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PERFORMANCE ANALYSIS OF A MECHANICAL SYSTEM TO BREAK AND SEPARATE PALM NUT-FIBRE CAKE

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ABSTRACT
This research seeks to test the performance of a palm nut-fibre cake breaker and separator machine to alleviate the problem of hand separation by local oil producers. It takes into consideration the standard cylindrical shape of a palm nut-fibre cake. The machine operated on an electric motor of 2.2 kW at 1420 rpm. The average throughput capacity of the machine was 107.72 kg/hr with the capacity weight of 120 kg. Test results indicated a separation efficiency of 92%. Also, cost estimation indicated that the annual savings in using the machine with less labour than manual labour entirely was $466. The study outcome is relevant to small-scale producers on the need to utilize a cost-effective machine to facilitate a high separation yield of nuts and fibres from the cake obtained from processing palm oil and improve the production output of palm kernel oil processed from the nuts.
Keywords: *Oil palm, Nut-fibre cake, Separator, Efficiency, Throughput capacity*

1. Introduction

Oil palm is a perennial plant that is commonly grown mostly in the southern parts of Ghana and Nigeria as well as on plantations in equatorial tropics in Southeast Asia and South America in different varieties(Murphy, et al., 2021; Mutsaers, 2019). Therefore, palm oil and palm kernel oil production in these areas on both small and large scales is commonplace. Traditionally, palm oil production has been done in Ghana by washing pounded fruit mashed in warm water and hand-squeezed to separate fibre and nuts from the oil/water mixture. The oil is then skimmed off the surface of the boiling wet mixture. This process has been mechanized in recent times with the use of a vertical digester which combines digestion, pressing and hot water dilution into one mechanical unit operation (Lawal and Malachi, 2019; Assian, et al., 2022; Israel, et al., 2020).

One of the by-products of the palm oil production process is palm nut/fibre cake obtained after the pounded/digested palm nuts have been squeezed/pressed for oil. The palm kernel from this cake serves as raw material for palm kernel oil production. A key challenge in the local production of palm kernel oil is the separation of cakes into nuts and fibres. This has often been done manually in local production sites in Ghana, a time-consuming process that affects productivity(Ola, et al., 2020; Binuyo, et al., 2022; Alade. 2020).

Some cake breaker and separation machines have been developed in an attempt to address this challenge over the years. These include those by Okolie et al. (2018), Nwankwojike et al. (2012), Adzimah and Seckley (2009), and Obincoweld (2015). Some of them exhibited relatively good separating efficiencies as high as 90% during testing (Nwankwojike et al., 2012). The study by Ologunagba et al. (2010), resulted in a separation efficiency of about 96%. However, these studies considered complex drive systems which increase maintenance and operational costs (Okolie et al., 2018; Adzimah and Seckley, 2009). There were also size limitations that prevent their use in small scale production yards, and the inability to separate relatively hard cakes that are obtained from a tight pressing of the digested palm nuts to extract more palm oil (Nwankwojike et al., 2012). In addition, due to their hopper designs, as well as the shape and hard nature of the cakes to be fed, some of these machines require the cakes to be pre-broken before being fed into the machines (Obincoweld, 2015), and some of them do not mechanize the final separation of nut from fibre), and so still require enough manual labour.

Against this background, this paper assesses an alternative design of a palm nut - fibre cake separation machine, which was developed considering ease of maintenance, operation, and. The machine takes the cylindrical shape of palm nut-fibre cakes often found in Ghana into consideration, and was designed to alleviate the problem of hand separation by local oil producers.

2. Research Methods

2.1 Overview of the Developed Palm-nut - fibre Caked Separation Machine

The objective of the evaluation criteria is to find a reliable, energy-efficient, yet accurate and suitable design for the palm nut-fibre caked separation machine. Four evaluation criteria were used as the basis to select an appropriate design. These were maintainability, manufacturability, initial cost and assembly. The design requirements of this research seek to design a simple palm nut-fibre separator. The machine has a rigid and strong base and a hopper to aid in feeding into the machine with cake fibre. There is a strongly geared tooth spike for breaking and separating the caked fibre, beneath it is a perforated sieve required to allow the nuts to exit as they are completely separated in the process. A fan blower is integrated into the features to tblow outut the separated fibre from the system to exit through the ejector which is located in between the two spike rollers. An electric motor of 3 horsepower with a voltage of 220 volts to 400 volts 3-phase power is used to transmit power to the system with the help of a pulley and a v-belt drive. The machine is expected to work for 8 hours a day for 5 days with a design life of 5 years. The design prototype should have effan iciency above 70%. The machine is a two-stage continuous process that is breaking off caked fibre in the first stage and the nuts separation in the second stage all in one entity. Further, the materials selected to be used are less corrosive, high quality and low cost.

Based on this approach, three concepts were developed with their working principles and orthographic views. These were evaluated based on maintenance, manufacture, ease of assembly, and initial cost to select a final design without any modification made. Fig. 1 shows the Isometric and Exploded views and the Parts list of the final conceptual design. The design specifications of the fifteen (15) parts were determined based on various design equations. Table 1 shows the dimensions, materials selected and the manufacturing processes used for the individual parts.

2.2 Experimental Procedure

A standard palm nut-fibre cake of weight 25 kg was fed into the hopper. After breaking and separating the fibre and nut, the ejected nuts were weighed and recorded as X kg and that of ejected fibre as Y kg. After separation, portions of nuts in the ejected fibres were separated manually and vice versa. The weight of nuts in the ejected fibres was recorded as A kg whereas the weight of fibres in the ejected nuts was recorded as B kg. The weights of palm nuts and fibres separated by machine were then determined and recorded as (X-A) kg and (Y-B) kg, respectively. This process was repeated for four other tests with the same weight of the nut-fibre cake and the results were recorded. The machine setup is shown in Fig. 2.

Table 1 - Design specifications

Part No.	Part Name	Dimension/Specification	Material used
1	Hopper	36 mm diameter x 50 mm length	Mild steel
3	Metal frame	3 mm by 500 mm Angle iron (4x)	Mild steel
4	Sieve Coarse	40 mm by 3 mm x 10 m	Mild steel
5	Tower Bearings	Diameter 20mm	Steel Alloy
7	Motor	1420 rpm	
8	Nut Ejectors		Mild steel
11	Geared Spike	100 mm diameter x 400 mm length	Galvanized steel
12	Pin Spike	80 mm diameter x 400 mm length	Galvanized Steel
14	Cover Plate	500 mm by 500 mm (4x)	Mild steel
15	Pulley		Cast Iron

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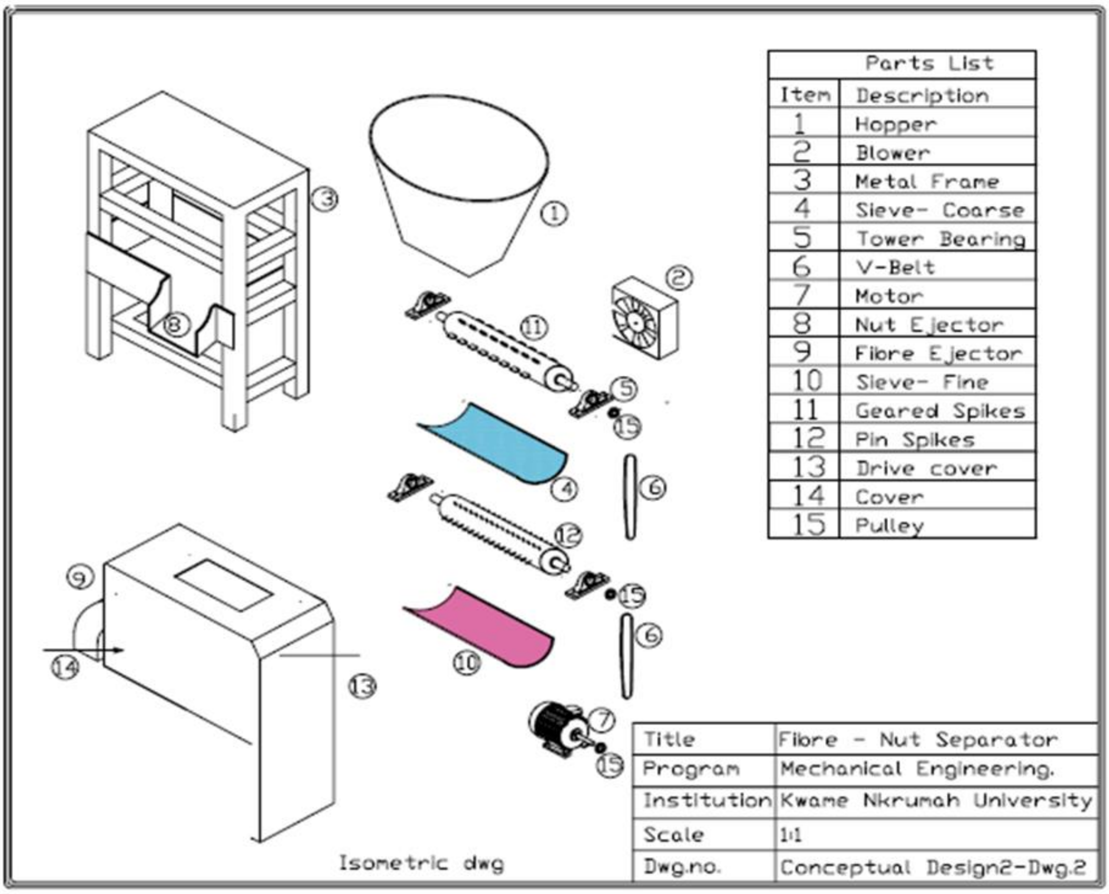

Fig. 1. Conceptual Design Details and Part List

Fig. 2. Experimental Setup

2.2 Determination of Machine Parameters and Production Efficiencies

Machine parameters such as throughput capacity, separation efficiency, power rating and design capacity are quantities that influence the machine performance. They are typically viewed as being held constant or varying slowly. The throughput capacity of the palm nut-fibre cake separator is the rate at which it segregates the nuts and fibre from the cake. It is the ratio of the average weight of palm nut - fibre cake separated in kg to the time used in hours. Therefore, throughput capacity in kg/h is evaluated using Eqn. (1).

$$C_W = \frac{W_N + W_F}{t} \tag{1}$$

Where W_N is the total weight of nuts separated, W_F is the total weight of fibre separated and t is the time taken for the separation in hours.

The separation efficiency, which is the ratio of the weight of the total nuts and fibre separated and the total weight of palm nuts-fibre cake fed into the machine is determined using Eqn. (2).

$$\eta_s = \frac{W_N + W_F}{Wt} \times 100\% \quad (2)$$

Where W_N is the total weight of nuts separated, W_F is the total weight of fibre separated and W_t is the total weight of palm nuts-fibre cake fed into the machine.

The power rating of the machine is the power consumed per hour. A fluke multimeter is clamped on the input power cables of the machine to measure and record the rate of the power consumption. The design capacity of the palm nut-fibre cake separator is the maximum possible output of the machine. It is the average volume of cake that can be fed into the hopper of the machine. The machine weight is determined by adding up the weight of the various components of the machine. The efficiency of a machine is the ratio of the output to its input. The palm nut-fibre separator was designed to eject nuts and fibre at different sides of the machine. Therefore, the efficiency of nuts and fibres efficiency is determined using the eqn. (3) and (4), respectively.

$$E_N = \frac{W_{N1}}{W_{N1} + W_{N2}} \times 100\% \quad (3)$$

Where W_{N1} is the weight of the nuts separated by machine as (X-A) kg and W_{N2} is the weight of nuts separated manually as (A) kg.

$$E_F = \frac{W_{F1}}{W_{F1} + W_{F2}} \times 00\% \quad (4)$$

Where W_{F1} is the weight of the fibres separated by machine as (Y-B) kg and W_{F2} is the weight of fibres separated manually as (B) kg.

The percentage loss of nuts and fibre is determined as (1- E_N) and (1 - E_F) respectively.

2.3 Determination of the sample error using t-distribution

The standard error of a statistic is the standard deviation of its sampling distribution. For a given sample size, the standard error of the mean equals the standard deviation divided by the square root of the sample size (Altman and Bland, 2015). The ranges for a standard parameter can be determined using the following equations;

$$E = E_{av} \pm \frac{t_{\alpha,v}s}{\sqrt{n-1}} \quad (5)$$

$$E_{av} = \frac{\sum E_i}{n} \quad (6)$$

$$\sqrt{\frac{\sum(E_i - E_{av})}{n}} \quad (7)$$

Where E is a standard parameter, E_{av} is the mean, s is the standard devation, $t_{\alpha,v}$ is t – distribution probability, and n is the sample size.

2.4 Cost Analysis

This section seeks to determine the effective cost of using the machine as compared to manual labour. The life span of the machine was determined by taking into consideration the speed of the machine, durability of components used and nature of work to be carried out. It was estimated to work for 5 days a week for 8 hours in 5 years.

The total cost incurred in the design and fabrication of the machine was determined and the cost of operation was determined by the power consumption of the machine. The cost of using manual labour was determined using the minimum daily wage and the number of people to be employed to carry out the same work as the machine.

3. Results And Discussion

The results of the measured parameters of the machine are shown in Table 2. These were the key variables that influence the operating process and were determined from the experiment procedure of the machine. These include machine speed, operating temperature, torque, design capacity and throughput capacity. The torque was calculated using the twisting speed of the shafts.

Table 2 - Measured parameters of prototype

Measured Parameters	Value
Rotational Speed	1400 to 1450 rpm.
The radius of Rotating shaft	10 mm
Size of Geared Spike roller	Dia. 100 mm x 400 mm
Size of Pin Spike roller	Dia. 80 mm x 400 mm
Power Rating	400v , 2.3 kW/h
Operating temperature	41- 42 °C
Machine Speed	1420 rpm
Torque	15.05 Nm
Weight	120 kg
Design Capacity	5,650 m^3
Throughput Capacity	107 kg/h
The average time taken for Separation	840 to 860 s

Fig. 3 shows the weights of the ejected nuts and fibres from the machine for the same sample of palm nut-fibre cake that was tested. At each test, the weight of the nuts were higher than corresponding weight of nuts. The separation time for all tests varied slightly. However, the weights of ejected nuts recorded had some fibre components which were separated manually and vice versa. Hence, the actual quantities of the nuts and fibres separated by the machine were determined after doing manual separation from each.

Fig. 4 therefore illustrates the actual weights of nuts and fibres based on machine separation. The throughput capacity of the fabricated fibre-nut separator was between 106 kg/h and 108 kg/h. From statistical analysis with a 95% confidence level, the value of $t_{0.05,4}$ was 2.132 from the t-distribution table. The mean, standard deviation and range for throughput capacity were 107.72, 1.259 and 107.72 ± 1.342 respectively.

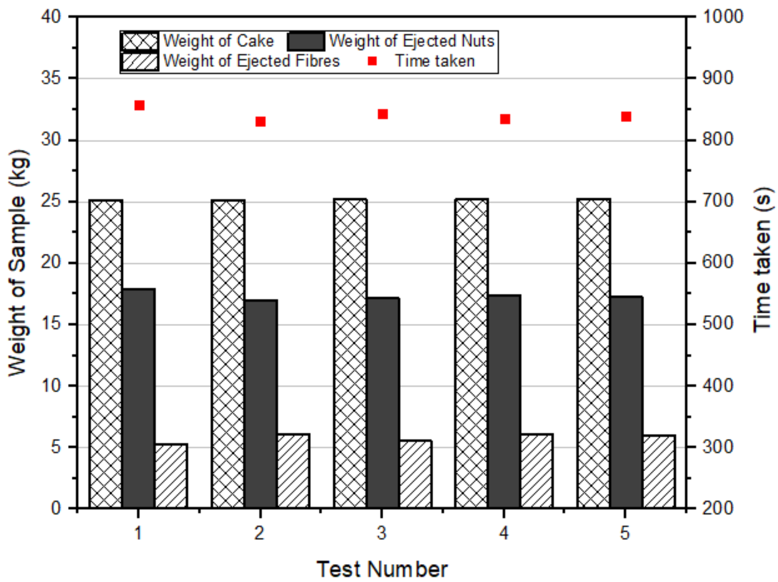

Fig. 3. Weight output of nuts and fibres from testing

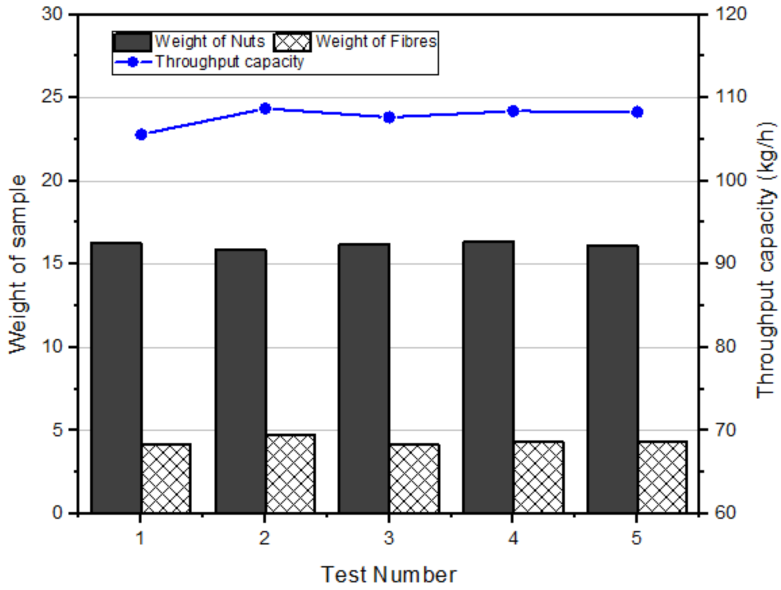

Fig. 4. Throuput capacity based on weights of nuts and fibres

The results of separation efficiency of the machine is shown in Fig. 5. At each test, the machine performance in separating the nuts and fibres was about 90% or more. For a 95 % confidence level, the value of $t_{0.05,4}$ was 2.132 from the t – distribution table. The mean, standard deviation and the range of separation efficiencies are 91.98%, 1.113 and 91.98 ± 1.186 respectively. The Efficiencies of nuts and fibre and the percentage loss of nuts and fibres are shown in Table 3. For each quantity of cake utilised in the experiment, the efficiency of nuts separated by the machine was higher than the efficiency of fibre separation. This was because, ejection of the nuts is aided by force of gravity whilst the fibre was ejected by air flow from the blower. This means more nuts were ejected than fibre for each quantity of palm nut-fibre cake used. From statistical data with 95 % confidence level, the value of $t_{0.05,4}$ was 2.132 from the t-distribution table. The percentage range for the loss of nuts and fibre were 8.67 ±0.763 and 19.55 ±1.378, respectively.

Table 3 - Efficiencies and percentage loss of nuts and fibres

Test Number	Quantity of Cake (kg)	Efficiency of Nuts (%)	Efficiency of fibre (%)	Loss of Nuts (%)	Loss of Fibre (%)
1	25.16	91.37	78.49	8.63	21.51
2	25.09	92.12	81.01	7.88	18.99
3	25.2	91.93	81.08	8.07	18.92
4	25.17	90.47	81.19	9.53	18.81
5	25.24	90.76	80.48	9.24	19.52

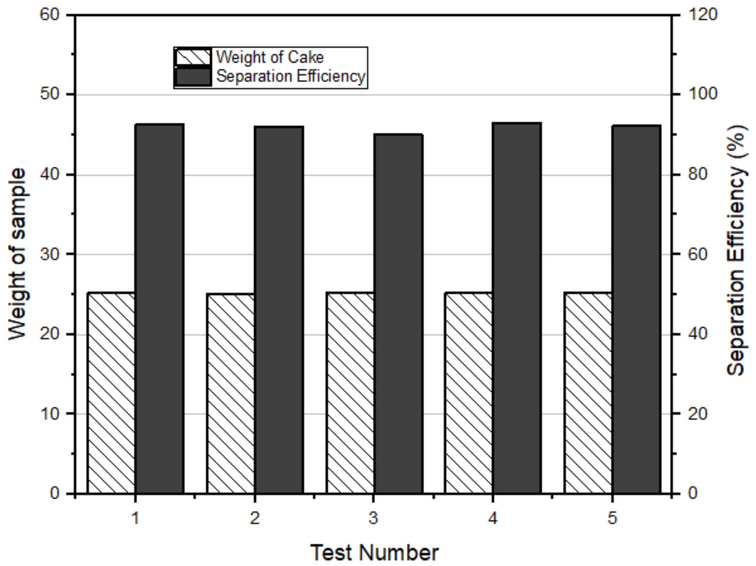

Fig. 5. Separation efficiency of prototype

The cost analysis of using the prototype against manual labour was evaluated to ascertain the effectiveness of the machine in terms of operating cost. It was determined from experiment that the throughput capacity of the machine was averagely 107.72 kg/hr. In the case of manual labour, capacity was 34.4 kg/hr. This indicates that the separation machine is about three times more efficient than using manual labour. The initial capital cost of the machine was US$1,000. The National daily minimum wage is US$2.02 (Otoo, 2018) whereas commercial electricity cost in Ghana is US$ 0.123/kWh (Quartey and Ametorwotia, 2017). The machine is designed to operate 5 days per week for 8 hours a day for 5 years, approximately 40,000 running hours with a rated power of 3 hp (2.2 kW). The machine operating cost is dependent on electricity consumption whereas the cost incurred from manual labour is dependent on daily minimum wage per individual. It is assumed that for manual breaking and separation of a 25 kg fibre-nut cake, 4 people are used whereas the use of the machine require 2 additional people. Hence, as shown in Table 4, the daily operating cost of using the machine to separate fibre-nut cake was US$ 6.18 whereas that of manual labour was US$ 8.08. The annual cost amounts to US$ 1473.60 for machine operation and US$ 1939.20 for the manual labour cost. For a 5-year period, considering the initial capital cost of fabricating the machine, the cost savings for using the machine with less labour amounted to about US$ 2328.

Table 4 - Cost analysis

Item	Machine	Manual labour
Daily operating cost	US$ 6.18	US$ 8.08
Yearly operating cost	US$ 1,473.60	US$ 1,939.20
5 year-operating cost	US$ 7,368.00	US$ 9,696.00

4. Conclusion

Throughout history, the cake breaker has been used and still being used in so many diverse ways. Although these cake breakers have served their purpose of use, this two-stage process of breaking and separating nut-fibre cake makes work much easier and convenient. It was concluded that the palm nut-fibre cake separation is more effective with the machine than manual labour. The average efficiency of nuts by machine is statistically greater than the average efficiency of fibre by machine given by the 5 % significance level of the one-tail test. The annual cost of using of the machine is US$ 1473.60 as compared to US$ 1939.20 for manual labour cost. For a 5-year running period, the cost savings of the machine amounted to US$ 2328. The study outcome is relevant to small-scale producers on the need to utilize a low cost machine to facilitate high separation yield of nuts and fibres from the cake obtained from processing palm oil. This will improve production output of palm kernel oil which is processed from the palm nuts. This has potential to contribute to poverty alleviation under sustainable development goal 17 which highlights the importance of global macroeconomic stability.

However, the nut-fibre cake breaker and separation machine can be improved by attaching a conveyor where the cake is fed, then drives it onto the hopper of the machine. This is an electrically operated system, however, diesel engine can be incorporated when there is an electrical failure or used at places without source of electricity. Chain drive systems must be implored to prevent slips during high torques. Much higher blowers must also be used to improve the efficiency of the fibre ejected.

References

Adzimah, S. K., & Seckley, E. (2009). Modification in the design of an already existing palm nut-fibre separator. *African Journal of Environmental Science and Technology, 3*(11).

Altman, D. G., & Bland, J. M. (2005). Standard deviations and standard errors. *Bmj, 331*(7521), 903.

Alade, E. I., Koya, O. A., & Omidiji, B. V. (2020). Development of a modified palm-nut cracker. *Agricultural Engineering International: CIGR Journal, 22*(1), 202-212.

Assian, U. E., Okoko, J. U., Alonge, F. A., Udoumoh, U. I., & Ehiomogue, P. (2022). Development of sustainable products from oil palm towards enhancing national food security: A review. *Poljoprivredna tehnika, 47*(1), 15-33.

Binuyo, G. O., Owolarafe, O. K., Ogunsina, B. S., Obayopo, S. O., Morakinayo, A. T., OKORIE, V. O., ... & Falana, O. B. (2022). Appraisal of Technological Capability of Selected Palm Oil Mills for Production of Special Palm Oil in Nigeria. *Available at SSRN 4087757*.

Israel, A. E., Koya, O. A., & Omidiji, B. V. (2020). Development of a modified palm-nut cracker. *Agricultural Engineering International: CIGR Journal, 22*(1).

Lawal, A. S. & Malachi, I. O. (2019). Development and Performance Assessment of an Improved Palm Oil Digester. *International Journal of Technical & Scientific Research Engineering, 2*(2), 15-29.

Murphy, D. J., Goggin, K., & Paterson, R. R. M. (2021). Oil palm in the 2020s and beyond: challenges and solutions. *CABI Agriculture and Bioscience, 2*(1), 1-22.

Mutsaers, H. J. W. (2019). The challenge of the oil palm: using degraded land for its cultivation. *Outlook on Agriculture, 48*(3), 190-197.

Nduka, N. B., Okay, O. A., & Jonah, A. C. (2012). Design, fabrication and evaluation of palm nut-pulp separator. *Journal of Emerging Trends in Engineering and Applied Sciences, 3*(1), 144-151.

Obincowelds Construction, "Palm nut-fibre seperator", 2015. http://obincoweldconst.blogspot.com/2015/05/palm-fruit-fibre-separator.html.

Okolie, C., Oluwadare, B., Ezenwa, O. & Azaka, O. (2018). Design and Production of Palm Nut and Fibre Separating Machine. *Advances in Research*, 17(2), 1-8.

Ola, F. A., Akande, F. B., Ogunremi, I. O., Balogun, A. L., & Busari, R. A. (2020). Selected Engineering Properties of Palm Nut (Elaeis Guineensis) Required in The Design Of Palm Kernel-Shell Separator. *Lautech Journal of Engineering and Technology, 14*(2), 49-54.

Ologunagba, F. O., Olutayo, L. A., & Ale, M. O. (2010). Development of Palm Kernel nut and Fibre Separator. *ARPN Journal of Engineering and Applied Science.,5*(12): 11, 14.

Otoo, K. N. (2018). Minimum wage fixing in Ghana. *In Labour Research and Policy Institute of Trade Union Congress Policy Paper*.

Quartey, J. D., & Ametorwotia, W. D. (2017). Assessing the total economic value of electricity in Ghana.