Uniosun Journal of Engineering and Environmental Sciences (UJEES), Vol. 8 No. 2, Sept., 2026
DOI: 10.64980/ujees.v8i2.027 **Adeaga et al.**
Published: September 30, 2026

DEVELOPMENT OF MOBILE SOLAR ENERGY POWERED COMMERCIAL EXTRUSION–COOKING MACHINE FOR SMALL AND MEDIUM SCALE ENTERPRISES

Oyetunde A. ADEAGA[1*], Folasade O. AFOLABI[2], Charles T. AKANBI[3], Idowu A. AYOADE[4], Oladeji O. OLANRELE[5], Iyabo I. ADEAGA[6]

[1,4]*Department of Mechanical and Mechatronics Engineering, Abiola Ajimobi Technical University Ibadan, Oyo State, Nigeria*
[2,3]*Department of Food Science and Technology, Abiola Ajimobi Technical University Ibadan, Oyo State, Nigeria*
[5]*Department of Industrial Production and Computer Engineering, Abiola Ajimobi Technical University Ibadan, Oyo State, Nigeria*
[6]*Department of Computer Engineering Technology, The Polytechnic, Ibadan, Oyo State, Nigeria*

[*]*Corresponding Author: oyeadeaga@tech-u.edu.ng*

Abstract
Extrusion machine is traditionally driven by electrical energy or internal combustion engine and mostly fixed in a position. Incessant outages and need to make the machine movable necessitated this research. This article explored a 3kW commercial extrusion machine with a view to applying solar energy for operation while making the entire system movable to and from the market for commercial purposes. Material balance equations were adopted and applied to extrude 50 kg of yam flour for 2 hours using star-perforated fixed die pattern during evaluation. Sunlight was trapped from sunrise to sunset through solar panels through charge controller and then stored as solar energy in two (2) lithium batteries. Solar energy components such as panels, battery, charge controllers and inverters were designed or sized. The supporting frames were fabricated with 2 and 1.5inches angle bar as the compartment for energy storage device (batteries). The two solar panels were mono-chrome in the capacity of 250 watts each. The evaluation of the developed machine was done only to discover 92% workability. Since the designed rating for the device was met but relatively heavy for movement for average adult person, therefore six (6) roller-tire supports were introduced to ease mobility of the set-up. Mass production of the set-up is recommended as it will be beneficial to both small and medium scale businesses and thereby reduce youth unemployment and environmental pollution from the product of combustion.

Keywords
Extrusion cooking, Solar, renewable, lithium, roller-tire

1. INTRODUCTION

More recently, solar energy is been explored in different aspects of life. The applications include space heating, water heating, industrial/domestic cooking, drying of agricultural products, solar cooling and photovoltaic generation of electricity. Energy from sun reaches the atmosphere to the tune of around 1.395k W/m^2, amounting to just a unit from 1010 of actual released from the sun with 3% explorable during hydrological cycle and photosynthesis in plants, 47% are absorbed back to the atmosphere, land and ocean to be converted to long wave radiation (terrestrial radiation) while 30% are reflected and scattered within space. [1]. Abiola Ajimobi Technical University, Ibadan (TECH-U) is on 200 hectares of land and located at kilometer 11, along Lagos–Ibadan Expressway, Ibadan, Oyo State and in approximate latitude 7°24′N and longitude 3°49′E with an elevation that ranges approximately from 150 m to 275 m (490 to 902 ft) above sea level. Lagos–Ibadan Expressway is one of Nigeria's busiest highways, while the campus is surrounded by multiple production companies. The population of the university is about 5000. The increasing population of the university is however the aim of the development of the machine to be able to move the machine around the campus without depending on electricity supply from the grid while eradicating environmental pollution that could arise from the use of internal combustion machines [2].
Extrusion technology is commonly applicable in the food and feed processing industries, utilizing specially designed equipment to process raw materials into products that meet logistical and functional requirements [3]. Continuous innovations in extruder design and integrated components have expanded versatility,

enabling manufacturers to address consumer demand for improved nutritional value, textural quality, and functionality. Extrusion cooking functions as a thermo-mechanical process where raw materials are cooked under pressure and extruded through a shaped die to achieve targeted dimensions and geometry [4]. Persistent innovations in designing the extruder and integrated components have prompted versatility while enabling the industry to catch up with increasing demands from consumers in terms of nutritional values, textural quality, and functionality. In recent past, extrusion cooking has been successfully applied as food processing technique in which raw materials (mostly foodstuffs) are processed through cooking and extruded through a designed die size that already has inscribed slots. An extrusion cooker is an aggressive, heavy inductive load. It relies on a heavy-duty electric motor (often an AC induction motor or a gear motor) combined with heating elements (barrel heaters) to cook and shape food under high pressure and temperature. Food processing in rural and urban areas of developing nations relies on inefficient, traditional technologies ("Food Processing And Preservation," 1973; "Food Processing and Preservation," 2000; Lajnaf *et al.*, 2022). These methods, often used at household or small-scale levels, face electricity shortages and high energy demand. Upgrading to affordable, user-friendly machinery addresses socioeconomic needs and promotes sustainability ("Food Processing and Preservation," 2000) [5]. Solar power offers a renewable alternative to fossil fuels and biomass in food processing. It powers cooking, drying, and preservation, reducing costs and emissions. Applications include solar dryers for fruits, vegetables, and herbs, which outperform open-sun drying by preventing contamination and shortening times [6]. Solar integration in machines like grating oil expellers, and roasting systems boosts efficiency for small enterprises. These innovations foster self-sufficiency, cut waste, and support rural economies [7].

This demonstrates the broader applicability and proven success of solar energy integration in diverse agricultural contexts, reinforcing the feasibility and impact of the proposed extrusion-cooking machine. The inherent advantages of solar energy, such as its environmental friendliness and cost-effectiveness compared to fossil fuel-dependent methods, further underscore its suitability for such applications [8]. Solar drying, for instance, offers a controlled environment that protects agricultural products from contaminants, thereby enhancing food safety and significantly reducing post-harvest losses. This is particularly crucial in developing countries where a lack of access to electricity often hinders appropriate post-harvest processing activities, leading to decreased profits for farmers [10]. Solar energy applications in food processing can significantly reduce greenhouse gas emissions by up to 430,714.76 tons annually, simultaneously decreasing operational costs by approximately $757.31 and increasing annual profits for farmers by $15,683 [11]. This economic and environmental benefit highlights the profound potential of adopting solar-powered technologies in agricultural practices to achieve sustainable development goals [12]. The financial benefits are substantial, with an estimated saving of 31.75 USD per year when substituting diesel oil with solar energy [13]. The implementation of such solar-powered systems also yields significant reductions in CO_2 emissions, with calculations indicating a potential decrease of 1.22 tons annually through the displacement of conventional energy sources[14].This economic viability, coupled with environmental stewardship, positions solar-powered extrusion-cooking as a transformative technology for small and medium enterprises in regions with abundant solar irradiation, enhancing both food security and economic resilience [15]. Furthermore, the long-term cost-effectiveness of solar systems, despite higher initial investments, is evident through substantial energy savings and favorable payback periods, making them a strategically sound choice for sustainable agricultural processing [16].

2. MATERIALS AND METHOD

A single screw extrusion machine was investigated to understand the working operations. All parts of the machines were identified and functions studied. The major part that needed solar power input is the motor which serves as the driver for the entire system. The olgar which it major part of the extruder induces vortex like motion in the screw thereby making the raw flour moves from the inlet to the exit at the die. [17]. The electric motor is housed in a gear box which primarily functions as speed reducer.

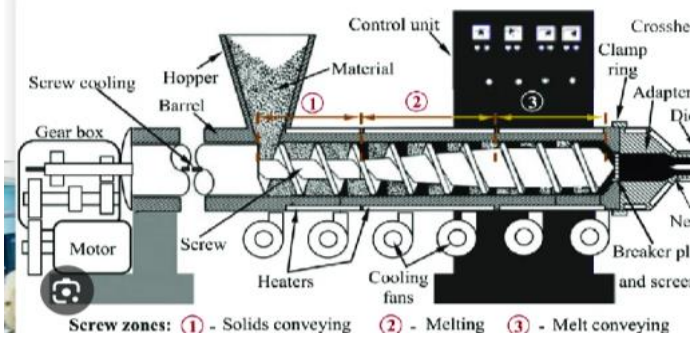


Fig. 1. Section of the extrusion machine

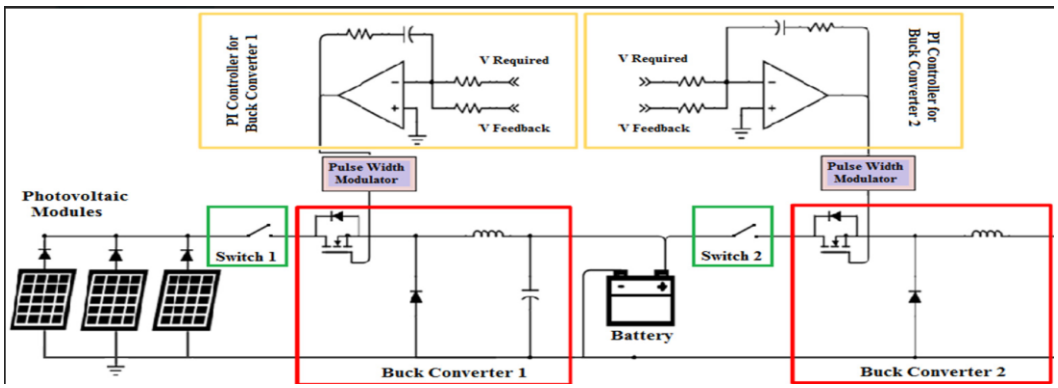


Fig. 2. Typical solar system circuit connection

Sizing solar energy system to drive a 3kW movable inverter for an extrusion cooking machine was carried out. While sizing the solar array and batteries, the electrical nature of the extrusion cooker was studied and analyzed, for dual challenge: thermal loads (heaters) and inductive loads (motors).
The system component is compact, and mechanically stable because of the expected mobility.
The design calculations were categorized into five (5) steps viz;
Step 1: Load Characterization
This was done in two stages as Continuous Running Power (P_{rm}) and Inrush/Starting Surge Power (P_{Surge})
Step 2: Battery Sizing: Daily Energy Consumption (E_{Daily}) was calculated and also required Battery Capacity (Ah)
Step 3: Sizing Solar PV (Panels) Array: System Loss concept was applied and also Peak Sun Hours
Step 4: Sizing Solar Charge Controller: Maximum Short Circuit Current was estimated and safety Margin applied
Step 5: The movable System: Considering vibration resistance and selection of appropriate sine wave inverter
The Load requirement of the Extrusion Cooker Profile was characterized as;
i. Continuous Running Power: True running wattage from the machine's nameplate was used. While the inverter is rated at 3kW, an extrusion machine often operates close to its limit or has a combined load of motor + barrel heaters totaling 2kW to 2.8kW.
ii. Inrush/Starting Surge: The electric motor drew 3 to 5 times their running current during startup.
The 3kW movable inverter has a high peak surge rating of 2x the continuous rating, i.e., 6kW for a few seconds) hence prevented from tripping or shutting down under a hard motor start. VFD (Variable Frequency Driver) extruder motor was used to significantly lowers this requirement.
The Battery Bank (Solar Energy Storage) was sized bearing in mind that Extrusion cookers pull high currents continuously. Running them heavily depletes batteries quickly, so the storage capacity must account for depth of discharge and high discharge rates (C-rated) and the d**aily energy Consumption (E_{daily}):**

Daily Energy (Wh) = Total Running Watts × Average Operating Hours per Day (1)

Extruder draws 2,500W and runs for 3 hours a day: 2,500 W × 3 hours = 7,500 Wh (or 7.5 kWh)
The required battery capacity (*Ah*) was also estimated as below:

$$\text{Battery Capacity (Ah)} = \frac{E\text{daily} \times \text{Days of Autonomy}}{\text{DOD} \times \text{Battery Efficiency} \times \text{Nominal System Voltage}} \quad (2)$$

The Depth of Discharge (DoD) is normally 80% (0.8) for Lithium-ion/LiFePO4, or 50% (0.5) for Lead-acid. (LiFePO4 is strongly recommended for movable/portable rigs due to weight and high-current capability) while the efficiency is approximately equal to 90% to 95% for Lithium.
For a 3kW inverter, the rated system voltage is 48V DC system voltage and it is the standard (minimizes current and cable thickness compared to 12V/24V).
Next was sizing the Solar PV Array (Panels) which replenishes the energy consumed daily by the extruder while accounting for system losses (dust, heat, inverter conversion inefficiencies, and wiring drops).
System Loss Factor was added as 20% safety margin to your daily energy requirement:

$$\text{Target Generation (Wh)} = E_{daily} \times 1.25 \quad (3)$$

Find the average peak sun hours for the deployment location (typically between 4 to 6 hours globally):

$$\text{Required PV Panel Wattage (Wp)} = \frac{\text{Target Generation (Wh)}}{\text{Peak Sun Hours}} \quad (4)$$

For 9,375 Wh adjusted and have 5 peak sun hours equals;

$$\frac{9375}{5} = 1875\ Wp$$

To be able to run heavy production machine reliably and account for cloudy weather, a 3kWp to 4kWp solar array was paired with a 3kW inverter system. Then the Solar Charge Controller (MPPT) was sized. The charge controller safely channels power from the solar panels into the battery bank. The Maximum Short-Circuit Current was calculated based on the total wattage of the solar panels and the system voltage as;

$$\text{Controller Amp Rating} = \frac{\text{Total PV Array Wattage (Wp)}}{\text{Voltage}} \quad (5)$$

Safety Margin was applied by multiplying the result by a 1.25 safety factor to handle cold-weather panel voltage spikes.
For a ~3kW panel array on a 48V system, 60 A MPPT solar charge controller was selected (or use the built-in MPPT all-in-one hybrid inverter).
For a Movable" set-up", Vibration Resistance and type of inverter must be carefully selected as Extrusion cookers vibrate heavily during operation. All solar racking, battery terminals, and internal inverter wiring must feature secure locking washers, heavy-duty lugs, and industrial-grade dampening. Also, careful choice of Inverter Type ensures Pure Sine Wave inverter. Extrusion machine control boards, digital displays, and sensitive motor windings will overheat or malfunction on modified sine wave power.
For a 3kW movable solar inverter driving an extrusion cooking machine, the underlisted steps were taken in the design.

Step 1: Extruder Power & Motor Surge Profile
An extrusion cooker combines two distinct electrical loads:
1. **Resistive Load:** Barrel/Die Heating Elements (Constant load, high thermal consumption).
2. **Inductive Load:** Drive Motor / Gearmotor (High starting surge, variable mechanical resistance).

Example Nameplate Specifications:

- **Drive Motor:** 1.5 kW (2.0 HP) AC Induction Motor
  Barrel Heaters: 1.0 kW total
- **Total Continuous Power (P_{run}):**

$$P_{run} = 1.5\ \text{kW} + 1.0\ \text{kW} = 2.5\ \text{kW} \quad (2{,}500\ \text{W})$$

Inrush (Starting Surge) Calculation:

- An AC induction motor without a Variable Frequency Drive (VFD) draws an inrush current of 4× to 6× its rated power upon direct-on-line (DOL) startup:

Psurge, motor = Pmotor × 5 = 1,500 W × 5 = 7,500 W

Total Peak Power Requirement:

$$P\text{peak} = P_{heaters} + P_{surge,\ motor} \quad (6)$$
$$= 1{,}000\ \text{W} + 7{,}500\ \text{W} = 8{,}500\ \text{W}$$

The rated 3 kW Continuous Inverter featured a surge capability (≥ 3×) of at least 8,500 W for ~ 2–5 seconds. The 3kW inverter peak capability was limited to 6,000 W, hence a Soft-Starter or VFD was installed on the extruder motor to cap the motor startup surge below 2,000 W.

Step 2: The Daily Energy Requirement was also calculated
Assuming the extrusion cooker operates for 5 hours per day at full operational load:
i. Daily Consumption (E_{load}):

$$E_{load} = P_{run} \times t_{hours} \quad (7)$$
$$= 2{,}500\ \text{W} \times 5\ \text{h} = 12{,}500\ \text{Wh/day} \quad (12.5\ \text{kWh/day})$$

ii. System Loss & Inverter Efficiency Factor (η_{sys}):
Accounting for inverter conversion losses (≈ 90%), battery round-trip efficiency (≈ 95%), and wire drops (≈ 3%):
$\eta_{sys} = 0.90 \times 0.95 \times 0.97 \approx 0.83$ (83% efficiency)
The Total Daily Energy Generation Target (E_{pv}):

$$E\text{pv} = \frac{E_{load}}{\eta_{sys}} = \frac{7{,}500\ \text{Wh}}{0.83} = 9{,}036\ \text{Wh/day} \quad (8)$$

Step 3: Battery Bank Sizing (LiFePO4)

For high-power industrial equipment on movable rigs, 48V DC is the standard system voltage (V_{sys} = 48V) to keep current low and wires thin. Lithium Iron Phosphate ($LiFePO_4$) is recommended. Therefore, it should be noted that Nominal Voltage (V_{sys}) be 48V, Max Depth of Discharge (DOD): 80% (0.80) and Days of Autonomy (N_{days}): 1 day (standard for mobile applications)
The usable energy capacity required;
E usable = E load = 7,500 Wh
Total Nominal Energy Capacity (Ebatt, nominal):

$$E\text{batt, nominal} = \frac{E\ usable}{DOD} = \frac{7500}{0.8} = 9{,}375\ \text{Wh (9.375 kWh)}$$

The Required Amp-Hour Rating (C_{Ah}):

$$C_{Ah} = \frac{E_{battery.nominal}}{V_{sys}} = \frac{9375\ Wh}{48\ V} = 195.3\ \text{Ah}$$

Battery Specification: 48V 200Ah $LiFePO_4$ Battery Bank (Nominal Energy:
48V × 200Ah = 9,600 Wh) was selected.
Discharge C-Rate & Maximum Current Check:
Under peak 2,500W running load, maximum continuous battery discharge current ($I_{batt, max}$) is:

$$I_{\text{battery, maximum}} = \frac{P_{run}}{V_{sys}} = \frac{E_{battery.nominal}}{V_{sys} \times \eta_{inverter}} = \frac{2500\ W}{48\ V \times 0.90} = 2{,}500\ \text{W} = 57.87\ \text{A}$$

$$\text{C-Rate} = \frac{57.87\ A}{200\ Ah} = 0.29\text{C (for LiFePO4 cells).}$$

Step 4: Sizing of Solar PV array
Target Energy Output (E_{pv}): 9,036 Wh/day
Average Peak Sun Hours (PSH): 4.5 hours/day
Solar Panel De-rating Factor (DF): 0.85 (accounts for dust, heat coefficient, wire losses) **1.** Array Peak Power Output (W_p):

$$Wp = \frac{E_{pv}}{PSH \times DF} = \frac{9036\ Wh}{4.5\ h \times 0.85} = 2{,}362\ \text{Wp}$$

Array Specification: Round up to 6 × 400Wp panels = 2,400 Wp total.

Step 5: MPPT Charge Controller Sizing
Output Current Rating to Battery (*I*mppt):

$$I\text{mppt, continuous} = \frac{Wp}{Vsys} = \frac{2400\ W}{48\ V} = 50\ \text{A}$$

To cater for Safety Factor (1.25× for irradiance spikes):
Imppt, required = 50 A × 1.25 = 62.5 A
Therefore, for controller specification, 48V / 80A) MPPT was selected

Table 1: Specifications of Components as designed and for sizing

Component	Standard Sizing Calculation	Recommended Specification
Inverter	3,000 W Continuous / ≥	**3kW / 48V Pure Sine Wave** (VFD on extruder)
Battery Bank	48V, 195.3 Ah min for 3h runtime	**48V 200Ah LiFePO4** (9.6 kWh)
Solar Array	2,362 Wp calculated	6 × 400Wp **Monocrystalline Panels** (2.4 kWp)
Controller	62.5 A min output rating	**48V / 80A MPPT Solar Charge Controller**



Fig. 3. Welding ongoing

3. RESULTS AND DISCUSSION

3.1 Results

The existing machine was developed to run on solar energy and also be movable from home to the marker and vice-versa. The ambient temperature, solar insolation, wind speed, wet period and also production rate were recorded as basic factors that could affect the choice of the inverter and capacity of the solar panels. Table 1 shows the Specifications of Components as designed and for sizing and installation. The table gives comprehensive values for major designed components for solar energy utilization arrangement for extrusion machines. Table 2 shows the variation of average weather conditions with extrusion output after evaluating the machine with 30 kg of raw flour.

Table 2: Measured average design parameters

Month	Average Temperature, (°C)	Average Insolation (kWh/m²/day)	Average Wind speed (m/s)	Average Wet period, d	Average Production rate / kg
January	26.02	5.99	3.12	0.7	1,670
February	26.33	6.18	3.23	2.5	2,500
March	25.94	5.45	3.35	6.1	3,000
April	25.70	5.09	3.13	9.6	1,200
May	25.65	3.95	2.65	11.1	1,000
June	24.66	3.81	2.68	14.2	1,200
July	23.62	4.66	2.81	13.9	1,400
August	23.60	5.25	2.87	14.99	2,600
September	24.66	5.89	2.70	14.61	2,000
October	24.42	4.59	2.41	13.22	2,500
November	24.65	4.15	2.74	3.23	2,200
December	25.13	5.56	2.79	1.4	2.700

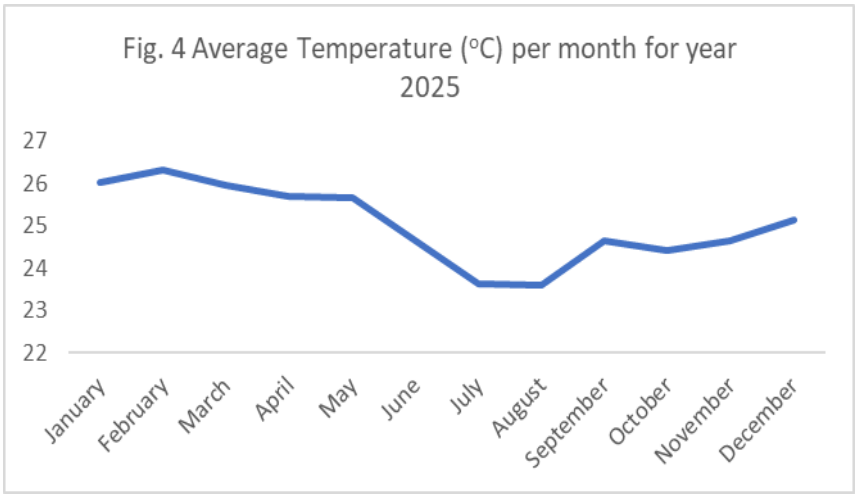


Fig. 4: Average Temperature Variation with Months of the year 2025 for 6 hours

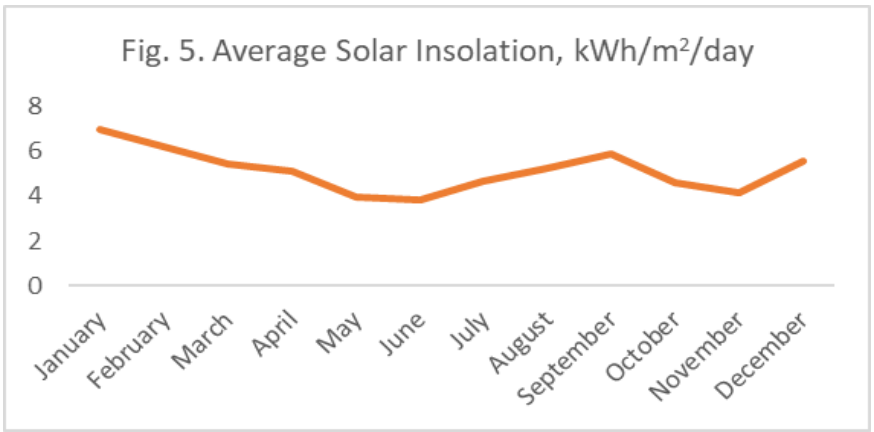


Fig. 5: Average solar insolation with Months of the year 2025 for 6 hours

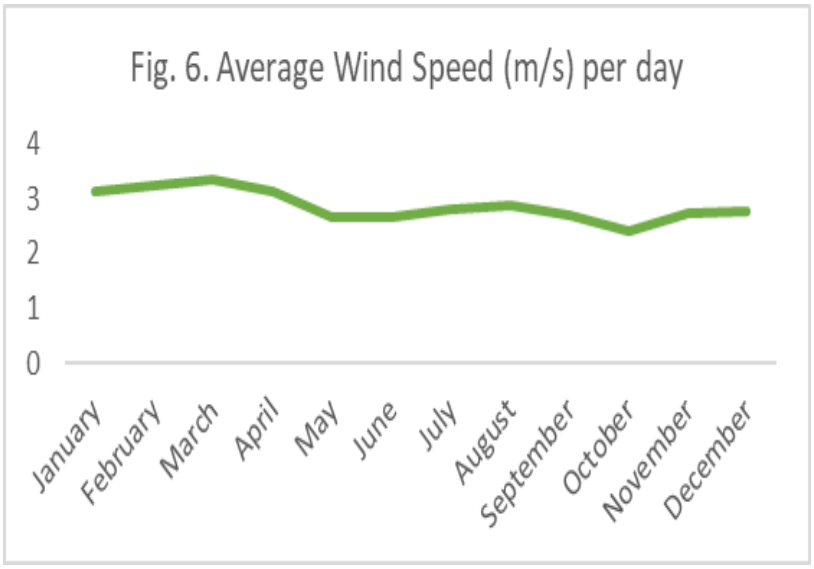


Fig. 6: Average wind speed with Months of the year 2025 for 6 hours

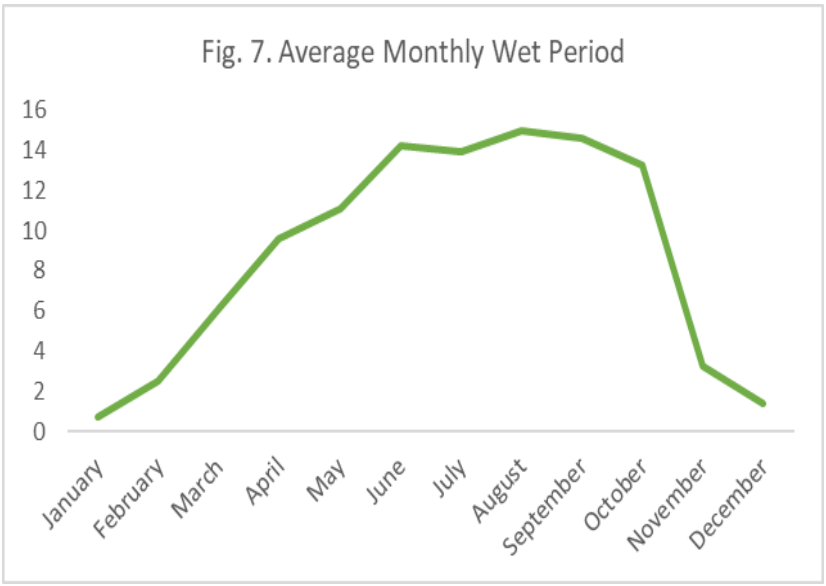


Fig. 7: Average wet period with Months of the year 2025 for 6 hours

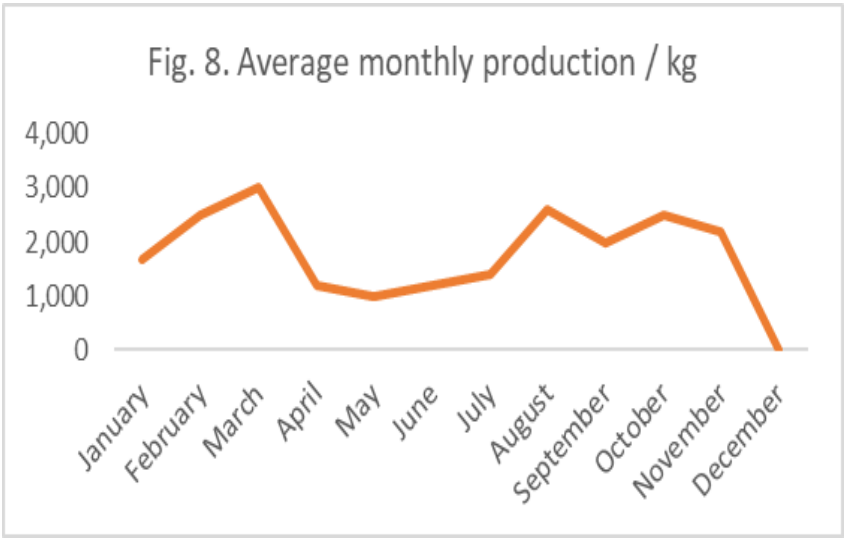


Fig. 8: Average product production with Months of the year 2025 for 6 hours

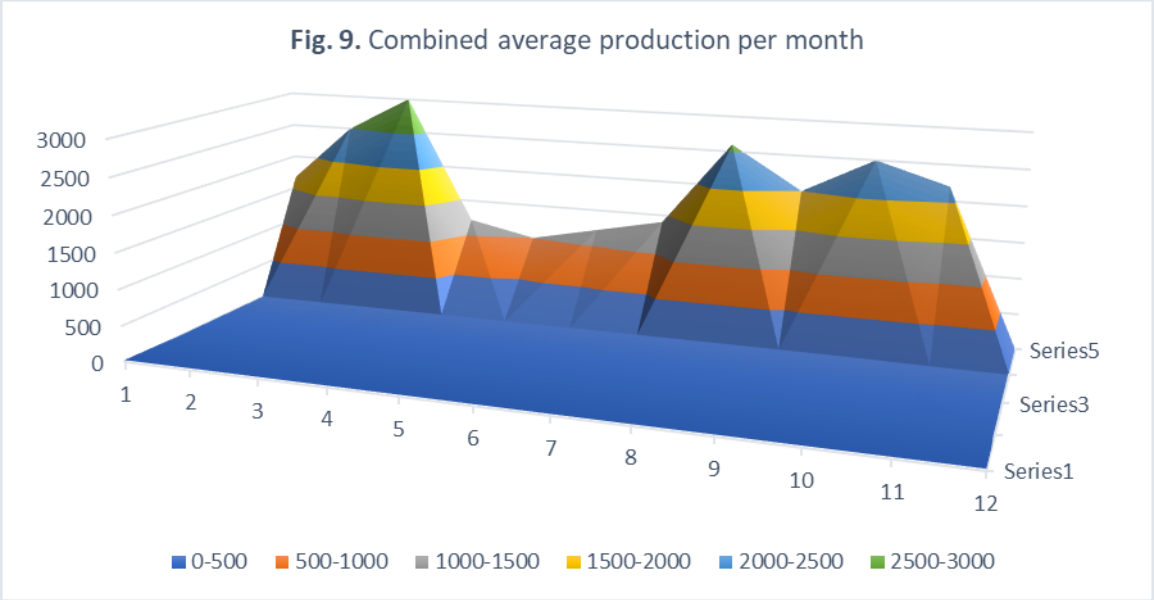


Fig. 9: Integral graphical average production per kg for Months of the year 2025 for 6 hours

3.2 Discussion

Fig.3 showed were the welding of the battery stark and other supporting frames were been fabricated. Figs. 4,5,6,8 and 9 shows that a common trend in the production rate of cookies from raw flour using solar powered extrusion machine varies with the time of the month which is dependent on the weather due to the location of the place of usage of the developed machine. All the results support the trend that extrusion cooking is possible with solar energy application. Nevertheless, major set-backs occurred during the experimental stage where two batteries were short circuited and burnt the primary side of the 3kw inverter which slowed down the pace of the work.

4. CONCLUSION

This article has revealed that the potential of a mobile solar powered extrusion machine for production of some cookies and edibles is possible towards enhancing robust economic and social assessment. The developed extrusion cooking machine underscores the potential for the indigenous solar-powered extrusion-cooking machine to serve as a pivotal technology for fostering sustainable development and economic empowerment in developing regions, thereby addressing critical food security and livelihood challenges. It is therefore recommended that robust economic analysis, including comprehensive cost-benefit ratios and return on investment studies, be carried out to substantiate the machine's commercial viability.

5. ACKNOWLEDGEMENT

Authors sincerely acknowledge and appreciate the sponsorship received from TETFund through Institution Based Research, reference number TETF/DR&D/CE/UNI/IBADANIBR/2023/VOL.I.

REFERENCES

[1] Adeaga, O. A., Dare, A. A., Raji, A., & Fatai, O. (2014). Potentials of industrial solar drying of agricultural produce. *International Journal of Science and Technology*, *3*, 2049-7318.

[2] Oyebode B. A., Oyeku J. S., Ojo O. S., Olaipo O. G., Oladeji O. S., Atanda K. F., Oke D. A., Oyekunle J. A. O. and Ogunfowokan A. O. (2026). Activity concentration, radiation hazard index, and health risk assessment of radionuclides of soil samples of Abiola Ajimobi Technical University, Ibadan, *Research Square (Preprint)*. https://doi.org/10.21203/rs.3.rs-9662188/v1]

[3] Harper, J. M. (1981). *Extrusion of foods* (Vols. 1–2). CRC Press.

[4] Riaz, M. N. (Ed.). (2000). *Extruders in food applications*. CRC Press. https://doi.org/10.1201/9781420014563

[5] Food Processing and Preservation. (2000). In *CRC Press eBooks* (p. 305). Informa. https://doi.org/10.1201/9781482270341-14

[6] Mkhize, M. M. (2025). Review of solar crop drying efficiency and its interconnection with meteorological factors. *Discover Energy*, *5*(1). https://doi.org/10.1007/s43937-025-00088-2

[7] Precoppe, M. (2024). Simulation-based Participatory Technology Development for Rural Enterprises. *BHM Berg- Und Hüttenmännische Monatshefte*, *169*(8), 444. https://doi.org/10.1007/s00501-024-01499-9

[8] Mohana, Y., Mohanapriya, R., Anukiruthika, T., Yoha, K. S., Moses, J. A., & Anandharamakrishnan, C. (2020). Solar dryers for food applications: Concepts, designs, and recent advances. *Solar Energy*, *208*, 321. https://doi.org/10.1016/j.solener.2020.07.098

[9] There, G., & Sharma, R. (2024). A Comprehensive Review of Design and Technological Advancements across Various Types of Solar Dryers [Review of *A Comprehensive Review of Design and Technological Advancements across Various Types of Solar Dryers*]. *Energy Engineering*, *121*(10), 2851. Taylor & Francis. https://doi.org/10.32604/ee.2024.049506

[10] Reza, Md. S., & Hossain, Md. A. (2024). Development and performance assessment of a hybrid solar cabinet dryer for fish drying. *Energy and Thermofluids Engineering*, *3*, 29. https://doi.org/10.38208/ete.v3.758

[11] Kimaro, D. N., Nyangarika, A., & Kivevele, T. (2024). Uncovering Socioeconomic Insights of Solar Dryers for Sustainable Agricultural Product Preservation: A Systematic Review [Review of *Uncovering Socioeconomic Insights of Solar Dryers for Sustainable Agricultural Product Preservation: A Systematic Review*]. *Heliyon*, *10*(23). Elsevier BV. https://doi.org/10.1016/j.heliyon.2024.e40726

[12] Muchoki, C., Ngala, S., & Okoth, M. (2025). A review of the process, effects and benefits on solar drying of African leafy vegetables [Review of *A review of the process, effects and benefits on solar drying of African leafy vegetables*]. *African Journal of Food Agriculture Nutrition and Development*, *25*(5), 26746. African Scholarly Science Communications Trust. https://doi.org/10.18697/ajfand.142.25605

[13] Hilali, S. (2020). Thermal solar energy applications on eco-extraction and drying of orange peels and rosemary leaves. *HAL (Le Centre Pour La Communication Scientifique Directe)*. https://tel.archives-ouvertes.fr/tel-03155410

[14] Sharma, K., Kothari, S., Panwar, N. L., & Patel, M. R. (2022). Influences of a novel cylindrical solar dryer on farmer's income and its impact on environment. *Environmental Science and Pollution Research*, *29*(52), 78887. https://doi.org/10.1007/s11356-022-21344-1

[15] Sher, A., Mazhar, S., Rahut, D. B., Ali, A., Watto, M. A., & Yuan, H. (2025). Assessing the impact of solar trolleys on farm household income in Punjab Pakistan. *Scientific Reports*, *15*(1). https://doi.org/10.1038/s41598-025-16214-y

[16] García, J. J., Aguilar-Torres, D., Luque-Zúñiga, G., Camacho-Martínez, J. L., Jiménez-Ramírez, O., & Vázquez-Medina, R. (2025). Evaluation of the efficiency and economic feasibility of an indirect solar dehydrator and its comparison with an affordable electric dehydrator. *Thermal Science and Engineering Progress*, *61*, 103505. https://doi.org/10.1016/j.tsep.2025.103505

[17] O. A. Adeaga, "Towards Numerical Investigation of Velocity Variation on Thin Ellipsoidal Aerofoil (NACA 3520) Using Surface Vorticity Method," 2023 International Conference on Science, Engineering and Business for Sustainable Development Goals (SEB-SDG), Omu-Aran, Nigeria, 2023, pp. 1-8, doi: 10.1109/SEB-SDG57117.2023.10124382.