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# Aquaponics for Biological Regeneration of Water Quality in the Red Tilapia (*Oreochromis* sp.) Farming Systems and Its Impact on the Ecuadorian Consumer's Perception

**Kenia Laz-Figueora[1], Juan Valenzuela-Cobos[2*], Fabricio Guevara-Viejó[2]**
[1]Universidad Técnica de Babahoyo, Babahoyo, Ecuador
[2]Centro de Estudios Estadísticos, Universidad Estatal de Milagro (UNEMI) , Milagro 091050, Ecuador
***Corresponding Author: juan_diegova@hotmail.com**

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## ABSTRACT

The red tilapia is an aquatic species widely farmed in Ecuador due to its commercial value and worldwide demand. However, as in all aquaculture activities, the culture of the red tilapia at high densities generates an excessive amount of ammonia and other harmful compounds that are usually treated with flocculation technology. In this study, aquaponic systems were developed as an alternative to flocculation technology. In total, 5 aquaponic systems (S1, S2, S3, S4, S5) were tested, consisting of *Oreochromis* sp. and two species of macrophytes (*Lemna* spp., *Pistia stratiotes*) recognized for their phytoremediation capacity. As a result, it was found that the floating plant *Lemna* spp. was the most adaptable macrophyte to the aquaponic system, showing significant growth in biomass and a high capacity to improve water quality. The S1 system was the most efficient, presenting the lowest levels of nitrite and biochemical oxygen demand (BOD), in addition to maintaining adequate concentrations of nitrate, pH and total nitrogen. Regarding the survey, participants indicated that the perception of safety and hygiene is the main factor when choosing a new product, and pointed to universities as the most reliable sources of information to reduce or increase the perception of risk upon using an unknown innovation.

## INTRODUCTION

*Oreochromis* sp., commonly known as the red tilapia, is an aquatic species developed from the hybridization of multiple parental tilapia species, capable of inhabiting both freshwater and saltwater environments. Originally from East Asia, the red tilapia has spread to other parts of the world, including Latin America and Africa. In Ecuador, a traditionally agricultural country, tilapia farming began to be encouraged in the 1960s. According to the **National Chamber of Aquaculture (2022)**, the country has established itself as one of the main producers and exporters of tilapia, with the United States as the main export destination, with exports estimated at 73,645 pounds of meat in 2022. Commercial exploitation of the species in the country is based on a series of superior qualities that benefit both small and large producers, such as a capacity for adaptability to adverse environmental conditions, rapid growth rate, high meat yield, tolerance to high population densities, resistance to disease and low feed requirements **(Arumugam *et al*., 2023)**.

The red tilapia production generates an excessive amount of ammonia and other harmful compounds, derived from rearing high densities of fish in limited volumes of water. The control of these compounds is one of the main concerns in fish farming; high levels deteriorate water quality and, consequently, trigger adverse effects on the fish, such as physiological stress, gill damage and even mortality. The survival of fish in intensive larval aquaculture is conditioned by the optimal quality of the water in which they are reared. In closed and semi-open aquaculture systems, metabolic wastes of aquatic organisms are conventionally captured as a source of nutrition by heterotrophic bacteria, through the use of bioflocculus technology **(Holland *et al*., 2022; Refaey *et al*., 2024)**. However, this technique exhibits certain drawbacks such as substantial accumulation of suspended solids and complex handling. In addition, the maintenance of aqueous enclosures under this sanitation methodology entails continuous investments, which, although feasible for large producers, represent a financial challenge for small aquaculture farmers **(Avnimelech, 1999; El-Hamid *et al*., 2024)**.

In search for improvements in ammonia management, new biological technologies that minimize the accumulation of aggregates in the water and facilitate the sustainable reuse of the effluent have been experimented. Productive diversification models based on aquaponics synergistically integrate aquaculture and hydroponic agriculture, promoting the sustainable development of both activities simultaneously **(Campos *et al*., 2015)**. Several aquatic plants have been recognized for their ability to absorb ammonia and other nutrients in water through biological filtration mechanisms, such as the macrophyte genera *Lemna* spp. and *Pistia stratiotes*. Phytoremediation, through the use of this type of plants, comprises an ecological method that allows the constant production of vegetables and fish in a reduced space, favoring the preservation of water resources and obtaining plant biomass that can later be used as raw material by nutritional pharmacology for the production of nutritional supplements **(Syamlal & Sayantan, 2024)**.

On the other hand, the creation of food products from aquaponics is a contemporary world issue with multiple discrepancies in their acceptance by local and specialized markets **(Abusin & Mandikiana, 2020)**. The uncertainty of the consumer sector is mainly associated with factors related to the lack of knowledge of the production system and food safety **(Guarnizo & Contreras, 2023)**. Other studies have reported that the purchase of aquaponic products is closely linked to price, consumer income level, and environmental concerns **(Suárez *et al*., 2021)**.

The objective of this research was to evaluate the water quality regeneration potential of an aquaponic system integrated by aquatic plants and the red tilapia, as well as its influence on the Ecuadorian consumer's perception in terms of economics and product quality.

## MATERIALS AND METHODS

### Selection of *Oreochromis* sp. fingerlings

The experimental study was carried out on the "Vladimir" farm, located in the San Isidro canton, province of Manabí, Ecuador. The red tilapia fry, selected based on a size of 2.00 to 2.50cm and free of visible diseases or physical abnormalities, were used.

### Artificial wetland design

An experimental model of aquaponics was developed at pilot scale using *Oreochromis* spp. fry and two species of macrophytes (*Lemna* spp., *Pistia stratiotes*). Phytoremediation systems were designed in triplicate with the following dimensions: 100cm long, 100cm wide and 40cm deep. The purpose of the system was to establish an integrated and sustainable cycle that favors the simultaneous production of fish and plants, thus optimizing the use of resources and promoting a productive and ecological environment.

The original water sample was obtained from a fish farming source, located in the same property, dedicated to the breeding of the red tilapia for commercial purposes. Following the recommendations of **Makori *et al*. (2017)**, the aquatic animals were fed twice a day (at 8:00 and 14:00). The amount of feed provided corresponded to 10% of body weight, and measurements were adjusted every seven days. The study had a total duration of 30 days.

The aquaponic systems consisted of 200L of water and were composed as follows:

System 1 (S1): 1kg of *Lemna* spp. + 50 fingerlings of *Oreochromis* spp.

System 2 (S2): 1.5kg of *Lemna* spp. + 50 *Oreochromis* spp. fry.

System 3 (S3): 1kg of *Pistia stratiotes* + 50 fingerlings of *Oreochromis* spp.

System 4 (S4): 1.5kg of *Pistia stratiotes* + 50 *Oreochromis* spp. fry.

System 5 (S5): 0.5kg of *Lemna* spp. + 0.5 *Pistia stratiotes* + 50 fingerlings of *Oreochromis* spp.

### Analytical procedure

For each aquaponic system, six sampling sites were identified and aliquots of water were collected on two occasions: at the beginning and at the end of the experiment.

Water quality monitoring was carried out using the corresponding electronic meters for the determination of dissolved oxygen content, biochemical oxygen demand, total ammonia nitrogen, total nitrogen and phosphate **(APHA, 2005)**.

Additionally, the absorption and transformation of water pollutants was evaluated through the quantification of pH, nitrites and nitrates, using a spectrophotometer (Hach, Model DR3900**) (Grijalva-Endara, 2005)**.

**Sampling and survey application**

To collect information regarding the perception of aquaponics, physical interviews were conducted with residents of the province of Manabí, Ecuador. A non-probabilistic sampling technique was used, with a sample size of 400 individuals at legal age.

Prior to taking the questionnaire, a brief induction was given on the objective of the study, and information was provided on the confidentiality and handling of the information collected.

The questionnaire was structured in two parts: the first collected demographic information on the participants, including gender, age, educational level, current occupation and income level. The second section captured individuals' perceptions of accessibility and preference for aquaponics-derived plant products. "A survey, adapted from a previously validated questionnaire used in **Short *et al*. (2017)**, served as the instrument for this study. The survey consisted of 13 items, all with closed-ended, multiple-choice responses, focusing on five dimensions: safety, knowledge, information sources, interest, and valuation.

**Data analysis**

The results obtained from the water quality analyses were analyzed using an analysis of variance (ANOVA) to determine the significance of the individual differences of the measured parameters, with a significance level of $P< 0.05$. Subsequently, Duncan's test was applied ($P< 0.05$). The data were processed using SPSS statistical software (ver. 26.0.0.0.0).

The qualitative indicators obtained from the survey were evaluated following a Likert reference scale that varied according to the dimension measured. For the dimension “Knowledge” a dichotomous scale was used, with the attributions of 1=Yes, 2=0. For the dimensions “Safety” and “Valuation”, the attributions 1= Strongly disagree, 2= Disagree, 3= Neutral, 4= Agree, 5= Strongly agree were used. For the dimension “Source of information”, the attributions cosidering1= Insecure, 2= Not at all credible, 3= Neutral, 4= Credible, 5= Very credible were used. Descriptive statistics were used to describe the basic characteristics of the survey data, providing simple summaries.

## RESULTS AND DISCUSSION

### 1. Analytical procedure

During the course of the experiment, the plants exhibited optimal growth, no mortality was recorded, and they all retained their characteristic green color. The water quality indicators corresponding to each aquaponics system are detailed in Table (1). The interpretations of the results were made according to **Cardozo Ramirez *et al*. (2024)**.

**Table 1.** Means ± standard deviation of water quality indicators

| Parameter | Indicator | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| Inorganic nutrients | $NO_2^-$ (mg/L) | 0.04 ± 0.01 | 0.06 ± 0.03 | 0.08 ± 0.02 | 0.06 ± 0.01 | 0.14 ± 0.05 |
| | $NO_3^-$ (mg/L) | 0.74 ± 0.06 | 0.99 ± 0.20 | 0.67 ± 0.30 | 1.51 ± 0.20 | 1.24 ± 0.60 |
| | $PO_4^{3-}$ (mg/L) | 2.34 ± 0.41 | 2.49 ± 0.43 | 2.07 ± 0.17 | 2.48 ± 0.47 | 2.43 ± 0.41 |
| Physicochemical | OD (mg/L) | 2.27 ± 1.94 | 4.19 ± 4.34 | 1.87 ± 4.27 | 3.51 ± 3.73 | 3.15 ± 5.19 |
| | pH | 7.75 ± 0.40 | 8.24 ± 0.19 | 7.69 ± 0.16 | 7.43 ± 0.41 | 7.78 ± 0.75 |
| Chemical | DBO (mg/L) | 239.25 ± 0.40 | 379.71 ± 0.40 | 274.70 ± 0.50 | 459.77 ± 0.30 | 273.66 ± 1.50 |
| | TAN (mg/L) | ND | ND | 0.04 ± 0.01 | ND | ND |
| | TN (mg/L) | 2.30 ± 0.30 | 2.50 ± 0.25 | 2.60 ± 0.38 | 2.49 ± 0.32 | 4.10 ± 0.54 |

Note: The following nomenclature was used for abbreviation of terms: S1= system 1, S2= system 2, S3= system 3, S4= system 4, S5= system 5, DO= dissolved oxygen, BOD= biochemical oxygen demand, TAN= total ammonia nitrogen, TN= total nitrogen.

At the beginning of the experiment, no detectable levels of DO were found. At the end of the 30-day culture period, the levels of the parameter varied between 1.87± 4.27 and 4.19± 4.34 among the different systems set up. The increase in DO, an indicator that explains the aeration of the water, was associated with the diffusion of oxygen from the outside, and not with the planting of macrophytes.

The BOD of the original water was 402.10± 3.14mg/ L and in the aquaponics systems, the measurements fluctuated between 239.25± 0.40 and 459.77± 0.30mg/ L. Waters treated with 1.5kg of *Lemna* spp. showed the least variation in BOD and denoted a 40.50% decrease in BOD after 30 days of treatment, being the treatment that improved BOD the most. In contrast, water treated with 1.5kg of *Pistia stratiotes*, corresponding to system S4 did not respond as expected and exhibited an increase of 14.34%. An elevated BOD indicates an excess of nutrients and is related to overfeeding of fish or accumulation of wastes in the water **(Díaz *et al*., 2024)**.

The initial total ammonia nitrogen content in the original water source was 10.0mg/ L. As observations, at the end of the 30-day duration of the experiment all aquatic plants achieved complete removal of total ammonia nitrogen (100%), except for system S3 in which 1kg of the macrophyte *Pistia stratiotes* was used. This finding suggests that *Lemna* spp. either individually or in combination with other aquatic plants has the ability to effectively remove the parameter. However, *Pistia stratiotes* showed a lower phytoremediation capacity, which could be due to the phenotypic and genotypic characteristics of each plant species, such as quantum efficiency and root length.

No nitrate-N content was detected in the original source water. However, at the end of the experiment the content increased for all aquaponic systems. Previous studies also reported the gradual increase at 12 days followed by a slight reduction **(Ng & Chan, 2018)**.

In the aquaponic systems, pH was maintained within an alkaline range, fluctuating between 7.75± 0.40 and 8.24± 0.19. Optimal pH ranges for the red tilapia culture oscillate between 6.7 and 8.4, values outside this range imply alterations in fish gill respiration and lead to mortality **(Cardozo Ramirez *et al.*, 2024)**. One of the factors responsible for variations in pH are alterations in the rate of photosynthesis in response to the daily photoperiod **(Boyd & Hanson, 2010)**.

In terms of phytoremediation, the use of 1.5kg of *Lemna* spp. corresponding to the S1 system was the most adequate. This system showed the lowest nitrite and BOD levels in addition to appropriate nitrate and pH concentrations, as well as the lowest total nitrogen level. Although the dissolved oxygen parameter did not reach the highest values, the other indicators compensated for this deficiency, guaranteeing a healthy environment for the fish. On the other hand, the S3 aquaponic system showed worrisome deficiencies in dissolved oxygen and detectable levels of total ammonia (TAN), which could represent a potential risk. In the case of treatment S4, the high BOD level showed the highest organic matter load and reduced amount of available oxygen. Finally, treatment S5 showed lower phytoremediation efficiency, exhibiting the highest total nitrogen content and relatively high BOD, factors that could compromise water quality for the red tilapia farming.

**Demographic characteristics of the participants**

Table (2) describes the demographic characteristics and profiles of the people who participated in the survey. The results indicate that 46.75% of the participants were women compared to 53.25% who were men. The most predominant age categories were over 61 years and 40-50 years, with a frequency of 27 and 25%, respectively. A considerable percentage of the respondents reported secondary education (38.25%) and only 2% indicated that they had no education.  In terms of current occupation, more than a third of the participants (39.75%) were dependent workers compared to a minority (3.50%) who reported being retired. Finally, the most common monthly income (45.25%) fell within the range of $400 to $600, followed by the $601 to $1,000 range (22.25%).

**Table 2.** Distribution of respondents according to their personal, social and economic characteristics

| Category | Frequency | Relative frequency |
|---|---|---|
| ***Gender*** | | |
| Female | 187 | 46.75% |
| Male | 213 | 53.25% |
| ***Age group*** | | |
| 18-28 years old | 72 | 18.00% |
| 29-39 years old | 66 | 16.50% |
| 40-50 years old | 120 | 30.00% |
| 51-60 years old | 64 | 16.00% |
| >61 years old | 78 | 19.50% |
| ***Educational level*** | | |
| No education | 8 | 2.00% |
| Primary school | 83 | 20.75% |
| Secondary | 153 | 38.25% |
| High school | 114 | 28.50% |
| Third level | 42 | 10.50% |
| ***Current occupation*** | | |
| Student | 22 | 5.50% |
| Dependent worker | 159 | 39.75% |
| Unemployed | 49 | 12.25% |
| Entrepreneur | 55 | 13.75% |
| Retired | 14 | 3.50% |
| Responsible for the household | 101 | 25.25% |
| ***Monthly income*** | | |
| Less than $400 | 70 | 17.50% |
| Between $400 and $600 | 181 | 45.25% |
| Between $601 and $1000 | 89 | 22.25% |
| Between $1001 and $2000 | 46 | 11.50% |
| More than $2000 | 14 | 3.50% |

## Perception of aquaponics products

The tabulation of the findings corresponding to the dimension “Knowledge” is shown in Table (3). It is observed that only 7.25% knew or had ever heard the term “aquaponics”. In addition, only 2.75% indicated that they were aware of some activity related to this term in Ecuador, while 97.25% stated that it was the first time they had heard of it. These results show a low level of familiarity and knowledge among the respondents.

**Table 3.** Tabulation of respondents according to indicators corresponding to the "Knowledge" dimension

| Indicator | Frequency | Relative frequency |
|---|---|---|
| ***Familiarity with the term "aquaponics"*** | | |
| Yes | 29 | 7.25% |
| No | 371 | 92.75% |
| ***Knowledge of aquaponics operations in Ecuador*** | | |
| Yes | 11 | 2.75% |
| No | 389 | 97.25% |

**Short *et al*. (2017)** noted that in their study, 33% of their respondents were aware of the term "aquaponics" and related the incidence to income level, given that the higher the range of annual income the greater the likelihood of recognizing the technology. This notion coincides with the research of **Suárez *et al*. (2021)**, which suggests that a high family income increases the willingness to consume organic products from aquaponics, even considering the possibility of assuming higher costs compared to the expenses associated with conventional foods.

Table (4) presents the indicators used to assess respondents' perceptions of the dimensions: Security, Source of Information, and Valuation. The indicators were weighted between 2.04 and 4.52, on a five-point Likert scale. For the most part, the indicators were weighted at levels close to response 3, which exhibits neutrality.

**Table 4.** Performance points of indicators corresponding to the dimensions Security, Source of information and Valuation.

| Dimension | Indicator | P.R. |
|---|---|---|
| ***Safety*** | Safe and clean method to raise fish and grow vegetables simultaneously. | 3.68 |
| | Aquaponics operations have a positive impact on the environment. | 3.14 |
| ***Source of information*** | Credibility of educational information provided by a grocery store. | 2.04 |
| | Credibility of educational information provided by a university. | 4.52 |
| | Credibility of educational information provided by the government. | 3.28 |
| | Credibility of educational information provided by aquaponics g rower. | 3.02 |
| | Credibility of educational information provided by a news reporter. | 3.36 |
| ***Valuation*** | Cultivation of products with high nutritional value. | 3.47 |
| | Humane method of fish farming. | 3.17 |
| ***Interest*** | Level of interest in learning about aquaponics. | 4.19 |

Note: P.R.: Performance point of each indicator.

Respondents expressed a greater appreciation for the cultivation of products with high nutritional value compared to the focus on humane methods of fish farming, corresponding to the Valuation dimension. Regarding the Safety dimension, the opinions reported that participants have a higher appreciation for the perception that the method is safe, compared to the positive impact it may have on the environment.

According to **Goddek *et al*. (2019)**, the limited understanding of aquaponic practices and the expectation of high costs could be important barriers to the acquisition of aquaponic products. Therefore, they suggest that education and marketing are tools with the potential to increase public acceptance.

Lack of understanding of aquaponics practices and the perception of high costs could be important barriers limiting consumers' willingness to adopt products from these systems. However, it highlights the need for more effective marketing and education approaches to broaden the consumer base and achieve greater public acceptance.

In the Information Source category, the lowest weighted indicator was the credibility of educational information provided by a grocery store, with a score of 2.04; in contrast, the highest weighted indicator was the credibility of educational information provided by a university. This result broadly exhibits that the source of information has the ability to dramatically increase or decrease the perception of risk associated with a new product.

Previous research has documented that the sources of information most frequently used by the European population are labels and retailers. Other sources, such as scientific reports and consumer associations, are less frequently consulted. However, they also recommended following the trend with caution due to the fact that they approximated responses to pretentious or draconian behaviors **(Zugravu *et al*., 2019)**.

Participants' reasons for rejecting aquaponic products were also evaluated, and the findings are presented in Fig. (1). The graph provided insight into what consumers' priorities and concerns are, regarding biotechnology in food production. Respondents indicated that the determining factor why they would not buy this type of product is safety or cleanliness. The factors breeding method, nutritional concerns and price are also influential, but to a significantly lesser extent. As for the factors that would least influence willingness in the first instance, they pointed to taste.

Respondents' impression of fish raised in aquaponic systems as unsafe or unhealthy protein sources may be influenced by several reasons. Lack of knowledge about the strict quality and safety controls implemented in these systems could generate mistrust. In addition, the misperception that fish share the same environment with plants and recycled water could be associated with an increased risk of contamination or exposure to pathogens. In addition, cultural factors and previous experiences could contribute to these negative views.

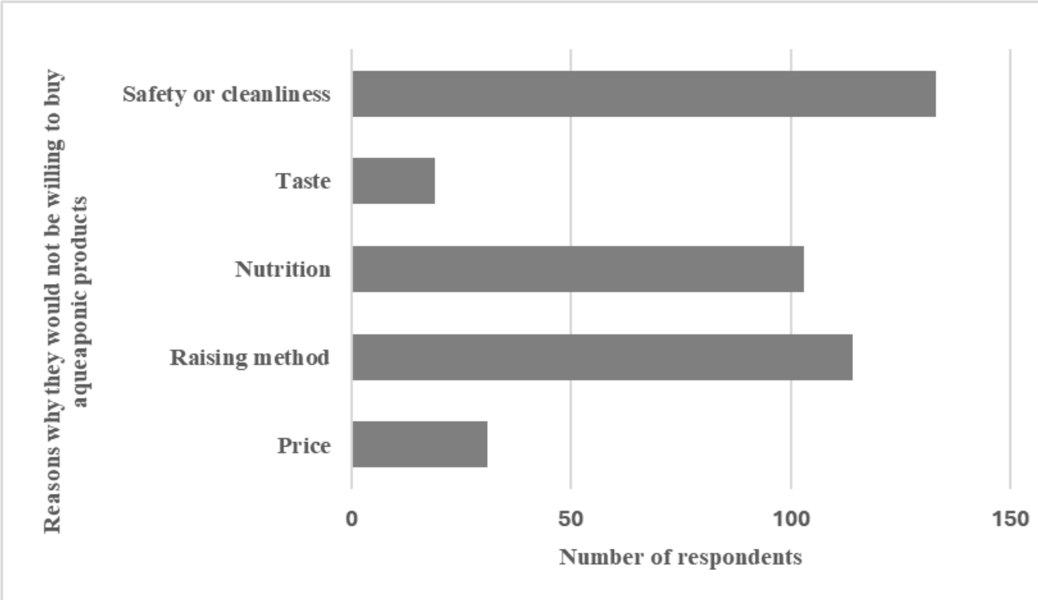


**Fig. 1.** Respondents' arguments for not buying aquaponic products

In a survey conducted in Romania, quality labeling and food safety information played an important role in the purchase of products from aquaponics systems such as fish. The authors explained these indications by indicating that consumers prioritize meeting their initial expectations by obtaining relevant information to make purchasing decisions **(Zugravu *et al*., 2019)**.

## CONCLUSION

Among the cultivated macrophytes, *Lemna* spp. is the plant species that best adapted to the aquaponic system, both for its biomass amplitude and its capacity to generate water sanitation.

The S1 aquaponic system was the most efficient, in addition to allowing the development of the aquatic plant, it emphasized the lowest levels of nitrite and BOD. It also had adequate concentrations of nitrates, pH and total nitrogen.

In relation to the survey, the participants indicated that the factor through which they determine the acquisition of a new product is the perception that it generates in terms of safety or cleanliness.

Information sources have the ability to dramatically increase or decrease the perception of risk associated with a new product. In this case, respondents indicated that universities are the most trusted sources of information.

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