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Research Article

Evaluating the Efficiency of Solar and Petrol-Powered Recirculating Aquaculture Systems for African Catfish (*Clarias gariepinus*) Fingerling Production

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Abstract

Accessibility of quality fingerlings is dependable on a hatchery system with the capacity to produce all year round. There are two hatchery systems operational in Nigeria namely, the flow-through and re-circulating systems. These two systems require electricity to power periodic or constant water supply and aeration. When electricity supply fails or non-existent, this will result in anxiety and hardship to hatchery operators with the subsequent low output. This paper, therefore, assessed the production efficiency of solar and petrol-powered generator recirculating aquaculture systems for African catfish *(Clarias gariepinus)* fingerlings production. The results obtained from the growth performance and survival percentage of *Clarias gariepnus* reared in the two recirculating systems (solar and generator powered recirculating systems) showed no significant difference (P> 0.05) in the initial weight, specific growth rate (SGR) and feed conversion efficiency (FCE) of *C. gariepnus* from the two-recirculating systems. However, the result showed significant differences (P<0.05) in the final mean weight, weight gained, and survival rate in the two-recirculating systems. Aligning with the guidelines outlined by the Food and Agriculture Organization (FAO), the means and range values of temperature (℃), dissolved oxygen (mg/l), pH and ammonia, observed from the two recirculating production systems indicated temperature (22.81℃ - 25.11℃), dissolved pH (7.10-7.42), dissolved oxygen (6.22- 6.62mg/l), ammonia (0.04-0.08mg/l) respectively. The survival rate of fry reaching 84% for the solar group and 64% for the generator at the end of 28- 56 days. Thus, this study revealed that solar energy might become the most promising energy source that can replace the usual source of energy for hatchery operations in Nigeria. This study, therefore, recommended that Solar Powered Recirculating Systems be adopted where feasible, given their demonstrated support for increased growth rates and higher survival rates to enhance efficiency and sustainability of aquaculture production systems.

Keywords

Production Efficiency, Solar Energy, Generator, Recirculating Aquaculture Systems

1. Introduction

Fish serves as a vital source of protein for over 2.9 billion people worldwide [1] and is especially crucial as an animal protein in tropical regions [2]. In Nigeria, fish accounts for approximately 40% of the animal protein intake [3], and

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globally, it constitutes about 20% of total animal protein consumption [1]. The fisheries and aquaculture sector has seen significant growth, reaching record highs in production, trade, and consumption in 2018 [4]. Since the early 1990s, increases in fish production have primarily been driven by aquaculture, as production from capture fisheries has remained stable or declined due to overexploitation.

In Nigeria, catfish and tilapia are the predominant species cultured for food [5], with catfish emerging as the preferred species due to its high growth rate and adaptability to aquaculture environments. Catfish production also offers economic benefits, as these fish can be sold live, fetching premium prices, and providing significant income streams.

However, the expansion of catfish production faces several challenges including low productivity, high mortality rates, water scarcity, expensive feed, and suboptimal management practices [6]. The limited production levels in Nigeria are attributed to a range of factors including poor quality of fish seeds, lack of information, high feed costs, traditional farming methods, small farm sizes, inefficient resource use, inadequate infrastructure, limited access to credit, and insufficient extension services [7-12]. A critical issue among these is the inadequate supply of quality fingerlings, which hinges on the capacity of hatcheries to produce them consistently throughout the year.

The recirculating aquaculture system (RAS) offers a potential solution by providing a year-round supply of fish seeds and supporting increased fish production. However, the high energy costs associated with RAS, which rely heavily on steady electricity for operations such as pumping, aeration, and filtration, pose a significant barrier. Despite Nigeria's status as an oil-producing nation, it struggles with providing reliable electricity. In 2020, Nigeria generated only 13,000 MW of power with a distribution capacity of 5,500 MW for a population of 190 million [13], compared to South Africa's 58,000 MW for its 59 million citizens [14, 15]. Consequently, hatchery operators often resort to using diesel or petrol generators, which not only contribute to environmental degradation but also become economically unsustainable during fuel shortages. Indeed, fuel scarcity has led to a 153% increase in fuel prices over a decade [16], exacerbating the operational challenges in aquaculture.

The integration of renewable energy sources, such as solar power, into aquaculture practices represents a viable alternative that could significantly reduce production costs and promote sustainability by providing a clean, inexhaustible energy supply for hatcheries. The transition to solar energy could fundamentally transform the production of catfish fingerlings, ensuring a reliable supply of high-quality seed to farmers while decreasing dependence on environmentally damaging and economically unstable fossil fuels. This study aims to evaluate the efficiency of solar and petrol-powered recirculating aquaculture systems (RAS) in the production of African catfish (*Clarias gariepinus*) fingerlings in Nigeria. It specifically investigates the potential of solar energy in catfish fingerling production and compares the operational costs associated with solar-powered and petrol-powered systems. By analyzing the economic and environmental impacts of these energy sources in aquaculture, this paper seeks to provide a detailed assessment of sustainable practices that could enhance productivity and profitability in the sector.

2. Methodology

2.1. The Study Area

The experimental study was conducted at Aquatek Fish Farm, situated in Igbe, within the Owo Local Government Area of Ondo State, Nigeria (Figure 1).

2.2. Study Design

The study was structured to develop and evaluate a prototype of a solar-powered Recirculating Aquaculture System (RAS) as the experimental unit (Figure 2), and a petrol-powered generator-driven RAS, situated within an established flow-through hatchery, as the control unit (Figure 3). Both units were concurrently utilized to conduct induced breeding using hormonal techniques, followed by the rearing of larvae to fingerlings of African catfish, (*Clarias gariepinus*). The objective was to assess the technical efficiency of these systems in the production of catfish fingerlings.

The research was conducted in two distinct phases. The initial phase focused on the design and construction of a prototype solar-powered hatchery, coupled with the installation of recirculating aquaculture systems in both the experimental and control units. The second phase involved the process of induced breeding utilizing acetone-dried pituitary glands, followed by the rearing of larvae over the first 28 days, and subsequent rearing of the 28-day-old fry for an additional 28 days.

During the first 28 days, key parameters such as hatchability, growth rates, and survival rates were measured. In the subsequent 28 days, the focus shifted to further assessing growth and survival rates. Due to the experimental nature of the study, a feeding regime of satiation was implemented. Battery voltage within the systems was recorded thrice daily at intervals of 6 AM, 12 noon, and 6 PM. Essential water quality parameters such as temperature and pH were monitored daily, while oxygen levels and ammonia concentrations were assessed on a weekly basis.

Source: Google Map as Adapted by the Author, [18]
Coordinates: 7°08’33.2”N 5°38’02.4”E

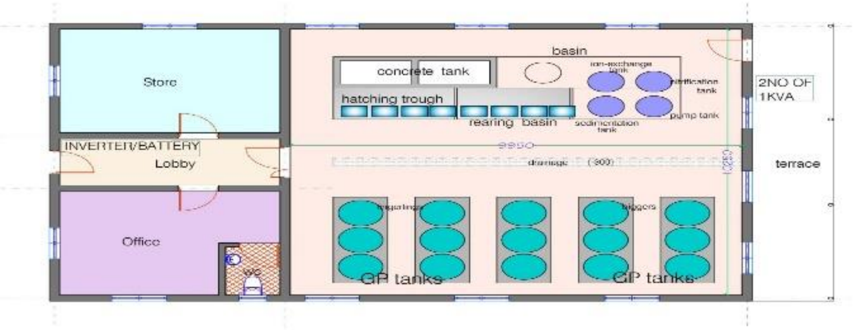
Figure 1. *Map of the Study Area.*

a b

Source: Authors Creation (Pictures and Plan), 2022

Figure 2. *a and b: Solar powered RAS hatchery.*

a



b

Source: Authors Creation 2021.

Figure 3. *a and b: Petrol powered generator RAS housed in existing flow-through hatchery.*

2.3. System Design

The petrol-powered generator-driven recirculating aquaculture system (RAS) and the solar-powered RAS are depicted in plates 4a and 4b, respectively. Each hatchery setup comprised the following components: Four hatching troughs (HT) with a capacity of 50 liters each, featuring dimensions of 0.63 meters in length, 0.3 meters in width, and 0.48 meters in height. Additionally, four spherical-shaped rearing basins (RB) with a capacity of 100 liters each were incorporated.

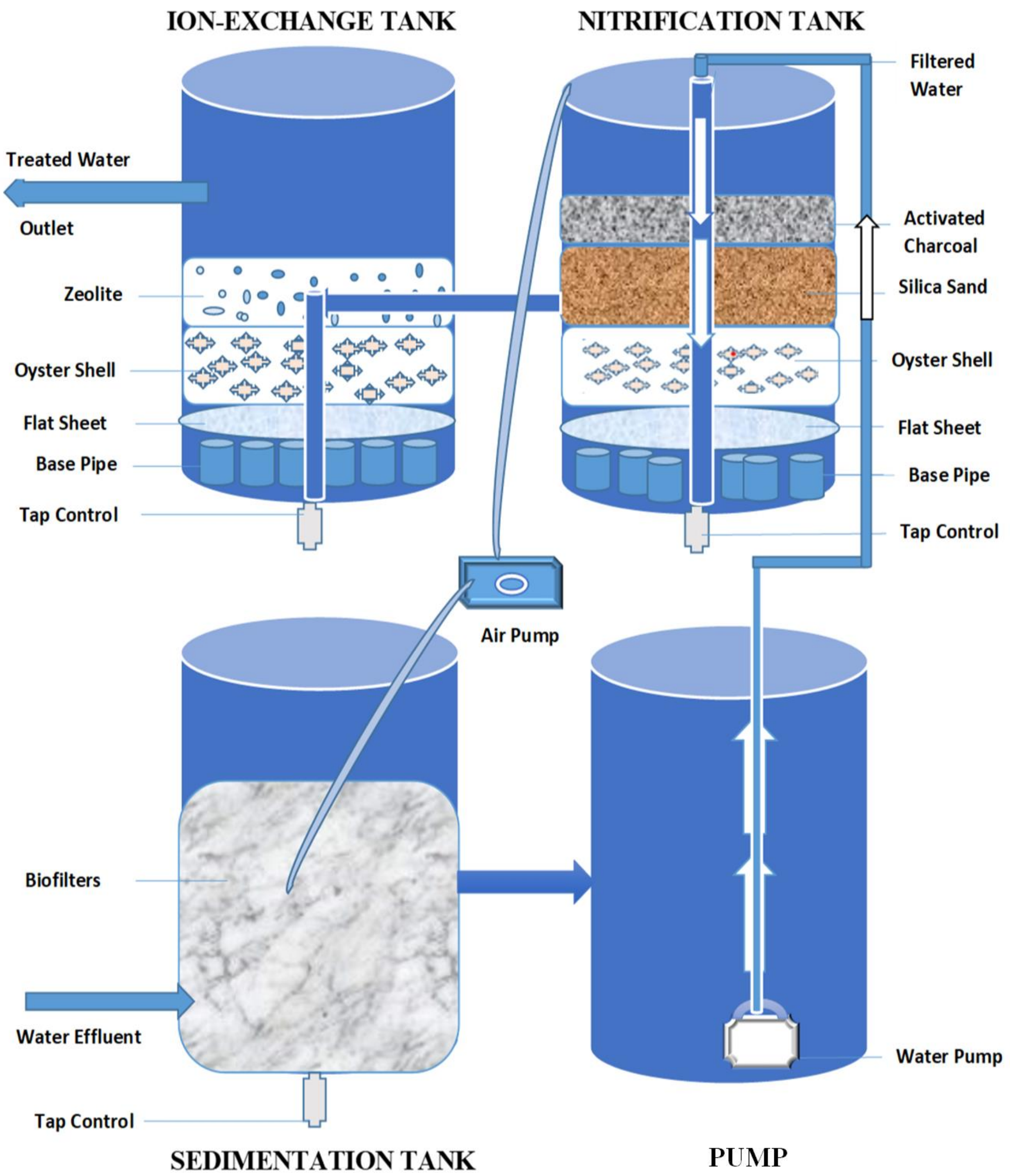
Furthermore, the water treatment unit, illustrated in Figure 5, consisted of various components including a 200-liter sedimentation tank, a 200-liter pump tank, a 200-liter denitrification tank, and a 200-liter ion-exchange tank. These components collectively contributed to the efficient management and treatment of water within the hatchery system, ensuring optimal conditions for the growth and development of the aquatic organisms housed within.

a

b

Source: Authors Creation 2021.

Figure 4. *a. Generator Powered Set-up; b. Solar Powered Set-up.*



Source: Authors Schematic Diagram, 2021.

Figure 5. Water Treatment Unit.

2.4. Recirculating Aquaculture System (RAS)

A locally fabricated recirculating aquaculture system (RAS) was installed in each of the two hatcheries, one powered by solar energy and the other by a generator (Figure 4). Each production unit comprised four plastic hatching troughs (HT) with a calibrated volume of 50 litres and four rearing basins (RB) with a calibrated volume of 100 litres. Additionally, the setup included one plastic sedimentation tank (200 litres), one plastic pump tank (200 litres), one plastic nitrification tank (200 litres), one ion-exchange tank (200 litres), and two aerators.

Water was introduced into each unit via an interconnecting flow line, which directed it from the hatching tanks to the rearing basins. The effluent then flowed by gravity into the sedimentation tank, where settleable solids were removed, and initial stages of oxidation and nitrification occurred. Subsequently, the partially treated effluent was pumped into the nitrification tank by a small submersible pump housed within the pump tank. Here, further oxidation and intense nitrification processes took place. The treated effluent then flowed into the ion-exchange tank for additional purification before returning to the hatching troughs, free from impurities.

Throughout the experiment, catfish (*Clarias gariepinus*) at various developmental stages were housed within the hatching troughs and rearing basins. The water within the system underwent continuous exchange at a rate of 600 litres per day, corresponding to the pumping capacity of the submersible pump, with the aim of maintaining optimal growing conditions. However, it's important to note that not all water within a RAS is completely exchanged, as complete removal of waste products via sedimentation is challenging. Typically, most culture systems recommend a water exchange rate of at least 5% to 10% per day, depending on stocking density and feeding rates [17].

2.5. Water Quality Parameters

Water quality serves as a pivotal determinant in the successful cultivation of aquatic organisms. To achieve optimal growth rates and ensure survival, it is imperative to monitor and maintain appropriate water quality parameters, which can vary depending on the species being cultured. Commonly monitored parameters in the aquaculture industry encompass temperature, dissolved oxygen (DO), pH, alkalinity, hardness, ammonia, nitrite, and nitrate. Depending on the specific culture system, additional parameters such as carbon dioxide, chlorides, and salinity may also warrant monitoring. While some parameters like alkalinity and hardness tend to exhibit relative stability, others such as dissolved oxygen and pH may exhibit daily fluctuations.

For this study, a standardized water quality testing protocol was meticulously adhered to. The recommended water quality parameters for catfish cultivation, as stipulated by the Food and Agricultural Organization, are as follows:

1. Dissolved Oxygen: 3-10 mg/l
2. Temperature: 18 ℃-30 ℃
3. pH: 6-10
4. Ammonia: 0-0.7 mg/l

Adhering to these specified ranges ensures the provision of an environment conducive to the optimal growth and development of catfish, thereby contributing to the overall success of the aquaculture endeavour.

2.6. Sampling Technique

Wastewater sampling techniques typically fall into two categories: in-situ (or grab) sampling and composite sampling. Both methods were utilized in this study in accordance with established standards and requirements. In-situ sampling was employed to capture instantaneous measurements of pH and temperature, as these parameters are classified as unstable [18]. In-situ sampling offers insights into the conditions prevailing at the precise moment of sample collection, provided proper sampling techniques are employed.

However, for parameters such as Dissolved Oxygen, Alkalinity, Hardness, Ammonia, Nitrite, and Nitrate, which are critical indicators of wastewater treatment facility performance, composite sampling techniques were deemed necessary [18]. Composite sampling involves the collection of multiple discrete samples at regular intervals over a predetermined duration, typically 24 hours.

Therefore, in this study, composite sampling was utilized for parameters including Dissolved Oxygen, pH, and Ammonia. This approach was chosen because aggregating samples over an extended period yields a more comprehensive and representative assessment of treatment plant performance. By collecting, storing, analyzing, tabulating, and averaging composite samples, a more reliable indication of treatment efficacy can be obtained.

2.7. Determination of Hatchability

Percentage hatchability was calculated using the formula:

% Hatchability= Number of hatchlings/Number of fertilized eggs × 100

2.8. Fish Feeding and Growth

The Rearing Basins (RBs), each containing 80 liters of water, were stocked with a total of 4,800 fry at a density of 60 fry per liter. Over the initial 28-day period, the fry were fed ad libitum for 25 days, followed by a switch to feeding based on the average weight of the fry for the remaining 3 days.

To assess fish growth and feed efficiency, all fish were weighed after the first 28 days of rearing. Subsequently, they were restocked at a density of 100 fry per RB for an additional 28 days to reach the fingerling stage. Utilizing data acquired from stocking and sampling, the feed conversion ratio (FCR) (Equation 1), specific growth rate (SGR) (Equation 2), and survival rate (SR) (Equation 3) of the various RAS and cohorts were calculated. Mean values per tank were utilized for the fish performance calculations. Furthermore, coefficients of variance (CV) were computed between the mean values recorded in the tanks to assess variability.

$$FCR = \frac{F}{G} \quad (1)$$

Given; F = feed as given (w, in g), G = growth (w, in g)

$$SGR\ (\%/day) = \frac{InBW_{final} - InBW_{initial}}{t} \times 100 \quad (2)$$

BW_{final}= body weight (ww) on the day of sampling at the end of the experiment, $BW_{initial}$ = body weight t = time in days of feeding (d).

$$SR\ (\%) = \frac{nfish_{final}}{nfish_{initial}}\ X\ 100 \quad (3)$$

$nfish_{final}$ = number of fish on the day of sampling at the end of the experiment, $nfish_{initial}$= number of fish on the day of sampling at the beginning of the experiment.

3. Results and Discussion

3.1. Water Quality Parameters

The water quality parameters measured in the two recirculating systems, namely the solar-powered and generator-powered systems, exhibited the following variations: temperature: Solar/Generator (22.87 ℃ - 25.11 ℃ / 22.81 ℃ - 25.10 ℃), pH: Solar/Generator (7.10 - 7.42 / 7.11 – 7.41), dissolved oxygen: Solar/Generator (6.32 - 6.62 / 6.22 – 6.47), and ammonia: Solar/Generator (0.05 - 0.08 / 0.04 – 0.08), respectively. These recorded water quality parameters in both recirculating systems remained within the favorable conditions suitable for *C. gariepnus* [19], aligning with the guidelines outlined by the Food and Agriculture Organization (FAO) (Table 1).

In aquaculture practices, the physical and chemical attributes of water, collectively referred to as water quality, are significantly influenced by the chosen technological approach and indirectly by factors such as fish waste accumulation and flow or exchange rates. Alabi and Ocholi [20] suggested that poor water quality, as dictated by species-specific requirements, can trigger a reallocation of energy resources from secondary physiological processes, such as growth and reproduction, towards primary physiological processes, including metabolism and immune function.

Table 1. *Comparison Between Physicochemical Parameters of Treated Effluents with FAO Standards for Aquaculture Wastewater Reuse.*

Parameters Determined	Solar Powered RAS	Generator powered RAS	FAO Standards
Temperature (℃)	23.2-25.11	23.20-25.10	18-30
pH	7.10-7.42	7.11-7.41	6.5-8.5
Dissolved Oxygen mg/l	6.32- 6.62	6.22 – 6.47	> 5
NH_3 (mg/l)	0.05-0.08	0.04 – 0.08	< 0.1

Source: Experimental work 2022

3.2. Treated Effluent pH and Its Implications on Wastewater Reuse in Aquaculture

Water pH plays a critical role in influencing the metabolism and physiological processes of fish, while also exerting a significant impact on the toxicity of ammonia [21]. The optimal pH range for fish is typically recognized as 6.5 to 8.5 [22]. Alkaline pH levels exceeding 9.2 and acidity below 4.8 have been reported to be lethal to salmonids, such as brown and rainbow trout, whereas pH values above 10.8 and below 5.0 can prove rapidly fatal to cyprinids, particularly carp [22]. Consequently, both salmonids and cyprinids are vulnerable to fluctuations in the pH of cultured water, highlighting the significance of considering pH levels when treating aquaculture wastewater for reuse.

Various factors can contribute to changes in aquaculture wastewater pH. For instance, elevated alkaline pH levels may occur in eutrophic reservoirs (ponds) where green plants, including blue-green algae, green algae, and higher aquatic plants, absorb substantial amounts of CO_2 during daylight hours for photosynthetic activities. This uptake of CO_2 affects the water's buffering capacity, leading to a rise in pH levels to 9.0–10.0 or even higher, particularly if bicarbonate is absorbed from waters with moderate alkalinity. Additionally, changes in water pH can result from the discharge or leaching of mineral acids, hydroxides, or other acidic or alkaline substances into water bodies, ponds, or lakes [22].

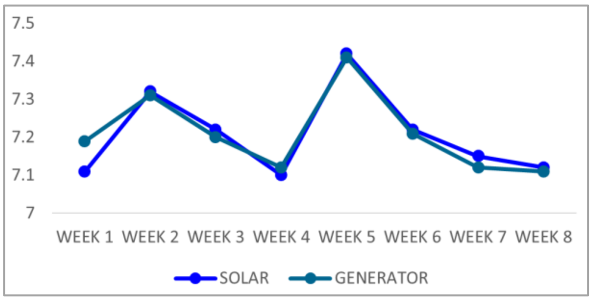


Figure 6. *Physicochemical Performance for pH in Solar and Generator Powered RAS.*

In the sampled wastewater, pH levels ranged from 7.31 to 7.42 (Figure 6), indicating minimal variations in water pH over the course of the experiment. These values fall comfortably within the optimum pH range recommended by FAO guidelines [22], suggesting favorable conditions for aquatic organisms in the two set ups.

3.3. Hatchability Rate of (*clarias gariepnus*) Egg Incubated in Solar and Generator Powered Recirculating Systems

In solar RAS, the estimated eggs hatched was 30,000 while 41,625 was recorded for generator RAS. It shows that the plastic hatching troughs (HT) used as incubators is suitable for hatching African catfish *(Clarias gariepinus*). The results obtained from the study indicated that the percentage hatchability in both the solar-powered and generator-powered recirculating systems exceeded the average threshold of 50%. However, the observed hatchability rates in the present study were slightly lower than those reported by Alabi et al. [23] in their study on the design, construction, and utilization of a model water recirculating system for the incubation and rearing of Cyprinus carpio. Nevertheless, statistical analysis revealed no significant difference ($p > 0.05$) in the hatchability percentage of C. gariepinus reared in the solar-powered and generator-powered recirculating systems. The higher survival rate of fry observed in the Solar Powered Recirculating System, in contrast to the lower fry recovery in the Generator Powered Recirculating System, may be attributed to noise pollution and vibrations. This finding corroborates with the results reported by Akinwole and Faturoti [24].

Noise pollution is increasingly prevalent in aquatic ecosystems, exerting detrimental effects on the growth, physiology, and behavior of organisms. However, limited information exists regarding how this stressor impacts animals during early ontogeny, a critical period for development and the establishment of phenotypic traits. In Zebrafish, physiological stress indicators such as cardiac rate, yolk sac consumption, and cortisol levels exhibited significant increases with rising noise levels, indicating heightened physiological stress [25]. Banner and Hyatt [26] similarly observed significant lethal effects on fish embryos (*Cyprinodon variegatus*, Cyprinodontidae) exposed to elevated noise conditions in a tank system with two distinct acoustic zones, although no effect was detected at the post-hatching stage.

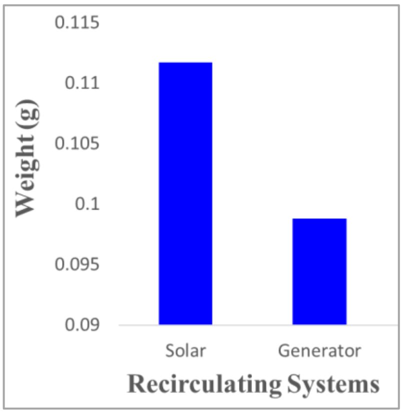


Figure 7. *Weight gain for Clarias gariepinus fry reared at 28 days in two recirculating systems.*

3.4. Growth Performance and Survival at Day 28 and Day 56

The initial mean weight of fry in both the Solar Powered Recirculating System and the Generator Powered Recirculating System was 0.001 grams. However, throughout the rearing period, high mortality rates were recorded. By day 28 (Table 2), the final mean weight (g) of fry in the solar-powered system was 0.112 grams, surpassing their counterparts in the generator-powered system, whose final mean weight was 0.099 grams (Figure 7). The fry in the solar-powered system exhibited a specific growth rate of 39%, which was higher than the 34% specific growth rate observed for fry in the generator-powered system at day 28. Additionally, a higher percentage of fry in the solar recirculated system survived compared to those in the generator recirculated system, with survival percentages of 7.6% and 4.3%, respectively. The feed conversion ratios, fry in the solar group had a ratio of 17.9, while those in the generator group had a ratio of 20.2.

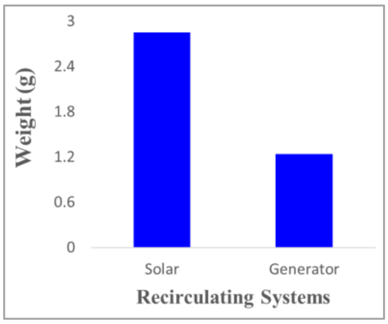


Figure 8. *Weight gain for Clarias gariepinus fry reared between 28-56 days in two recirculating systems.*

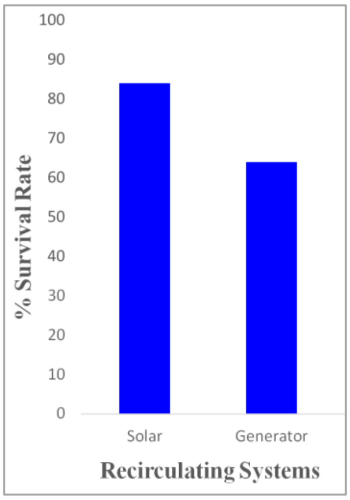


Figure 9. *Survival rate for Clarias gariepinus fry reared between 28-56 days in two recirculating systems.*

The initial mean weight of fry in both the Solar Powered Recirculating System and the Generator Powered Recirculating System was 0.001 grams. By day 56 (Table 3), the final mean weight (in grams) of fry in the solar-powered system reached 2.852 grams, surpassing their counterparts in the generator-powered system, whose final mean weight was 1.337 grams (Figure 8). Fry in the solar-powered system exhibited a specific growth rate of 5%, which was higher than the 2% observed for fry in the generator-powered system at day 56. Between Day 28 and Day 56, mortality significantly decreased, with the survival rate of fry reaching 84% for the solar group and 64% for the generator group. Over the entire observation period from Day 1 to Day 56, more fry in the solar recirculated system survived compared to fry in the generator recirculated system, with a survival percentage of 6.3% for the solar group and 2.7% for the generator group. The feed conversion ratios, fry in the solar group had a ratio of 2.4, while those in the generator group had a ratio of 5.2.

The findings from this study revealed a consistent increase in the mean body weight of *Clarias gariepinus* fry in both the solar-powered and generator-powered recirculating systems throughout the study period. Notably, *C. gariepinus* fry reared in the solar-powered recirculating system exhibited a greater weight gain compared to those in the generator-powered recirculating system (Solar: 2.85; Generator: 1.34) respectively (Figure 9). The superior growth performance displayed by *C. gariepinus* reared in the solar-powered recirculating system in this study aligns with observations made by Alabi and Ocholi [20] in their investigation of hatchability, growth performance, and survival of African catfish (*Clarias gariepinus*) across various aquaculture production systems.

Table 2. *Growth performance and survival at day 28.*

Parameters	Solar Powered Recirculating System	Generator Powered Recirculating System
Initial Mean Weight (g)	0.0012	0.0012
Final Mean Weight (g)	0.1117	0.0988
Weight Gain (g)	0.1105	0.0976
SGR (%/day)	0.3946	0.3486
Survival (%)	7.552083333	4.270833
Feed Intake	2	2
FCR	17.90510295	20.24291

Table 3. *Growth performance and survival at day 56.*

Parameters	Solar Powered Recirculating System	Generator Powered Recirculating System
Initial Mean Weight (g)	0.0012	0.0012
Final Mean Weight (g)	2.8516	1.3373
Weight Gain (g)	2.8504	1.3361
SGR (%/day)	5.0901	2.3858
Survival (% Day 28 – 56)	84.25	63.75
Survival (% Day 1 – 56)	6.362630208	2.722656
Feed Intake	7	7
FCR	2.454734651	5.234604

Despite receiving the same quality of feed, the variance in growth performance of *C. gariepinus* in the solar-powered recirculating system may be attributed to enhanced fish consumption or improved absorption and conversion of nutrients from their diet in a stress-free environment [27, 28] as compared to the psychological stress induced by vibrations and noise from the constant use of generators [26]. Reproductive success in fish species has been reported to be influenced by various factors including broodstock sex ratio, stocking density, age, size, nutrition, and feeding regime [29, 30]. Furthermore, the quality of broodstock is affected by their nutritional status [31], which in turn impacts the quality of eggs, ultimately determining hatchability and larvae survival.

4. Conclusion

In conclusion, the findings of this study underscore the potential of recirculating aquaculture systems (RAS) to facilitate high fish production under optimal conditions while ensuring fish health and minimizing environmental impact. The analysis of salvage values and estimated useful life in RAS powered by solar energy suggests that solar-powered systems offer superior performance compared to generator-powered systems, despite their higher initial capital investment. It is envisaged that the successful implementation of small-scale solar-powered RAS could serve as a catalyst for the development of commercial-scale RAS in the country. Furthermore, small-scale farmers may have the opportunity to expand their operations both in terms of capital investment and knowledge, potentially transitioning into medium and large-scale farmers.

Moreover, this study has contributed valuable insights into the hatchability and growth performance of *Clarias gariepinus* across different recirculating production systems, aiming to identify the optimal system for achieving maximum hatchability, growth, and survival of fish hatchlings. The results indicate that hatchability and early fry survival were notably higher in solar-powered recirculating systems compared to generator-powered systems. Additionally, mean weight gain and protein efficiency ratio were observed to be superior in solar-powered systems while water quality parameters remained optimal for *Clarias gariepinus* in all tested systems.

This study, therefore, recommended that Solar Powered Recirculating Systems be adopted where feasible, given their demonstrated support for increased growth rates and higher survival rates. This recommendation underscores the potential benefits of utilizing renewable energy sources to enhance the efficiency and sustainability of aquaculture production systems.

Abbreviations

RAS Recirculating Aquaculture System

Author Contributions

Betty Anyanwu-Akeredolu: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Writing – original draft

Mosunmola Lydia Adeleke: Conceptualization, Investigation, Supervision, Validation, Writing – review & editing

Adekunle Ayokanmi Dada: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing

Oyedapo Fagbenro: Conceptualization, Supervision, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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