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Fish–Plant Interaction: Productive Performance and Water Quality in Aquaponics

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ABSTRACT

Aquaponics is an alternative production system of high interest for communities with limited resources because it combines aquaculture and hydroponics in one system to produce fresh and nutritious food in a sustainable way. This technology uses water and inputs efficiently, reduces agrochemicals, and protects the natural environment. Aquaponic systems help food self-sufficiency, improve nutrition indicators of the population, and support environmental sustainability. However, aquaponic systems have some limits and technical challenges. The main risks are plant and fish diseases and pests. In some regions, water is scarce, which limits plant growth and fish development. Also, bad climate conditions, especially low rainfall, can affect the stability of the system. Lack of knowledge about fish, plants, and system management can produce bad results and project abandonment. Because of this, there is a need to develop strategies and tools to make the management of aquaponic systems easier and to improve the technical skills of users. This research is important because it looks at the problems of knowledge and management in aquaponic systems. It creates strategies to improve operations and to promote aquaponics as a sustainable, productive option. The main objective is to understand and show how the functional integration of aquaculture and hydroponics can produce food in a sustainable and resilient way. The research studies important topics like the use of aquaponic systems in different regions, the selection and management of aquatic species, the diversity of plants that can be grown, and the influence of inputs and materials. It also looks at the structure, components, and operation of the system to create rules for its implementation and optimization in different contexts.

Keywords: aquaponics; hydroponics; grow beds; water efficiency; biofilters

INTRODUCTION

Aquaponics is an alternative productive system of high interest for communities with limited resources, because it allows for to obtain of fresh and nutritious food through integrated sustainable production systems. This approach combines the controlled breeding of aquatic organisms with the hydroponic cultivation of vegetables, optimizing the use of water and available inputs. Its implementation promotes food self-sufficiency, improves the nutritional indicators of the population, and contributes to environmental sustainability by reducing the use of agrochemicals and conserving natural resources.

Among the main limitations identified in the research are the phytosanitary and zoosanitary risks linked to the presence of pests and diseases in both plant crops and aquatic organisms. Also, water scarcity in some regions is a restrictive factor for the optimal growth of vegetables and the development of aquatic species. Adverse climatic conditions, especially low rainfall, are another significant factor for the stability of the system. The control and maintenance of water pH is one of the most critical operational challenges in aquaponics, because it has a direct impact on the health of organisms and the availability of nutrients.

Finally, spatial limitation is a relevant factor because it restricts the density and yield of crops under controlled conditions.

Despite the growing interest that aquaponics generates, many people stop its implementation when they recognize the technical complexity and the level of dedication that the operation and maintenance of an aquaponic system require. The lack of knowledge in key aspects such as the management of aquatic species, plant cultivation, and the integral administration of the system can produce unsatisfactory results and the abandonment of the project.

In this context, this research is relevant because it addresses the lack of knowledge and management about the care and maintenance of aquaponic systems. The development of strategies and tools to optimize its operation helps to promote the adoption of this practice as a sustainable, productive alternative, increasing the availability of fresh and nutritious food. This approach has a positive impact on food security, environmental sustainability, and the quality of life of the involved communities, and also creates bases that make it easier the transfer knowledge and the formation of future aquaponists.

The research on aquaponic systems has the objective to understand and show how the functional integration of aquaculture and hydroponics allows to production of food in a sustainable and resilient way. It wants to show the efficiency in the use of water resources, the reduction of waste, and the valorization of nutrients, generating scientific evidence that helps to develop innovative and environmentally responsible production systems.

This project is in a context of growing concern about environmental sustainability and food safety, responding to the need to optimize production using natural resources in a rational way and minimizing negative impacts. It also attends communities with limited availability of water and fertile soils, and it is oriented to the implementation of emerging technologies. In this sense, the research wants to answer the current demands of responsible production, efficiency in the use of inputs, and respect for the natural environment.

During the research development, key aspects will be studied, such as the importance of the use of aquaponic systems in different geographic regions, considering their potential to optimize resources and improve food security. Also, the selection and management of aquatic species, the diversity of plant crops possible to integrate into the system and the influence of the used inputs will be analyzed.

METHODOLOGY FOR THE STUDY AND OPERATION OF AN AQUAPONIC SYSTEM

General Description of the Aquaponic System

The aquaponic system is based on a closed recirculation model, integrating biological and chemical flows to optimize resource use. The operational cycle is methodologically described in the following stages:

I. *Waste Generation:* Fish, as a result of their metabolism, produce organic waste that accumulates in the aquaculture tank water.

II. *Bacterial Transformation:* A microbial consortium composed of bacteria and rhizobacteria is established, responsible for the decomposition of nitrogenous waste. This process transforms organic compounds into inorganic nutrients available to plants.

III. *Plant Absorption:* Plants absorb dissolved nutrients in the water through their roots, using these compounds for growth and development.

IV. *Filtration and Purification:* Hydroponic beds and biofilters are used to remove impurities and suspended particles, improving water quality.

V. *Recirculation:* The purified water is returned to the fish tank, completing the system's biological and physical cycle

1. Location and Experimental Design

The study was conducted at the facilities of the Technological University of Tlaxcala, Mexico. The aquaponic system was designed for educational and experimental purposes, focusing on evaluating the impact of physical variables in cold climatic conditions characteristic of the region, on both fish health and plant growth. The structure of the system is detailed below:

- *Main Aquaculture Tank:* A 150 L capacity container for fish cultivation.

- *Auxiliary Tanks:* Three 10 L tanks used for filtration and water recirculation processes.

- *Flow Structure:* A metal frame assembled with 2-inch PVC pipes that enables continuous water flow throughout the system, using gravity and a controlled pump system.

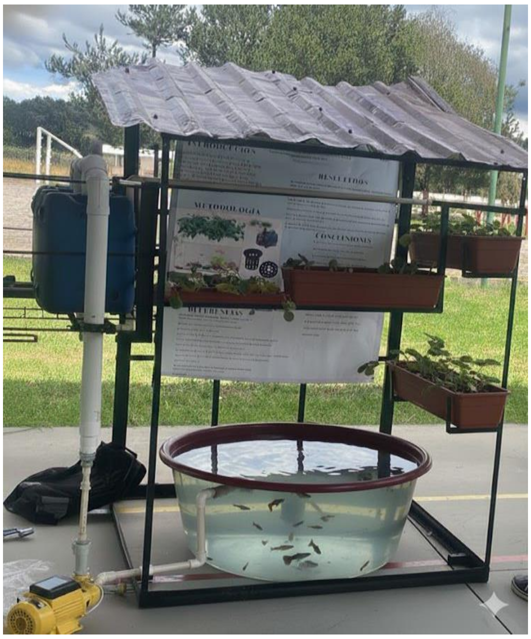

FIGURE 1: Experimental Aquaponic System Setup.

2. Water Quality Monitoring Protocol

The performance of the aquaponic system is evaluated by monitoring and controlling the physicochemical conditions of the water. The critical parameters in this study include:

- *Dissolved Oxygen (O_2):* Concentration levels are maintained above 3 mg/L, with an ideal concentration above 5 mg/L to prevent hypoxia.
- *pH:* Maintained between 6.8 and 7.2 to ensure nutrient bioavailability and fish health. Sodium bicarbonate is avoided due to potential phytotoxic effects.
- *Electrical Conductivity (EC):* Monitored as an indicator of salinity and ion concentration, with a maximum limit of 1500 µS/cm.
- *Total Hardness: Maintained between 60 and 140 mg/L $CaCO_3$ to provide adequate buffering capacity against acidity from nitrification.*

3. Aquaculture Tank Management

The aquaculture tank is managed as the core of the system, ensuring adequate volume, oxygenation, and thermal stability for uniform fish growth. High-density plastic or polyethylene materials are used for durability and corrosion resistance. Underground ponds are avoided due to poor ventilation. Tank color is selected to facilitate organism observation while minimizing algae proliferation. A maximum biomass of 10 to 15 kg of fish per 1,000 L of water is established, equivalent to 50–70 juvenile tilapia depending on size.

4. Recirculation System Implementation

A recirculation system is used to maintain oxygenation and nutrient circulation. A submersible pump controlled by regulating valves and a programmable timer ensures at least two complete recirculation cycles per hour. Flow is calculated based on total system volume. Pump selection depends on the number of tanks, pipe length, and required flow rate. Water level is monitored in real time using an HC-SR04 ultrasonic sensor.

5. Selection and Management of Biological Organisms

- *Aquatic Species:* Tilapia (Oreochromis sp.) and mojarra were selected for their high thermal tolerance and adaptability to closed recirculation systems. Stocking density was maintained at 20–25 kg/m^3, with temperatures kept between 22–28 °C.
- *Plant Species:* Radish (Raphanus sativus) was selected due to its short growth cycle, hydroponic adaptability, and moderate nutrient demand.

RESULTS

During the 45-day operation period, the aquaponic system maintained stable conditions that supported the development of all organisms involved. The biofilter adapted quickly, enabling efficient conversion of ammonia into nitrates and maintaining biological balance. Water circulation ensured consistent oxygenation and prevented toxic compound accumulation. Water parameters stayed within recommended limits for tilapia and the selected plants. Dissolved oxygen ranged between 5.0 and 6.3 mg/L, pH between 6.9 and 7.1, and total hardness between 90 and 120 mg/L $CaCO_3$. Electrical conductivity averaged 1,120 µS/cm, indicating no harmful salt accumulation.

Tilapia juveniles showed consistent growth, increasing from an average weight of 6.4 g to 25.8 g, with a feed conversion ratio of 1.3. No fish deaths or disease symptoms were observed. Plants also showed strong growth, with lettuce producing an average fresh weight of 160 g per plant. Roots appeared clean and white, and leaves displayed a bright green color. Nitrate concentration decreased to about 10 mg/L by the end of the cycle due to plant absorption.

The biofilter played a key role in maintaining system stability. Initial nitrite spikes (up to 0.48 mg/L) declined as bacterial communities matured, stabilizing below 0.1 mg/L after day ten. Overall, the system demonstrated over 95% water recovery, with no complete water replacements needed. Compared to traditional farming, the system used 90% less water and 80% less fertilizer, while increasing plant growth by 25%.

CONCLUSION

The aquaponic system successfully demonstrated effective integration of tilapia cultivation and hydroponic plant production at a small scale, using accessible materials and simple operational mechanisms. The manual control of water flow, pH, and filtration was essential to maintaining equilibrium. Both fish and plants exhibited healthy development, confirming the viability of aquaponics in low-complexity, non-automated systems.

The system provided valuable practical learning regarding biological relationships and environmental parameter control. Despite challenges such as potential pH fluctuation and manual maintenance demands, the project proved that ecological balance can be maintained through basic recirculation and biological filtration processes, without the need for sophisticated technology.

TABLE 1: Temperature, Nitrogen, Dissolved Oxygen Levels, and Protein Requirements for Aquatic Species Used in Aquaponics.

Species	Temperature (°C) Vital | Optimal	Total Ammoniacal Nitrogen (mg/L)	Nitrites (mg/L)	Dissolved Oxygen (mg/L)
Common Carp	3-34 | 25-30	<1	<1	>4
Nile Tilapia	14-36 | 27-30	<2	<1	>4
Catfish	5-34 | 24-30	<1	<1	>3
Rainbow Trout	10-18 | 14-16	<0.5	<0.3	>6

REFERENCES

[1] Acuaponia: Producción de plantas y peces | Intagri S.C. (s. f.).

[2] Okomoda, V. T., Oladimeji, O., Ogundele, O. O., et al. (2022). Aquaponics production system: A review of historical development, systems, and trends. Food Science & Nutrition, 10(11), 3957-3974.

[3] Atique, F., Erhardt, A., & Ventura, B. (2022). Is aquaponics beneficial in terms of fish and plant growth and water quality? Water, 14(9), 1447.

[4] Khater, E.-S., Bahnasawy, A., Ali, S., Abbas, W., & Morsy, O. (2023). Study on the plant and fish production in the aquaponic system as affected by different hydraulic loading rates. Scientific Reports, 13, 17505.