Bima Journal of Science and Technology, Vol. 8(3) Sept, 2024 ISSN: 2536-6041

DOI: 10.56892/bima.v8i3.769

Aquaponics Aquaculture System as the Most Efficient, Sustainable and Green Aquaculture System: A Review

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ABSTRACT

Aquaculture in Nigeria has witnessed significant growth and development in recent years, contributing to food security, employment, and economic growth in the country. Aquaponics aquaculture system involves simultaneous used of both hydroponics and fish rearing forms of aquaculture system. Therefore, the end product of this system provides more organic plants and fish species in a manageable environmental condition without affecting the survival, growth and reproduction of other species that are not part of the system. This review aimed at highlighting the efficiency, sustainability and ecologically friendly of aquaponics aquaculture system. Finally, it is reviewed that these systems offer several advantages over conventional farming methods, including efficient nutrient recycling, reduced water usage, and lower environmental impacts. This farming system is devoid of pest and diseases that may likely affect the fish and plant species, it also helps in water conservation, performance increases, stability of food, minimal ecosystem pollution and production at all season. Despite its important and valuable in improving the aquaculture system, it attracts challenges that render it undesirable for all. In Nigeria for example the acceptability of aquaponics system will be limited due to the cost of start- up capital and inadequate technical know-how among our rural community members, Furthermore, It is of paramount important to provide a synergy where local people can access resources for the continued existence of this environmentally friendly system.

Keywords: Aquaponics System, Hydroponics, Efficient, Sustainable and Green System.

INTRODUCTION

Globally, aquaculture is the fastest-growing nutriment-creating sector that adopt a number of varieties of production systems (Food and Agriculture Organisation, FAO, 2019). Among these systems, aquaponics is painstaking one of the most efficient and environmentally sustainable means of the 21st century (Oladimeji, Olufeagba, *et al*., 2020; Oladimeji, Okomoda, *et al.,* 2020).

Aquaponics is an integral culture of fish and plants in a simultaneous recirculating system. The unceasing recirculation of nutrient and solvents particularly water within the structure play a crucial role in minimizing the waste generated by fish and also enhanced the growth performance of plant resulted from the nutrients obtained in fish excreta (Okomoda *et al.,* 2023).

Aquaculture in Nigeria has experienced significant growth and development over the past few decades, making it the second-largest aquaculture producer in Africa (FAO, 2022). The sector plays a crucial role in the country's economy, providing employment opportunities, contributing to food security, and improving the livelihoods of Nigerians. The primary species cultured in Nigerian aquaculture include African catfish (*Clarias gariefinus*), Nile tilapia (*Oreochromis niloticus*), and Heteroclarias (a hybrid of Clarias and Heterobranchus species) (FAO, 2022). Aquaculture production in Nigeria occurs mainly in earthen ponds, with semi-intensive and extensive culture systems being the most common practices (Otubusin *et al.,* 2021). Key challenges facing the Nigerian aquaculture sector include the high cost of feeds, inadequate access to quality fish seed, and insufficient extension services. However, opportunities exist for capacity building, improved infrastructure, and investment in research and development (Egwunatum *et al.,* 2021).

Aquaponics systems are regarded as one of the most efficient and sustainable forms of aquaculture due to their unique combination of fish farming and hydroponic plant cultivation. These systems offer several advantages over conventional farming methods, including efficient nutrient recycling, reduced water usage, and lower environmental impacts (Goddek *et al.,* 2015; Egwunatum *et al.,* 2021). Aquaponics promotes efficient nutrient cycling by converting fish waste into plant nutrients, reducing the need for synthetic fertilizers and minimizing waste discharge. This closed-loop system can result in up to 90% less water usage compared to traditional soil-based agriculture (Love *et al.,* 2015). Additionally, aquaponics can produce high yields of both fish and plants in a relatively small space, making it suitable for urban and peri-urban areas with limited land availability (Goddek *et al.,* 2015). Aquaponics systems demonstrate strong potential for environmental sustainability. The integrated design helps conserve resources and minimize waste by reusing water and recycling nutrients (Rakocy *et al.,* 2006). Furthermore, the reduced need for chemical inputs, such as fertilizers and pesticides, lowers the overall environmental footprint of aquaponics compared to conventional agriculture (Love *et al.,* 2015). Aquaponics is widely recognized as one of the most eco-friendly forms of aquaculture due to its innovative design, resource efficiency, and minimized environmental impact (Goddek *et al.,* 2015). The integration of fish farming and hydroponic plant cultivation leads to several environmental benefits, including:

Aquaponics systems use up to 90% less water than traditional soil-based agriculture, as water is recirculated and reused within the system (Love *et al.,* 2015). This water efficiency reduces pressure on freshwater resources and contributes to the overall sustainability of aquaponics. Aquaponics relies on the natural nutrient cycling between fish and plants, eliminating the need for synthetic fertilizers and pesticides. This reduces the environmental footprint associated with the production, transportation, and application of chemical inputs (Rakocy *et al.,* 2006). By converting fish waste into plant nutrients, aquaponics facilitates efficient nutrient recycling, minimizing waste discharge and the pollution of surrounding ecosystems (Goddek *et al.,* 2015). Aquaponics can be established in urban and areas, providing locally grown produce and reducing the carbon emissions associated with transportation in the global food system (Lennard, 2017). These environmental benefits, combined with the potential for high yields and adaptability to a range of settings, make aquaponics an attractive option for sustainable food production. These systems maximize resource efficiency and promote a more sustainable and diversified farming approach (Olukunle and Afolabi, 2012).

AQUAPONICS SYSTEM DESIGN AND SETUP

The design of an aquaponics system plays a crucial role in ensuring its efficiency and effectiveness. Several components and design considerations must be taken into account to create a functional and sustainable system. Here are some key aspects of aquaponics system.

System components

A typical aquaponics system consists of a fish tank, a biofilter to convert fish waste into plant-usable nutrients, a hydroponics subsystem for plant growth, and a sump tank for water circulation and aeration (Rakocy *et al.,* 2006). Fish tank: This is the habitat for aquatic animals such as fish, prawns, or crayfish. The fish waste generated in the tank serves as a primary nutrient source for plants (Rakocy *et al.,* 2006).

Grow beds

These containers are filled with a substrate (e.g., gravel or clay pellets) that anchors plant roots and provides a surface area for beneficial bacteria growth (Diver, 2006). Plants absorb the nitrates and other nutrients from the water, helping to purify it before it's returned to the fish tank.

Water pump

The water pump ensures continuous water circulation between the fish tank and grow beds, maintaining proper oxygenation and nutrient delivery to both fish and plants (Lennard, 2017).

Biofilter

This component houses nitrifying bacteria that convert toxic ammonia from fish waste into nitrites and then into nitrates, which are less toxic to fish and serve as nutrients for plants (Love *et al.,* 2015).

Aeration system

To maintain adequate oxygen levels in the water for fish and other aquatic animals, an aeration system is necessary. This can include air pumps, airstones, or other aeration devices (Wurts and Masser, 2016).

Plumbing and fittings

An efficient plumbing system connects the various components of an aquaponics system, ensuring proper water flow and minimizing water loss or leaks. This includes pipes, valves, and fittings (Diver, 2006).

Monitoring and control equipment

To ensure optimal system performance and the health of fish and plants, monitoring and control equipment such as thermometers, pH meters, dissolved oxygen sensors, and automatic feeders can be used (Love *et al.,*2015).

NUTRIENTS UTILIZATION IN AQUAPONICS SYSTEM

Nutrient utilization efficiency in aquaponics systems is a critical aspect of their overall performance. The system's ability to effectively recycle and utilize nutrients contributes to its sustainability and productivity. Aquaponics relies on the nitrogen cycle to convert fish waste (ammonia) into nitrites and then nitrates, which plants can absorb as nutrients (Rakocy *et al.,* 2006). The efficiency of nitrogen utilization depends on factors such as the nitrification rate, plant uptake, and system design. Properly balanced systems can achieve high nitrogen utilization efficiency, reducing the need for external nutrient inputs (Diver, 2006). Phosphorus is another essential nutrient for plant growth in aquaponics systems. Fish feed is the primary source of phosphorus, and its utilization efficiency depends on factors such as feed composition, fish species, and plant types (Lennard, 2017). The use of phosphorus-solubilizing bacteria and other strategies can enhance phosphorus availability and uptake by plants (Love *et al.,* 2015). Although potassium is an essential macronutrient for plants, it is not typically supplied in sufficient quantities by fish waste alone. Therefore, external potassium supplementation is often required in aquaponics systems to support optimal plant growth (Wurts and Masser, 2016). Micronutrients, such as iron, manganese, zinc, and copper, play vital roles in plant growth. Their utilization efficiency in aquaponics depends on factors such as their availability in fish feed, water chemistry, and the presence of chelating agents that enhance plant uptake (Lennard, 2017). The conversion of ammonia to nitrite and then to nitrate by beneficial bacteria (nitrification) is a crucial process in aquaponics. This process occurs most efficiently within the pH range of 6.8 to 7.2. Outside this range, the efficiency of the nitrification process can be inhibited, which may negatively impact plant growth (Rakocy *et al.,* 2006).

Water Conservation Potentials in Aquaponic System

Aquaponics is widely recognized for its efficient water conservation compared to conventional agriculture and aquaculture practices. This efficiency is largely attributed to its closed-loop, recirculating design, where water is continuously reused and recycled between fish tanks, biofilters, and grow beds (Lennard, 2017). Key aspects of water conservation efficiency in aquaponics systems are; water is cycled through the system, reducing the need for frequent water changes. This process allows the same water to be utilized multiple times, saving a significant amount of water compared to traditional farming methods (Rakocy *et al.,* 2006). Aquaponics systems minimize evapotranspiration by maintaining controlled growing environments and reducing exposure to direct sunlight. This helps to conserve water that would otherwise be lost to evaporation and plant transpiration (Goddek *et al.,* 2015). Aquaponics systems retain nutrients within the closed-loop system, reducing the need for frequent water discharge and minimizing the discharge of nutrient-rich wastewater into the environment (Lennard, 2017). Regular monitoring of water quality parameters ensures optimal conditions for fish and plant growth. Maintaining a balanced system helps to avoid the need for excessive water changes (Love *et al*., 2015). As a result of these integrated processes, aquaponics can conserve up to 90% of the water used in conventional agriculture (Lennard, 2017). This high-water conservation efficiency makes aquaponics an attractive and sustainable approach for food production, particularly in water-scarce regions.

Plants Species Suitable for Aquaponics System

In Nigeria, selecting suitable plants for aquaponics systems involves considering the local climate, nutrient availability, and market demand. Some of the plants that have been successfully grown in Nigerian aquaponics systems include:

- **Lettuce (*Lactuca sativa*):** Lettuce is a popular choice for aquaponics in Nigeria due to its fast growth and low nutrient requirements (Benjamin *et al.,* 2020). It can be grown in various systems, including raft-based and media-filled grow beds.
- **Watercress (*Nasturtium officinale*):** Watercress is a leafy green that thrives in aquaponics systems and can tolerate a range of water conditions. It has been grown successfully in Nigerian aquaponics systems (WhyFarmIt, 2023).
- **Tomatoes (*Solanum lycopersicum*):** Tomatoes are a popular and versatile crop that can be grown in Nigerian aquaponics systems, particularly in media-filled grow beds (Benjamin *et al.,* 2020). They require adequate support structures due to their vining growth habit.

- **Basil** ***(Ocimum basilicum):*** Basil is an herb that grows well in Nigerian aquaponics systems with adequate nutrient availability and proper environmental conditions (Love *et al.,* 2015). It can be grown in multiple varieties, providing a range of flavors and culinary applications.
- **Cucumbers (*Cucumis sativus*)**: Cucumbers are a vining plant that can be grown in Nigerian aquaponics systems, given proper trellising or support structures (Love *et al*., 2015). They can be grown in media-filled grow beds or in nutrient film technique (NFT) systems.
- These plants, along with other suitable crops, can contribute to improved food security and nutrition in Nigeria through the implementation of aquaponics systems.

Fish Species Suitable for Aquaponics System

In Nigeria, there are several fish species that are suitable for use in aquaponics systems. Some of the most commonly used and recommended fish species include:

- **Tilapia (*Oreochromis niloticus*):** Tilapia is one of the most popular fish species for aquaponics due to its hardiness, fast growth rate, and adaptability to various water conditions. The Nile tilapia (*Oreochromis niloticus*) is particularly well-suited for aquaponics in Nigeria (Dauda, 2018). Tilapia is one of the most common fish species used in aquaponics due to its adaptability, fast growth rate, and ability to tolerate a range of water conditions. They are also known for their high reproduction rate and omnivorous diet (Diver, 2006).
- **African Catfish (*Clarias gariepinus*):** African catfish are another excellent choice for aquaponics in Nigeria. They are highly adaptable, tolerate a wide range of water conditions, and grow quickly, making them an ideal candidate for both small and large-scale aquaponics systems (Benjamin *et al.,* 2020). Both African catfish (*Clarias gariepinus*) and channel catfish (*Ictalurus punctatus*) are popular choices for aquaponics. They are hardy, adaptable, and have a high tolerance for fluctuating water conditions. Catfish are also known for their fast growth rate and efficient feed conversion (Love *et al.,* 2015).
- **Nile Catfish (*Synodontis batensoda*):** Nile catfish are known for their resilience and adaptability to varying water conditions. They are omnivorous and can thrive on a variety of feeds, making them an attractive choice for Nigerian aquaponics systems (Ogbonna *et al.,* 2022).
- **Heterobranchus *spp.* (*Heterobranchus bidorsalis and Hetebrunchus longifilis*):** Heterobranchus species are popular in Nigerian aquaculture and can be successfully integrated into aquaponics systems. They have a high tolerance for environmental variations and are resistant to diseases (Woyni *et al.,* 2022).

Physicochemical Parameters of Aquaponics Systems

In an aquaponics system, maintaining proper physicochemical properties is essential for the health and growth of both fish and plants. Nigerian aquaponics systems must consider the following key parameters:

- **Temperature:** The optimal temperature range for most fish species and plants in aquaponic systems is between 25°C and 30°C (Benjamin *et al*., 2020). Given the variable ambient temperatures in Nigeria, monitoring and maintaining appropriate water temperatures are crucial. In aquaponics system, maintaining the appropriate temperature range is essential for optimal growth and health of both fish and plants. Although the ideal temperature can vary depending on the specific fish and plant species used, a general recommended range is between 20°C and 30°C (68°F to 86°F) for most common aquaponics setups (Rakocy *et al.,* 2006). Fish species have their specific temperature preferences, but most aquaponics fish, such as tilapia and catfish, thrive in water temperatures between 25°C and 30°C. Temperatures variation outside this range can lead to stress, reduced growth rates, and increased susceptibility to diseases (Love *et al.,* 2015). Plants in aquaponics systems typically grow well within the same temperature range (20°C to 30°C). However, some plants might have specific temperature requirements for optimal growth. For example, cool-season crops like lettuce and kale prefer temperatures between 15°C and 21°C, while warm-season crops like tomatoes and cucumbers grow best in temperatures between 24°C and 30°C (Wurts and Masser, 2016).

- **pH:** A pH range of 6.8 to 7.2 is ideal for aquaponics systems, as it ensures nutrients are available for fish and plants (Love *et al.,* 2015). Regular monitoring and adjustment of pH levels are necessary for maintaining a balanced environment. In aquaponics systems, pH plays a critical role in maintaining a healthy environment for both fish and plants. The ideal pH range for most aquaponics setups is between 6.8 and 7.2, with a slightly neutral to acidic pH being optimal (Rakocy *et al.,* 2006). Fish generally prefer a pH range of 6.5 to 8.5, but this can vary depending on the species. For instance, tilapia, a common fish used in aquaponics, thrives in a pH range of 6.5 to 9.0, while trout prefer a slightly more acidic environment with a pH range of 6.5 to 7.5 (Love *et al*., 2015). Plants typically absorb nutrients more effectively in slightly acidic environments. Most plants in aquaponics systems grow well within the pH range of 6.0 to 7.5. However, some plants may have specific pH requirements for optimal growth (Wurts and Masser, 2016).

- **Dissolved Oxygen (DO):** Adequate dissolved oxygen levels are vital for fish health and overall system function. Levels should be maintained between 4 and 6 mg/L, depending on fish species and stocking density (Lennard, 2017). Proper aeration and water circulation are key to maintaining optimal DO levels. Dissolved oxygen (DO) is a critical factor in aquaponics systems as it ensures the well-being of fish and supports the overall system's functioning. DO levels in aquaponics should be maintained between 4 and 6 mg/L, depending on fish species and stocking density (Lennard, 2017). Adequate DO levels are essential for fish health and survival. Fish require oxygen for respiration, and low DO levels can lead to stress, reduced growth rates, and even mortality. Different fish species have varying oxygen requirements, and factors such as water temperature, fish size, and feeding rates can also influence oxygen demand (Rakocy *et al.,* 2006). Although plants produce oxygen during photosynthesis, they also consume oxygen through respiration, especially during nighttime. Maintaining proper DO levels helps ensure that plants receive sufficient oxygen for healthy growth (Love *et al.,* 2015). Nitrifying bacteria, which play a crucial role in converting ammonia to nitrite and then to nitrate, also require oxygen for their metabolic processes. Maintaining adequate DO levels is essential for the efficiency of the nitrification process (Wurts and Masser, 2016).

- **Ammonia, Nitrite, and Nitrate**: Ammonia and nitrite levels should be kept below 0.5 mg/L to prevent fish toxicity, while nitrate levels should be between 10 and 150 mg/L to provide sufficient nutrients for plant growth (Rakocy *et al.,* 2006). Ammonia (NH_3/NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-) are essential components in aquaponics systems, as they represent different stages of the nitrogen cycle and play crucial roles in fish health and plant growth. Ammonia is a toxic waste product excreted by fish. Its levels should be kept below 0.5 mg/L to prevent fish toxicity and ensure a healthy environment (Rakocy *et al.,* 2006). High ammonia levels can cause stress, reduced growth rates, and mortality in fish. Nitrite is an intermediate product in the nitrogen cycle, produced by the oxidation of ammonia by nitrifying bacteria. Like ammonia, nitrite is also toxic to fish, and its levels should be maintained below 0.5 mg/L to prevent toxicity (Lennard, 2017). Nitrate is the final product of the nitrification process and serves as a primary nutrient source for plants. Nitrate levels should be maintained between 10 and 150 mg/L to provide sufficient nutrients for plant growth (Rakocy *et al.,* 2006). Low nitrate levels can lead to nutrient deficiencies and reduced plant growth, while excessively high levels may cause plant toxicity and promote algae growth.
- **Electrical Conductivity (EC):** Electrical Conductivity measures total dissolved solids in water, and in aquaponics, should be maintained between 1.0 and 2.5 mS/cm to ensure balanced nutrient availability for plants (Diver, 2006). The ideal EC range for aquaponics systems is typically between 1.0 and 3.0 mS/cm, depending on the fish species and plant types (Rakocy *et al.,* 2006). This range provides a balance between the needs of fish and plants while minimizing potential risks associated with low or high EC levels.

CONCLUSION

Aquaponics systems are regarded as one of the most efficient and sustainable forms of aquaculture due to their unique combination of fish farming and hydroponic plant cultivation. These systems offer several advantages over conventional farming methods, including efficient nutrient recycling, reduced water usage, and lower environmental impacts. Despite its important and valuable in improving the aquacultural system it fascinates challenges that render it undesirable for all. In Nigeria for example the acceptability of aquaponic system will be partial due to the cost of start- up capital and inadequate technical know-how among our rural community members, Furthermore, the government should provide a synergy where locals can access the resources for the continued existence of this environmentally friendly system.

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