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Development of a Recirculating Flood and Drain Aquaponic System Using Palm Kernel Shells as Growth and Biofiltration Media

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Abstract

A less complex, flood and drain Recirculatory Aquaponic System (RAPS) was developed. The growth medium for the system was palm kernel shells instead of the more commonly used materials like gravel, quartz and pebble balls. This paper reports the development considerations, materials used and the effectiveness of the system, based on water analysis, fish growth rate and plant growth rate. The system consists mainly the culture tank, media bed, 0.5hp pump, twin timer and storage tank. These components were developed based on specific parameters which include: capacity of culture tank, stocking density, fish biomass, daily feed need, area of media bed, hydraulic loading rate, hydraulic retention time and bulk density of the growth medium (PKS). The system was operated for 6 hours (11am-5pm) daily between the periods of 45 days under controlled condition. A total of 40 African catfish (Clarias gariepinus) of average initial weight of 148 g were stocked in two culture tanks (20 fish in each tank) at 15 kg/m^3 density. Twelve days old healthy Amaranthus cruentus seedlings were transplanted to the grow bed after stocking of the fish. The efficacy of the system was determined based on quality of treated water compared with WHO standard for aquatic life. The average gained in weight per fish was 109.83 g and average feed consumed was 188.26g throughout the experiment, an average FCR of 1.71. For the control tank, the corresponding values were 103.8 g, 187.43 g, and 1.81; respectively. The survival rates of fish in the aquaponic system and control tank were 100% and 95%, respectively. A higher plant growth rate was observed in the aquaponic system (1.06 cm/day) than in traditional method (1.01 cm/day).

Keywords: *Recirculatory Aquaponic System, African catfish, amaranthus cruentus, feed conversion ratio, palm kernel shells.*

1.0 Introduction

In recent decades, the demand for sustainable food production systems has intensified as the global population continues to grow and environmental degradation becomes increasingly apparent. Traditional agricultural practices, often characterized by excessive resource consumption and pollution, are no longer tenable in meeting the world's food needs. Concurrently, aquaculture and hydroponics have emerged as promising alternatives to conventional farming methods. However, both systems face limitations, such as water pollution in aquaculture and nutrient inefficiency in hydroponics (Goddek *et al.*, 2019). Aquaculture is one of the fast-growing businesses in Nigeria. It is one of the major sources of high-quality protein of less cost and easy assessable. The need for producing aquacultural (especially fish production) food will increase as the world population increases because these days the primary question is whether food production and the human population can grow simultaneously while adhering to environmental standards (Aslanidou *et al.*, 2023).

Recirculating Aquaculture System (RAS) is usually designed to solve the problem of water requirement and management especially in area with water scarcity. The system minimizes water consumption, control culture conditions and allow wastewater to be fully managed (Singh *et al*. 2021). Little water is required for the production of fish and other aquatic food by treating the water to remove toxic component of the wastewater and reuse it. When the water is recycled for a long period of time, it usually resulted to the accumulation of organic matter and non-toxic nutrients which can affect the fish, this problem can be solved through the introduction of another system (secondary system) that has economic value. Plants are secondary product that can be integrated into the systems due to the present of dissolved nutrients that are generated from the microbial breakdown of fish wastes. Recirculatory Aquaculture System (RAS) had been developed for fish culture since the 1960s. However, the expansion in awareness of aquaponics' ability to address important global concerns including food security, water conservation, and sustainable agriculture is seen in the expanding trend of aquaponic research, especially in areas that are susceptible to resource constraints and climate change (Nishanth *et al.*, 2024; Okomoda *et al.*, 2023).

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Aquaponics is an integrated system that combines ideas, skills and technology of aquaculture (fish production) with hydroponic (vegetables, flowers, and herb production) farming systems. In recent times, aquaponics has been the suitable means of producing fish and vegetables, and one of the most efficient and environmentally sustainable farming methods of the twenty-first century (Oladimeji *et al.*, 2020). In this system, the nutrient-rich wastewater from aquaculture excreted by the fish or produced from the microbial breakdown of organic wastes is absorbed by plants in the media bed while plants assist in purifying the water, creating a symbiotic environment conducive to sustainable food production (Somerville *et al.*, 2014). The medium material in media bed and plant root serves as a biofilter, and therefore a separate biofilter is not needed as in other recirculating systems, other benefits of using aquaponics systems for food production are reduced pollution, enhanced performance, food security, water conservation, and low energy usage (Okomoda *et al.*, 2023). Similarly, Adebayo *et al.* (2025) investigated the effectiveness of using palm kernel shell as growth medium in a flood and drain Aquaponic system, a higher growth rate was observed in the aquaponic system when compared to the traditional method.

A Recirculatory Aquaponic System (RAPS) reuse most of its water, the system consumes relatively less amount of water compared to other types of culture systems which make it affordable especially in areas with water scarcity (Singh *et al.* 2021). Some of Aquaponic System designs include; gravel bed, clay bed, floating raft, and deep-water culture (Paudel, 2020; Din et al., 2024). Murray et al. (2014) reported that many commercial RAS have failed because of poor design and inferior management. Also, Graber and Junge (2008) reported that Aquaponics take advantage of nutrient cycles by utilizing fish waste as potential crop biomass. They conducted research comparing aquaponic yields to hydroponic yields, to determine how much of a gain is experienced using this advantage.

However, Oladimeji *et.al.* (2020) worked extensively on two agricultural wastes (periwinkle shell and palm kernel shell) for their suitability as growth beds in the propagation of pumpkin *Telfaria occidentalis*. In their studies, the researchers observed a superior growth and yield of the pumpkin plant and therefore concluded that the use of periwinkle shells and palm kernel shells are suitable as media beds in aquaponics production of fluted pumpkin, *Telfaria occidentalis*. Oladimeji *et al.* (2020) earlier reported that periwinkle shell is better as a grow bed in catfish-pumpkin aquaponics system for pumpkin production. Yet, report on the development of a recirculatory aquaponic system using palm kernel shell as the growth medium is missing.

Hence, there is a need to check for the effectiveness of using palm kernel shells as growth medium in a flood and drain aquaponic system. Therefore, the objectives of this study were to develop a recirculatory aquaponic system with palm kernel shells as growth medium and examine the efficacy of the material as growth medium in aquaponic system.

2.0 Materials and Methods

2.1. Materials

The materials used for the development of the recirculating flood and drain aquaponic system included two culture tanks which were constructed according to Dunn (2014), grow beds which was developed based on Pattillo (2013), water pump which was selected according FAO (2014) specification, PVC pipes, fittings and valves were procured from plumbing materials marked in Ilorin Kwara State, Palm Kernel Shells (PKS) were obtained from Ede in Osun State and vegetable seeds gotten from Kwara State Ministry of Agriculture and Rural Developments . These materials were selected due to their availability, durability, and suitability for aquaponic system construction.

2.2. Development Consideration

Some parameters considered for the development of this system were: volumetric flow rate, hydraulic flow rate, hydraulic retention time and discharge rate through bell. Other parameters considered were:
Fish stocking density and Plant density (15 kg/m^3 according to FAO (2014)).

Fish biomass=capacity of the tank × stocking density (1)

Daily Feed Need=fish biomass × % of the body weight feeding (2)

G.A = (daily feed need)/(60/m^2/ day) (3)

$$HLR = \frac{discharge\ rate\ (Qw)}{bed\ area} \tag{4}$$

$$\boldsymbol{HRT} = \frac{As \times hw \times \phi}{Qw} \tag{5}$$

HLR = hydraulic loading rate
HRT = hydraulic retention time
As = surface area of the medium
hw = depth of water in growth bed
ϕ = porosity of growth bed medium (63.6% Evbuomwan *et al.*, 2013)

Properties of palm kernel shells considered include: Large surface area for bacterial growth, good drainage properties, neutral pH, inert, light-weight, easy to work with, sufficient space for water to flow through the medium, available and cost-effective.

2.3 Processing of Palm Kernel Shells (PKS)

The palm kernel shells obtained from Ede in Osun State were washed and soaked in water for two days to remove impurities. The material was later sun-dried for 72 hours to reduce moisture content and sorted to obtained uniform particle sizes ranging between 10–25 mm, which are suitable for both plant anchorage and microbial biofilm development. The processed shells were soaked in clean water for 24 hours prior to installation in the grow bed to stabilized the media

The palm kernel shell particles were arranged in three layers (wet zone, wet-dry zone and dry zone.). Wet Zone is the bottom of the bed that remains permanently wet. In this zone, the small particulate solid wastes accumulate, and, therefore the organisms that are most active in mineralization are located here. Dry-wet zone is the zone that has both moisture and high gas exchange. In this method (flood-and-drain techniques), this is space where the media bed intermittingly floods and drains. Most of the biological activity will occur in this zone. The root development, the beneficial bacteria colonies and beneficial micro-organisms are active in this zone. Dry-zone is the top of the bed above standpipe, which functions as a light barrier, preventing the light from hitting the water directly which can lead to algal growth. It also prevents the growth of fungus and harmful bacteria at the base of the plant stem, which can cause collar rot and other plant diseases.

2.4. System Description

The system contained culture tank with a specific capacity (500 litres), aquaponic media bed incorporated with automatic bell siphon, 0.5 hp pump and water source. The system was arranged in a way that both culture tank and media bed were at different level (the media bed was placed above the culture tank). The effluent from culture tank was pumped in to the media bed via 0.5hp pump. The effluent flew through the medium (palm kernel shells) and plant root (vegetables) where filtration, mineralization and biofiltration took place simultaneously. Palm kernel shells (PKS) served as growing bed for the plant and filter for solid particles of the effluent.

The PKS also served as medium for the growth of bacteria (*Nitrobacter* and *Nitrosomonas*) that help to covert potentially toxic ammonia from fish waste in to non-toxic nitrate for plant use (fertilizer). Purified water (which can be reused by fish) was drained back to the culture tank via automatic bell siphon as shown in Figure 1. An exploded view of the system is presented in Figure 2.

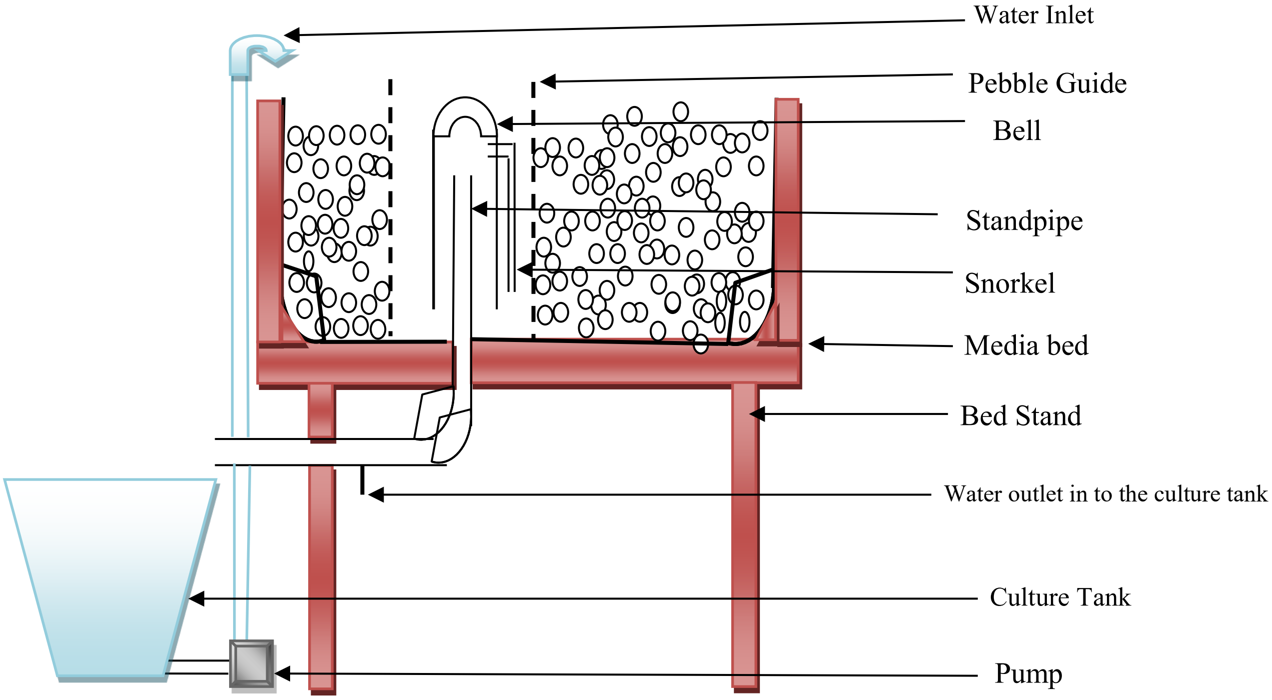

Figure 1: Schematic Sectional View of the Recirculating Aquaponic System (RAPS)

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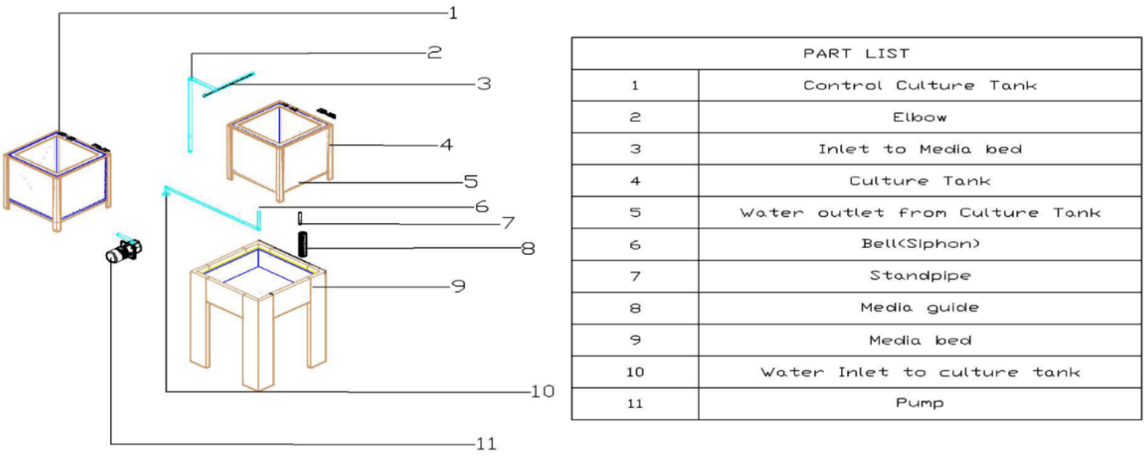

PART LIST	
1	Control Culture Tank
2	Elbow
3	Inlet to Media bed
4	Culture Tank
5	Water outlet from Culture Tank
6	Bell(Siphon)
7	Standpipe
8	Media guide
9	Media bed
10	Water Inlet to culture tank
11	Pump

Figure 2: Exploded View of the Aquaponic System

2.5. Construction of the Aquaponic System

The recirculating flood and drain aquaponic system used in this study was developed by the authors using locally available materials. The fish tank was positioned at the base of the system while the grow bed was elevated on a supporting frame. A 0.5hp water pump installed in the fish tank pumped nutrient-rich water through PVC pipes into the grow bed. The grow bed was filled with processed Palm Kernel Shells which served as plant support media and biofiltration substrate for nitrifying bacteria. A bell siphon mechanism was installed at the base of the grow bed to regulate periodic flooding and draining cycles. During the flood cycle, water filled the grow bed until the siphon activated, automatically draining the water back into the fish tank.

2.5 Evaluation of the System

The developed aquaponic system as demonstrated in Figure 3 was evaluated based on water parameters, Fish Feed Conversion Ratio (FCR) and Plant Growth Rate (PGR). The water analysis was carried out at every 48hours to determine the pH, Total Dissolved Solid (TDS), Electrical Conductivity, Dissolved Oxygen (DO) and Temperature of both effluent and influent using combo pH probe produced by HANNA instruments (Model No; HI 98129). Also, chemical analyses were carried out in the University of Ilorin Central Research Laboratory at every two weeks (15 days) interval, to determine the Dissolved Oxygen, Total Dissolved Solid (TDS), Ammonia, Nitrite ion, Nitrate ion, temperature, Electrical Conductivity and pH of both effluent and influent.

The system was operated for 6 hours daily between for a period of 45 days under controlled condition. A total of 40 cat fish (*Clarias gariepinus*) of average initial weight of 148 g were stocked in culture tanks at $15kg/m^3$ density. Twelve days old healthy *Amaranthus cruentus* seedlings were transplanted to the grow bed after stocking of the fish. The system was also evaluated based on feed conversion ratio of fish and plant growth rate using equations 6 and 7.

$$FCR = \frac{total\ amount\ of\ feed\ comsumed}{total\ gain\ in\ weight\ by\ the\ fish} \tag{6}$$

$$PGR\left(\frac{cm}{day}\right) = \frac{(final\ height - initial\ height)of\ the\ plant}{total\ number\ of\ \ days} \tag{7}$$

where:
FCR = Feed Conversion Ratio, and
PGR = Plant Growth Rate in cm/day

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3.0 Results and Discussion

A less complex, flood-and-drain recirculatory aquaponic system as presented in Figure 3 was configuration to integrates fish and vegetable production using palm kernel shells (PKS) as the sole growth medium. Effluent from the fish tanks was pumped into the PKS-filled media bed, where it percolated through the medium and plant roots, and was then drained back to the culture tanks via the bell siphon in a cyclic flood-and-drain pattern. Development of the system was guided by a set of design and management parameters that included culture tank capacity, stocking density, fish biomass, daily feed requirement, media bed area, hydraulic loading rate, hydraulic retention time and bulk density of the PKS medium as described by Oladimeji et al. (2020). PKS were chosen because they offer large specific surface area for bacterial colonisation, good drainage, near-neutral pH, low bulk density and ease of handling, as reported by Akinwole and Dauda (2014).

Figure 3: Developed Aquaponic System

3.1 Water quality and system stability

The findings demonstrated that throughout the 45-day experimental period, the major physico-chemical parameters remained within recommended ranges for aquaponic organisms, establishing the functional stability of the recirculatory aquaponic system with PKS as medium as presented in Figure 4. Across effluent and influent samples (S1–S3), temperature ranged between 26–33 °C, pH between 6.3–7.4, dissolved oxygen (DO) between 2.1–6.8 mg/l, total dissolved solids (TDS) between 126–277 ppm, and electrical conductivity (EC) between 255–554 μS/cm. These values align findings reported by (Hassan et al., 2025) with optimal aquaponic operation typically occurs at pH 6.0–7.5, moderate TDS of <1,000–2,000 mg/l and temperatures adequate for warm-water species such as African catfish and leafy vegetables.

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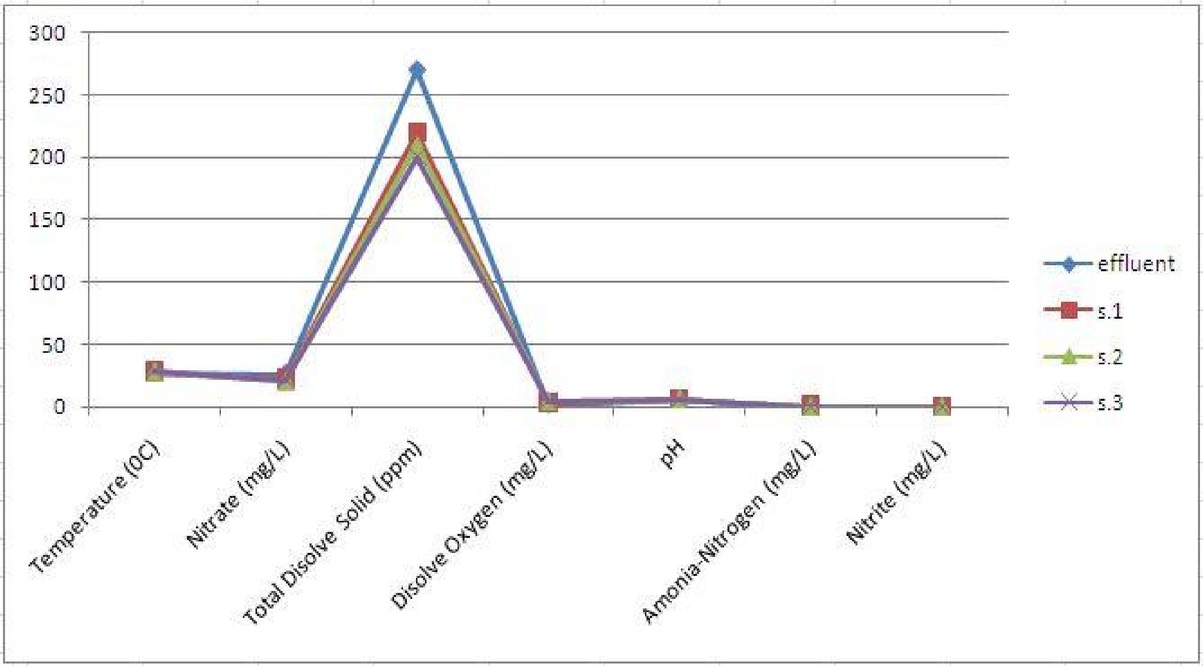

Figure 4: Comparison between effluent and three influent samples

The observed pH range supports both nitrification and plant nutrient availability, while remaining acceptable for African catfish (Clarias gariepinus) performance. A recently report on aquaponic practice by Danladi Mohammed et al. (2025) emphasize maintaining pH in the slightly acidic to neutral range to balance fish health, nitrifying bacteria activity, and micronutrient solubility, which is consistent with the present system's operation. DO values occasionally dropped near 2 mg L^{-1} in effluent but recovered to higher values in influent streams after passage through the PKS media bed, stating active re-aeration and biological consumption dynamics of the media-based aquaponic.

The Ammonium nitrogen declined over time, nitrite remained very low (approximately 0.001–0.002 mg L^{-1}), and nitrate accumulated gradually in the water column. This pattern indicates a better functional nitrifying biofilm in the PKS bed, when compare to findings reported Abdissa et al. 2025) that gravel bed demonstrated lowest ammonia concentration (0.074 mg/L).

3.2 Fish growth and feed conversion

Fish performance in the PKS-based aquaponic system was comparable to, and slightly better than, that of fish in the control tank operated as a conventional recirculating aquaculture unit. The average weight gain per fish in the aquaponic system was 109.83 g with an average feed intake of 188.26 g, giving a mean feed conversion ratio (FCR) of 1.71. In contrast, fish in the control tank gained 103.8 g with 187.43 g feed consumed, corresponding to an FCR of about 1.80–1.81, indicating marginally poorer feed utilization efficiency relative to the aquaponic treatment. A paired t-test on FCR showed a statistically significant difference at the 5% level in favour of the aquaponic system, demonstrating that integration with the PKS plant bed did not compromise, and may enhance, fish growth performance.

These FCR values are within the range reported for African catfish in recent aquaponic and recirculating systems by Omboga. (2024), where typical FCR values between 1.2 and 1.3 are considered acceptable under practical conditions. Comparative experiments conducted by Chukwu et al. (2025), between aquaponic setups and conventional ponds likewise observed equal or slightly improved growth and FCR for African catfish in aquaponics, often attributed to more stable water quality and reduced buildup of toxic metabolites. The 100% survival rate in the aquaponic system, compared with 95% in the control tank, further supports the notion that the PKS-based bed effectively moderated water quality and provided a favourable culture environment.

3.3 Plant growth and productivity

Amaranthus cruentus grown in the PKS-based aquaponic bed exhibited slightly higher growth rates than plants under conventional soil-based cultivation. The average plant height in the aquaponic system increased from approximately 1.36 cm to 49.25 cm over 45 days, corresponding to a plant growth rate (PGR) of 1.06 cm $day^{-1}$the corresponding soil-grown plants increased from about 1.42 cm to 46.75 cm, giving a PGR of 1.01 cm day^{-1}. The number of leaves per plant followed a similar pattern, with aquaponic plants consistently bearing

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more leaves than the control (soil-based counterparts) at each observation time, this indicates an improved vegetative development in favour of aquaponic plant.

These results are in consistent with report documented by Babatunde et al. (2019) on leafy vegetable production in African catfish–amaranth aquaponic systems, which shown strong amaranth growth, high biomass accumulation, and efficient nutrient use when plant densities and hydraulic loading rates are appropriately balanced.

4.0 Conclusion and Recommendation

This study developed a recirculating flood and drain aquaponic system using Palm Kernel Shells as plant growth and biofiltration media. The results showed that Palm Kernel Shells can serve as a low-cost and locally available alternative to conventional aquaponic media while maintaining suitable conditions for fish and plant production. The study demonstrates the potential of utilizing agricultural waste materials in sustainable aquaponic systems

The system evaluation was based on most important water parameters for aquaponics organisms, feed conversion ratio (FCR) and plant growth rate (PGR) using juvenile catfish (*Clarias gariepinus*) and *Amaranthus cruentus*. The range values of the chemical parameters obtained were; pH 6-7.4, Dissolved Oxygen 4.1-6.8 mg/L, Total Dissolved Solid 126-201 ppm, nitrate ion 21-26 mg/L, nitrite ion 0.001-0.002mg/L and Ammonium Nitrogen 0.4-0.5 mg/L of water were within the permissible level as compared with WHO specification and optimal water quality for aquaponic organism (FAO, 2014) of corresponding values; 6-7.5, 4.9 mg/L, <2000 mg/L, < 150mg/L, < 1 mg/L and < 1 mg/L; respectively, the average feed conversion ratio was 1.71 which was better than that of control culture (1.80), a higher plant growth rate was observed in the aquaponics system (1.06 cm/day) than in traditional method (1.01 cm/day).

It is recommended that further studies should investigate the long-term durability of Palm Kernel Shells in aquaponic systems, optimization of media particle size, and the performance of the system with different crop and fish species.

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