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*Research article*

# Integrated Aquaponics System by Combining Japanese Cucumber Cultivation with Efficient Hybrid Catfish Farming for Enhanced Farmer Quality of Life

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**Abstract:** Farmers are currently facing the challenge of inadequate water quality in aquaculture, which negatively impacts the health of aquatic animals and their growth and survival rates. To address this issue, this study aims to assess the potential of raising hybrid catfish using an aquaponics system. The approach involves cultivating fish in a recirculating water system while growing Japanese cucumbers over 14 weeks. The treatment started with a hybrid catfish with an initial body weight of approximately 10 g and a length of 10 cm. They were fed according to a protocol using commercially prepared pellet feed, administered twice daily (morning and evening). The findings of the study revealed that the combined yield of hybrid catfish and Japanese cucumbers per production cycle was 112 and 3.20 kilograms, respectively. Additionally, the aquaponics recirculating system was found to efficiently utilize resources and promote the growth of both plants and fish. This integrated system offers a solution to wastewater management challenges in aquaculture, reduces associated costs, and enhances the value of wastewater by implementing aquaponics. A financial feasibility analysis was conducted to evaluate the economic viability of the hybrid catfish farming method. The analysis considered production costs, benefits, and discount rates, revealing positive net present values, benefit-to-cost ratios exceeding 1, and internal rates of return surpassing the cost of financing. This analysis underscores the feasibility and commendability of adopting hybrid catfish farming with aquaponics. Furthermore, it is highly suitable for developing and promoting small-scale or household-level businesses. Participants who underwent practical training in the "Aquaponics Fish Farming" course expressed great satisfaction and the ability to seamlessly integrate fish farming with crop cultivation.

**Keywords:** Aquaponics; catfish; Japanese cucumber; Circular economy system; Wastewater

## 1. Introduction

The hybrid catfish, resulting from the crossbreeding of female *Clarias macrocephalus* and male *Clarias gariepinus* catfish, is achieved through artificial insemination. This process combines the characteristics of both parent species, encompassing morphology, behavior, and flesh quality. As a freshwater fish, the hybrid catfish holds significant economic importance in Thailand and Southeast Asia [1,2] due to its remarkable attributes: rapid growth, versatile diet, disease resistance, and adaptability to diverse environments. In 2020, the annual production of farmed catfish in Thailand was approximately 109,409 tonnes, valued at about 160 million USD [3]. Notably, the catfish's flesh is prized for its yellowish hue, tenderness, non-mushy texture, and delightful taste, appealing to discerning consumers. Consequently, the hybrid catfish has gained widespread popularity, leading to its extensive cultivation.

The Aquaponic System is an innovative method that combines aquaculture (fish farming) with hydroponics (soilless plant cultivation) in a closed recirculating system [4-6]. Its main purpose is to efficiently eliminate waste, including solids, suspended particles, and dissolved substances. Utilizing the nutrients generated from fish waste and leftover food eliminates the need for chemical fertilizers as the plants absorb these nutrients. To further enhance water quality, the system includes a treatment process where water from the fish tanks is filtered through plants that use nitrification and denitrification to absorb nutrients. This process creates a safe and healthy environment for fish [7], especially for sensitive species like catfish and tilapia [8,9]. The Aquaponic System offers numerous advantages, such as improved water quality, increased crop yield, enhanced fish growth and survival rates, reduced infrastructure costs, affordable food production, and the potential to decrease poverty rates [10]. Given these benefits, it is recommended that farmers consider transitioning from traditional fish farming to this combined approach of catfish farming and soilless plant cultivation, which mitigates risks and promotes sustainable agriculture. As such, integrating efficient hybrid catfish farming with aquaponics offers numerous advantages for farmers. Firstly, it allows for a more sustainable use of resources, particularly water. Aquaponics uses a recirculating system that requires less water than traditional farming methods [4-6]. The water where the fish are reared is continuously circulated to the hydroponics subsystem, where the plants absorb the nutrients and filter the water, improving its quality. This efficient water usage is crucial in regions with limited water availability. Moreover, farmers can diversify their income streams by combining fish farming with plant cultivation [11]. In addition to catfish, various vegetables and herbs can be grown in the aquaponics system, providing additional revenue opportunities. The plants benefit from the fish's nutrient-rich water, resulting in healthy and productive crops. The integrated aquaponics system also improves farmers' overall quality of life. It reduces the reliance on synthetic fertilizers and pesticides, promoting environmentally friendly and sustainable farming practices. Additionally, the system provides a controlled and optimized environment for fish and plant growth, ensuring farmers' better productivity and financial outcomes [11].

Farmers who rear catfish often face challenges with high stocking density during the 120-150-day rearing period. This can lead to poor water quality in the tanks, hindering optimal growth and increasing the risk of diseases and thermal death. Several factors contribute to this issue, including temperatures outside the range of 27-29 degrees Celsius [12], conductivity levels of 80-200 milligrams per liter, alkalinity of 7.5-8.5, dissolved oxygen levels exceeding 5 milligrams per liter [13], and varying nutrient concentrations (such as $NH_4$: 0.02-1.0 milligrams per liter, $NO_3$: 0-3 milligrams per liter, total phosphate (TP) less than 0.5 milligrams per liter, and orthophosphate: 0.1-5 milligrams per liter) [14]. These factors, including fish waste and feeding patterns, primarily nitrogen, can be toxic to the fish [15,16]. Imbalances in feeding practices, fish density in the tanks, and the use of chemicals can result in residue buildup and the formation of stagnant, deteriorating water, negatively impacting fish health. To address these challenges, farmers should prioritize wastewater management during the breeding and harvesting stages and make efficient use of available resources within the framework of a circular economy. For instance, adopting a recirculating water system for rearing Nile tilapia while simultaneously cultivating chili peppers [16], tomatoes, cucumbers, lettuce, and pumpkins [17,18] in the same water circulation system demonstrates the effectiveness of combining organic agriculture with aquaponics technology. This integrated approach enables optimized land and water management, aligning with the principles of a circular economy. Such initiatives align with the sustainable development strategies emphasized by His Majesty King Bhumibol Adulyadej the Great during his reign as the ninth monarch of Thailand.

Researchers conducted a study on breeding hybrid catfish and cultivating Japanese cucumbers to address the mentioned challenges. This study offers valuable guidance for farmers involved in fish breeding and rearing in regions with limited water resources. The approach involves creating a customized system that mimics the natural habitat of the fish, enabling the establishment of production cycles. By adopting this initiative, farmers can promote environmentally sustainable food production worldwide in the long term.

## 2. Materials and Methods

### 2.1 Aquaponics system experiment

#### *2.1.1. Fish samples*

Hybrid catfish fry, aged 30 days and measuring 9-10 centimeters in length, were meticulously selected, resulting in 1,000 individuals being transferred to a holding pond. The fry was aerated and nourished with pelleted food to ensure optimal health. Throughout 7 days, their feeding behavior was closely observed during water quality checks, and a sufficient amount of food was provided until they reached satiation. Subsequently, the fry was randomly chosen from the holding pond, and their length and weight were measured before being released into individual experimental concrete tanks. These tanks measured 80 cm in height and 100 cm in diameter, with a water capacity of approximately 22 liters, and could accommodate 100 individuals. In total, 9 tanks were utilized for the experiment.

#### *2.1.2. Japanese cucumber samples*

Japanese cucumber Roberto seeds were used in this treatment. The process began by germinating the Japanese cucumber seeds in seedling trays. Once the seeds had sprouted and grown 2-3 leaves, the resulting seedlings were delicately transplanted into designated rows next to the fish-rearing pond. Thirty plants were grown per sub-pipeline, with 270 plants per treatment.

#### *2.1.3. Aquaponic System*

A water pumping system was installed to support the simultaneous cultivation of Japanese cucumbers and the rearing of hybrid catfish. The cucumber planting rows were strategically positioned adjacent to the hybrid catfish rearing pond, while continuous aeration was maintained to create optimal growing conditions. This system ensured a consistent water supply, with the fish-rearing system delivering 400 liters per hour to the hydroponic plant-growing system. The water flowed through the plant roots, circulated through the hydroponic system, and continuously returned to the fish-rearing pond. This reliable pumping system operated flawlessly throughout the entire 14-week experimental period.

#### *2.1.4. Treatment*

The experiment was conducted over 14 weeks, aligning with the typical growth period before harvesting (3-4 months) [19] (Figure 1). A random sample of 80 fish from the concrete tanks was chosen every week to assess their growth, considering the average hybrid fingerling survival rate of 80-85% [20]. These fish were provided with commercially prepared floating pellet feed containing more than 30% protein, more than 3% fat, less than 8% crude fiber, and less than 12% moisture. They were fed twice a day, at approximately 8:00 AM and 6:00 PM, until they reached a state of satiation. The satiation experiment involved feeding the fish floating pellet feed in 3 g increments until they no longer consumed it. Simultaneously, standardized methods [21-23] were used to measure water quality parameters in the aquaponics system every week. These parameters included temperature (measured using the electrometric method) [21], pH (measured using the electrometric method) [21], electrical conductivity (measured using the electrical conductivity method) [20], dissolved oxygen (measured using the membrane-electrode method) [21], hardness (measured using the EDTA titrimetric method) [21], nitrate as nitrogen (measured using the nitrogen, nitrate colorimetric method with brucine) [22], and phosphate as phosphorus (measured using the ascorbic acid method) [23]. Each week, the experiment was replicated three times (n=3).

**Figure 1.** The fish rearing pond and Japanese cucumber cultivation bed.

**2.2 Recording experimental data of aquaponics system**

The experiment collected and analyzed data on weight, length, and food consumption to assess each experimental group's growth and survival rates. The evaluation followed the methodology described by Halver [24]. It focused on several parameters: final weight (FW), weight gain (WG), average total length (ATL), feed conversion ratio (FCR), survival rate (SR%), stocking densities, total yield, and productivity by following these equations.

Average weight gain (g/duration) = (Final average weight - Initial average weight) / Duration of fish rearing

Average length gain (cm/duration) = (Final average length - Initial average length) / Duration of fish rearing

Fish survival rate (%) = (Number of surviving fish / Initial number of fish) x 100

Feed conversion ratio (FCR) = Total feed consumed by fish (kg) / Total weight of harvested fish (kg)

Stocking densities (fish/$m^2$) = Number of fish in a pond / Volumn of water in a pond

Total yield (kg/year) = Overall production yield per cycle x Total cycle per year

Productivity (kg/$m^2$/year) = Overall production yield in each tank per cycle x Total cycle per year

For Japanese cucumber production, harvesting is conducted at 75 days of age to ensure suitability for sale. The fresh weight and length of the cucumbers are then measured.

**2.3 Financial feasibility analysis**

The analysis of the cost structure and financial feasibility in hybrid catfish farming involves several key components, including investment costs, fixed costs, variable costs, total costs, total revenue, profit (calculated as total revenue minus total costs), and the revenue-to-cost ratio (total revenue divided by total costs). The evaluation of financial feasibility employs a comprehensive cost-benefit analysis (CBA) framework, which integrates metrics like Net Present Value (NPV), Benefit-to-Cost Ratio (BCR), and Internal Rate of Return (IRR). This thorough CBA analysis spans 5 years, with a discount rate of 7% applied to this study. As of August 2023, the exchange rate is 1 US dollar (US$) to 34.86 Thai Baht (THB). The NPV, BCR, and IRR are computed using the following formulas:

Net Present Value (NPV)

The Net Present Value (NPV) represents the current value of the net benefit stream. The NPV is determined using the following formula:

$$\text{NPV} = \sum_{t=0}^{t=5} [(B_t - C_t)/(1 + r)^t]$$

in which: $B_t$ = benefits in year t; $C_t$ = cost in year t; r = discount rate.

Benefit-Cost Ratio (BCR)

Net benefits for a specific period were determined by deducting costs from the corresponding benefits. The Benefit-to-Cost Ratio (BCR) compares the total present value of net profits accrued during years with positive net profits and those with negative net profits. This value is derived through the following formula:

$$\text{BCR or B/C} = [\sum_{t=0}^{t=5} (B_t - C_t)/(1 + r)^t]/[\sum_{t=0}^{t=5} (C_t - B_t)/(1 + r)^t]$$

Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) represents the interest rate obtained by equating total costs' present value to total revenues. A business is deemed feasible if the IRR value exceeds the opportunity cost of capital. In this study, the IRR was calculated using the following formula:

$$\text{IRR} = i + [\text{NPV}/(\text{NPV}' - \text{NPV}'')][i' - i'']$$

where: i' = discount rate resulted from NPV positive, i'' = discount rate resulted from NPV negative, NPV' = NPV in interest level i', NPV'' = NPV in interest level i''.

**2.4 Sensitivity analysis**

Sensitivity analysis is a widely used approach to assess economic feasibility by analyzing how variations in different situations or conditions influence outcomes. Our study used sensitivity analysis to gauge the impact of modifying production costs, benefits, and discount rates within the hybrid catfish farming framework, specifically utilizing an aquaponic system.

## 3. Results and Discussion

**3.1. Production performance analysis of hybrid catfish using aquaponics system**

Several noteworthy observations were made during 14 weeks of rearing hybrid catfish in a recirculating system with Japanese cucumber treatment (Table 1). The hybrid catfish exhibited an impressive survival rate of 74.67%, outperforming the survival rates observed in catfish (*Clarias gariepinus*) farming systems with aquaponics water spinach (*Ipomoea reptans*), which ranged from 55% to 67% over 40 days [25]. It is important to mention that while the hybrid catfish's survival rate in this study is slightly lower than the rates observed in catfish (*Clarias* sp.) farming systems with aquaponics, utilizing water spinach, caisim, and tomato (77-80%), these systems require more complex aquaponic design and construction, involving physical and additional biological filters [26]. The feed conversion ratio (FCR) calculations yielded a value of 1.22, which means that around 1.22 kilograms of feed were required to increase the fish's weight by 1 kilogram. This ratio aligns with findings from various studies, such as those involving catfish raised with water spinach [25,27]. The fish exhibited increased live weight as time progressed, concurrent with their length growth. Before the experiment, the average weight and length of the hybrid catfish were recorded as 10.05 grams and 10.41 centimeters, respectively. After the 14-week rearing period, the average weight and length of the fish reached 50.37 grams and 16.67 centimeters, respectively, as illustrated in Figure 2. The average weight gain was 2.88 grams per week, and the average length gain was 0.45 centimeters per week. The overall production yield per cycle amounted to 112 kilograms (12.44 kilograms per tank). These findings align with a study by Rittiruk *et al*. [28], which reported an average weight and net weight of hybrid catfish as 13.32 and 12.39 kilograms per cubic meter, respectively. However, it is important to note that despite maintaining a consistent fish density of 100 fish per tank in our study, the optimal density predicted by the second-degree polynomial mathematical model was 107 fish per cubic meter to achieve maximum production. Any further increase in fish density resulted in compromised water quality and reduced growth performance, with the minimum growth capacity observed at a density of 120 fish per cubic meter.

Several investigations have been conducted on cucumber growth and catfish rearing. One study focused on the impact of aquaponic systems on the stress and welfare of African catfish [29]. In this experiment, they established one aquaculture system combined with a floating raft hydroponic unit to cultivate cucumbers using the process water. In contrast, another system was the control without the plant cultivation unit. The researchers regularly monitored water quality and assessed the fish's physiological stress parameters. The findings revealed that the aquaponic system design did not significantly affect fish growth rates or stress hormone levels. However, there was a notable difference in the number of external injuries on the fish, such as on their skin, fins, and barbels, which were significantly lower in the aquaponic system compared to the control system. These results suggest that co-cultivation of fish and plants, including cucumber cultivation, might offer welfare benefits to the fish. Furthermore, another study combined African catfish production with spearmint cultivation in aquaponics [30]. The study reported the successful growth of African catfish when combined with cucumber and basil, lettuce, and tomatoes. The nutrient levels from African catfish production were suitable for spearmint growth in the aquaponics system. Hence, it can be inferred that cucumber growth can be positively influenced and supported by the presence of African catfish in an aquaponic system. This phenomenon is attributed to the exchange of nutrients between the fish and the plants in the closed-loop water system of aquaponics. Cucumbers and other crops can benefit from the waste products generated by the catfish, leading to enhanced growth and overall system productivity.

**Table 1.** Production performance of hybrid catfish farming systems with aquaponic Japanese cucumber.

| Item | value |
|---|---|
| Rearing duration (week/cycle) | 14 |
| Stocking densities (fish/m$^2$) | 45 |
| Survival rate (%) | 74.7 ± 1.2 |
| Feed conversion ratio (FCR) | 1.22 |
| Average weight gain (g/week) | 2.88 |
| Average length gain (cm/week) | 0.45 |
| Total yield (kg/year) | 448.0 ± 3.0 |
| Productivity (kg/m$^2$/year) | 62.22 ± 1.0 |

The growth of Japanese cucumbers in an aquaponics system was studied for 75 days. After harvesting, the cucumbers were carefully weighed and measured. The findings revealed that 90 cucumber plants yielded a fresh weight of 3,200 grams (3.2 kilograms), with an average weight of 160 grams per cucumber and an average length of 26.2 centimeters. While the average weight of the cucumbers was slightly lower than that of conventionally cultivated cucumbers (200 grams), their length was comparable. It was determined that Japanese cucumbers (Cucumis sativus) thrive under specific environmental conditions for optimal growth. These include a seed germination temperature of 30-35 degrees Celsius, a cultivation temperature range of 18-25 degrees Celsius, a pH range of 5.8-6.5, and an electrical conductivity of 1.7-2.5 millisiemens per centimeter. When these conditions were met, the cucumbers exhibited a fresh weight of 200 grams, a vibrant dark green color, and a length of approximately 8-10 inches [31]. No significant differences were observed regarding water quality within the recirculating aquaponics system ($p < 0.05$) regarding electrical conductivity and pH values, as indicated in Table 2. However, the electrical conductivity and pH values were not within the suitable range for cultivating Japanese cucumbers. Furthermore, the water temperature during cultivation exceeded the optimal range, which could have adversely affected the growth and yield of the cucumbers, as mentioned earlier. Nonetheless, water has the potential to support plant growth effectively and can serve as an alternative solution to address water quality concerns arising from hybrid catfish aquaculture in recirculating systems. This approach helps reduce costs associated with wastewater management and enhances the value of wastewater in aquaponics systems.

According to previous studies, African catfish (*Clarias gariepinus*) has shown remarkable growth in aquaponic systems when co-cultivated with various plants, including cucumbers [29,30]. The aquaponic environment, with its efficient filtering and nutrient supply, creates an ideal setting for supporting the growth of plants like cucumbers. However, it's crucial to note that the documents don't directly address the specific impact of catfish raising on cucumber growth. Nonetheless, they suggest that catfish can thrive in aquaponic systems alongside various plants, including cucumbers. For a comprehensive understanding, further research may be required to explore the precise relationship between catfish raising and cucumber growth in aquaponics systems.

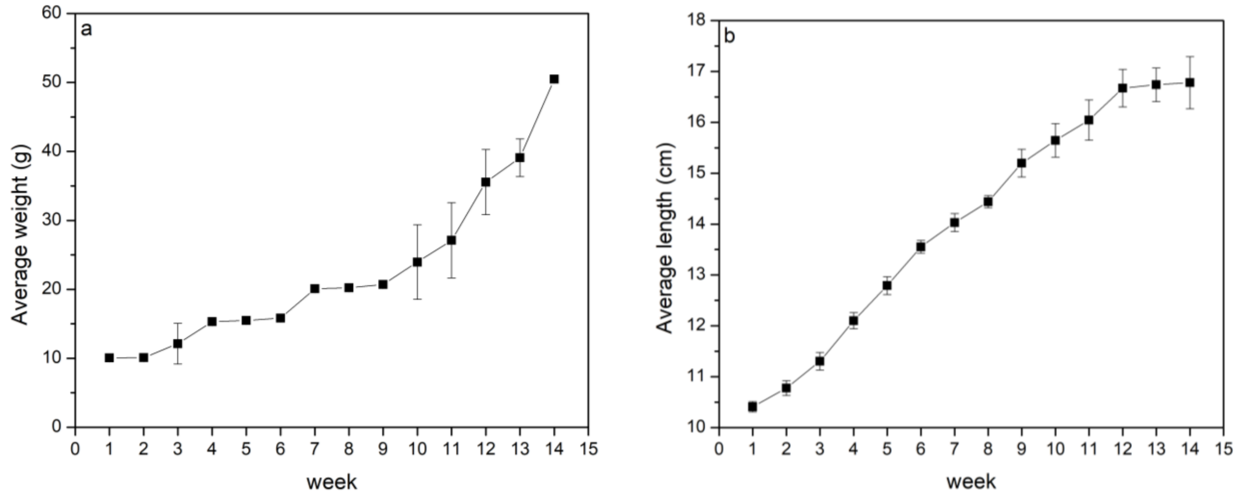


**Figure 2.** Fish growth (a) fish average weight (b) fish average length.

**Table 2.** Water quality in the fishpond.

| Rep. | pH | EC (mS cm$^{-1}$) | T ($^{o}$C) | DO (mg mL$^{-1}$) | Hardness (mg L$^{-1}$ as $CaCO_3$) | $PO_4^{\equiv}$-P (mg L$^{-1}$) | $NO_3^{-}$-N (mg L$^{-1}$ as N) |
|---|---|---|---|---|---|---|---|
| 1 | 7.91 | 0.376 | 27.48 | 3.930 | 164.36 | 0.959 | 0.931 |
| 2 | 7.88 | 0.361 | 27.43 | 3.832 | 150.57 | 0.882 | 0.830 |
| 3 | 7.85 | 0.345 | 27.36 | 3.339 | 132.50 | 0.789 | 0.799 |
| Average | 7.88 | 0.36 | 27.42 | 3.70 | 149.14 | 0.88 | 0.85 |
| SD | ± 0.03 | ± 0.02 | ± 0.06 | ± 0.32 | ± 15.98 | ± 0.09 | ± 0.07 |
| LSD | ns | ns | ns | ns | ns | ns | ns |
| %CV | 7.17 | 65.48 | 11.70 | 51.01 | 31.11 | 66.03 | 80.50 |

EC: electrical conductivity; T: temperature; DO: dissolved oxygen; $PO_4^{\equiv}$-P: phosphate-phosphorus ; $NO_3^{-}$-N: nitrate-nitrogen ; LSD: Latin Square Design ; %CV: Coefficient of Variation ; ns: non-significant

### 3.2 Financial feasibility analysis of rearing hybrid catfish using aquaponics systems

The breakdown of investment components in catfish farming is elaborated in Table 3. The primary allocation revolves around pond construction, while the remaining portion is dedicated to aquaponic equipment. Delving into the operational cost structure, Table 4 delineates fixed and variable costs. The magnitude of these costs significantly shapes the profitability of the hybrid catfish enterprise. Across all study systems, fixed costs constitute 86.29% of the allocation, while variable costs constitute 13.31%. This allocation of higher fixed costs can be attributed to electricity, given the water pumps required for the water exchange process. On the other hand, variable costs predominantly encompass feed expenses, accounting for 9.13%. It's noteworthy that in this study, the feed cost for hybrid catfish farming was notably lower than in other instances, where feed costs represented 22.6% [32], 35% [33], and 40.17% [34] of aquaponics-based fish farming. The overall production, as indicated in Table 5, influences total revenue size.

**Table 3.** Hybrid catfish farming investment on Japanese cucumber aquaponic system.

| Item | Cost (US$) |
|---|---|
| Pond | 38.97 |
| Aquaponic equipment | 14.42 |
| Water pump | 11.53 |
| Total investment | 64.92 |

**Table 4.** The operational cost structure of hybrid catfish farming with Japanese cucumber aquaponic system.

| Item | | Cost | |
|---|---|---|---|
| | | US$ | % |
| Fixed cost | Electricity | 416.93 | 80.71 |
| | Depreciation | 28.84 | 5.58 |
| Total fixed cost | | 445.77 | 86.29 |
| Viable cost | Fingerling | 15.00 | 2.90 |
| | Feed | 47.16 | 9.13 |
| | Seed Japanese cucumber | 8.64 | 1.67 |
| Total viable cost | | 70.80 | 13.71 |
| Total cost | | 516.57 | 100.00 |

A financial feasibility analysis was employed and presented in Table 6 to gauge the sustainability of the hybrid catfish farming enterprise. Derived from revenue and business analysis, the calculations demonstrated the venture's profitability, yielding positive profit values. The calculated R/C (Revenue-to-Cost) ratio for hybrid catfish farming employing aquaponic technology was 1.43. The R/C ratio for catfish farming combined with aquaponic water spinach was 1.00 [34]. The financial feasibility assessment underscores the substantial benefits of aquaponics-based catfish farming. Financial feasibility values for catfish aquaculture within aquaponics encompassed 841.02 US$ (Net Present Value, NPV), 12.95 (Benefit-to-Cost Ratio, BCR), and 340.14% (Internal Rate of Return, IRR). Consistent outcomes were noted across various studies. For example, Diatin et al. [34] documented a BCR value of 12.57, significantly surpassing the BCR values reported by Bosma et al. [32] at 1.23 and Aheto et al. [35] at 1.11 for catfish farming. These results collectively suggest elevated profitability and feasibility for development.

Furthermore, it's paramount to recognize the importance of comprehensive wastewater treatment through a plant-based approach [36] when evaluating environmental aspects. This environmentally sustainable method bolsters the long-term viability of combining fish rearing and vegetable cultivation. Moreover, it nurtures the establishment of small-scale enterprises, generating profits for fish farmers.

**Table 5.** The annual profit for hybrid catfish farming with Japanese cucumber aquaponic system.

| Item | Profit |
|---|---|
| Yield hybrid catfish (kg) | 448.00 |
| Hybrid catfish price (US$) | 1.59 |
| Yield Japanese cucumber (kg) | 12.80 |
| Japanese cucumber price (US$) | 0.90 |
| Total revenue (US$) | 737.52 |

**Table 6.** Financial feasibility analysis of hybrid catfish farming with Japanese cucumber aquaponic system.

| Item | Value |
|---|---|
| Total investment (US$) | 64.92 |
| Fixed cost (US$) | 445.77 |
| Viable cost (US$) | 70.80 |
| Total cost (US$) | 516.57 |
| Total revenue (US$) | 737.52 |
| Profit (US$) | 220.95 |
| Average cost/kg (US$) | 1.15 |
| Revenue-cost ratio | 1.43 |
| NPV (US$) | 841.02 |
| BCR | 12.95 |
| IRR (%) | 340.14 |

### 3.3 Sensitivity analysis of rearing hybrid catfish using aquaponics systems

The fluctuation in hybrid catfish production performance is pivotal in the production process. A comprehensive sensitivity analysis was undertaken to gauge the implications of potential changes in production costs, benefits, and discount rates. This analysis involved a meticulous comparison of production costs, benefits, and a baseline discount rate of 7% against variations of 10% and 20%. The outcomes of this meticulous sensitivity analysis relevant to hybrid catfish farming are meticulously presented in Table 7. Across all examined scenarios, the Net Present Value (NPV) consistently maintains a positive stance, the Benefit-to-Cost Ratio (BCR) consistently exceeds the pivotal threshold of 1, and the Internal Rate of Return (IRR) consistently surpasses the cost of financing. These results provide unequivocal support for the feasibility and commendation of the hybrid catfish farming endeavor. Notably, the analysis underscores the paramount influence of production costs on the financial sensitivity of the project. Moreover, it's noteworthy that several sensitivity analyses concerning catfish farming have been documented, delving into various variables such as selling prices, investment costs, and feed prices [37-39].

**Table 7.** Sensitivity analysis in hybrid catfish farming with Japanese cucumber aquaponic.

| Item | | NPV (US$) | BCR | IRR (%) |
|---|---|---|---|---|
| Cost | +20% | 404.43 | 5.19 | 1,277.61 |
| | +10% | 622.72 | 8.72 | 236.52 |
| | -10% | 1,059.31 | 18.13 | 466.49 |
| | -20% | 1,277.61 | 24.60 | 624.32 |
| Benefit | +20% | 1022.21 | 15.75 | 408.29 |
| | +10% | 931.61 | 14.35 | 374.22 |
| | -10% | 750.42 | 11.56 | 306.03 |
| | -20% | 729.70 | 11.24 | 280.83 |
| Discount rate | +20% | 808.05 | 12.45 | 340.14 |
| | +10% | 824.29 | 12.70 | 340.14 |
| | -10% | 858.25 | 13.22 | 340.14 |
| | -20% | 876.02 | 13.49 | 340.14 |

### 3.4 The Aquaponics Fish Farming course

Following the experiment, we conducted practical training sessions for farmers in the area to facilitate the adoption of fish rearing in aquaponics systems. The workshop included a lecture on the importance of aquaculture and growing hydroponic plants in an aquaponic system. It also included training in hydroponic plant cultivation and a simulation of how to grow aquatic animals using an aquaponic system. Additionally, there was a session on investment and profit calculations based on information obtained from research. 65 individuals (100%) who had expressed a keen interest in the subject actively participated in the training program (Figure 3). The assessment of participant satisfaction unveiled that none of them had previously received any training specifically focused on the core content of the "Aquaponics: Fish Farming Combined with Vegetable Cultivation" course. Notably, a significant majority of the trainees (63.08%) were females aged 19-30 years (56.92%), representing the emerging young workforce. These participants exhibited remarkable enthusiasm towards the course material and demonstrated a notable aptitude to assimilate the knowledge and skills imparted during the training. The trainers garnered an outstanding average rating of 4.80-4.81 from a maximum score of 5, reflecting their exemplary expertise and profound understanding of the subject matter. Notably, the activities aligned with the intended objectives, as evidenced by the participants' solid comprehension of fish rearing in aquaponics systems and their utmost satisfaction, as indicated by an average rating of 4.78-4.79 from a maximum score of 5.

**Figure 3.** The practical training on fish rearing in a recirculating aquaculture system combined with plant cultivation.

## 4. Conclusions

During 14 weeks, rearing hybrid catfish and cultivating Japanese cucumbers yielded 15.64 kilograms per cycle. This approach maximizes product value while maintaining environmentally friendly practices through a circulating water system. This system improves water quality by treating it in the cucumber bed, creating a suitable environment for fish rearing and reducing water pollution. The circulating aquaponics system supports plant growth and fish rearing, addressing water quality concerns and reducing wastewater management expenses. The financial feasibility analysis evaluated cost structure, total revenue, profit, and revenue-to-cost ratio using metrics such as Net Present Value (NPV), Benefit-to-Cost Ratio (BCR), and Internal Rate of Return (IRR). This system is suitable for small-scale business development, providing practical training for farmers to enhance their skills, support household food production, and generate sustainable income.

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