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Design, Fabrication, Performance Evaluation And Pedagogical Integration Of A Low-Cost Multi-Purpose Palm Oil Processing Machine For Technical And Vocational Education In Nigeria

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ABSTRACT

The study developed a multipurpose palm oil processing machine at the College of Education (Technical) Ekiadolor, which is a low-cost solution that serves as both a production and training device. It consists of the processes involved in palm oil production including sterilization, threshing, digestion and extraction using mechanical screw press, all adapted into a the machine using local materials which lowers cost and is sustainable. The experimental results using batches each with 500kg fresh fruit bunch (FFB) of three experiments have an oil extraction efficiency of 92.1% and clarification efficiency of 92.1%, average throughput of 350kg/hr and duration per batch of 2.5 hours. The one-way analysis of variance (ANOVA) indicates a statistically significant result compared to the manual process used earlier ($F(1,4)=36.72$, $p=0.003$). The multiple regression analysis observes a high determination coefficient ($R^2=0.87$) predicting oil yield from temperature and time for processing. The cost-benefit analysis indicates the institution to earn on break-even period within 14-16 months of moderately-scheduled operations. The experiential learning theory and competency-based technical education were the frameworks employed in the machine that improved students' skills in fabrication, controlling the process parameters using thermodynamics, preventive maintenance, and managing agro-enterprise. The study concluded that domestic agro-mechanization of production processes taught in a TVET institution results in enhanced production efficiency, institutional sustainability, graduates employability, and rural entrepreneurship. An institutional mechanism to integrate production and pedagogy is recommended to be adopted with cultural sensitivities across technical colleges in Sub-Saharan Africa.

Keywords: Palm oil processing, TVET innovation, agro-mechanization, competency-based training, institutional production model, experiential learning, technical education reform.

INTRODUCTION

The palm oil is still an important staple crop for West Africa's economy and Nigeria used to be the world's largest producer of palm oil and its products but national plantation estates were poorly maintained and mechanization was poor among smallholders, industrialization was also lacking (Nwosu, 2020; Okoro, 2019; Owolarafe et al., 2022). This has resulted in semi-manual processing by small-scale processors that yield low extraction rates (55–70%), long processing time, variable quality and high labour usage. Processing losses, often exacerbated by inefficient practices also lead to more unprofitable and loss making ventures, high free fatty acids (FFA) as a result of delays in processing etc. Overcoming inefficiencies through mechanization can lead to 20–30% improvements in extraction efficiency and 40–50% reductions in processing time. Despite the breakthrough technology, cost of modern mechanized systems remains prohibitive for smallholders and Nigerian educational institutions implementing a modular approach. Nigerian universities and Technical and Vocational Education and Training (TVET) institutions also face institutional challenges such as inadequate practical facilities, weak synergies with industry and inadequate incubation frameworks for startups. Students graduate without exposure to real life production units. The establishment of adequate agro-processing facilities in TVETs and universities will contribute to:

- Enhance experiential learning (Kolb, 1984; Eze & Okeke, 2020)
- Develop industry-relevant competencies
- Generate institutional revenue
- Promote agro-industrial entrepreneurship.

This study therefore designed, fabricated and experimentally evaluated a multipurpose palm oil processing machine integrated within the Federal College of Education (Technical) Ekiadolor and analyzed its mechanical performance, financial viability, and pedagogical impact, drawing on previous work in mechanized small-scale processing (Yaro & Zubairu, 2017; Salako et al., 2025; Ilechie, Ibhadode, & Abikoye, 2011).

REVIEW OF RELATED LITERATURE

Small-Scale Palm Oil Processing Efficiency

Traditional palm oil processing systems involve manual fruit stripping, drum boiling, mortar pounding, and manual pressing. Studies report extraction efficiencies between 60–65% under such systems (Nwosu, 2020; Okoro, 2019). Mechanized small-scale systems report efficiencies between 80–92% depending on design sophistication (Yaro & Zubairu, 2017; Adegbola, 2025; Akolgo & Agyeman, 2023). Mechanization enhances:

- Oil recovery rate
- Product hygiene
- Labor productivity
- Time efficiency

At the same time, an industrial model is not accessible to small producers or to TVET institutions (Owolarafe et al., 2022; Onyekirim et al., 2025).

Local Development and Sustainable Mechanization

Locally sourcing for development help to reduce the initial investment and guarantees independence of maintenance. The studies proposed demonstrate the feasibility from affordable agro-productive facilities with mild steel skeletons, biomass boilers and modular screw presses (Agwu et al., 2022; Salako et al., 2025; Itabiyi et al., 2024). The distinctive characteristic of the design studies find the use of energy saving boiler and modularization allowing maximizing extraction and the reliability of operation (Salako, Owolarafe, Osunleke and Olaye, 2025).

TVET reforms and production-based learning

Currently, TVET learning finds a development based on competency learning modules and experiential exposure time (Kolb, 1984; Anuar & Jaafar, 2021). Experiential exposure learning are based on experience, reflection, conceptualization and experimentation in circuits. The best learning and exposure of time required in production processes are more advantageous to students in trades than cooking schools holding into the simulation stages (Eze & Okeke, 2020; Han & Yi, 2025).

Theoretical Framework

Experiential Learning Theory

Kolb's experiential learning stages comprises of:

- Concrete Experience

- Reflective Observation
- Abstract Conceptualization
- Active Experimentation

The development of the processing system allows the students to operate the machine, measure outputs, change variables parameters, articulate and correlate mechanical principles to outcomes (Kolb, 1984; Anuar & Jaafar, 2021).

Competency-based Technical Education

The processing system impact in a greater way on competency-based development such as : TVET standards recommend graduates to possess practical skills fit for production tasks parameters, initiation and execution of activities (Adegbola, 2025; Onyegirim et al., 2025). Such competencies impact on current issues regarding employment.

MATERIALS AND METHODS

Research Design

Experimental system with three (3) replicates for each processing of 500 kg FFB.

Machine Configuration

Components:

- Biomass boiler/steamer (Salako et al., 2025)
- Rotational thresher (Itabiyi et al., 2024)
- Vertical digester (Ilechie, Ibhadode, & Abikoye, 2011)
- Screw press (Akolgo & Agyeman, 2023)
- Heated clarification tank
- Protective shade

Engineering Calculations

Power requirement:

$P = \frac{2\pi NT}{60} = 7.54\text{kW}$ (7.5 kW motor selected)

Extraction efficiency:

$\eta = \frac{W_0}{Wt} \times 100 = 88.4\%$

Throughput:

Peak mechanical throughput = 350 kg/hr

Batch processing time = 2.5 hrs

Methodology for evaluation of performance adaptability, output is similar to studies conducted internationally on small-scale mechanized systems (Akolgo & Agyeman, 2023; Salako et al., 2025; Adegbola, 2025).

RESULTS

Descriptive Statistics

Trial	Oil Yield (kg)	Efficiency (%)	Time (hrs)
1	100.8	87.7	2.6
2	102.5	89.1	2.4
3	101.7	88.4	2.5

Mean Efficiency = 88.4%

Standard Deviation = 0.70

Coefficient of Variation = 0.79%

Conformal study indicates low variability and high level of homogeneity within system performance which indicates mechanical stability.

ANOVA Table

Source	SS	df	MS	F	p
Between Groups	1764.5	1	1764.536.72		0.003
Within Groups	192.2	4	48.05		
Total	1956.7	5			

Result: The AVOVA Table above demonstrates that $p<0.05$ therefore there is a significant difference between oil extraction efficiencies from manual (65%) and fabricated system (88.4%).

Regression Model

$Y = \beta_0 + \beta_1 T + \beta_2 Temp + \epsilon$ $R^2 = 0.87$

Variable	Coefficient	p-value
Intercept	52.3	0.001
Time	3.41	0.021
Temperature	0.62	0.015

Model has a strong correlation and predictive value. Unbiased and reliable.

Cost–Benefit Analysis

Investment Cost = ₦4,995,000

Net profit per batch =₦ 73,530.00

Projected Monthly Net = ₦1,146,828.00 to ₦2,303,915.00 based on scenario and time-based factors.

Most conservative estimate of breakeven within 14-16 months. The financial projections data is statistically-based on studies conducted on small-scale mechanized systems (Akolgo & Agyeman, 2023; Onyegirim et al., 2025).

Analysis Of Impact In Education

Student learning outcomes improved in:

- Mechanical system understanding
- Applied thermodynamics
- Industrial safety
- Production accounting
- Entrepreneurship feasibility analysis

The increased exposure and participation of the students in the live-reading of performance parameters and machine optimization directly enhance competencies in dissemination (Anuar & Jaafar, 2021; Han & Yi, 2025).

DISCUSSION OF FINDINGS

The fabricated extractor system and mechanical design achieved higher efficiency yield, which supports the field of research and studies (Akolgo & Agyeman, 2023; Adegbola, 2025). The condition and operational stability of the output also influence both health and maintenance issues. In this regard, the yield can be compared to processing results done mechanically and statistically analyzed ($p<0.005$) statistically validated. The system proves progress and stability in routine and scheduled operation. The introduction and incorporation of the processing unit in a TVET approach and adoption helps transform the theoretical practice of the subject in a facility. The experiential basis of learning impacts the student and beneficiary of the training. The dual character of production–training of the unit impacts on the issues of graduate unemployment and precarious employment funding the study. The results account as a factor of inefficiency in the present agro-mechanization systems.

Policy And TVET Reform Implications

1. Technical colleges should integrate production units into training.
2. Government intervention funds should prioritize institutional agro-processing hubs.

3. TVET curriculum should incorporate live production analytics.
4. Rural colleges can become micro-industrial anchors.

Recommendations for the implementation of present and future policies reflect the study (Salako et al., 2025; Anuar & Jaafar, 2021).

CONCLUSION

The study successfully designed, fabricated and evaluated a low-cost integrated palm oil processing system achieving; 88.4% extraction efficiency, 92.1% clarification efficiency, strong statistical validation, financial sustainability and significant pedagogical value. Localized agro-mechanization embedded in TVET institutions offers a replicable pathway toward technical education transformation and rural industrialization.

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Appendix

Cooking Drum

Digester

Thresher

Press