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Design and Construction of an Aquaponics System: A Sustainable Approach to Enhancing Local Food Security in Offa, Nigeria

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Abstract: *The design of an aquaponics system is a major drive in achieving a sustainable agricultural practice, tackling environmental problems, and food security. Aquaponics provides a conservative technique that integrates both hydroponics and aquaculture in regions with minimal arable land. This current study aims to design and build an aquaponics system that is suitable and beneficial to its environment. The objectives of building the aquaponics system are to cultivate fish and plants in a closed system that can reduce the requirement for chemical-based nutrients and increase water-use efficiency. Preliminary assessment, design, and preparations of drawings were applied to obtain a suitable plan for the aquaponics system. Civil, construction, plumbing, welding, and planting works were conducted to physically implement the aquaponics system. A farm base of 8 m X 4 m (hydroponics) was built alongside a concrete tank base of (3 m x 2 m x 0.6 m) to hold the fish tank of 2000 L (aquaculture). A canopy material was then laid to hold water in the hydroponics section. Twelve pieces of polystyrene (2.1 m X 1.2 m) were laid to float inside the hydroponics system with each one carrying 9 lightweight disposable cups to serve as planting mediums. Rice husk and palm kernel shells were filled into the cups to grow the plants (cucumber and pepper). Plant and growing medium weights were considered in determining the number of growing mediums(cups) in the hydroponics system. Other works done included plumbing for water, welding for the aquaponics structure, and installation of a cover. This current study incorporates organic waste materials as systematically grown mediums to create additional nutrients, increase grow mediums for optimized plant production, and reduce cost. The result of the study showed a shorter growth cycle for the plants (pepper and cucumber) between germination and flowering indicating a higher infusion of nutrients created by the hydroponics system. The result of the study can be applied as a guide to designing and building an effective aquaponics system and a tool for developing systems that can reduce food insecurity and farming techniques.*

Keywords: *Aquaponics, Hydroponics, Construction, Food Security, Aquaculture*

1. INTRODUCTION

The expression “soil-less culture” refers to cultivating crops without soil. Here, alternative media called substrates are used instead of soils that retain water and offer support to plants. Irrigation systems in this media introduce a nutrient solution into the plant root zones. This solution contains all the nutrients needed for growth by plants. Hydroponics is the most common type of soil-less growth technique where plants grow on a substrate or aqueous solution having no roots.

Pests and soil-borne illnesses that harm monoculture crops have been reduced using soil-less agriculture. With hydroponics, soil-borne pests can be managed because soil-less media can be cleaned and reused between crops [1].

One of the most significant advances in science, business, and technology in the agricultural sector over the past 200 years is soil-less farming. Generally, there is an increased demand for off-season high-value crops, but the situation is even worse in developed countries with temperate climates. This is because of enhanced living standards. In response to this rising demand, various forms of protected farming systems have emerged to increase production capacity and extend the crop supply all year round. Farming within these guarded systems can be done using soil [2]. Hydroponics is one of the best solutions where arable land is limited because it does not require any soil. Instead, soil-less agriculture can be established in salty areas, drought-prone plains, urban and suburban settings, or anywhere else where the adoption of extensive production systems becomes inevitable due to adverse climatic conditions or pressures on land and water resources. Soil-less agriculture has its appeal when it comes to ensuring food security or the development of microscale farming with zero food miles due to its high productivity for minimal space [3].

The concept of aquaponics underscores its merits as sustainable, fresh producing, and space-wise water conserving [4], [5]. This sets the stage for the objectives of this study which includes developing, cost estimation, construction, and testing of an aquaponic system at Federal Polytechnic Offa. As already mentioned in the background, the objective of this research is in line with the promotion of environmentally friendly behaviour and sustainable agriculture. This connection highlights how much valuable information and assistance can be derived from a polytechnic's aquaponics systems to help resilient communities have enough food that is also produced sustainably.

Aquaponics takes on multiple challenges such as scarcity of water, land constraints, degradation of the environment and hunger through a holistic approach towards farming while upholding sustainability, creativity and community empowerment. The cost-effectiveness nature, as well as the need for land and water conservation embodied in aquaponics, makes it an attractive option among Nigerian farmers who will be provided with regular supplies throughout the year. Despite the initial expenses incurred during the installation period coupled with the learning curve that comes along with new technology for farmers in Nigeria; however, these systems are becoming increasingly popular because they are more efficient and sustainable than other systems. This study aims to construct an aquaponics system in Federal Polytechnic Offa, Kwara State by designing and building the aquaponics system.

2. LITERATURE REVIEW

Over the past two decades, aquaponics which is a synergistic merger of hydroponics and aquaculture has attracted a lot of attention. The efficiency with which this sustainable agricultural system uses resources especially water as well as its potential for urban agriculture have been recognized. The review that follows summarises the most recent research on aquaponics, with an emphasis on system designs, advantages, difficulties, and financial feasibility.

According to Tyson et al. [6], aquaponics is a sustainable agriculture system that minimizes the use of non-renewable resources, maximizes the use of natural biological cycles to supply nitrogen, and combines the hydroponic production of plants and the aquaculture production of fish.

Over the years, this system could bring out great economic gains. This has received much attention in recent years as an integrated system because it can help solve food security, resource use efficiency, and environmental sustainability challenges. The subsequent literature examines some key aspects of aquaponics including its principles, benefits, constraints, and areas of current research. Aquaponics is built upon the closed-loop principle where fish waste provides essential nutrients for plant growth while plants on the other hand filter and purify water which is then used by fish. Fish waste contains ammonia that is toxic to fish but through microbial communities such as nitrifying bacteria, it gets converted into nitrate that plants can absorb as nutrients.

Goddek et al. [8] have provided an elaborate review of nutrient recycling which highlights the role of microorganisms in balancing the system. This study stressed that efficient management of nutrient dynamics is crucial for optimizing fish and plant production. Rakocy et al. [9] addressed the building of the University of the Virgin Islands' aquaponic system, a novel model that influenced general aquaponic designs. This technique described that it is possible to combine the production of fish and plants in a recirculating aquaculture system while managing the nutrient and water quality. Aquaponics has received commendations for being resource-efficient and sustainable. The concept of nutrient recirculation in the system reduces waste, conserves water, and lessens the need for chemical fertilizers. Somerville et al. [10] evaluated the ability of aquaponics to improve food security specifically in urban and semi-urban areas. The study reported the minimal usage of water and land use by the practice of aquaponics making it a good option for regions with limited resources.

Love et al. [11] surveyed aquaponics users and found that sustainability, water conservation, and organic food production were among the main drivers for adopting aquaponics. The study also highlighted the operational characteristics and benefits observed by the users of aquaponics in the United States. Quagrainie et al. [12] analyzed the economic feasibility of aquaponic systems in the Midwest USA. The study found that while aquaponics can be profitable, it requires careful management of production costs and market prices. The authors emphasized the importance of achieving economies of scale to enhance profitability. Miličić et al. [13] reviewed the technical and economic challenges associated with aquaponics, such as energy consumption, nutrient management, and system design. The study called for further research to optimize system components and reduce costs, making aquaponics more accessible and economically viable. Thomaier et al. [14] discussed the potential of aquaponics in urban farming, highlighting its role in sustainable city planning. The authors explored how aquaponics can contribute to urban resilience by reducing food miles, enhancing local food systems, and making efficient use of space. Konig et al. [15] examined the sustainability of aquaponics in urban environments, emphasizing its role in promoting circular economies. The study also addresses the challenges of integrating aquaponics into urban infrastructure, such as regulatory barriers and the need for public awareness.

More recently, researchers have focused on technological advancements in aquaponics with the target on improving system efficiency, reducing labor costs, and enhancing productivity through automation and smart systems. This was reported in the work of Goddek & Körner [16] who explored the integration of renewable energy sources and smart technologies in aquaponics. The study discusses how automation and real-time monitoring can optimize system performance, making aquaponics more viable for commercial applications. Also, Junge et al. [17] reviewed innovations in aquaponic system design, including the development of more efficient biofilters, improved integration of fish and plant production, and advancements in system control. These innovations aimed to overcome current limitations and expand the scalability of aquaponic systems.

Other area of focus by researchers is the positive environmental and social impacts aquaponics has the potential to deliver, particularly in the context of sustainable agriculture and community development. Tokunaga et al. [18] evaluated the environmental impacts of aquaponics compared to conventional agriculture. The study found that aquaponics has a lower environmental footprint, particularly in terms of water use, energy consumption, and waste production. Furthermore, Rizal et al. [19] examined the social benefits of aquaponics, particularly in community-based projects. The study highlighted the potential of aquaponics to enhance food security, provide educational opportunities, and engage communities in sustainability [20], scaling up production, and exploring new applications. Research is needed to improve system efficiency, reduce costs, and develop standardized practices that can be adopted widely. Palm et al. [21] discussed the future of commercial aquaponics, emphasizing the need for interdisciplinary research to address technical, economic, and regulatory challenges. The authors suggested that advances in biotechnology, system design, and market development will be crucial for the commercialization of aquaponics. Villarroel et al. [20] highlighted the importance of education and training in aquaponics, arguing that building a skilled workforce and increasing public awareness is essential for the growth and adoption of aquaponics as a sustainable agricultural practice.

There are different methods of design applied in aquaponics [22], [23] systems that are workable and efficient. Such designs include the Deep-Water Culture (DWC) or floating rafts setup, the Nutrient Film Technique (NFT) system, the drip system, the wick system, and others. However, the most common techniques in aquaponics are the Media-Bed system, the Nutrient NFT [24], [25], and the DWC systems.

Although the study area provides a vast area for arable farming practices, the recent urbanization level has reduced up to 23 square kilometers of this area [26]. Furthermore, an investigation of the rate of urbanization expansion in Offa by Mohammed (2021) [27] showed agricultural losses suffered the highest loss to urbanization. To provide alternative and simple practices for enhancing food security, aquaponics is applied in this current study to assess its productivity and suitability.

Conclusively, aquaponics represents a promising approach to sustainable food production, offering significant benefits in terms of resource efficiency, environmental sustainability, and urban agriculture. However, the technology faces challenges related to economic viability, technical complexity, and scalability. Ongoing research and innovation are crucial to overcoming these barriers and realizing the full potential of aquaponics.

3. MATERIALS AND METHODS

This section describes the materials and techniques applied in designing and building the aquaponics system.

3.1 Study Area

The study area for implementing an aquaponics system is at the Department of Civil Engineering in Federal Polytechnic Offa, Kwara State, Nigeria, with geographic coordinates of 8.1318281N and 4.7107188E. It involves assessing land suitability, infrastructure availability, and environmental considerations within the campus.

This includes evaluating physical characteristics, such as topography and soil quality, as well as ensuring access to utilities like electricity and water. Stakeholder engagement and educational opportunities are prioritized, with collaboration across departments and integration into academic programs. The project presents a unique opportunity for hands-on learning, research, and sustainable development initiatives within the institution, fostering interdisciplinary cooperation and practical applications in agriculture and engineering.

3.2 Methodology

This section describes the method applied in designing and constructing the aquaponics system. The aquaponics design applied in this current study is the integration of the floating raft set-up and NFT [22] and the construction framework adopted in this study is a combination of conceptual theories and physical implementation. This study applies lightweight composite materials (polystyrene and plastic disposable cups) in the hydroponics section to simulate the floating raft setup. By applying this method, the study creates use for organic waste material such as rice husk and palm kernel shells intending to maximize the hydroponics system. Furthermore, nutrient from the fish tank is recirculated to the hydroponics system and vice versa. The procedures executed in this study to fulfil the objectives are summarized and presented in Figure 1. The framework was built to effectively achieve the objectives and is summarized as follows: i) site assessment; ii) aquaponics system design; iii) and construction of the aquaponics system. Each major process described in Figure 1 is further explained below:

3.2.1 Site assessment

A thorough assessment of the site including available space, sunlight exposure, land clearing, grading, and access to water and electricity was conducted. The aquaponics system layout was designed considering factors such as fish tanks, grow beds, plumbing, and filtration components. The determination of the size and capacity of each component is based on production goals, available space, and budget constraints. Figures 2 and 3 show the farm and steel layout of the aquaponics system respectively.

3.2.2 Cost analysis and purchase of materials

This cost analysis aims to provide insights into the financial considerations of establishing an aquaponics system in Nigeria. To conduct a comprehensive cost analysis, the following steps were carried out:

i. **Market Research:** Data on the prices of materials and equipment needed for aquaponics systems from local suppliers and vendors were gathered, collection of information on labor costs for system installation, operation, and maintenance was carried out, and determination of the availability and cost of essential inputs such as fish feed and seeds were made.

ii. **Cost Estimation:** Calculation of the total cost of infrastructure based on the chosen system size and design specifications was done, and estimation of operational costs on a monthly or yearly basis, considering factors such as energy consumption, labor, and inputs were done, and determination of the initial stock cost based on the desired fish and plant species was made.

iii. **Financial Projections**: Forecasting of revenues based on projected fish and vegetable yields was done.

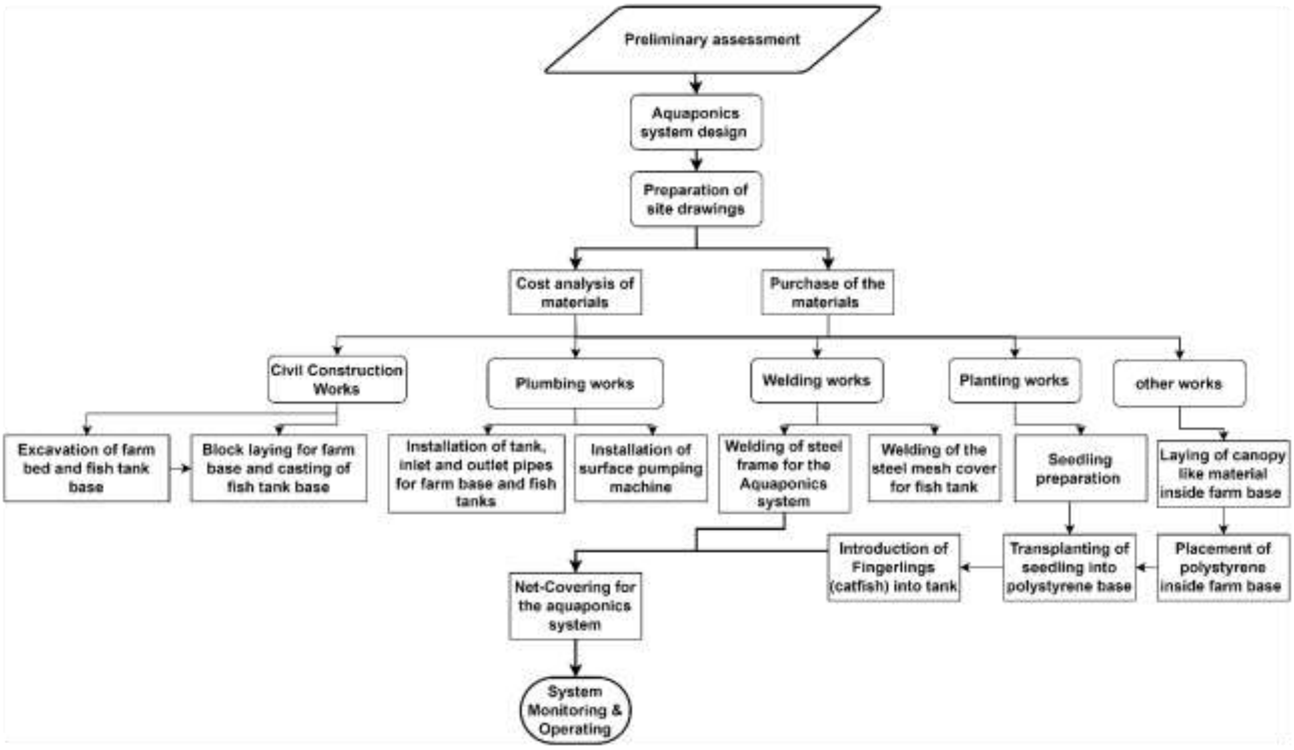

Figure 1: The framework of the design and construction of the aquaponics system

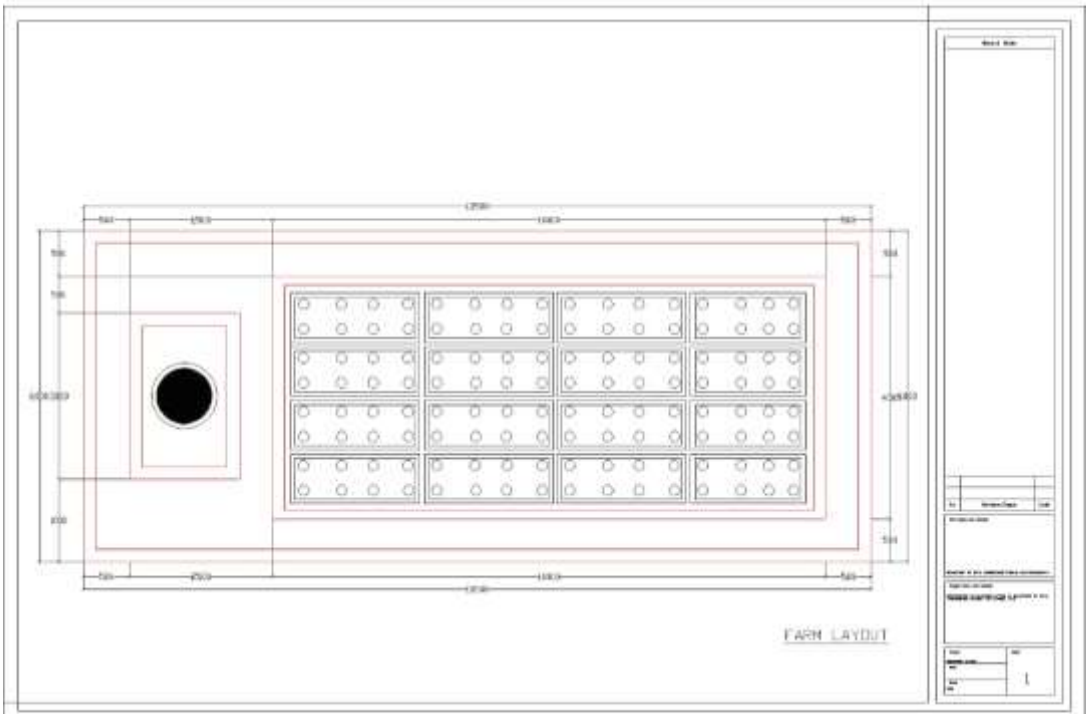

Figure 2 Farm layout of the aquaponics system

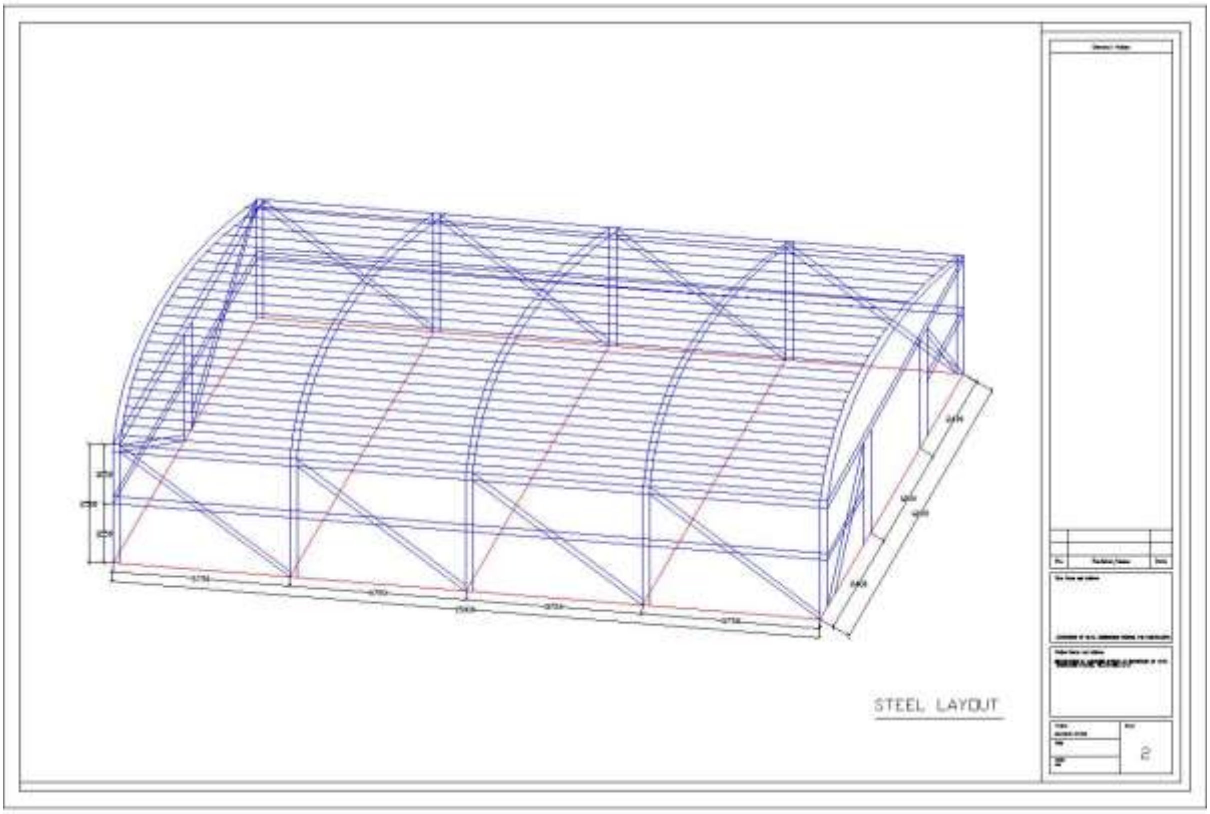

Figure 3: Steel layout of the aquaponics system

3.2.3 Civil and construction works

i. **General layout of the aquaponics system:** The hydroponics system consists of a bed of carefully arranged polystyrene on an excavated farm base. This farm section which forms the hydroponics system was covered with a steel structured canopy (see Figure 2) to serve as an anchor for plants and a protection system against pests, etc. The tank shown in Figure 2 was placed on a concrete base that serves as the fish tank which will have pipes connected for water inlet and outlet to the hydroponics system.

ii. **Design:** The application of the right specification during the design involved the estimation of loadings (weight of tank, water at full capacity, and fish) on the tank base allowing the construction of a sustainable foundation for the aquaculture system (fish tank and its base). The depth of the grow bed was determined by estimating the maximum amount of water to be retained in it and subsequently the strip foundation choice for the foundation. The sizes of the pipes for inlet and outlet works were determined considering the depth of the farm base, volume of the fish tank, and the desired pressure

iii. **Construction:** The construction phase required several civil works while building an aquaponics system. The planning, building, and installation of the physical infrastructure needed to support the aquaponics system are referred to as civil works. The essential civil works elements needed for aquaponics construction were (i) excavation works for the farm base, fish tank base (plinth), pipes (1 inch), outlet drain, and steel frame; (ii) laying blocks for the farm base (8 m x 4 m); (iii) casting of fish tank base (3 m x 2 m x 0.6 m).

3.2.4 Plumbing works

Installing a network of pipes will allow water to be circulated between the farm base, fish tank, inlet, and outlet drains from both. This covers overflow pipes, drainage lines, and supply lines. Pipes were connected from the closest source of water in the study area.

i. **Pump System:** To transfer water throughout the system, pumps are required. A surface pump (Atlas 125 1 horsepower) was installed for the pumping of water for the fish tank (1500 litres) and the farm base of 32 m^2.

ii. **Pipe networking:** 1-inch pipes and other appurtenances were used to create water flow from the source to the fish tank, from the fish tank to the farm base and vice-versa, and outlet drain from the farm base.

3.2.5 Welding works

When building an aquaponics system, welding is essential, especially when building strong, robust, and long-lasting structures. The steel layout shown in Figure 3 serves as the cover of the aquaponics was put together by 10 lengths of $1^{1/2}$ inches round steel rods, 20 lengths of 1-inch round steel rods, 3 lengths of flat bars, and other accessories via welding and bracing into the excavated ground with concrete (see Figure 4).

Figure 4: Welding of the aquaponics system cover steel frame

3.2.6 Planting works and fish selection

Nutrients can be managed through the optimization of plant seedlings or seeds in the grow beds using a suitable growing medium such as the polystyrene that was installed in the farm base. 12 pieces of polystyrene (2.1mx1.2m) were laid in the farm base. Seedlings were prepared off-site for transplanting to the hydroponics system. Furthermore, plant varieties that thrive in aquaponics systems, such as leafy greens, herbs, and fruiting crops like tomatoes, cucumbers, and peppers were planted.

The weights of plants proposed for the hydroponics section, the disposable cups, grow medium (rice husk and palm kernel shells) were evaluated to avoid the sinking of the polystyrene and maintain the required water balance for the germination of the plants. Additionally, strings that can anchor cucumber were placed across the horizontal framework of the hydroponics section.

Selection of fish species suitable for aquaponics such as tilapia and catfish were considered based on factors like water temperature, compatibility with plant species, and market demand. Catfish was selected because of its suitability for aquaponics and high market demand in Nigeria. Figure 4 shows the aquaponics after the completion of the tank and farm base installation.

3.2.7 Greenhouse covering

The measurement of the steel framework for the aquaponics system was taken to evaluate the size of the covering required. 200 square meters of shade net, 90 meters of net, wiggles, and steel profiles are assembled to cover the entire aquaponics system. This unit serves as a temperature regulator and protector from pests and others.

4. RESULTS AND DISCUSSION

This section explains the results of all the processes carried out to complete the construction and implementation of the aquaponics system.

4.1 Construction of Aquaponics

The steps described in Section 3.2.3 allowed the construction of a safe and sustainable aquaponics system as shown in Figure 5. This was done by following design considerations (such as the volume of the tank, shape, flow rates, loadings, and materials).

4.2 Greenhouse Construction and Effectiveness

The greenhouse construction successfully provided a controlled environment essential for the aquaponics system. The galvanized steel frame offered strong structural support, while the use of insect and shade nets helped regulate sunlight and temperature inside the greenhouse (see Figure 5). Key results from the greenhouse construction include:

i. **Structural Integrity**: The galvanized steel pipes and arc design for the cover of the aquaponics maintained stability and strength, resisting wind and weather pressures. The plastering of the insect net's base added further stability and helped prevent pest entry at ground level.
ii. **Environmental Control:** The black shade net on the roof permitted adequate sunlight for plant photosynthesis while mitigating overheating. This balance proved beneficial for both fish and plants, as it maintained an environment conducive to growth.
iii. **Protection from Predators:** The enclosure protected fish from birds and other predators, while the insect net limited pest access to plants, reducing the need for pesticides.

4.3 Plumbing and Water Circulation

Efficient water circulation between the fish tank and grow beds is critical in aquaponics. The PVC piping, coupled with a pump of 1 horsepower, allowed for a consistent flow rate that met the system's needs. The system was tested for leaks, and no significant issues were observed as shown in Figure 6.

i. **Pump Performance:** With a capacity for a maximum flow of 5.2 cubic meters per hour (22.9 gallons per minute) and a maximum head of 20.6 meters (68 feet), the pump effectively circulated water throughout the system, supporting nutrient distribution and aeration for the fish and plants. The pump's performance was optimal for the greenhouse's size, maintaining adequate flow.

ii. **Water Filtration and Return:** The grow bed filtered water efficiently, returning nutrient-rich water to the fish tank. Proper filtration was observed, promoting plant health and a clean fish habitat.

iii. **Working Platform for Safe Access:** A stable working platform made of foam, cubes and a plank allowed safe movement around the farm base without disturbing the planted crops or stepping on the grow bed itself. This setup enabled efficient plant management and transplanting and reduced plant disturbance thereby contributing to healthier growth.

Figure 5. Aquaponics system

Figure 6. Pumping and Piping works for the aquaponics system

4.4 Fish Growth

Aquaponics system fish growth is dependent on many factors. These factors include water quality, the species of fish, the stocking density of fish, nutrition, and management of the entire system. This current study obtained hybrid species of catfish because of their observed resilience and reduced arate of cannibalism. 100 pieces of this species of fish was imported into the fish tank for the pilot study phase. Sustainable fish and plant environments can only be achieved through regular monitoring, maintenance, and adjustments. Figure 7 shows the fish development at 3 weeks.

Figure 7: Fish at 3 weeks old in the aquaculture system (fish tank)

4.5 Planting and Growth Observations

i. **Initial planting:** Cucumber, ewedu (jute leaves), efo (vegetables), and pepper seeds were initially planted in designated zones within the grow beds. The use of grow bags and polystyrene-supported planting cups provided easy management and a flexible setup, allowing for crop rotation and seasonal adjustments.
ii. **Seedling growth and transplanting:** After the initial seedling phase, the pepper plants grew well, indicating favourable growing conditions. The cucumber and pepper seedlings were subsequently transplanted into the cups fitted in the polystyrene sheets. Observations include healthy growth. The seedlings, especially the cucumber and pepper, adapted well to the aquaponic environment (see Figure 8), showing vibrant growth and indicating effective nutrient availability from the fish waste. Additionally, the transplanting was a success. This was due to the design of the planting cups and spacing on the polystyrene sheets allowed for unimpeded growth. The balanced water circulation supported both plant hydration and root aeration.
iii. **Performance of the system over time:** After full setup, the system operated continuously, with water discharged regularly to the grow beds. The plants showed consistent growth, and the fish were observed to be healthy, demonstrating that there was balance in the aquaponics system. This was because nutrient and oxygen levels remained stable due to the efficient pump and regular water flow, creating a balanced ecosystem.

iv. **Environmental conditions:** The greenhouse's controlled environment, especially the combination of shade and insect nets, ensured that plants received sufficient sunlight without overheating, while the fish habitat remained cool and shaded.

Figure 7: Hydroponics system after transplanting

4.6 Challenges and Considerations for Future Improvements

Although the aquaponics system demonstrated successful integration, a few challenges were noted:

i. **Water filtration maintenance:** As nutrient levels increase over time, periodic maintenance of the filtration system may be required to prevent clogging and ensure continued efficiency.

ii. **The water in the hydroponics system turned green:** In a hydroponics system (see Figure 7), water turning green typically indicates an overgrowth of algae. Algae can thrive in a hydroponic setup when certain conditions promote its growth. These were observed to be due to: excessive light exposure indicating improvement is required for the shade net; nutrient-rich environment allowed the algae to thrive requiring nutrient balance; stagnation of water which requires proper recirculation; and warm temperature indicating more aeration for the system.

iii. **Temperature regulation in current hot season:** Although the shade net mitigates heat, adding ventilation options or shading strategies could improve conditions during hotter months to avoid potential plant stress.

iv. **Backup power consistency:** While the backup generator provided stability, exploring solar options could further enhance sustainability and reduce reliance on non-renewable energy. This is to be considered in the next phase of the study

The result of the study yielded a built aquaponics system. The synthesization of the organic material in the hydroponics system and re-circulation of nutrients from the fish tank and hydroponics system created both a cost-effective and nutrient-based system. It was observed that the plants in the hydroponics system presented a faster growing period when compared to the conventional growing period. After transplanting the pepper from the nursery, it took 11- 13 days to flower and produce seeds in comparison to the normal 2 weeks. Additionally, the cucumber plants took 25 days to flower in comparison to the normal 28 days. This indicated a shorter growth cycle because of the continuous supply of nutrients in the aquaponics system in the hydroponics system of this current study.

5. CONCLUSION

Overall, building an aquaponics system in Nigeria has the potential to positively impact food security, resource sustainability, economic development, and environmental stewardship. The result of this study showed shorter growing periods for the plants grown in the hydroponics system. This is indicative of the constant supply of water and provision of nutrients from the aquaculture. Therefore, it can be concluded that aquaponics allows for the simultaneous cultivation of fish and vegetables, resulting in a higher yield of food per unit area compared to traditional farming methods. This can contribute to addressing food security challenges in the study area (FEDPOFFA and environs) providing a sustainable source of fresh plant produce and protein-rich fish.

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