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DEVELOPMENT AND TESTING OF A HOMESTEAD SOLAR-POWERED FISH FEED PELLET DRYER

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ABSTRACT

A homestead solar-powered feed pellet dryer was developed and tested at the old teaching and research farm in the Water Resources Department of Aquaculture and Fisheries Technology at the Federal University of Technology, Minna, to alleviate problems associated with the traditional method of drying in Nigeria. The machine consists of six main parts (base, drying chamber, slide-out trays, 110-watt fan, door, and solar power system). Performance evaluation was conducted on the dryer to assess the moisture content and drying rate of the pellets. Three kg of pellets with an initial percentage moisture content (%MC) of 28.62 % were used to test the dryer using the first three layers with 1 kg of the pellets evenly spread on the 1st, 2nd, and 3rd trays at air velocities of 6.0 m/s, 2.7 m/s, and 0.5 m/s, respectively, and at a temperature range of 28-31°C. The results disclosed that the % MC of the pellets was reduced to 8.62 %, 11.32 %, and 15.02 %, while the drying rate at constant rate period decreased from 0.125 g/hr to 0.094 g/hr, and 0.072 g/hr, in the 1st, 2nd, and 3rd trays, respectively, after six hours of drying. Overall, the dryer was effective in drying pellets to a safe moisture level.

Keywords: aquaculture, drying, performance evaluation, drying efficiency, dryer.

INTRODUCTION

Nigeria ranks among the world's leading producers and consumers of fish, with an annual demand of approximately 2.1 million metric tons. However, local production remains at around 800,000 metric tons per year, leaving a shortfall of 1.3 million metric tons (Akinsorotan *et al*., 2019; Chan *et al*., 2024). This significant gap between demand and supply highlights the urgent need to expand the fish farming subsector. In intensive commercial culture systems with high stocking densities, natural fish food sources become inadequate, necessitating the use of artificial diets to compensate for nutritional deficiencies. One of the persistent challenges hindering the rapid expansion of fish farming in Nigeria is the production of high-quality fish feed. According to Isyaki *et al*. (2009), feed costs account for approximately 40 to 60 per cent of total fish farming expenses. In reality, this cost is often even higher, discouraging potential investors from entering the industry. Additionally, during the rainy season, many small-scale farmers struggle to dry their feed adequately due to unfavourable weather conditions. This results in feed shortages, leading to stunted fish growth and, ultimately, stock losses.

Artificial feed plays a crucial role in boosting aquaculture practices and maximising yields from freshwater resources (Bhosale *et al*., 2010; Pailan and Biswas, 2022). Fish meal is widely viewed as the most suitable element due to its high compatibility with the protein needs of fish (Okolie *et al*., 2019; Hodar *et al*., 2020). The production of artificial fish feed involves the use of various ingredients, including groundnut cake meal, wheat or maize meal, soybean meal, fish meal, and blood meal, along with other additives such as fish premix, lysine, salt, Vitamin C, and bone meal. These ingredients are carefully measured, mixed in appropriate proportions, and processed into pellets using a pelleting machine to create a nutritionally balanced diet. At this stage, the moisture content of the pellets is typically above 30%, creating favourable conditions for mould and microbial growth. Therefore, proper drying of fish feed is crucial to enhance its shelf life and preserve its quality (Adedeji *et al*., 2020; Rasul *et al*., 2022).

The traditional open-air drying or sun-drying method is the most commonly utilised technique for drying fish feed and other agricultural products in tropical regions, including Nigeria. However, this method has several limitations, primarily its dependence on solar energy availability and low humidity levels. Large-scale drying of fish feed using this approach is also challenged by potential damage from birds, domestic animals, rodents, reptiles, and rainfall. Additionally, contamination from dirt, dust, and debris poses a significant concern. The process is labour-intensive and time-consuming, requiring constant monitoring during the day to deter pests and covering at night for protection. Furthermore, drying is often uneven, leading to insect infestations, mould growth, and nutrient loss due to excessive exposure to sunlight. Another drawback is the requirement for a large drying area (Lokesh *et al*., 2015).

Despite their eco-friendliness and cost-effectiveness, existing conventional solar dryers face several limitations: the majority of existing solar dryers rely entirely on solar radiation, making them inefficient during cloudy, rainy, or nighttime conditions (Lingayat *et al*., 2020). This often resulted in interrupted drying cycles and potential microbial growth in the product (Alp and Bulantekin, 2021). Many solar dryers suffer from poor air circulation and uneven temperature distribution, resulting in non-uniform moisture removal, which affects product quality and shelf life (Pandey *et al*., 2024). Therefore, there is a need for a simple yet efficient solar-powered feed dryer to serve as an alternative drying method, ensuring year-round availability of fish feed while providing a dual power source (solar and biomass) and a fan for effective air circulation within the system, thereby enhancing aquaculture productivity. The study focuses on the development of a solar dryer with energy-efficient drying capabilities, capable of achieving 50-60% energy reduction, and is scalable, durable, and requires low maintenance with high capacity, ultimately reducing carbon emissions (Pandey *et al*., 2024; Acar *et al*., 2022; Tyagi *et al*., 2024). This study aims to develop a homestead solar-powered dryer to address the challenges associated with traditional fish feed drying methods in Nigeria.

MATERIALS AND METHODS

Materials and sources

The materials utilized for constructing the feed pellet dryer included Melina wood, brown-faced plywood, phenolic black film-faced plywood, nails, screws, top bond gum, stainless steel wire mesh, tie rods, tarpaulin, cabinet hinges, hasp and staple, medium and glossy paint, a propeller fan, a solar panel, a solar power inverter, a battery, a solar charge controller, cables, and clips. All materials were sourced locally within Minna, Niger State. Melina wood and tie rods were procured from the Timber Shed, while plywood, nails, gum, net, and paint were bought from Talba Market, Minna Niger State. The air conditioner propeller fan was procured from Shango, a suburb in Minna; the solar panel and battery were sourced from Synchronous Logic Engineering Limited. Additionally, the solar power inverter was acquired from Amalex (NIG.) The enterprises obtained the solar charge controller, cables, and cable clips from Mandon Destiny Electrical Co.

Design consideration

The design of the pellet dryer put the following factors into consideration: (1) easy mode of construction (2) uses of locally available materials (3) use of moderately light materials (4) Adequate temperature control (5) nonstop supply of air in the drying chamber (6) movability of the dryer.

Dryer Design Calculations

The cabinet size of a solar dryer is a critical design parameter that directly affects drying efficiency, product quality, capacity, and airflow distribution. The selection of cabinet size was based on the following considerations:

The cabinet size determines the total drying surface area and thereby the volume of product that can be dried per batch. It must align with the target processing capacity (e.g., household, farm-scale, or commercial level). Oversized cabinets lead to heat loss, while undersized ones limit throughput (Ray, 2023).

The cabinet's dimensions ensure efficient airflow and uniform temperature distribution, which are essential for even drying. Oversized cabinets without proportionate airflow may cause air stagnation and uneven moisture removal (O'Sullivan *et al*., 2014).

The cabinet's outer dimension

Length= 91.44 cm

Breadth= 91.44 cm

Height= 213.36 cm

Area= Length x Breadth (1)

Area = 8,361.27 cm^2

The Drying chamber

Length= 83.82 cm

Breadth= 83.82 cm

Height= 203.20 cm

Area= Length x Breadth

Area= 7,025.79 cm^2

Volume= Length x Breadth x Height (2)

Volume = 1,427,641.02 cm^3

Layers

First layer;

Length= 83.82 cm

Breadth= 83.82 cm

Height= 38 cm

Area= Length x Breadth

Area= 7,025.79 cm^2

Volume= Length x Breadth x Height

Volume= 266,980.11 cm^3

Second to eighth layers;

Length= 83.82 cm

Breadth= 83.82 cm

Height= 22 cm

Area= Length x Breadth

Area= 7,025.79 cm^2

Volume= Length x Breadth x Height

Volume= 154,567.38 cm^3

The slide-out trays

Length= 76.20 cm

Breadth= 76.20 cm

Height= 5.08 cm

Area= Length x Breadth

Area= 5,806.44 cm^2

Volume= Length x Breadth x Height

Volume= 29,496.72 cm^3

Vents

Diameter, d = 1 cm

Area = $\pi (d/2)^2$ (3)

Area = 3.1429 x $(1/2)^2$

Area = 3.1429 x 0.25

Area = 0.786 cm^2s

The door

Length= 91.44 cm

Breadth= 210.82 cm

Area= Length x Breadth

Area= 91.44cm x 210.82 cm

Area= 19,277.38 cm^2

Components of the feed dryer

Dryer's base

The base is constructed using Melina wood measuring 3.8 cm by 8.9 cm, with a height of 2.54 cm, to provide structural support for the other components of the dryer.

Drying chamber

A rectangular drying chamber, measuring 83.82 cm × 83.82 cm × 203.20 cm, was constructed using 2" × 4" Melina wood. The chamber was divided into eight layers, each equipped with a rollout tray designed to collect and dry the feed. The first layer had dimensions of 83.82 cm × 83.82 cm × 38 cm, while the second to eighth layers each measured 83.82 cm × 83.82 cm × 22 cm. To facilitate the drying process, a fan was installed at the top of the chamber to ensure proper airflow.

The slide-out trays

The drying chamber is equipped with eight detachable trays, each made from 1" x 2" wooden frames and measuring 76.20 cm × 76.20 cm × 5.08 cm. The bases of the first to seventh trays are covered with a 1.2 mm mesh net, functioning as drying compartments. Meanwhile, the eighth tray, with its base lined with a tarpaulin, is designed to collect feed particles that escape from the drying compartments.

Propeller fan

A propeller fan with a 36 cm diameter and six blades, each measuring 13 cm in diameter, along with a 4.75 microfarad capacitor, was installed on the roof of the drying chamber to facilitate the necessary airflow for the drying process. The inclusion of the fan is critical to enhance the efficiency, uniformity, and reliability of the drying process. The size of the fan was selected to ensure uniform airflow across the drying chambers, which promotes even moisture removal from all parts of the product. Without forced airflow, drying tends to be uneven, leading to reduced product quality. The fan size was selected to accelerate the drying process by reducing the boundary layer resistance and increasing the heat and mass transfer coefficients. This leads to shorter drying times and improved throughput.

The door

The door, measuring 91.44 cm by 210.82 cm, was built using 1" × 3" Melina wood and 3/4" phenolic black film-faced plywood. It was fitted with a hasp to safeguard the drying chamber from external contaminants and minimise heat loss from the system.

Solar power system

A solar panel is mounted outdoors to capture solar energy, which serves as the power source for operating the fan. The captured energy is stored in a battery through a solar charge controller. In contrast, a solar power inverter converts the stored Direct Current (D.C.) into Alternating Current (A.C.) for efficient use.

Solar panel sizing

Assumption

110 W DC Fan working for 6 hours requires 660 Wh

5 W Controller working for 6 hours requires 30 Wh

Total energy requirement per day = 690 Wh

Assuming 80 % system efficiency, i.e, Loss factor of 1.25.

$$Required\ energy\ from\ solar\ panel = \frac{energy\ reuirement\ per\ day}{system\ efficiency}$$

$$= \frac{690}{0.8}$$

$$= 862.5\ Wh/day$$

Solar panel energy output per day

Using the Peak Sun Hours (PSH) of 6 hours per day

$$Energy\ output\ per\ panel\ per\ day = Panel\ power \times PSH$$

Selecting a 200 W Panel and PSH of 6 hours

$$Energy\ output\ per\ panel\ per\ day = 200 \times 6$$

$$= 1200\ Wh/day$$

Final Solar Panel Sizing

$$Required\ Solar\ Panel\ Power\ (W) = \frac{Daily\ Load}{PSH} \times Loss\ Factor$$

$$= \frac{690}{6} \times 1.25$$

$$= 179.69$$

Therefore, 200 W Solar panel was selected for safety and future flexibility

Battery Sizing

Assuming a day solar radiation absence

Energy requirement per day = 690 Wh

Using a 12 V battery

$$Battery\ Capacity\ (Ah) = \frac{690}{12 \times 0.8}$$

$$= 71.875\ Ah$$

Therefore, $12\ V, 75\ Ah$ battery was selected

Charge Controller Sizing

$$Controller\ Current\ (A) = \frac{Panel\ Power}{Battery\ Voltage}$$

$$= \frac{200}{12}$$

$$= 16.67\ A$$

Therefore, 20 A Charge controller was selected.

Construction of the cabinet

The cabinet frame was constructed using 2" × 4" and 2" × 3" Melina wood. The wood was marked with a pencil, squared using an angle square, and manually cut to the required size with a hand saw. It was then smoothed with a jack plane before being assembled. The frame components were joined by creating a mortise (hole) in the vertical frame wood using a chisel, into which the tenon wood (horizontal pieces for length and breadth) was implanted. These joints were secured with top bond adhesive and clamped tightly to ensure firmness and strength.

Eight tray runners were attached to the frame at designated intervals using 2-inch nails. The drying chamber was divided into eight layers, each containing a tray. Each tray was constructed from 1" × 2" wood, with dimensions of 76.20 cm × 76.20 cm × 5.08 cm. The base of each tray was covered with a mesh, supported by tie rods, and fixed in place with 1-inch nails. The tray frame was assembled using 1½-inch nails, and additional wood was attached to the sides to allow the trays to slide along the tray runners, which were made from 1" × 2" wood.

The entire cabinet was enclosed with ¾-inch thick brown-faced plywood. The door, made from 1" × 3" wood and phenolic black film-faced plywood, was affixed to the cabinet using hinges to secure the drying chamber. A staple was nailed to the cabinet, while a hinge and hasp were installed on the door for locking. Small vents were formed on the sides and at the bottom of the eighth layer to allow moisture to escape from the drying chamber. These openings, drilled with a 10 mm bit, were covered with 1.2 mm mesh to prevent the entry of foreign objects.

The cabinet body was scraped using a scraper, then smoothed with both rough and fine sandpaper, and finally painted with both medium and glossy paint for a refined finish. Finally, a propeller fan was fitted on the roof of the drying chamber, braced by 2" × 2" wooden beams and secured with screws.

Installation of the solar power system

The solar panel was mounted on a platform above the cabinet to capture solar energy, which serves as the power source for operating the fans. A cable from the solar panel, consisting of live and neutral wires, was connected to the positive and negative terminals of the charge controller, respectively. The live and neutral wires from the charge controller were then linked to the corresponding terminals of the battery. To utilize the stored energy, the inverter cable was attached to the battery terminals, allowing the inverter to convert the Direct Current (DC) from the solar panel into Alternating Current (AC) to power the propeller fan.

Determination of the moisture content of the sample

The moisture content of the sample was analyzed following the AOAC (2003) standard methods. The determination was carried out using the oven-drying technique. A 5-g portion of the feed sample was accurately weighed into a clean, dry crucible (W1). The crucible was then placed in an oven set at a temperature of 100-105 °C and heated for 6-12 hours until a constant weight was achieved. After drying, the crucible was transferred to a desiccator and allowed to cool for 30 minutes to prevent absorption of ambient moisture. Once cooled, the final weight (W2) was recorded. The moisture content percentage was then calculated using the following formula:

$$\%\text{Moisture content} = \frac{\text{W1} - \text{W2}}{\text{Wt of sample}} \qquad (4)$$

Where:

W1= Initial weight of crucible + sample

W2= Final weight of crucible + sample

Determination of the drying rate of the dryer

Locally pelletized fish feed was used to test the drying rate of the dryer. The first three layers were used for the experiment. Three kilograms of feed were dried for the experiment, with each tray carrying 1 kilogram of feed at a density of 33.90 kg/m³. The fan was set at a high speed of 910 r.p.m. for 6 hours. The feed was dried between 11:30 am and 5:30 pm. 5 g of sample was taken for each tray with three replicates at an interval of 1 hour to determine the moisture content of the sample. The air velocity of the dryer was within the range of 0.5 to 6.0 m/s. The air velocity was determined by a digital anemometer AM-4812 with a velocity probe connected to it, which has an accuracy of ±2% n +2d. The air velocity was recorded after entering the trays.

The drying rate at the constant rate period was evaluated as follows:

Drying rate $\dot{m}_c = \frac{w_c - w_o}{t_c}$ (5)

Where:

$\dot{m}_c$ = moisture removal rate (kg/s)

w_c = initial moisture content (kg water/kg dry solids)

w_o = critical moisture content (kg water/kg dry solids)

t_c = time for constant rate period (s)

Energy efficiency

To calculate energy efficiency

$$\eta = \frac{Q_{useful}}{Q_{solar}} \times 100$$

Where Q_{useful} = useful energy used for moisture evaporation

Q_{solar} = total solar energy input to the dryer (kJ)

Useful energy for evaporation (Q_{useful})

$$Q_{useful} = m_w \times L$$

m_w = mass of water evaporated (kg)

L = latent heat of vaporization (~2400 Kj/kg @ 30-60 °C)

Mass of water evaporated m_w

$$m_w = m_i \times \left(\frac{mc_i - mc_f}{100 - mc_f}\right)$$

m_i= initial mass of wet product (kg)

mc_i = initial moisture content (% wet basis)

mc_f = final moisture content (% wet basis)

Total solar energy input (Q_{solar})

$$Q_{solar} = I \times A \times t$$

I = average solar radiation during drying period (kW/m^2)
A = area of the solar collector (m^2)
t = Drying time (s)

Initial moisture content = 28.62 % = 86 %
Final moisture content = 8.62 % = 26 %
Initial weight of the sample = 3 kg
L = 2400 kJ/kg
A = 0.85 m^2
I = 0.138 kW/m^2
t = 6 hours = 6×3600 s

mass of water removed

$$m_w = 3 \times \left(\frac{28.62 - 8.62}{100 - 8.62}\right)$$

$$m_w = 0.657\ kg$$

Useful energy

$$Q_{useful} = 0.657 \times 2400$$

$$Q_{useful} = 1576.8\ kJ$$

Solar energy input

$$Q_{solar} = 0.138 \times 0.85 \times 6 \times 3600$$

$$Q_{solar} = 5{,}508\ kJ$$

Efficiency

$$\eta = \frac{1576.8}{2533.68} \times 100$$

$$\eta = 0.6223 \times 100$$

$$\eta = 62.23\%$$

Statistical analysis

The data collected were analyzed using Minitab statistical software, and means were separated using Tukey's test for pairwise comparison.

Bill of Engineering Measurement

S/N	Material	number	cost (#)
1.	2 by 4 inch Melina wood	4 lengths	2,000
2.	2 by 3 inch Melina wood	10 lengths	3,500
3.	1 by 2 inch Melina wood	14 lengths	4,200
4.	1 by 3 inch Melina wood	3 lengths	900
5.	2 by 2 inch Melina wood	1 length	350
6.	Plywood	4½ sheets	28,000
7.	Nails	7 pan	2,100
8.	Top bond gum	1	2,000
9.	Net	14 yards	11,200
10.	Tie rods	30 lengths	3,000
11.	Tarpaulin	1 yard	1,200
12.	Medium paint	1 jerrican	3,000
13.	Glossy paint	1 jerrican	3,000
14.	Rough and smooth sand paper	4 pieces each	1,600
15.	Hinge, hasp and staple	3, 1, 1	500
16.	Solar panel (200 W)	1	80,000
17.	Air conditioner propeller fan (110 W)	1	10,000
18.	Solar power inverter (500 W)	1	9,500
19.	Solar charge controller (20 A)	1	4,500
20.	Battery (12V/75 AH)	1	15,000
21.	Solar cable	6 yards	2,100
22.	Tools/equipment rent		5,000
Total cost			**192,650**

RESULTS AND DISCUSSION

Table 1 presents the results on how drying air velocity affects the moisture content of feed pellets, while Table 2 illustrates its impact on the drying rate. The dryer's performance was evaluated at air velocities of 6.0 m/s, 2.7 m/s, and 0.5 m/s for the first, second, and third trays, respectively, within a temperature range of 28–31°C over six hours. Before drying, the average initial moisture content of the 5 g samples was 1.431 g, and the initial drying rate was zero, as no weight loss occurred during the initial stage of the drying process.

Table 1 Effect of drying air velocity on moisture content of the pellets

Feed sample	Air velocity (m/s)	Moisture content (%)
First tray	6.0	8.62 ± 0.01^{c}
Second tray	2.7	11.32 ± 0.01^{b}
Third tray	0.5	15.02 ± 0.02^{a}

Means with different superscripts in the same column are significantly different at ($p<0.05$)

Table 2 Effect of drying air velocity on drying rate of the pellets

Feed sample	Air velocity (m/s)	Drying rate (g/hr)
First tray	6.0	0.125 ± 0.001^{a}
Second tray	2.7	0.094 ± 0.002^{b}
Third tray	0.5	0.072 ± 0.002^{c}

Means with different superscripts in the same column are significantly different at ($p<0.05$)

Table 3. Drying pattern of the pellets with respect to time

Time (h)	First tray (%)	Second tray (%)	Third tray (%)
0	28.62	28.62	28.62
1	22.14	27.20	27.82
2	18.42	23.44	26.08
3	15.68	18.32	20.54
4	13.52	15.30	18.04
5	10.72	13.86	16.64
6	8.62	11.32	15.02

As indicated in Table 1, the feed samples on the first tray experienced the highest reduction in moisture content due to the highest drying velocity. In contrast, the lowest moisture reduction was observed in the third tray, which had the lowest velocity. This aligns with previous research, which suggests that an increase in wind speed enhances the initial evaporation rate and reduces the transition time between successive evaporative stages (Davarzani *et al*., 2014). Additionally, Table 1 highlights a significant difference in the moisture content of the feed pellet samples. The sample on the third tray had the lowest mean value and was significantly different from the second tray sample, which in turn showed a significant difference from the first tray sample, which had the lowest mean value.

Table 2 and Figure 1 illustrate that the first tray, which experiences the highest air velocity, demonstrates the fastest drying rate. In contrast, the third tray, with the lowest air velocity, exhibits the slowest drying rate. This finding aligns with the study by Bolaji *et al*. (2011), which reported that the efficiency of a solar wind-ventilated cabinet dryer increases with air velocity. Table 2 also showed that there is a significant difference in the final drying rates of the feed pellet samples. The third tray has the lowest mean value and is significantly different from the second-highest mean value of the feed pellet on the second tray on the second layer, which is also significantly different from the feed pellet sample on the first tray in the first layer in the drying chamber.

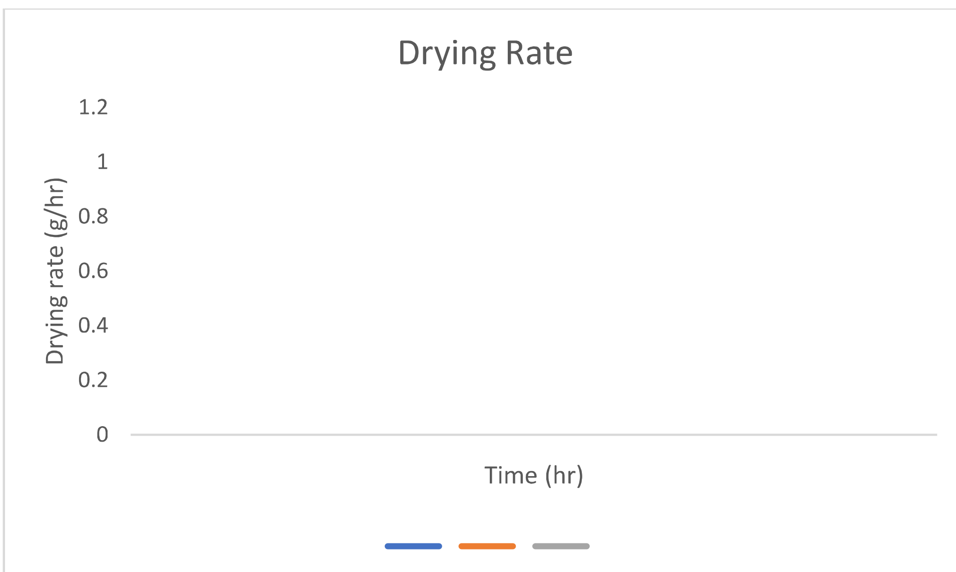


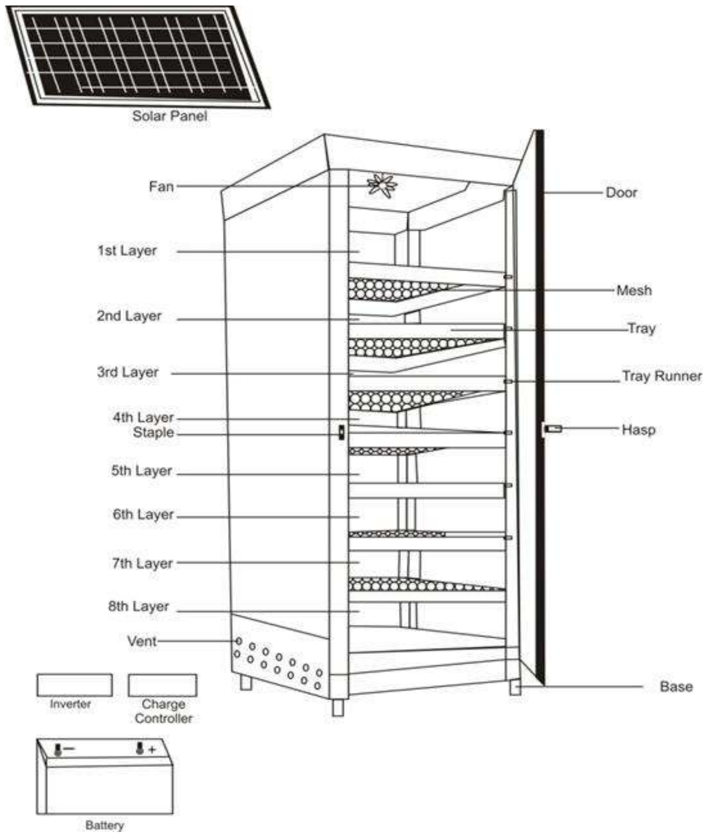
Figure 1: Drying rate of the feed samples against time

A homestead solar-powered feed dryer was designed and fabricated. The trial showed that the dryer is environmentally friendly due to its source of power (solar energy). Figure 1 illustrates that the first tray is the most efficient in terms of drying, which is likely due to the higher air velocity received and its proximity to the heat source. Bolaji *et al*. (2014) stated in their study that the system's efficiency increased as the air velocity within the system increased.

Table 3 depicts the initial moisture content of the pellet as 28.62%, and it was dried to 8.62%, 11.32%, and 15.02% in the first, second, and third trays, respectively, after 6 hours. The air velocity in the drying chamber ranged from 0.5 to 6.0 m/s. The reduction in moisture was found to be rapid in the feed samples on the first tray, resulting in excellent weight loss. This conforms with other studies that state that increasing wind speed increases the first-stage evaporation rate and decreases the transition time between successive two evaporative stages (Davarzani *et al*., 2014).

Putra and Ajiwiguna (2016) also concluded that increasing temperature and air velocity bring about a higher evaporation rate. However, the effect of temperature is less significant when the air velocity is high. Additionally, for the drying rate, the mass decreases as the moisture content is evaporated. The mass decrease tends to be at a steady state at long durations of the drying process. It shows that evaporation becomes more difficult when the water content is low. Putra and Ajiwiguna (2016) also concluded that the evaporation process requires more energy when the water present in the material is low.

The time required for drying is dependent on the size of the feed, the initial moisture content, and the uniformity of air velocity. Moreover, the feed dryer is enclosed, which guarantees the intensity and uniformity of airflow, leading to efficient dehydration of feed. Unlike traditional dryers, which lose excessive heat to the environment, resulting in wasted energy. The dried samples obtained from individual trays dried evenly. The dryer components and dimensions are shown in Figure 2.



Figures 2: Schematic diagram of dryer component and design

CONCLUSION

The present study developed and tested a homestead solar-powered fish feed pellet dryer to address challenges associated with the traditional drying methods in Nigeria. The performance evaluation of the dryer evaluates the influence of drying air velocities on the moisture content of the feed pellets and the drying rate of the dryer. The results of this study reveal that pellets experiencing the highest drying air velocity have the lowest moisture content and the highest drying rate. In contrast, those with the lowest drying air velocity have the highest percentage of moisture content and the lowest drying rate. Overall, the dryer was effective in reducing the pellets' moisture content to a safe level.

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