kg of leaves, every year under normal growth conditions an average of 12 to 15 new leaves are formed by the palm and consequently, the same amount can be expected to be cut as part of the maintenance of the palm **(FAO, 2010)**. Date palm leaves, called fronds, are pinnate, compound leaves spirally arranged around the trunk. the date palm frond consists of two main parts: rachis and leaflets **(Zayed et al., 2014)**. The annual formation is 10 to 26 new leaves. These leaves vary in length and weight. The length of fronds is typically 3 to 6m (4m average) and has a normal life expectancy of 3 to 7 years, almost falling or trimming. The color of a frond varies between the shades of green. Fronds are strong, tough, and crooked **(Eldeeb, 2017)**. **Alabdali, et al., (2023)** noted that fronds and mesh (Fig. 2) represent a high part of the residue from the date palm pruning process and are available throughout the year. Little can be found in the literature about the use of midribs compared to the use of mesh since the mesh is already in fiber form and does not require a lengthy extraction process.

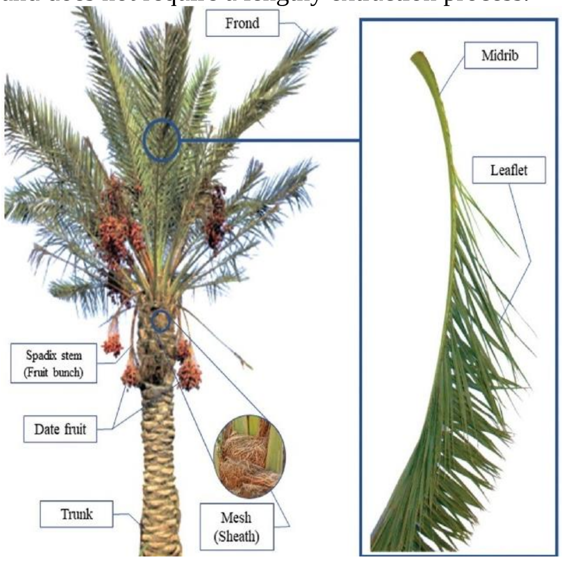

Fig. 2. Date palm tree parts. According to Alabdali, *et al.*, (2023).

The Siwi cultivar (Fig. 3) considered one of Egypt's top cultivars of semi-dry dates. It is one of the most widespread cultivars in most of palm plantations.

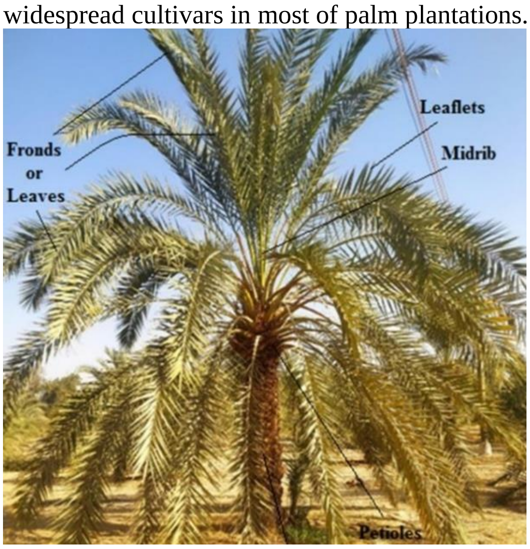

Fig. 3. Siwi (Saeedi) palm trees with pruning products According to Ahmed, *et al.*, (2024).

Accordingly, this study aimed to determination of some physical and mechanical properties of the most important pruning products which can be considered a cornerstone for designing advanced technology for mechanical processing. In addition to employing the data obtained to propose a prototype design for the leaflets separator.

Materials and Methods:

Physical and mechanical properties of the fronds were measured immediately after the pruning process and the moisture content was recorded. The measured samples were randomly selected from three commercial date palm plantations. The palm plantations are Al-Sharif farm in the Assiut Valley, New Assiut City; Al-Ashwal farm in Al-Kharga city and Al-Hindao farm in the Al-Dakhla city. Cultivars in the three farms were Siwi (Saidi). Some properties of fronds were determined by the existing moisture contents. The moisture contents were determined and recorded. Palm fronds are feather-shaped green leaves. The complete frond includes two main components, as shown in (Fig. 4) the leaflets and the midrib. Although these components are present on the same leaf, they can have a variety of textures and engineering properties. Therefore, the methods of handling and utilizing these components will differ.

Fig. 4. Fronds or palm leaves.

Palm midribs

The palm midrib is the middle part of the palm frond after separating the leaflets as shown in (Fig. 5).

Fig. 5. Siwi palm midrib.

The leaflets

The leaflets are distributed along the midrib in a feather-like shape. Length is a maximum longitudinal dimension, and the width is the largest possible width of the leaflet as shown in (Fig. 6).

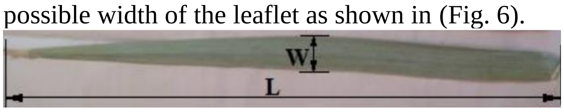

Fig. 6. The axial dimensions of the leaflets.

Leaflet was separated manually to measure some important engineering properties. This process is often done using a sharp knife, as shown in (Fig. 7).


Fig. 7. The leaflets were separated manually.

Mass of fronds, midrib and leaflets

To determine the mass of individual fronds or palm leaves ("M_f", in kg) 100 were randomly selected and weighed separately using a digital electronic platform scale with an accuracy of 1g. Also, in the same way, random samples of midribs and leaflets were selected to determine the mass of individual midrib ("M_m", in kg), total leaflets per one frond ("M_{Lt}", in kg), and the mass of individual leaflet ("M_L", in g).

Percentages of leaf parts

100 palm leaves were randomly selected, and masses of individual leaflets were determined using a digital electronic platform scale with an accuracy of 1g as shown in (Fig. 8).

Fig. 8. Weight of leaflets removed from one palm leaf.

The leaflets were weighed to determine the percentage of leaf parts (%, by wt.) from leaflets and midribs to whole leaves as shown in the following equations:

$$\text{Leaflets, (\%, wt)} = \frac{\text{Leaflets mass}}{\text{Mass of leaf}} \times 100 \ldots\ldots (1)$$

$$\text{Leaflets} = \frac{\text{Leaf mass} - \text{Leaflets mass}}{\text{Mass of leaf}} \times 100 \ldots\ldots (2)$$

Required force to remove the leaflets from the midrib

The cohesion force of the leaflets to the midrib varies depending on the position of the leaflets on the midrib therefore, the required force to remove the leaflets varies from one place to another on the midrib. so, the frond was divided into bottom, middle, and top zones. 100 palm leaves were randomly selected, and the data of each frond was recorded. The required force was determined using a digital electronic balance with an accuracy of 0.1g as shown in (Fig. 9). The balance was connected to the leaflet using a thin wire and pulled the leaflet toward the bottom of the midrib, the device held the force peak value when each leaflet was removed.

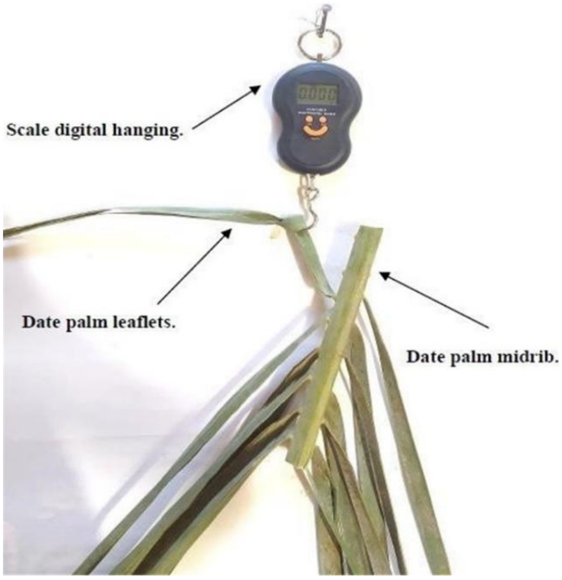

Fig. 9. Required force to remove the leaflets from the midrib.

Axial dimensions and cross-section of palm midribs

A digital Vernier caliper with an accuracy of 0.01 mm and tape were used to measure the axial dimensions of randomly selected 100 palm midribs after the leaflets were manually removed. The axial dimensions and cross sections were named according to their position on the midrib and only the cross-section of B for the top, middle, and bottom parts was drawn as an illustrative example as shown in (Fig. 10).

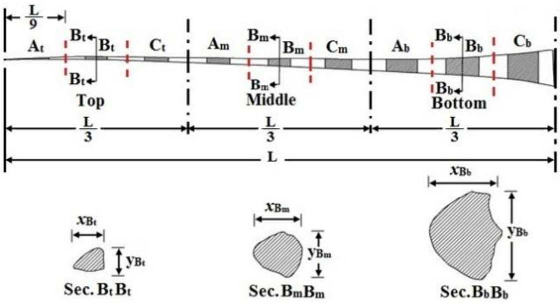

Fig. 10. The axial dimensions and cross-sections of the midrib.

The total length of the midrib (L) was divided into three main parts (Top, middle, and bottom). Each part was divided into three sub-parts (A, B, and C). At the center of each sub-part, a cross-section was drawn, and axial dimensions were determined. The axial dimensions of the midrib are namely thickness “x, in mm” (Indicates the thickness of the midrib), width “y, in mm” (Indicates the width of the midrib). Table (2) shows details of the axial dimensions and cross-sections of the midrib.

Table 2. Details of the axial dimensions and cross-sections of the midrib.

Cross-sections	Axes	Identification
Sec. A_tA_t	xAt	Sub-part thickness (A) of the top part
	yAt	Sub-part width (A) of the top part
Sec. B_tB_t	xBt	Sub-part thickness (B) of the top part
	yBt	Sub-part width (B) of the top part
Sec. C_tC_t	xCt	Sub-part thickness (C) of the top part
	yCt	Sub-part width (C) of the top part
Sec. A_mA_m	xAm	Sub-part thickness (A) of the middle
	yAm	Sub-part width (A) of the middle
Sec. B_mB_m	xBm	Sub-part thickness (B) of the middle
	yBm	Sub-part width (B) of the middle
Sec. C_mC_m	xCm	Sub-part thickness (C) of the middle
	yCm	Sub-part width (C) of the middle
Sec. A_bA_b	xAb	Sub-part thickness (A) of the bottom
	yAb	Sub-part width (A) of the bottom
Sec. B_bB_b	xBb	Sub-part thickness (B) of the bottom
	yBb	Sub-part width (B) of the bottom
Sec. C_bC_b	xCb	Sub-part thickness (C) of the bottom
	yCb	Sub-part width (C) of the bottom

Projected area for cross-sections of palm midribs and leaflets

The cross-sections and leaflets were scanned to capture the image of midrib sections at a natural flat position by mobile camera (Xiaomi Redmi Note8, 48 megapixels). The images were exported and analyzed using the ImageJ program to calculate the projected area (A_P, “mm^2”) as shown in (Fig 11).

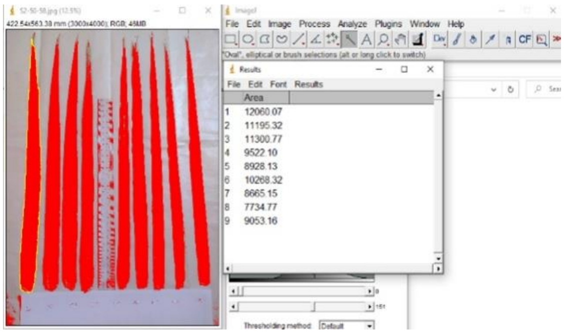

Fig. 11. Projected area of the leaflets using the ImageJ program.

Cutting force at cross-sectional positions

The cutting force required at cross-sectional positions (shown above) of midribs was measured by using a digital universal material tester as shown in (Fig. 12). Laboratory tests were carried out in the Faculty of Agricultural Engineering, Al-Azhar University, Cairo, Egypt. The midrib samples dimensions x (thickness) and y (width) were measured by a digital Vernier caliper with an accuracy of 0.01 mm. Then, cutting force was applied to the midrib samples by the cutting blades. The blade was fixed at the crosshead of the compression material tester. The maximum cutting force that appeared on the digital screen, which led to cutting the sample in half, was recorded.

Fig. 12. Universal material tester during the cutting force measurement.

Three sharpening angles of cutting blades of 15, 30, and 45° (single bevel) were used in this test with perfectly straight, smooth surface edges, fabricated in the workshop Faculty of Engineering of Assiut University, Assiut, Egypt by using material structure stainless steel (Grade 304). The dimensions of these blades are 100 mm in height, 75 mm in width, and 1.5 of thickness. (Fig. 13) shows the schematic diagram of the cutting blades. The blades are sharpened after each set of experiments.

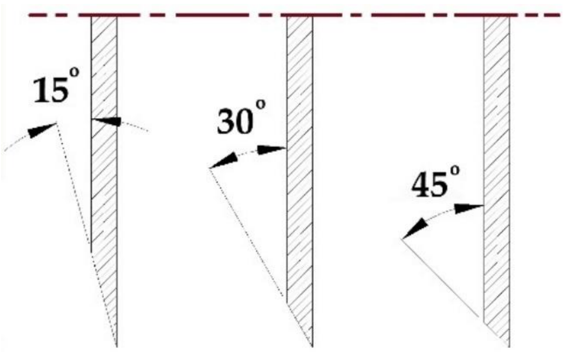

Fig. 13. Cross section of cutting blades.

Axial dimensions of leaflets

A digital Vernier-caliper with an accuracy of 0.01 mm and tape were used to measure cross sections and the axial dimensions of randomly selected 100 palm leaflets. The axial dimensions of the leaflets were length (L) and width (W).

Results and Discussion

The data shown in Table (3) indicates the summary of the physical properties of the pruning products.

Table 3. Physical and mechanical properties of date palm fronds.

Properties	Min.	Max.	Mean	SD	CV.
M_f, kg	2.2	3.27	2.76	0.2	8.2
M_m, kg	1.6	2.40	2.00	0.1	9.2
M_{Lt}, kg	0.57	0.9	0.76	0.1	8.6
M_L, g	4.05	5.00	4.47	0.2	5.5
F_L, cm	340	412	373	17	4.7
L, mm	270	470	399.4	40	10
W, mm	20	48	35.68	6.7	19
xAt, mm	7	13	10.1	1.8	17
yAt, mm	5	8	6.0	0.8	13
xBt, mm	9	16	12.6	6.4	50
yBt, mm	6	9	7.5	3.6	48
xCt, mm	12	19	15.2	1.8	11
yCt, mm	8	13	10.5	1.2	11
xAm, mm	14	22	17.9	1.6	9.1
yAm,mm	11	17	14.6	1.5	10
xBm,mm	19	22	21.2	10	50
yBm,mm	17	21	18.4	9	49
xCm, mm	22	26	23.7	0.9	4.1
yCm, mm	20	26	23.0	1.2	5.2
xAb, mm	24	29	26.5	1.3	4.8
yAb, mm	24	31	27.5	1.6	5.9
xBb, mm	26	33	29.4	13	47.
yBb, mm	30	36	34.6	16	46.
xCb, mm	30	38	33.3	1.5	4.6
yCb, mm	34	41	38.9	1.2	3.1

Fronds mass

The results showed that the mass of individual fronds or palm leaves ("M_f", in g) ranged from 2.20 to 3.27 kg with a mean value ± SD was 2.76 ± 0.23 kg.

Percentages of leaf parts

(Fig. 14) shows the percentage of leaf parts (%, by wt.) from leaflets and midribs to whole leaves.

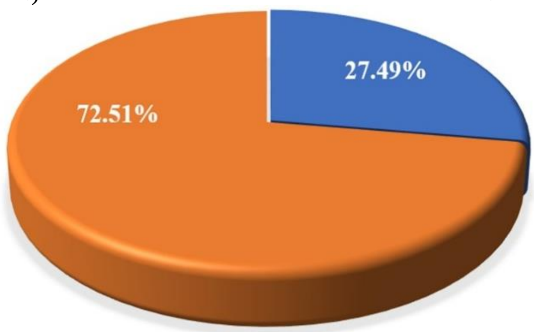

Fig. 14. Percentages of leaf parts (%, by wt.)

The percentage of leaflets and midribs ranged from 25.91 to 27.52 and 72.73 to 73.39 % and the mean values were 27.49 ± 0.65 and 72.51 ± 0.18 %, respectively. These results may help in determining the percentage of leaf parts (%, by wt.) from leaflets and midribs to whole leaves using the following equation:

$$\text{Leaflets}, (\%, \text{wt}) = 0.2749 \ \ \text{Mass of Leaf} \ldots \ldots. (3)$$

$$\text{Midrib} \ (\%, \text{wt}) = 0.7251 \ \ \text{Mass of Leaf} \ldots \ldots \ldots (4)$$

Required force to remove the leaflets from the midrib

Fig. (15) shows the force measured to remove leaflets from the midrib at all fronds. The bottom area of the frond included older leaflets that were found difficult to remove, so it requires a force higher than the top area (younger leaflets). The maximum forces required to remove the leaflets from the frond were 4.75 kg, 3.5 kg, and 2.6 kg for the lower, middle, and upper frond, respectively.

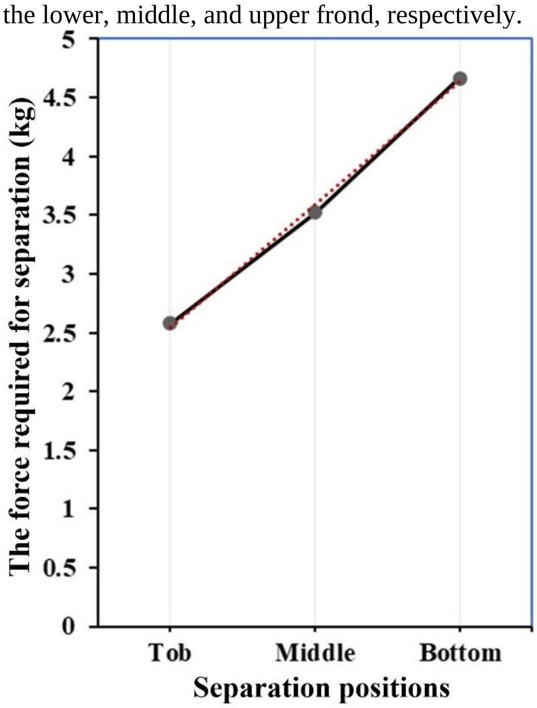

Fig. 15. Force measured to remove leaflets from midrib at all frond positions.

Palm midribs mass

From Fig. 16 and Table (3), these results showed that the mass of individual midrib (“M_m”, in kg) ranged from 1.6 to 2.4 kg with a mean value of 2 ± 0.18 kg.

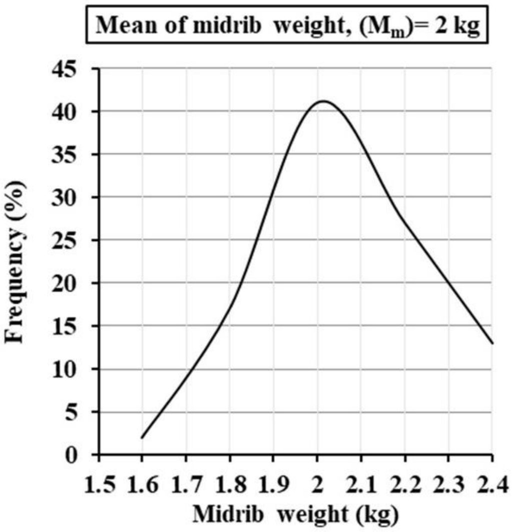

Fig. 16. Frequency distribution curve of the mass of individual midrib (“M_m”, in kg)

Projected area of midrib cross-sections

Average projected area of the midrib ranged from 54 to 68 mm^2, 260 to 385 mm^2 ,560 to 910 mm^2 at the top, middle and bottom, respectively.

Cutting force at cross-sectional positions

The cutting force is not a constant value, but it varies according to the conditions of the cutting process, the position of cutting and blade sharpening angle are the most important factors that affect the cutting force required for midribs. Average moisture contents were 57.2, 54.3, and 53.3% at the base, the middle and top, respectively.

At the top of midrib

Fig. 17. shows the effect of blade sharpening angle on average cutting blade sharp.

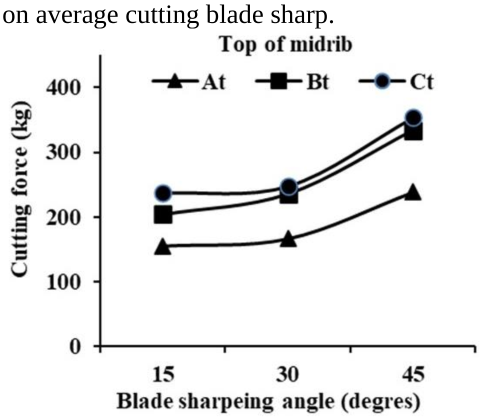

Fig. 17. Effect of blade sharpening angle on average cutting blade sharp at midrib top.

Cutting force at the blade sharp 15º ranged from 155.27 to 237.11 kg, while cutting force at the blade angle 45º ranged from 238.6 to 353.7 kg.

At the middle of midrib

Fig. 18. shows the effect of blade sharpening angle on average cutting blade sharp.

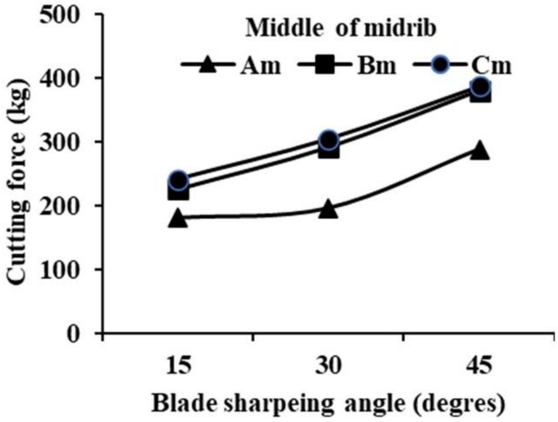

Fig. 18. Effect of blade sharpening angle on average cutting blade sharp at midrib middle.

Cutting force at the blade sharp 15º ranged from 180.27 to 241.12 kg, while cutting force at the blade angle 45º ranged from 287.4 to 386.69 kg.

At the bottom of midrib

Fig. 19. shows the effect of blade sharpening angle on average cutting blade sharp.

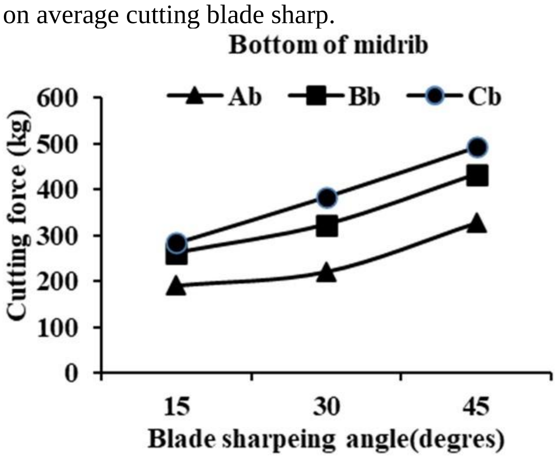

Fig. 19. Effect of blade sharpening angle on average cutting blade sharp at midrib bottom.

Cutting force at the blade sharp 15º ranged from 191.3 to 284.35 kg, while cutting force at the blade angle 45º ranged from 328.27 to 492.6 kg.

The results indicated that the cutting force increased by increasing the blade sharpening angle at all positions of Midribs. This may be due to the increased force required to overcome the lateral friction force with the large blade sharpening angle during the cutting process. Therefore, it is recommended to use sharp cutting angles when designing mechanical processing elements for grinding machines.

Relationship between cutting force and cross-sectional area at the three angles of cutting blades

Fig. 20. shows the relationship between cutting force and cross-sectional area at three sharpening angles of cutting blades of 15, 30, and 45°.

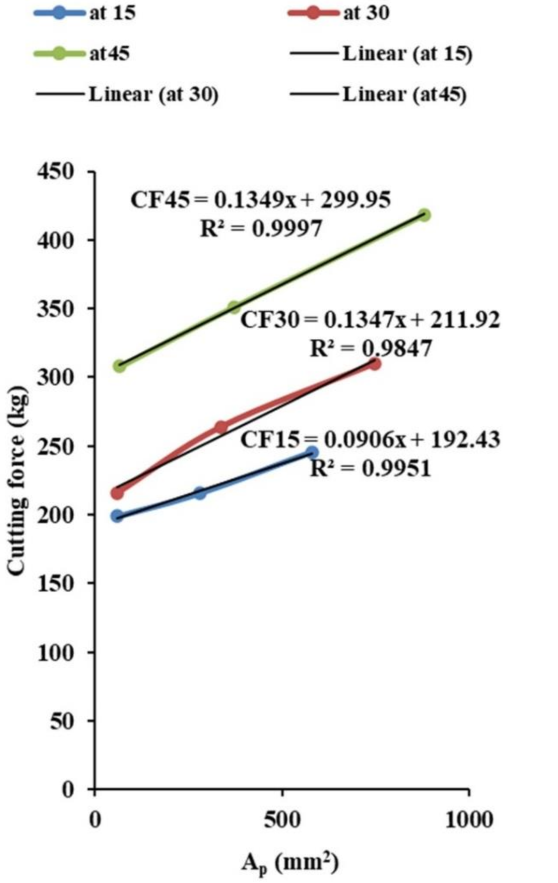

Fig. 20. Relationship between cutting force and cross-sectional area at the three angles of cutting blades.

These results indicated that the cutting force increase from 198.8 to 245.77 kg at increase cross-sectional area from 59 to 580 mm^2 under blade sharp angle 15^o. The cutting force can be estimated from the following equation:

$$C_{f_{15}} = 0.0906Ap + 192.43 \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Also, the cutting force increase from 216 to 310 kg at increase cross-sectional area from 60 to 748 mm^2 under blade sharp angle 30^o the cutting force can be estimated from the following equation:

$$C_{f_{30}} = 0.1347\,Ap + 211.92 \quad \ldots\ldots\ldots\ldots\ldots (6)$$

While the cutting force increase from 308 to 418 kg at increase cross-sectional area from 65 to 808 mm^2 under blade sharp angle 30^o the cutting force can be estimated from the following equation:

$$C_{f_{45}} = 0.1349Ap + 299.95 \ldots\ldots\ldots\ldots\ldots (7)$$

Leaflets mass and axial dimensions

The mass of an individual leaflet ranged from 4.05 to 5 g with a mean value of 4.47 ± 0.25 g. The results showed that the width of leaflets ranged from 20 to 48 mm with a mean value of 35.68 ± 6.78 mm. The length of leaflets ranged from 270 to 470 mm with a mean value of 399.4 ± 40.8 mm.

Projected area of the leaflets

The projected area of the leaflets ranged from 7282 to 22680 mm^2 with a mean value of 15545± 3781 mm^2. Fig. 21. shows the relationship between the largest length and largest width (L×W) and the projected area.

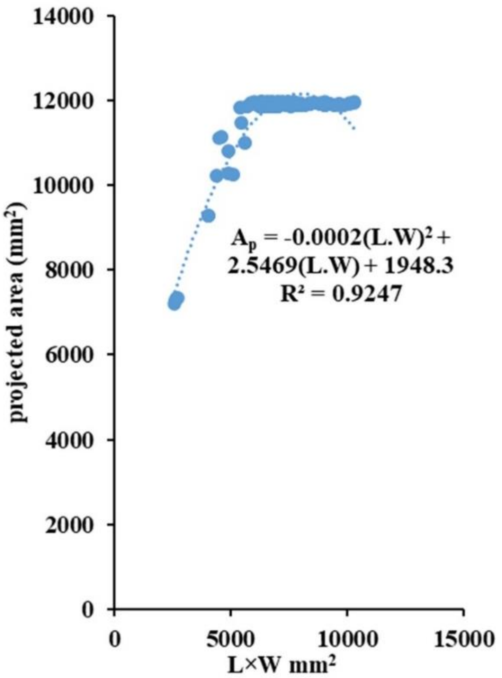

Fig. 21. Relationship between the largest length and largest width (L×W) and the projected area.

The projected area of the leaflets can be estimated by knowing the largest length and largest width of the leaf from the following equation:

$$\mathbf{Ap = -0.0002(L.W)2 + 2.5469(L.W) + 1948.3 \ldots\ldots\ldots\ldots\ldots (8)}$$

Proposed design for the Leaflets Separation Machine

Fig. 22. shows proposed design for the leaflets separating machine. The machine consists of a frame, a gasoline or electric engine power source, cleaning elements, a feed inlet and feed rollers. The effective mechanical elements of the machine are cleaning rollers. These rollers contain a dense metal brush. The brushes are braided and interlocked. The leaflets separating machine's working theory is based on the presence of two feeding rollers at the front of the feed inlet. The rollers force the frond to pass between the cleaning rollers. The cleaning rollers rotate in the opposite direction of the frond inlet. The engineering properties of the leaflets vary from the palm midrib, although they are on the same of the frond. Therefore, separating the palm leaflets

from the frond will enhance the benefit of each of them separately. Mechanical processing is most appropriate for the ease of handling palm fronds, and this is congruence with Elkaoud, (2020) the mechanical processing of agricultural waste (Wood residues from trees branches and manufacture of furniture) is considered the best primary method (Eco-friendly) through converting these wastes into biomass energy.

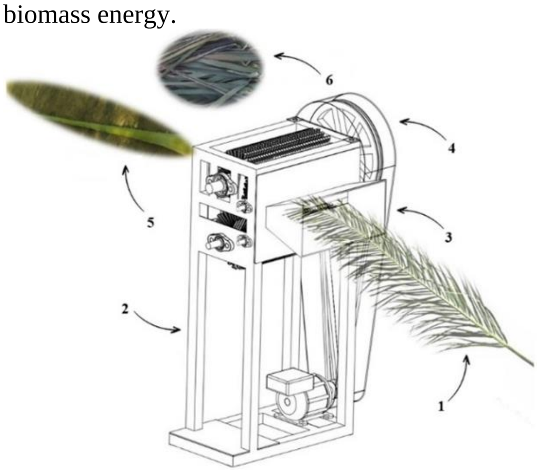

Fig. 22. Proposed design for the leaflets separating machine: 1- Frond, 2- Frame, 3- Feed inlet, 4- Transmission system means, and 5- Midrib, 6- Leaflets.

Conclusion

To design a mechanical processing machine for palm fronds, the most important engineering factors that affect the performance of the machine must be determined. In this study, a prototype design for a palm leaflets separation machine was proposed based on the most important measured engineering properties. It is recommended to design this type of machine that enhances the efficiency of utilizing palm tree waste, especially fronds. There is an urgent need for palm farms to create a suitable technology for easy handling of palm tree waste, especially fronds.

Consent for publication:
All authors declare their consent for publication.

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The manuscript was edited and revised by all authors.

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The author declares no conflict of interest.

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