Mechanical processing of banana slices-stem for fiber extraction

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Abstract: This research aimed to manufacture a simple fiber extraction machine. The machine prototype consisted of available raw materials. The beater cylinder is the most significant component in this machine. The electric motor of 0.75 kW was used to rotate the beater cylinder. The machine theory is based on the repeated rapid beating of the beaters on a slice-stem of banana. This beating simulated what labor does by using hand hammers to eliminate the juice and extract the fibers. The machine was tested under three rotational speeds of the beater cylinder 650, 750, and 850 rpm and using three beater cylinders with a different number of beaters 8, 10, and 12. The fibers produced by the machine were straight, of good quality, and not shredded, this was achieved in abundance when using the cylinder that has 10 beaters with 750 rpm rotational speeds of the beater cylinder. Thus, under these operating conditions, the extraction efficiency, the time required, and machine productivity were 88%, 40 min, and 8.6 kg h^{-1}, respectively. The minimum value of the power required was 0.45 kW at the rotational speed of 650 rpm and using the eight beaters. While the maximum value of the power required was 0.64 kW at the rotational speed of 850 rpm and using the number of beaters 12. At the machine productivity of 8.6 kg h^{-1}, the production cost will be 2.7 L.E. kg^{-1}. While the costs of manual extraction of the fibers were 10 L.E. kg^{-1}.

Keywords: banana fiber, banana residues, mechanical extraction

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1 Introduction

Despite the challenges faced by Egypt related to the water issue, bananas (*Musa paradisiaca*) have great economic importance, and the cultivated area is expanding annually. At present, the total area used for fruit cultivation in Egypt is about 700,854 hectares (Elkaoud and Mahmoud, 2022). Banana production is the fifth largest fruit crop in Egypt after citrus, mangoes, olives, and grapes. The most grown varieties are Williams, Grandnain, and Maghrabi (El-Shereif and Abou Elyazid, 2016). The total cultivated area of bananas in Egypt is estimated at about 30,389 hectares, with a total annual production of 1,359,297 tons according to FAO (2019). The top ten producers of bananas are India, China, Indonesia, Brazil, Ecuador, Philippines, Guatemala, Angola, Tanzania, and Colombia. The climate of Egypt is suitable for banana cultivation (Helaly et al., 2022). Within a group of 98 producing countries, Egypt ranked 18th in 2020 (Helgi Analytics, 2020). After the fruit is obtained from banana plants, the plant is thrown away

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giving rise to an increase in waste. Billion tons of stems and leaves are thrown away annually. Banana fiber is extracted from leftover banana stems, with aim of maximizing the utilization of waste and reducing the environmental pollution resulting from burning it, also obtaining a large amount of fiber which represents additional income for the farmer. The stem sheath is divided into circular layers along the stem that contain the inner fibers, and banana fibers are natural cellulose fibers, and it has many properties that make them fine-quality fibers. Natural fibers possess several advantages over synthetic fibers such as low density, appropriate stiffness, mechanical properties, and high dispensability and renewability. Also, they are recyclable and biodegradable. One characteristic of the banana stem and pineapple leaf fiber over all other fibers of its class is the great strength and resistance to the action of water, therefore its adaptability for marine ropes (Majlish, 2020). Praful and Lanjewar (2017) mentioned that the natural fibers are obtained from natural sources, these fibers have high specific properties with low density, they are eco-friendly unlike synthetic fibers because they are biodegradable and non-abrasive, and disposal of natural fiber composites is easy, they can be easily combusted or composted at the end of their product lifecycle. (Barathkumar and Gokulprakash, 2018) reported that banana fibers are most useful for textiles, building construction, etc., and have the best strength, moisture absorption, hardness, and fineness. The future of natural fiber composites appears to be bright because they are cheap, light, and environmentally superior to glass fiber composites. Future research should hence focus on achieving the equivalent or superior technical performance and component life (Joshi et al., 2004). The new banana fiber extraction machine can be designed with higher efficiency. The factors affecting the quality of fiber are roller speed, feed angle and clearance also affect the production quantity of fiber. By choosing these factors correctly, the quality and production of fiber can be increased (Ravi et al., 2018). The new banana fiber extraction machine can be designed with higher efficiency and will reduce manual work and is suitable for mass production (Sheikh and Awata, 2016). Before this research, traditional methods for extracting banana fibers were investigated. The most important outcomes were that it requires a hard human effort, is expensive, takes a long time, in addition to an urgent need to provide extraction machines with locally available raw materials, easy to maintain, and safe to operate. Therefore, this research aimed to extract banana fiber mechanically.

2 Material and methods

2.1 Location

One of the most important features of the machine was that it consisted of available raw materials, therefore it can contribute to the establishment of small projects for young people and maximizing the utilization of banana waste. The prototype of the banana fiber extraction machine was constructed in a local workshop in Saqultah Center, Sohag Governorate, Egypt. All the experiments were carried out in March 2022. All measurements were done using a random sample of the stems of a banana plant. Longitudinal slices were prepared manually from the stems immediately after harvest and fed to the machine.

2.2 Design description of the banana fiber extraction machine

The machine consisted of a pair of guide rollers and a beater cylinder. The slices were fed to the beater cylinder through the guide rollers that serve as the outlet and inlet of the slices. The slices will pass in the clearance between the pressing roller and the beaters cylinder. The fibers are manually pulled out of the guide rollers and dried in the shade. The final product of banana fibers is shown in Figure 1.

Figure 1 The final product of banana fibers

Components of the machine: Figure 2 shows the main components of the banana fiber extraction machine.

The prototype consists of the following parts:

Frame: The frame was fabricated from welded steel, and it was formed with certain dimensions of 600 mm wide, 700 mm length, and 900 mm height. Two hinges are assembled at the cover of the frame to control the opening and closing, to protect the laborer against the beater cylinder.

Beater cylinder: The beater cylinder is the most important element in this machine. It consists of two opposite flanges with a diameter of 250 mm and 550 mm between them. The flanges are connected by longitudinal beaters. The longitudinal beater dimensions were 550 mm in length, 20 mm wide, and 10 mm thickness. The beater cylinder was connected to the frame by a pair of bearings.

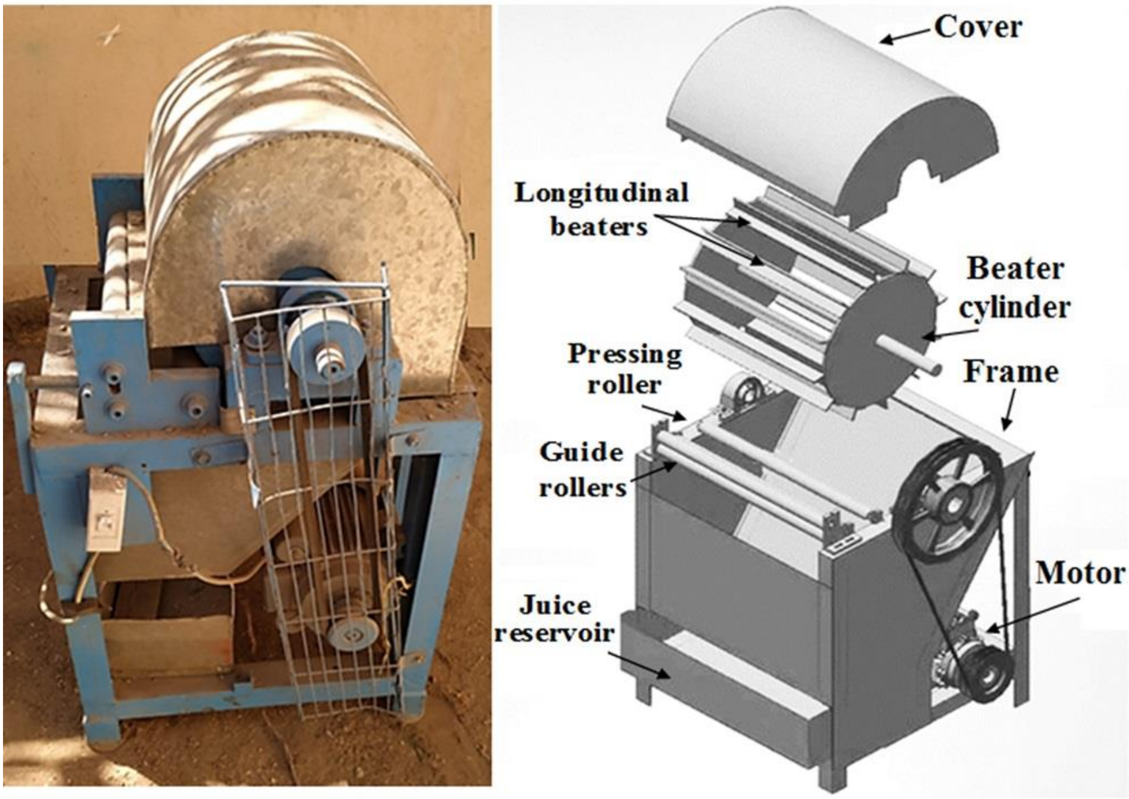

Figure 2 Prototype of the banana fiber extraction machine

A pair of two pulleys and a belt are used to transmit rotational motion from the engine to the beater cylinder. When it is rotated at a speed, longitudinal beaters can compress the slice-stem to extract the fibers by the clearance between the beater and the pressing roller.

Electric motor: The electric motor of 0.75 kW (Model No. Y2, Brand: TOPS Motor) and 1200 rpm was used to rotate the beater cylinder.

Power transmission system: The power is transmitted from the electric motor to the beater cylinder by two pulleys and a V-belt, one of the pulleys with a diameter of 100 mm and was connected by the motor shaft. Three types of the other pulley with diameters of 185, 160, and 141 mm were connected by the beater cylinder for getting a rotation speed of 650, 750, and 850 rpm respectively.

Pressing roller: The pressing roller was a solid roller made of steel. Its dimensions were 550 mm length and 20 mm diameter. This roller plays an important role in the extraction process, as it creates a clearance between it and the beaters. Also, it applies the necessary pressure force on the banana stem slice to separate the fibers. The clearance can be adjusted by the pressing roller according to the thickness of the banana stem used.

Guide rollers: A pair of free rotating rollers are used to guide and protect the user's hand when feeding and receiving slices of banana stem. The rollers were solid rollers made of steel. The dimensions of the roller were 550 mm length and 30 mm diameter. The clearance between them can be controlled according to the thickness of the banana stem used.

Juice reservoir: The process of pressing on banana stems slices to extract the fiber will produce juice and pulp that will be collected by the juice reservoir. The volume of the reservoir was 12 liters. It is located at the bottom of the machine.

2.3 Working theory of extraction machine

The working theory of the extraction machine is shown in Figure 3. The machine theory is based on the repeated rapid beating of the beaters on a slice-stem of banana. This beating simulated what labor does by using hand hammers to eliminate the juice and extract the fibers.

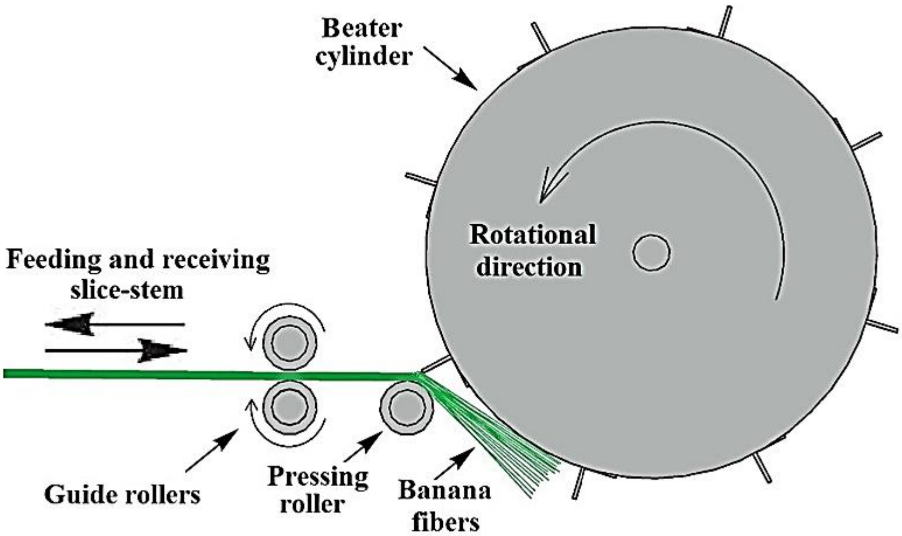

Figure 3 Working theory of the extraction machine

Pressing roller works on pressing of the slice-stem which will pass in the clearance between pressing roller and beaters cylinder, also it will maintain a degree of tautness in the fibers during processing. The optimum rotation speed of the beater cylinder to fiber extraction will be determined by practical experiments. The fibers are manually pulled out of the guide rollers and dried in the shade.

2.4 Variables of experiments

The banana fiber extraction machine was tested considering the possible variables related to prototype performance to realize the purpose of this research. The beater cylinder is the most important component of the machine, and it is the active element, which affects the quality of the fibers. Therefore, the variables that affect the performance of this component have been chosen. Variables of experiments are as follows:

2.4.1 Rotational speeds of the beater cylinder (N_b)

The machine was tested under three rotational speeds of the beater cylinder 650, 750, and 850 rpm.

2.4.2 Beater cylinder shape (Bn)

The machine was tested using three beater cylinders with a different number of beaters 8, 10, and 12.

2.5 Measurements

2.5.1 Extraction efficiency

The extraction efficiency of the machine (η, %) was estimated by comparison with manual extraction, where manual extraction is 100% efficient. Banana fiber extraction was carried out using random samples of banana stems. The banana stems were prepared manually using a sharp tool to extract the slices, then the slices were cut to a length of one meter. Experiments were conducted using random samples of these slides. The mass of each sample was 20 kg. The process of extracting the fibers was done manually using a single laborer and traditional tools. At the same time, the process of mechanically extracting banana fibers was carried out using the extraction machine operated by a single laborer. The fibers were weighed immediately after the extraction process and before the drying step. The experiments were repeated 10 times, and the averages were taken. Assuming that (M_1, kg) is the average mass of fibers extracted manually from the given sample and (M_2, kg) is the average mass of fibers extracted mechanically from the corresponding sample. Thus, the extraction efficiency percentage can be obtained by the following relationship:

$$\eta = \left(1 - \frac{M_2 - M_1}{M_2}\right) \times 100 \quad (1)$$

2.5.2 Machine productivity

Machine productivity was estimated by using the following equation according to Mahmoud (2021):

$$Q = \frac{M_t}{t} \quad (2)$$

Where:

Q = Machine productivity, kg h^{-1}.

M_t = Total mass of the banana fiber, kg.

t = The extraction time, h.

2.5.3 Required power and consumed energy

A clamp meter was used to measure the current intensity and the potential difference during the operation of the machine. The required power was calculated using the following equation according to Chancellor (1981):

$$P = V \times I \times \cos\theta \quad (3)$$

Where:

P = The required power, W.

V = Potential difference, Voltage (Single phase = 220 voltage).

I = Current consumed with the load, Amperes.

$\cos\theta$ = Power factor = 0.64.

The specific energy was calculated using the following equation:

$$Specific\ energy\ (kw\,h\ Kg^{-1}) = \frac{Required\ power\ (kw)}{Machine\ productivity\ (kg\ h^{-1})} \quad (4)$$

2.5.4 Cost estimation

Total operating costs of the machine include fixed costs (depreciation, interest on investment, shelter, taxes, and insurance) and variable costs (repair, maintenance and lubricants, electrical energy, and labor costs).

(1) Fixed costs

Depreciation rate: The depreciation rate was estimated using the following equation:

$$D = \frac{P_m - S}{L_m} \quad (5)$$

Where:

D= Depreciation rate, L.E. y-1

ρ_m= The machine purchase price (Estimated price = 12000 L.E)

S= Salvage price (L.E) = 10% purchase price (Hunt, 1977)

L_m= Life-expectancy of the machine (10 years). Assumed that yearly operating days = 150 days y-1 and daily operating hours = 8 hours

Investment interest: Investment interest was estimated using the following equation:

$$I = \frac{(P_m + S)i}{2} \quad (6)$$

Where:

Interest on investment, *L.E.* y^{-1};

Interest is compounded annually, *rate* y^{-1}.

Shelter, taxes, and insurance: Shelter, taxes, and insurance costs assumed 2% of the machine purchase price, according to (Elkaoud, 2020).

(2) Variable costs

Repair, maintenance, and lubricants: Repair, maintenance, and lubricant costs were assumed 100 % of depreciation costs.

2.5.5 Electrical energy costs (Ec)

Ec (L.E. h^{-1}) = Electricity consumption (kW) × Electricity price (Assumed 1.5 L.E. kW^{-1} hr^{-1}).

2.5.6 Labor cost.

Labor cost is defined as payment for an operator who operates the machine (L.E. h^{-1}). Labor wage (One laborer) = 20 L.E h^{-1}.

2.5.7 Production costs

Production cost was calculated according to the following equation:

$$\text{Production cost}(L.E.kg^{-1}) = \frac{\text{operation cost}(L.E.kg^{-1})}{\text{Machine productivity}(kg\,h^{-1})} \quad (7)$$

3 Results and discussion

3.1 Manual fiber extraction

Table 1 shows the results of manual fiber extraction experiments using 20 kg of prepared banana stems per batch. From Table 1, fibers mass (M_1) after extraction process and before drying step ranged from 4.8 to 5.4 kg. The average value of fibers mass was 5 kg. The time required for manual extraction was between 145 and 160 minutes, with an average of 150 minutes. Average productivity for a single laborer was 2 kg h^{-1}.

Table 1 Results of manual fibers extraction experiments

Batches	M_1, kg	Time, min	Q, kg h^{-1}
1	5.4	155	2.09
2	5.1	155	1.97
3	4.9	150	1.96
4	5.2	160	1.95
5	4.8	145	1.99
6	4.8	147	1.96
7	5.2	150	2.08
8	5	145	2.07
9	4.8	147	1.96
10	4.8	146	1.97
Max.	5.4	160	2.09
Min.	4.8	145	1.95
Average	5	150	2.00

3.2 Mechanical fiber extraction

Table 2 shows the results of mechanical fiber extraction experiments using 20 kg of prepared banana stems per batch. From Table 2, at the rotational speed of beater cylinder N_b = 650 rpm, fibers mass (M_2) after extraction process and before drying step ranged from 7.5 to 9.1 kg depending on shape of the beater cylinder (B_n), the average values of the fiber mass were 8.6, 8.2, and 7.9 kg using number of beaters 8, 10, and 12, respectively. The time required was between 45 and 60 minutes, with an average of 55, 52, and 50 minutes with the number of beaters 8, 10, and 12, respectively. While at the rotational speed N_b = 750 rpm, fiber mass (M_2) ranged from 5.1 to 6.8 kg, the average values of fiber mass were 6.5, 5.7, and 5.6 kg using the number of beaters 8, 10, and 12, respectively. The time required was between 35 and 50 minutes, with an average of 47, 40, and 38 minutes with number of beaters 8, 10, and 12, respectively. Finally, at the rotational speed N_b = 850 rpm, fiber mass (M_2) ranged from 5 to 6.5 kg, the average values of fiber mass were 6.3, 5.5, and 5.4 kg using the number of beaters 8, 10, and 12, respectively. The time required was between 33 and 43 minutes, with an average of

40, 38, and 35 minutes with the number of beaters 8, 10, and 12, respectively.

Table 2 Results of mechanical fibers extraction experiments

Variables of experiments																		
N_b, rpm	650						750						850					
B_n	8		10		12		8		10		12		8		10		12	
M_2, kg Tim, min.	M_2	T	M_2	T	M_2	T	M_2	T	M_2	T	M_2	T	M_2	T	M_2	T	M_2	T
1	9.1	60	7.5	54	7.5	45	6.2	45	5.3	38	5.1	35	6.2	42	5.4	37	5.3	36
2	8.6	56	7.9	50	8	52	6.5	46	5.5	44	5.3	38	6.3	43	5.2	36	5	33
3	8.5	54	8.2	52	7.9	55	6.8	50	5.7	40	5.6	42	6.5	43	5.6	36	5.5	38
4	8	52	8.5	50	8	52	6.5	47	6.2	42	6	40	6	40	5.8	41	5.6	35
5	8.5	55	8.2	55	7.9	48	6.3	45	6	38	5.7	38	6.1	38	5.3	38	5	36
6	9	57	8.2	49	8	52	6.7	49	5.7	41	5.5	37	6.4	39	5.7	40	5.4	37
7	8	50	8.1	48	7.9	54	6.5	47	5.5	42	5.6	35	6.5	40	5.6	38	5.5	35
8	9.1	58	8.2	55	8	48	6.2	46	5.7	38	5.8	38	6.3	37	5.5	40	5.6	33
9	9.1	58	8.5	55	7.8	47	6.5	47	5.6	37	5.7	39	6.4	38	5.4	36	5.6	34
10	8.1	50	8.7	52	8	47	6.8	48	5.8	40	5.6	38	6.3	40	5.5	38	5.5	33
Max.	9.1	60	8.7	55	8	55	6.8	50	6.2	44	6	42	6.5	43	5.8	41	5.6	38
Min.	8	50	7.5	48	7.5	45	6.2	45	5.3	37	5.1	35	6	37	5.2	36	5	33
Ave.	8.6	55	8.2	52	7.9	50	6.5	47	5.7	40	5.6	38	6.3	40	5.5	38	5.4	35

3.3 Extraction efficiency

The results of mechanical extraction by the machine were then compared to those of manual extraction to give an indicator of the machine's performance. The obtained results of extraction efficiency were summarized in Table 3.

Table 3 The obtained results of extraction efficiency

The average mass of fibers extracted manually (M_1) = 5 kg.						
Extraction process	N_b rpm	B_n	M_2 kg	Time min	η %	Q kg h^{-1}
Manually			-	150	100	2
Mechanically under variables of experiments	650	8	8.6	55	58	9.4
		10	8.2	52	61	9.5
		12	7.9	50	63	9.5
	750	8	6.5	47	77	8.3
		10	5.7	40	88	8.6
		12	5.6	38	89	8.8
	850	8	6.3	40	79	9.5
		10	5.5	38	91	8.7
		12	5.4	35	93	9.3

From Table 3, the mechanical extraction efficiency ranged from 58% to 93% under variables of experiments. However, high efficiency does not indicate optimal operating conditions, but the quality of the fibers must be considered. By examining of fibers during the experiments, the fibers produced by the machine were straight, good quality, and not shredded, this was achieved in abundance when using the cylinder that has 10 beaters with 750 rpm rotational speeds of the beater cylinder. Thus, under these operating conditions, the extraction efficiency, the time required, and machine productivity were 88%, 40 min, and 8.6 kg h^{-1}, respectively.

3.4 Effect of rotational speed and shape of the beater cylinder on extraction efficiency

Figure 4 shows the effect of rotational speed and shape of the beater cylinder on extraction efficiency. These results showed that increasing the rotational speed from 650 to 850 rpm and increasing the number of beaters from 8 to 12 has led to an increase in extraction efficiency from 58% to 93%. But side by side, the quality of the extracted fibers is falling, this may be due to an exaggeration in expelling the juice from the banana stems, thus increasing the speed of rotation of rotation with an increase in the number of beaters may lead to shredding of the fibers.

3.5 Effect of rotational speed and shape of the beater cylinder on time required

Figure 5 shows the effect of rotational speed and shape of the beater cylinder on time required. These results showed that increasing the rotational speed from 650 to 850 rpm and increasing the number of beaters from 8 to 12 has led to a decrease in the time required from 55 to 35 min.

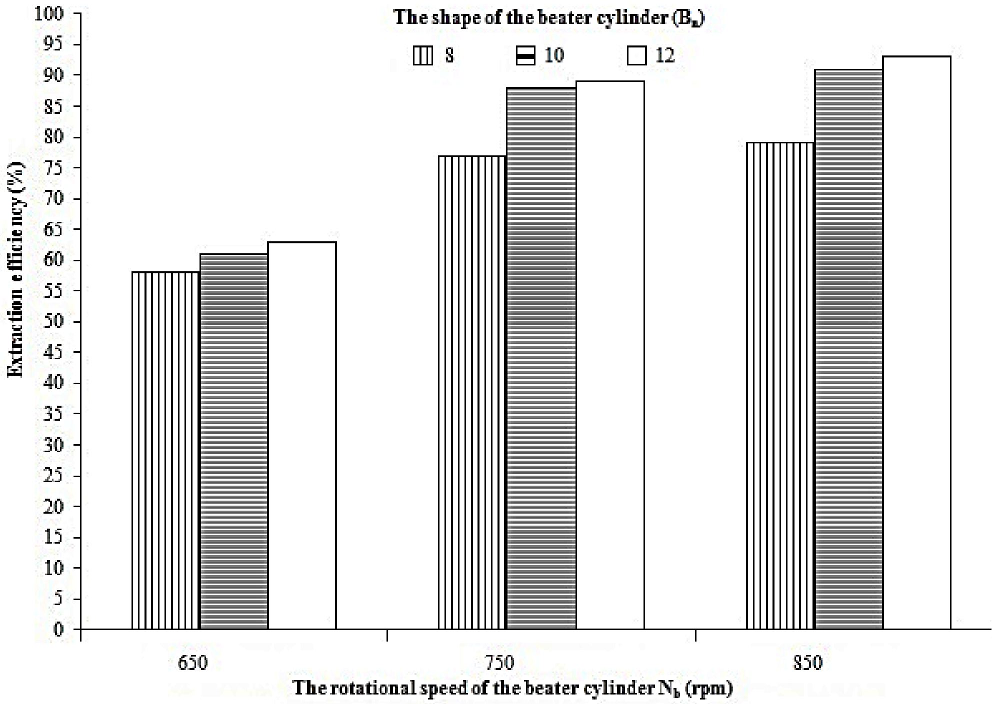

Figure 4 Effect of rotational speed and shape of the beater cylinder on extraction efficiency

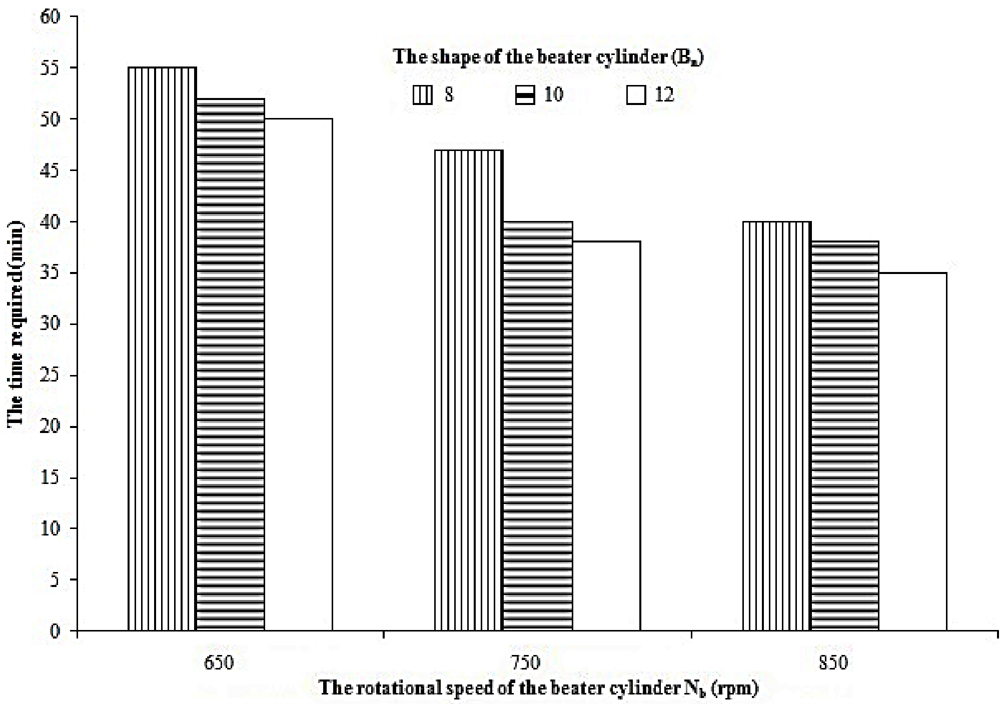

Figure 5 Effect of the cylinder speed and shape on the time required

3.6 Required power and consumed energy

Figure 6 shows the effect of rotational speed and shape of the beater cylinder on required power to operate the machine.

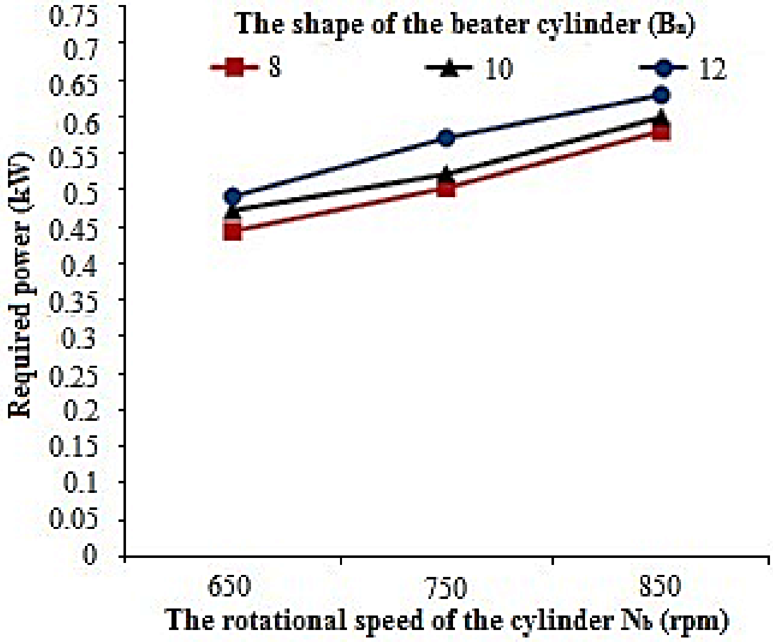

Figure 6 Effect of the cylinder speed and shape on required power

Generally, these results indicated that the required power to operate the machine increased slightly by increasing rotational speed from 650 to 850 rpm and increasing the number of beaters from 8 to 12. The minimum value of power required was 0.45 kW at rotational speed of 650 rpm and using number of beaters 8. While the maximum value of power required was 0.64 kW at rotational speed of 850 rpm and using number of beaters 12. The energy consumption was calculated by dividing the power required on the machine productivity. Results show that the minimum value of consumed energy was 47.87 kW h Mg^{-1} at rotational speed of 650 rpm and using number of beaters 8. While the maximum value of consumed energy was 68.82 kW h Mg^{-1} at rotational speed of 850 rpm and using number of beaters 12.

Cost estimation: The operating costs of the banana fiber extraction machine have been estimated at the maximum value of power required. The results indicated that the total fixed costs were 1.65 L.E. h^{-1} and the total variable costs were 21.86 L.E. h^{-1}. So, the total costs will be 23.5 L.E. h^{-1}.

Production costs: Production costs were calculated under operating conditions which resulted in an acceptable performance of the machine in terms of fiber quality. At the machine productivity of 8.6 kg h^{-1}, the production cost will be 2.7 L.E. kg^{-1}. While the costs of manual extraction of the fibers were 10 L.E. kg^{-1}.

4 Conclusion

The banana fiber extracting machine was fabricated to maximize the utilization of banana tree waste by an eco-friendly method. One of the most important features of the machine was that it consisted of locally available raw materials, therefore it can contribute to the establishment of small projects for young people. The mechanical extraction efficiency ranged from 58% to 93% under variables of experiments. The high efficiency does not indicate optimal operating conditions, but the quality of the fibers must be considered. The machine reduced fiber extraction costs by about a quarter compared to the traditional manual method.

References

Barathkumar, R. V. K. G. K., and K. A. E. Gokulprakash. 2018. A study of banana fiber: a review. *International Journal for Scientific Research and Development*, 6(13): 127-131.

Chancellor, W. J. 1981. Substituting information for energy in agriculture. *Transactions of the ASAE*, 24(4): 802-0807.

Elkaoud, N. S. M. 2020. Sawdust machine prototype for utilizing wood waste and trees pruning products.

Journal of Soil Sciences and Agricultural Engineering, 11(3): 67-72.

Elkaoud, N. S., and R. K. Mahmoud. 2022. Design and implementation of sequential fruit size sorting machine1. *Brazilian Journal of Agricultural and Environmental Engineering*, 26(10): 722-728

El-Shereif, A. R., and D. M. Abou Elyazid. 2016. Tropical and subtropical fruits in Egypt. *Chronica Horticulturae*, 56(3): 28-31.

FAO STAT. Crops and Livestock Products. Available at: http://www.fao.org/faostat/en/#data/QC/visualiz. Accessed Dec., 2019.

Helaly, M. N., H. M. El-Hoseiny, N. I. Elsheery, H. M. Kalaji, S. de Los Santos-Villalobos, J. Wróbel, and S. M. Alam-Eldein. 2022. 5-aminolevulinic acid and 24-epibrassinolide improve the drought stress resilience and productivity of banana plants. *Plants*, 11(6): 743.

Helgi Analytics. 2020. Banana Production in Egypt; Helgi Library: Prague, Czech Republic. Available at: https://www. helgilibrary.com/indicators/banana-production/Egypt/. Accessed on 2020.

Hunt, D. R. 1977. *Farm Power and Machinery Management*. **2nd ed.** USA: Press Ames.

Joshi, S. V., L. T. Drzal, A. K. Mohanty, and S. Arora. 2004. Are natural fiber composites environmentally superior to glass fiber reinforced composites? *Composites Part A: Applied Science and Manufacturing*, 35(3): 371-376.

Mahmoud, W. A. 2021. Manufacture of tomatoes halving prototype for natural drying process. *Misr Journal of Agricultural Engineering*, 38(4): 279-292.

Majlish, F. K. 2020. Design and fabrication of combined fiber extracting machine for banana stems and pineapple leaves. Ph.D. diss.,Dep. of Industrial and Production Eng. in Partial Fulfilment, Bangladesh U. of Eng. and Technology Dhaka, Bangladesh.

Praful, P., and N. P. A. Lanjewar. 2017. Review paper on design and modeling of multipurpose fiber extracting machine. *International Journal of Engineering Research*, 6(4): 328-334.

Ravi, V., S. Rahamaththulla, S. Premnath, S. Madheswaran, and N. Jayakumar. 2018. Design and fabrication of banana fiber extracting machine. *International Journal for Scientific Research and Development*, 6(1): 390-393.

Sheikh, S., and N. P. Awata. 2016. A review paper on design and development of banana fiber extraction machine. *International Journal of Engineering Sciences and Research Technology*, 5(3): 841-847.