VOL. 11 NO. 5,
FEBRUARY, 2026
E-ISSN 3027-1339
P-ISSN 3026-8257

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Systematic, Evaluation and Diversity Engr. (JSEDE)

Design and Modification of an Integrated Digester-Separator Palm Fruit Machine with a Self-Cleaning System

Nwadinobi C. P.[1]; Nwosu J. O.[2]; Doreen E. C.[3]; Daniel C. O.[4]; & Kelechi J. E.[5]

[1]Department of Mechanical Engineering, Abia State University, Uturu, Abia State.
[2,3,4,5]Department of Mechanical Engineering, Gregory University, Uturu, Abia State.
Corresponding Author: chibundop@gmail.com
DOI: https://doi.org/10.70382/ajsede.v11i5.024

Abstract

This project focuses on the design and modification of an integrated digester–separator palm fruit machine equipped with a self-cleaning system. The research addresses the limitations of traditional and semi-mechanized palm oil processing methods, particularly the challenges of the drudgery, labour-intensive cleaning and product contamination risks. The machine was designed to combine digestion, fibre–nut separation, and automated cleaning into a single compact unit. A gravity-fed water distribution system was incorporated to flush residues from the digester, thereby minimizing downtime and improving hygiene. The design and fabrication process involved engineering analyses of power requirements, shaft dimensions, belt transmission, and material selection. Performance evaluation of the machine indicated an average throughput capacity of 169.0 kg/hr, digestion efficiency of 91.8%, separation efficiency of 88.8%, and cleaning effectiveness of 85.2%. These results demonstrate that the modified design not only enhances productivity but also reduces operator fatigue and improves safety. The project contributes to sustainable palm oil processing by providing a cost-effective, locally manufacturable solution for small and medium-scale processors.

Keywords: Oil Palm, Vegetables, Digester–Separator Machine, Self-Cleaning System, Palm Fruit Processing, Efficiency Evaluation.

Introduction

Palm oil remains one of the most important vegetable oils globally, with significant applications in food, pharmaceuticals, cosmetics, and biofuel industries, (Basiron, 2007; Eze & Ezeanya, 2018). Nigeria, along with other West African nations, is a major producer of oil palm (Elaeis guineensis), yet the processing of palm fruits is still largely dominated by small-scale farmers who rely on manual or semi-mechanized methods, (Ugochukwu & Adeyemi, 2017; Azodo & Onyekwere, 2023). Traditional processing techniques such as hand pounding and rudimentary pressing are highly labor-intensive, time-consuming, and characterized by low oil recovery efficiencies. These limitations have contributed to significant post-harvest losses and restricted the growth of the local palm oil industry, despite the vast availability of raw materials in palm-growing regions, (Adeleke & Musa, 2019). To address these challenges, mechanical innovations are essential for improving the efficiency, hygiene, and productivity of palm fruit processing, (Ayodele & Ibe, 2019; Unabor & Ugbeni, 2025). One of the most critical stages in palm oil production is the digestion and separation of palm fruits, (FAO, 2015; Ugwu & Nwachukwu, 2017; Eze, 2020). Digestion serves to loosen the mesocarp from the nut, while separation involves isolating the fibrous mesocarp from the hard palm kernel, (Udoh & Abiola, 2016; Udoh, 2018; Ugwu & Musa, 2019). In small- and medium-scale processing, these operations are often carried out separately using independent machines, thereby increasing cost, space requirement, and processing time, (Onwuka, 2018; Adetola et al., 2022). The development of integrated digester–separator machines offer an effective solution by combining both processes into one compact unit, (Musa & Bello, 2020; Musa & Akande, 2020). This integration reduces handling losses, improves throughput capacity, and ensures better overall efficiency, (Adeleye & Ologunde, 2014; Akinlabi, et al., 2014; Adetola & Okafor, 2016)). However, one persistent challenge with existing machines lies in cleaning. The digestion chamber, after repeated use, accumulates fibre residues that are difficult to remove manually. This results in longer downtime, increased drudgery, and sometimes compromises product quality due to poor hygiene. Several researchers have made efforts to address these issues. Adzimah & Seckley (2018) modified the design of an existing palm nut–fibre separator to enhance performance, achieving higher separation efficiency through improved beater and sieve arrangements. Okolie *et al.,* (2018) designed and produced a palm nut and fibre separating machine emphasizing the importance of optimized shaft and pulley arrangements in reducing fibre carry-over. Zakaria *et al.,* (2015) explored a novel approach using an air classifier system for palm fibre and nut separation, reporting high efficiency but at the expense of higher energy consumption and the need for controlled airflow conditions. Nwankwojike *et al.,* (2012) designed, fabricated, and evaluated a palm nut–pulp separator, achieving a separation efficiency of 90%, but the machine required frequent manual cleaning. Similarly, Fashina *et al.,* (2017) developed and evaluated an oil palm fruit digester that recorded high

digestion efficiency but lacked a separation mechanism, necessitating a separate machine for fibre–nut separation. More recently, Onyenanu & Okiemute (2023) designed and fabricated a palm fruit digester with improved stirring performance but without integration of a separation or cleaning system.

From these works, it is evident that while progress has been made in integrating digestion and separation functions, the issue of cleaning remains largely unaddressed. Manual cleaning is tedious and time-wasting, leading to reduced productivity during large-scale processing, (Alabi & Popoola, 2018; Eze & Akinlabi, 2019). This study therefore introduces a modified integrated digester–separator palm fruit machine with a cleaning system, designed not only to digest and separate palm fruits effectively but also to reduce downtime by incorporating an automatic rinsing mechanism using water nozzles connected to an overhead tank. By addressing digestion, separation, and cleaning simultaneously, the machine enhances overall efficiency, reduces drudgery, and improves the hygienic conditions of palm oil production, thereby contributing to sustainable mechanization in the sector.

MATERIALS AND METHODS

The methodology for this research focused on integrating three functional units; digestion, separation, and cleaning into a compact, efficient, and affordable palm fruit processing system.

Materials

The integrated digester–separator palm fruit machine with a cleaning system was fabricated mainly from mild steel instead of stainless steel due to its lower cost and also because this is a prototype. Other materials include mild steel sheet metal (5mm thickness), the water nozzles in the cleaning system, ball bearings (internal diameter of 28mm), V-belts for power transmission (an A-61 belt linking the engine to the compound pulley, an A-42 belt linking the compound pulley to the digester, and an A-24 belt linking the compound pulley to the separator), an overhead tank, angle bars, shafts, bolts and nuts, pulleys, a fuel engine, a speed reducer (ratio 1:30), flushing valve, spray and overhead plastic water tank. The prime mover used was a 13 hp fuel engine, which is suitable for rural processing environments without reliable electricity supply.

Design Concept and considerations

Design decisions were made based on functional requirements, local material availability, and cost considerations. Key design considerations included the following:

i. Unlike earlier designs that treated digestion and separation separately, this machine combines both in one unit, improving workflow.
ii. The hopper and digester were designed to process at least a paint bucket (approximately 20kg) of sterilized palm fruits per batch. To align with smallholder operations.

iii. A compound pulley with three slots was employed to distribute engine power to the digester and separator. The 13 hp engine, reducer, and pulley belts ensured robust and flexible power distribution to both digester and separator.
iv. Mild steel was chosen for affordability, but corrosion protection was ensured by painting. Brass was chosen for nozzles due to water exposure.
v. Designing the stirrers to optimize mesocarp breakdown without excessive nut damage.
vi. A gravity-fed overhead tank to eliminate the need for pumps.

Design Methodology and Analysis

The design process involved the determination of the machine's power requirement, pulley and belt selection, shaft design, and analysis of the digester and separator units.

Determination of Volume Capacities of the Digester and Separator

The volume capacity of the machine is crucial in determining the maximum batch size of palm fruits that can be processed at a time. The digester was designed as a cylindrical chamber with an internal diameter of 330 mm, a height of 370 mm, and a wall thickness of 5 mm. The internal volume, V_d, of the digester is given by:

$$V_d = \pi \left(\frac{D}{2}\right)^2 H \quad (1)$$

Where: D = 0.33m (internal diameter), H = 0.37m (height)

$$V_d = \pi \left(\frac{0.33}{2}\right)^2 (0.37) = 0.0316m^3$$

Since the bulk density of palm fruit mash is approximately ρ = 1060kg/m^3 (Nwankwojike *et al.,* 2012), the maximum mass capacity of the digester is:

$$M_d = \rho V_d \quad (2)$$

$M_d = 1060 \times 0.0316 = 33.5kg$

Thus, the digester can process about 33.5 kg of palm fruit mash per batch.

For the separator, the spiked shaft has a length of 0.89 m and a casing width approximated to 0.12 m around the shaft. Assuming an annular trough cross-section:

$$V_s = \pi r^2 L \quad (3)$$

Taking radius; r = 0.06m and length; L = 0.89m

$V_s = \pi(0.06)^2(0.89) = 0.010m^3$

Thus, the separator can handle about $0.010 \times 1060 = 10.6kg$ of digested mash at once. This confirms that the separator must operate continuously in sync with the digester output.

Selection of Pulleys

The pulley system transmits motion and power from the 13 hp fuel engine (via the 1:30 speed reducer) to the digester and separator shafts. The compound pulley has a diameter of 180 mm, while the driven pulleys for both digester and separator are 110 mm.

Velocity ratio (VR) is given by:

$$VR = \frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (4)$$

Where: N_1 = speed of driver pulley, N_2 = speed of driven pulley, D_1 = 180mm, $D_2 = 110mm$

$$VR = \frac{110}{180} = 0.61$$

Thus, the driven shafts rotate at about 61% of the speed of the compound pulley.

Assuming the engine runs at 3000 rpm (typical small petrol engine speed), the speed reducer output is:

$$N_{out} = \frac{3000}{30} = 100\ rpm$$

Hence, the digester and separator speeds are:

N_{driven}= 0.61× $100 = 61\ rpm$

This speed is appropriate for effective digestion and separation without excessive mechanical stress.

Design for Belt

According to Okafor, (2016), the length of each V-belt is estimated using:

$$L = 2C + 1.57\,(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4C} \quad (5)$$

Where C is the center-to-center distance. Assuming C = 400mm:

For digester drive (A-42 belt, $D_1 = 180mm, D_1 = 110mm$):

$$L = 2(400) + 1.57\,(180 + 110) + \frac{(70)^2}{41600} = 1259mm$$

Which corresponds closely to standard A-42 belt length (1067 mm effective).

For separator drive (A-24 belt): calculation yields approximately 610 mm, which matches standard A-24 size.

For engine-to-compound pulley (A-61 belt): Calculated belt length is about 1550 mm, near the A-61 standard (1550 mm). Thus, belt selection is validated.

Shaft Design

The digester shaft is subjected to torsion due to stirring. The torque, T, transmitted is:

$$T = \frac{9550P}{N} \quad (6)$$

Where: P = 9.7 kW (13 hp), N = 61 rpm

$$T = \frac{9550 \times 9.7}{61} = 1518Nm$$

For a solid shaft of diameter

d = 35mm = 0.035m, shear stress is:

$$\tau = \frac{16T}{\pi d^3} \quad (7)$$

$$\tau = \frac{16(1518)}{\pi(0.028)^3} = 179.5MPa$$

Mild steel has allowable shear stress ≈ 200 MPa, hence the shaft is safe. For the separator shafts (spiked: 88 mm, screw: 74 mm), the larger diameters provide adequate strength under torsion and bending due to conveyed load, ensuring safe operation.

Selection of Prime Mover (Fuel Engine)

The total power requirement of the machine includes digestion (approx. 4.0 kW), separation (approx. 2.5 kW), and transmission/frictional losses (20%).

$$P_{total} = (4.0 + 2.5)(1.2) = 7.8 \text{ kW}$$

A 13 hp engine corresponds to:

1 hp = 0.746 kW. Therefore, $13 \times 0.746 = 9.7\ kW$

Thus, the 13 hp fuel engine exceeds the calculated requirement, providing a safety margin for prolonged use and load variations.

Cleaning System Design and Analysis

One of the key features of this machine is its integrated self-cleaning mechanism, which reduces downtime and maintains hygiene. The system is designed to flush out residual palm pulp and oil from the digester chamber using strategically placed water nozzles. The design flow rate from the tank through the nozzles was estimated using Torricelli's theorem:

$$Q = C_d A\sqrt{2gh} \quad (8)$$

The total discharge is: $Q_T = nQ$

The water consumption per rinse cycle:

$$W = Q_T \times t \quad (9)$$

Where: C_d= Coefficient of discharge, A= Nozzle area, g= Acceleration due to gravity, h= Head of water, n= Number of nozzles, t= time of flushing

A cleaning cycle is recommended after every 3–4 batches, or more frequently if residue buildup is observed.

Machine Description

The integrated digester–separator palm fruit machine is developed as a compact unit that incorporates all essential components required for efficient processing. The system is powered by a 13 hp petrol engine coupled with a 1:30 speed reducer, which transmits motion through a compound pulley and V-belt arrangement to both the digester and separator units. The digester consists of a cylindrical chamber with an internal diameter of 330 mm and a height of 370 mm. At its center, a 35 mm diameter shaft fitted with stirrer blades rotates to effectively mash the palm fruits, thereby loosening the mesocarp from the nuts. The digested mixture is subsequently directed into the separator unit, which comprises a spiked shaft of 88 mm diameter and a screw shaft of 74 mm diameter. These components operate simultaneously, with the spiked shaft agitating the material while the screw shaft conveys it forward, resulting in the separation of fibrous mesocarp from the nuts. Separation is facilitated by discharge outlets strategically positioned to ensure that nuts and fibres are expelled independently based

on their density differences. To improve hygiene and operational efficiency, the machine integrates a cleaning system consisting of an overhead water tank fitted with brass nozzles positioned around the hopper and discharge outlets. Following several processing cycles, the system is activated to flush water into the digester chamber, effectively removing residual fibres and minimizing downtime associated with manual cleaning. The entire assembly is supported by a robust frame fabricated from mild steel angle bars measuring 1020 × 500 × 1385 mm, ensuring structural stability and durability. This configuration not only enhances the efficiency of palm fruit processing but also reduces operator fatigue while maintaining sanitary operating conditions.

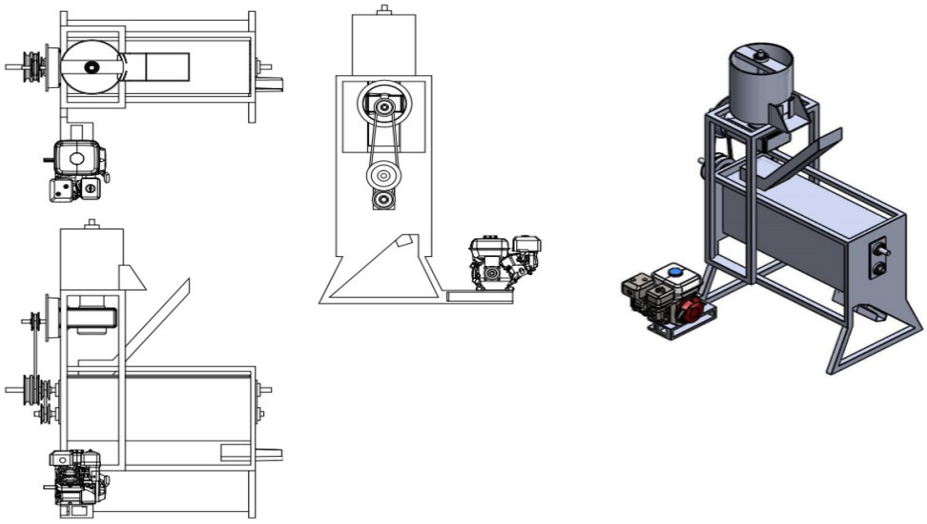


Figure 1: 3D drawing of the constructed machine showing the isometric projection, front view, side view and top view

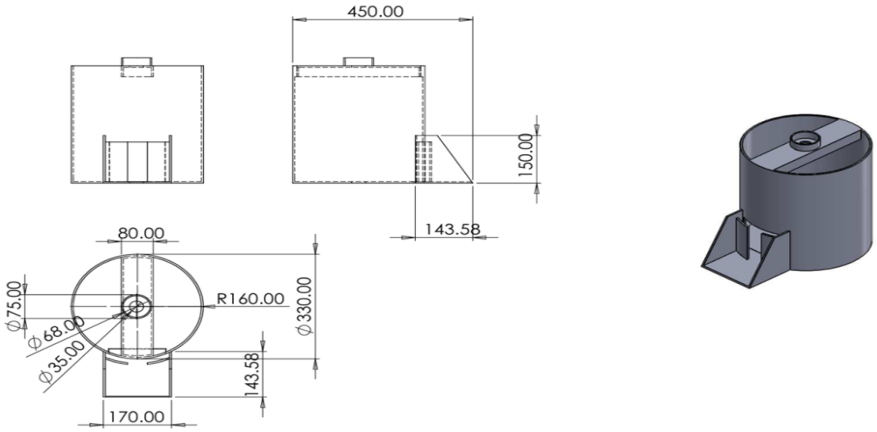


Figure 2: Orthographic Projection of the Digester

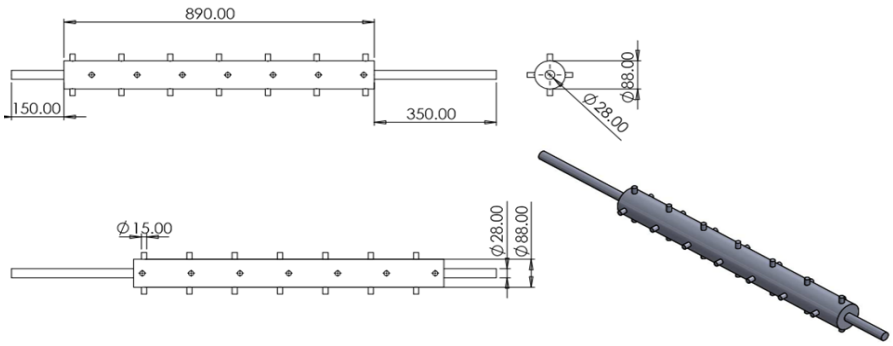


Figure 3: Orthographic projection of the spiked separator

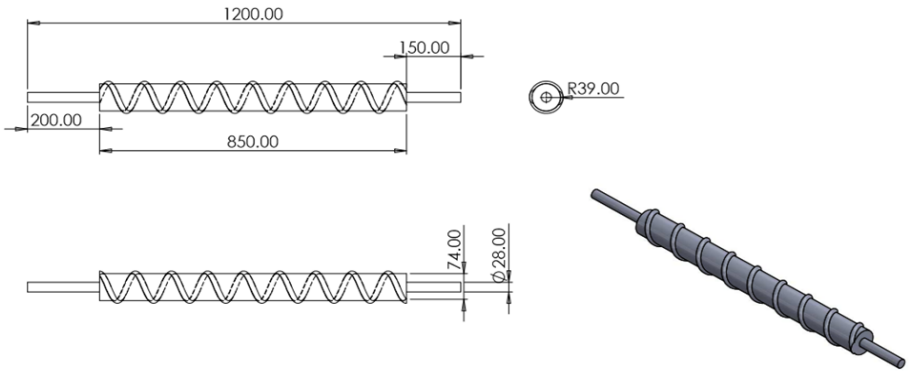


Figure 4: Orthographic projection of the screwed separator

For each batch of performance evaluation of the machine, the following parameters were assessed:

a) Throughput Capacity: $C_t = \frac{W_f}{t}$ (10)

Where C_t = mass of fruits processed (kg), t= time taken (s or hr). Often expressed in kg/hr.

b) Separation Efficiency: $\eta_s = \frac{W_n}{W_f} \times 100\%$ (11)

Where W_n = weight of nuts correctly separated, W_f = weight of feed (nut + fibre composite).

c) Digestion Efficiency, η_d: Analogous to separation, but measures how much of the mesocarp is softened/digested to the required level.

$\eta_d = \frac{W_{digested}}{W_{input}} \times 100\%$ (12)

Where $W_{digested}$ = mass of fruit properly digested (may measure through manual inspection or by scraping).

d) Cleaning Effectiveness, η_c: You will run the cleaning system after a certain number of batches. Measure residue before cleaning (R_b) and residue after cleaning (R_a), then:

$\eta_c = \frac{R_b - R_a}{R_b} \times 100\%$ (13)

RESULTS AND DISCUSSION

The performance of the integrated digester–separator palm fruit machine with a cleaning system was evaluated using five 20 kg batches of palm fruits. For each batch, the throughput capacity, digestion efficiency, separation efficiency, and cleaning effectiveness were determined.

Table 1: Recorded data of Experimental data

Batch	Mass of Palm Fruits (kg)	Time Taken (min)	Mass of Digested Nuts (kg)	Mass of Total Nuts (kg)	Mass of Separated Nuts (kg)	Residue Before Cleaning (kg)	Residue After Cleaning (kg)
1	20	7.1	8.3	9.1	8.0	1.3	0.2
2	20	7.0	8.4	9.1	8.1	1.2	0.2
3	20	7.2	8.2	9.1	7.9	1.4	0.3
4	20	7.1	8.5	9.1	8.3	1.3	0.2
5	20	7.15	8.3	9.1	8.1	1.2	0.2

Table 2: Performance results of the Machine

Batch	Mass of Palm Fruits (kg)	Throughput Capacity (kg/hr)	Digestion Efficiency (%)	Separation Efficiency (%)	Cleaning Effectiveness (%)
1	20	168.4	91.5	88.2	84.7
2	20	172.6	92.3	89.1	86.2
3	20	165.8	90.2	87.5	83.9
4	20	170.2	93.1	90.4	85.4
5	20	167.9	91.7	88.9	86.0
Average	20	169.0	91.8	88.8	85.2

First, the necessary data were recorded was shown in Table 1, then it was used to conduct performance evaluation as shown in Table 2. The results were obtained and Throughput Capacity was recorded as 169.0 kg/hr, digestion efficiency as 91.8%, Separation Efficiency as 88.8% and Cleaning Effectiveness as 85.2%

CONCLUSION

The design and modification of an integrated digester–separator palm fruit machine with a cleaning system was carried out with the objective of improving palm oil processing efficiency, reducing labour requirements, and addressing hygiene concerns associated with traditional methods. The developed system integrates three critical operations; digestion, fibre–nut separation, and automated digester cleaning into a single machine. This integration not only simplified the workflow but also reduced the overall time and energy required for palm fruit processing. Performance evaluation of the machine revealed encouraging results. The digester unit achieved high levels of mesocarp disintegration, reflected in an average digestion efficiency of 91.8%, while the separator unit effectively separated fibres from nuts with an efficiency of 88.8%. The throughput capacity of 169.0 kg/hr demonstrated that the

machine is suitable for small- to medium-scale processing applications. Moreover, the cleaning system, which uses an overhead tank and strategically placed nozzles, achieved an effectiveness of 85.2%, ensuring that residues were adequately removed from the digester chamber between processing cycles. Compared with traditional and semi-mechanized methods, the developed system represents a significant improvement in efficiency, labour reduction, and hygienic standards. The integrated digester–separator palm fruit machine with a cleaning system offers an effective, reliable, and economically viable solution for palm oil processors, particularly in rural and small-scale production settings. Its adoption has the potential to enhance productivity, reduce drudgery, and improve the overall quality of palm oil processing, thereby contributing positively to food security and rural industrial development.

REFERENCES

Adeleke, O. A., & Musa, L. A. (2019). Evaluation of small-scale palm oil processing equipment. Journal of Agricultural Mechanization, 11(2), 45–56.

Adeleye, O. T., & Ologunde, A. O. (2014). Development of a small-scale screw press for palm oil extraction. Journal of Agricultural Engineering, 5(3), 211–220.

Adetola, A. A., & Okafor, C. U. (2016). Design of integrated agricultural machines. Nigerian Journal of Technological Research, 11(2), 60–68.

Adetola, B.O., Salami, A.O., Bello, S.A. (2022). Improving Safety Features In Palm Oil Processing Equipment: A Case Study of Local Fabrication technologies in Nigeria. Journal of Agricultural Engineering and Technology, 30(2), 115-127.

Adzimah, S. K., & Seckley, E. (2018). Modification in the design of an already existing palm nut–fibre separator. International Journal of Scientific & Technology Research, 7(8), 77–83.

Alabi, A. O., & Popoola, S. O. (2018). Design of gravity-fed cleaning systems for agro-processing machines. Journal of Mechanical Design and Applications, 6(2), 14–20.

Ayodele, T., & Ibe, C. (2019). Effect of self-cleaning mechanisms on machine downtime. African Journal of Industrial Engineering, 10(3), 121–129.

Azodo, A., & Onyekwere, S.O. (2023). Acoustic Safety Assessment of Palm Oil Mill Workers. Environmental Research and Technology, 6(3): 183-188.

Basiron, Y. (2007). Palm oil production through sustainable plantations. European Journal of Lipid Science and Technology, 109(4), 289–295.

Eze, A. J., & Akinlabi, O. A. (2019). Application of fluid mechanics in agro-machine nozzles. Journal of Fluid Engineering, 141(2), 1–9.

Eze, C. (2020). Design review of palm oil machines with cleaning systems. International Journal of Agro-Engineering, 14(1), 25–37.

Eze, C. J., & Ezeanya, C. I. (2018). Sustainability in palm oil processing machines. African Journal of Sustainable Engineering, 9(1), 21–29.

FAO, (2015). Engineering for rural development in West Africa. FAO Technical Paper. Rome: FAO.

Fashina, A. B., Durodola, O. S., & Hammed, A. (2017). Development and performance evaluation of an oil palm fruit digester. Nigerian Journal of Technological Development, 14(1), 25–32.

Musa, L. A., & Bello, M. O. (2020). Modelling of palm fruit digestion processes. International Journal of Engineering Innovation, 8(4), 234–243.

Musa, O. J., & Akande, A. O. (2020). Improving efficiency in palm oil processing through integration. Journal of Agro-Engineering Research, 19(2), 88–97.

Nwankwojike, B. N., et al. (2012). Development of an integrated palm oil processing machine. Nigerian Journal of Technology, 32(3), 391–400.

Nwankwojike, B. N., Odukwe, A. O., & Jonah, C. (2012). Design, fabrication and evaluation of palm nut–pulp separator. Journal of Agricultural Engineering and Technology, 20(2), 34–45.

Okafor, J. O. (2016). Analysis of belt drive systems for palm oil machines. Nigerian Journal of Mechanical Engineering, 8(2), 80–89.

Okolie, P. C., Oluwadare, B. S., Ezenwa, O. N., & Azaka, O. A. (2018). Design and production of palm nut and fibre separating machine. International Journal of Engineering Research and Technology, 7(5), 142–150.

Onwuka, N. S. (2018). Performance evaluation of palm nut–fibre separator. African Journal of Engineering Research, 6(1), 12–19.

Onyenanu, I. U. & Okiemute, G. E., (2023). Design and Fabrication of a Palm Fruit Digester. International Journal of Engineering Research & Technology (IJERT), Vol. 12 Issue 06, Pp. 370-378.

Udoh, A. J., & Abiola, S. O. (2016). Comparative evaluation of palm fruit digesters. Journal of Agricultural Mechanization, 12(1), 71–78.

Udoh, J. (2018). Dynamics of separator shafts in palm oil processing machines. Journal of Applied Mechanics, 17(1), 65–73.

Ugochukwu, A., & Adeyemi, K. (2017). Development of integrated agro-processing equipment. Agricultural Engineering International, 19(3), 101–110.

Ugwu, H. U., & Nwachukwu, A. N. (2017). Comparative study of manual and mechanized palm oil processing. Nigerian Journal of Engineering, 23(1), 99–107.

Ugwu, I. J., & Musa, L. (2019). Performance improvement of palm oil separation machines. Journal of Mechanical Engineering Research, 14(2), 123–134.

Unabor, P. O. & Ugbeni, V. O., (2025). Safety and Oil Palm Processing Equipment: Challenges and Innovations. Nigeria Journal of Engineering Science Research (NIJESR), 8(2): 17-22.

Zakaria, A. H., Salleh, M. A. M., Ismail, M. H. S., & Aziz, M. K. A. (2015). Palm fibre and nut separation by air classifier system. Journal of Applied Sciences, 15(3), 467–474.