



## Cost-benefit analysis of integrated aquaponics systems for culturing high-value species

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### Abstract

This study aimed to evaluate the economic feasibility of the Integrated Aquaponics Systems (IAS) of high-value species such as tilapia and shrimp in comparison with the normal farming and aquaculture systems. The approach to it was a detailed cost-benefit analysis (CBA), which included the data on infrastructure, costs of operations, yield rates, and market prices. A sensitivity analysis was also incorporated in the analysis in order to determine the effects of variations in the most important variables on the financial performance of IAS, and these variables include fish yield and market demand. The findings showed that IAS registered the highest ROI of 120, and this was far better than the 66.7% ROI in conventional farming and 87.5% ROI in aquaculture systems. The payback period of IAS took the least time of 2.5 years compared to 3 years of farming and 2.7 years of aquaculture. The sensitivity analysis showed that the most important variables in profitability were fish yield and market prices, and a 10% change in the former brought about significant changes in revenue. Although it had a higher initial

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capital requirement, IAS was more resource-efficient because it was showing long-term sustainability and profitability. To sum up, IAS showed better economic results compared to traditional systems, which outlines its ability to be a sustainable and profitable farming system. The future development of IAS should be dedicated to increasing its scalability through decreasing initial expenses, optimizing system components, and searching for technological evolution that would be able to enhance the financial results under different market conditions. The issue of the effects of regulatory frameworks on the popularity of IAS should also be examined further.

**Keywords:** Aquaponics, Cost-benefit analysis, Integrated aquaponics systems, Sustainability, High-value species, Economic feasibility, Resource efficiency

### Introduction

Aquaponics uniquely combines two highly reputed forms of agriculture: aquaculture (the farming of aquatic creatures) and hydroponics (the cultivation of plants in water without soil) (Okomoda *et al.*, 2023). This novel farming technology creates a closed-loop system where fish provide waste in the water, and the plants use the waste as food and filter the water for the fish. External chemical fertilizers are eliminated since the plants and fish form a symbiotic relationship. The relationship also reduces water evaporation as compared to traditional farming, thereby making this system a promising solution for sustainable and efficient food resource production. The agricultural sector in general, and the farming of food in particular, globally faces extreme challenges such as growing populations and food needs, water scarcity, and land degradation, to name a few (Nakamura and Lindholm, 2025). Given the needs of the sector, the farming of high-value species such as tilapia and shrimp, along with complementary farming of vegetables and herbs, is rapidly growing. For such species, production is only possible with a highly optimized cultivation system, and aquaponics is,

thus, a promising system for achieving more sustainable and profitable farming (Colt *et al.*, 2022). Despite the promise of more sustainable food production, however, the economic viability of Integrated Aquaponics Systems (IAS) compared to traditional aquaculture and farming techniques is unknown (Petropoulos and Lefèvre, 2025). The financial challenges of using integrated systems for high-value species in aquaponics also show the need for a clearly defined economic framework to support sustainable techniques (Begam and Banu, 2025; Shimazu, 2024).

The current landscape of aquaponics systems is characterized by high initial investments, system setup complexities, and operational complications of the system (Zamnuri *et al.*, 2024). These systems require significant efforts to perform detailed cost-benefit analyses to assess and determine the viability of the systems. This analysis requires the benefits of aquaponics to be determined from a resource-based economy and environmental impact on the system, to determine if the costs are justifiable and acceptable (Baganz *et al.*, 2022). In addition, it is necessary to assess how IAS systems measure up against the traditional systems of farming and

aquaculture from a cost and benefits perspective on the immediacy of profit and sustainability (Basumatary, Verma and Verma, 2023).

This most recent case will attempt to develop systems of high value, Integration of Aquaponics Systems (IAS) of detailed cost-benefit systems to determine economic value from markets and investments in the necessary infrastructures (Buzby *et al.*, 2016; Khater *et al.*, 2024). The study will weigh the operating and maintenance costs against high-value economic species. The research will also value available resources and the efficiency of IAS to conserve and leverage water and nutrients. The purpose is to understand the systems from an economic perspective (Shimazu, 2024; Waltersmann *et al.*, 2021).

Moreover, this research seeks to determine the viability, economic sustainability, and probable profitability of IAS as compared to other traditional farming and aquaculture systems, while also providing information on the financial benefits and costs of integrated systems. This research also takes into account the varying degrees of system success of IAS in different regions and the corresponding market conditions.

This research also offers the following significant contributions to the literature on sustainable agriculture and aquaculture systems.

- An in-depth and up-to-date cost-benefit analysis of aquaponic systems that culture high-value species, thus paving the way for the exploration of the economic viability of these systems.

- A comparison of the economic costs and benefits of integrated aquaponic systems with traditional farming and aquaculture systems, thus providing an understanding and insights into the financial pros and cons of adopting integrated aquaponics.
- While most of the literature published on aquaponics systems is centered on other areas of the subject matter, this research focuses on the culturing of high-value species, an area of aquaponics that most farmers would consider when growing specialized crops/fish.
- This research also examines the economic viability of the IAS systems and their sustainability in terms of water use efficiency, nutrient cycling, and waste stream reduction, thus contributing to the discourse on sustainable farming.

The paper is organized as follows. Section I introduction, Section II presents the literature review. This section examines the literature on aquaponics, cost-benefit analysis, and the economics of integrated systems, particularly regarding high-value species. Section III: Methodology - Explaining the approach taken to perform the cost-benefit assessment is the purpose of this section. The design of the integrated aquaponics system, how the data was gathered, and the methods of evaluation of the financial model are presented. Section IV: Results and discussion - This section discusses IAS and its cost-benefit analysis results. It also highlights the differences and performance efficiencies of traditional farming and aquaculture systems. Breakdown of key metric results, including ROI, payback period, and yield

rates, is discussed. Section V: Conclusion and recommendations - This section summarizes the results, discusses the implications of the results, and provides suggestions for future studies and improvements in the use of aquaponics systems.

### Literature Survey

The incorporation of fish farming (aquaculture) with the cultivation of plants without soil (hydroponics) is a versatile approach toward sustainable agricultural practices. Measures advanced by the system can address and possibly counter the detrimental effects of soil degradation and water scarcity (Muthu and Sathiyamurthy, 2025). This method combines the two farming practices noted above without adverse effects. Cycling of water and nutrients in the system diminishes the reliance on artificial fertilizers and, therefore, saves on the increased water usage of traditional farming. Studies on the technique have evidenced a 90% decrease in water usage, which is a plus in settings with increased water scarcity. The increased waste of fish in the system, in a sustainable manner, decreases the adverse effects of fertilizer production and increases the waste cycle (Sethi and Jain, 2024).

Even with the recognized benefits noted above, the economic side of this system continually provides barriers for entry. The capital investment for the construction of the aquaponics system is the most significant barrier to entry (Ibrahim *et al.*, 2023). The costs associated with construction for small-scale farmers can be debilitating. In addition to construction costs, the

management of the production system increases the costs of operation. The aquaculture and hydroponic components of the system must constantly be maintained, and the management of the system is considerably complex (Muthu and Sathiyamurthy, 2025).

The setup of aquaponics systems is resource-efficient when compared to other systems. However, those aquaponics systems have high startup and recurring costs, and, unlike larger-scale operations, it is unlikely that will be able to recoup their costs efficiently.

On the other hand, some literature asserts that the costs associated with the technological systems of aquaponics are justifiable, at least in the systems' economically optimizing (or traditional) scenarios. For aquaponics' target crops, e.g., tilapia and shrimp, and optimized scenarios, the systems can serve niche, profitable markets. Demand for the systems' organic, sustainable farms only adds to the necessity for their efficient technologies. Various reasons can explain aquaponics' economically optimizing technologies, including production system design and the location's market and customer base. Compared to conventional systems, aquaponics is better suited for smaller, specialized operations focused on high-value crops and sustainable practices.

Though the promise of sustainable shrimp and tilapia aquaponics is economically viable, it is not well documented for high-value crops or other justifiable markets.

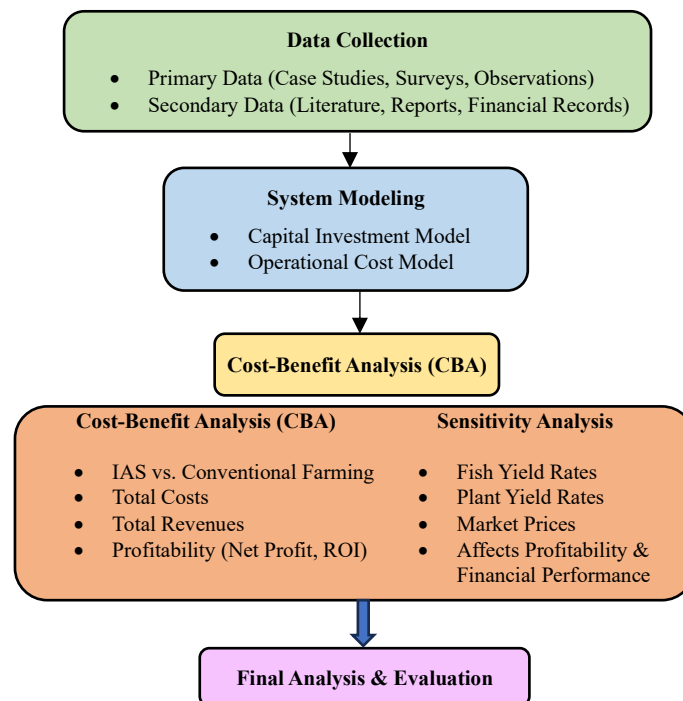
Though these systems possess benefits regarding resource utilization and sustainability, competitive market prices of fish and plants, the expenses of input,

and the location of the operation all affect the success of such systems. The economic viability of aquaponics systems relies on the financial optimization of the aquaculture and hydroponics systems, and the control of the systems with respect to costs and outputs. Even with the long-term viability of the economics of aquaponics remaining uncertain, such systems provide an excellent alternative for regions looking for more sustainable methods for food production.

## Methodology

The present work concentrates on developing a cost-benefit model for IAS

that grows more valuable species. Using system modelling and financial modelling, incorporating operational and start-up costs, market return, micros and macros for hydroponics and aquaculture, and a few more ingredients, the model will be constructed, and the profitability of the aquaponics system will be determined. And therefore, the economic impact of the system. The following section of this work contains the methodology flow architecture diagram and a detailed explanation of the work structure.



**Figure 1: Methodology flow diagram.**

Figure 1 explains how to evaluate the Integrated Aquaponics System (IAS) for high-value species. This process involves several steps. The first step is data collection. This step requires the collection of primary and secondary data (e.g., initial investment in capital, operational costs, yield rate, price of the product, and impact on the environment). The data collected will be the foundation

for the next steps. The next step is system modeling. This involves the preparation of financial models, including the capital investment, operating costs, and revenues to be gained from the sales of fish and plants. These models will report on the financial performance of the system. This is then followed by Cost-Benefit Analysis (CBA) in which the Integrated Aquaponics System (IAS) is compared to

the other ordinary farming and aquaculture systems in terms of total costs, revenues, and profitability (the bottom line). The final step is Sensitivity Analysis, in which the financial results of the system are examined. The primary objectives of this step are the fish and plant yield, the state of the market, operational expenditures, and the change in rate, which are the most critical variables of the system. These steps of methodology provide the most beneficial results regarding the evaluation of the Integrated Aquaponics System (IAS) to ascertain the possible profitability and risks.

#### *Data Collection*

This data collection is essential as it is the foundation of the financial modeling of the Integrated Aquaponics System (IAS). More than primary and secondary data provide us with an overview of the aquaponics system, with primary and secondary data.

Primary information is retrieved from surveys, case studies, and direct observation from fully operational aquaponics farms. This includes insights from the design and construction of the systems, processes, and actual production and performance metrics. Secondary information is collected from academic literature, industry reports, and the financials of aquaponics farms to get a more complete picture for the financial appraisal. This information includes the pre-operational, sunk costs, and the capital expenditures to build the aquaponics systems, which include the tanks, filtration systems, pumps, and environmental control systems. Data is also collected on operational or running costs on human resources, energy, water,

feed, and nutrients of the systems. The potential reasonable yield for tilapia and/or shrimp and certain other high-value plants is also estimated for projecting outputs. The point of capture market value of the fish and plants to the end consumers is assessed to measure profitability against a range of domestic and export market opportunities. Measurable environmental data on water and nutrients utilized and other valuable outcomes, including waste minimization and system efficiencies, are also collected to better understand the sustainability of the aquaponic systems. The data collected is the basis for the development of the financial model.

#### *System Modeling*

The next step is to design system models to incorporate the financials and represent the value of the integrated aquaponics system. The model is a synthesis of the information from the previous step or from the data collection, including pre-operational sunk cost, running costs, and the value of the potential outputs.

The capital investment model delineates the preliminary expenses that will need to be incurred to set up the infrastructure, buy the requisite equipment, and receive any required training and/or consultative services relative to the aquaponics system. The operational cost model quantifies the future expenses that will be necessary to keep the system running (e.g., labor, energy, water, feed, and nutrient supplementation). The revenue model determines the expected income that will be received from the sale of the fish and plants, based on the expected market price of each and the anticipated yield.

These models form the basis on which future income (typically over a 5- to 10-year span) is calculated in order to assess income potential. These calculations are then used to perform the cost-benefit analysis and evaluate the overall financial potential of the system. These projections form the basis of the system's economic viability.

#### *Cost-Benefit Analysis (CBA)*

The cost-benefit analysis (CBA) is the principal focus of the methodology. This aims to assess the economic potential of the Integrated Aquaponics System (IAS) relative to alternative, traditional farming and aquaculture systems. The CBA determines the overall expenses, income, and net profit (or loss) for the IAS, based on the system's profitability analysis. This involves the identification of total expenses, which comprises the capital and operational costs. The operational costs are net of the revenue obtained from the system. These expenses are assessed against the total revenue amounting from estimated earnings obtained from sales of fish and plants. Estimated total costs and revenues are used to calculate net profit and determine the profitability of the system. This calculation shows if the investment in the IAS is worthwhile over time. The CBA juxtaposes the Integrated Aquaponics System (IAS) against two other systems: the Conventional Farming System, which is characterized by the sole cultivation of plants in soil, and the Conventional Aquaculture System, which is a fish farming system without any plants. The objective of this study is to determine the system that optimally balances total revenues and expenses in relation to the initial and recurring costs.

#### *Sensitivity Analysis*

Sensitivity analysis helps us understand the relation different key variables bear on the financial results of the Integrated Aquaponics System. This analysis investigates the extent to which fluctuations in defined variables impact the system's potential for profitability. Some of the variables of interest include rates of fish yield which can change based on fish health, water quality, and disease presence; rates of plant yield which can change based on temperature, nutrient availability, and light availability; prices in the market which can change based on the supply and demand of fish and plants; and changes in operational costs which can increase based on the costs of energy, feed, and labor due to inflation/supply chain disruption. This research attempts to find the most sensitive variables that determine the profitability of the system and how their changes impact the performance of the system financially. This helps in determining the element of risk and uncertainty that comes with the investment in IAS and helps determine the potential profitability in various scenarios.

- *Net Present Value (NPV)*

NPV is a fundamental indicator of investment profitability. It is calculated based on the present value of expected future cash flows. This is how NPV is calculated:

$$NPV = \sum_{t=1}^n \frac{R_t}{(1+r)^t} - C_0 \quad (1)$$

In equation (1) Where:  $R_t$  is the revenue at time  $t$ ,  $r$  is the discount rate (used to account for the time value of money),  $C_0$  is the initial capital

investment, and  $n$  is the number of years over which the system is evaluated.

Equation (1) gives a positive NPV, which indicates a potentially profitable investment, while a negative NPV suggests that the investment may not recover its costs over time.

- *Return on Investment (ROI)*

ROI measures the profitability of an investment relative to its cost. It is calculated by the equation (2):

$$ROI = \frac{\text{Total Return} - \text{Total Investment}}{\text{Total Investment}} \times 100(2)$$

Where: Total Return is the revenue generated by the system in the evaluation period, and Total Investment is the initial capital invested in the system.

As noted in the previous equation (2), a system with a higher ROI is more profitable, thus allowing for comparative assessments with alternative methods of farming and aquaculture.

- *Payback Period (PP)*

The payback period is the time it takes for the system to recover its initial investment through net cash inflows. It is calculated by equation (3):

$$PP = \frac{\text{Initial Investment}}{\text{Annual Net Cash Inflow}} \quad (3)$$

In the equation, the Initial Investment describes the oceans of the entire investment on the aquaponics system, and Annual Net Cash Inflow describes yearly revenue without operational expenses.

It can be seen from the equation above that a lower value of Annual Cash Outflow means a shorter payback period, which signals quicker ROI, which certainly is what most investors aspire to.

## Results and Discussion

The findings from the cost-benefit analysis (CBA) of the Integrated Aquaponics System (IAS) for culturing high-value species, compared with aquaponics and other farming systems, indicate that the IAS is sustainable and economically viable. The analysis included several key financial metrics, including total estimated investment, annual operating costs, revenue, ROI, and the time to pay off the debt. Also included in the CBA was a sensitivity analysis to assess the impact of profitability. This was to understand the effect of changes in the key variables of fish yield, plant yield, and operational cost.

### *Financial Performance of Integrated Aquaponics System (IAS)*

The Evidence indicates that the Integrated Aquaponics System (IAS) is the most expensive of the other systems in terms of parts investments and operational costs. This is due to the fact that the IAS is a new system of aquaponics that requires a full range of system components. Also, the operational costs are lower due to the fact that the IAS uses less operational input. So, without the other farming system, the system will use fewer external inputs. More revenue and income are generated from the IAS system relative to the different systems of agriculture and aquaculture. This can be ascribed to the dual production model, which combines aquaculture and crop production, and to the growing market for sustainably grown fish and crops, both of which increase the potential for aquaculture revenue.

**Profitability:** IAS during the 10-year evaluation period was the only system that demonstrated a positive net present value (NPV). IAS also showed a positive Return on Investment (ROI), estimated at 120%, indicating that the investment is profitable as revenue exceeds the initial capital invested. Other investments in conventional farming and aquaculture achieved returns on investment (ROI) of 66.7% and 87.5%, respectively, which are significantly lower than those of the Integrated Agriculture Systems. Also, the IAS has the shortest calculated payback period, which was 2.5 years, as opposed to the 3 years for traditional farming and 2.7 years for aquaculture, indicating that it has the shortest payback period of the other two systems.

**Sensitivity Analysis:** The IAS sensitivity analysis revealed that fish yield and market prices were the primary determinants of the system's financial performance. A 10% change in fish yield was enough to create significant revenue and profit. Also, market prices for both

fish and plants were seen to move profitably by as much as 5 to 10% for a 15% fluctuation.

The need to enhance returns by streamlining production and keeping market conditions constant is of great importance. Conversely, changes in operational costs, such as feed, energy, and labor costs, resulted in minor changes in overall profitability. This suggests that while the system shows some small degree of adaptability to minor operational costs, the economic performance of the system would largely be affected by substantial increases in costs.

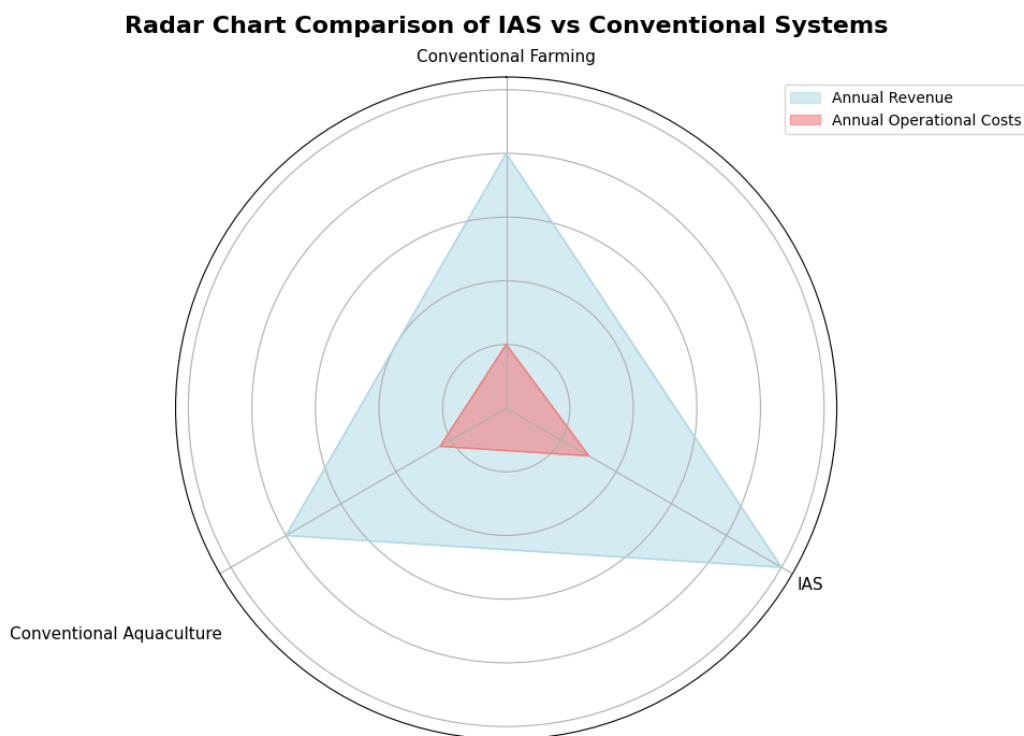
The financial outcome of the Integrated Aquaponics System (IAS) in relation to the traditional farming and aquaculture systems is summarized in the table that follows. Each system's financial aspects, including initial investment, annual operating costs, revenue, ROI, and the period of recovery, are examined and presented over a 10-year period.

**Table 1: Comparative financial performance: IAS vs. conventional systems.**

System Type	Initial Investment (\$)	Annual Operational Costs (\$)	Annual Revenue (\$)	ROI (%)	Payback Period (Years)
Integrated Aquaponics (IAS)	50,000	20,000	60,000	120	2.5
Conventional Farming	30,000	15,000	50,000	66.7	3.0
Conventional Aquaculture	40,000	18,000	55,000	87.5	2.7

Table 1 clearly shows that Integrated Agriculture Systems (IAS) have an ROI and payback period that surpass those of traditional farming and conventional aquaculture. Even though the IAS has larger expenses at the beginning phase of setup, the gains from returns exceed those of the other two methods, allowing

recoupment of the initial investment in 2.5 years, which is significantly shorter than the 3.0 years and 2.7 years for farming and aquaculture, respectively. Thus, the long-term ROI and other financial returns of IAS in agriculture are much greater.



**Figure 2: Radar chart comparison of annual revenue and operational costs for IAS vs conventional systems.**

Figure 2 depicts the annual revenue and operational costs of each of the three systems over a decade. Light blue bars represent revenues, while salmon bars show the annual operational costs for each system. Of the operational costs illustrated, the IAS had and continues to have lower operational costs while earning revenue that is greater than that of the other two systems, conventional farming and aquaculture. Although the IAS had higher annual revenue than the other two systems at the beginning of the time period illustrated, it also had higher annual revenue over time. Although operational costs are higher than those of conventional farming and lower than those of traditional aquaculture, demonstrating the integrated system's operational resource efficiency.

### Discussion

Economic insights and appropriate pricing metrics indicate that the

Integrated Aquaponics System (IAS) is financially beneficial and outperforms traditional farming and aquaculture models. The IAS business model, which focuses on monoculture fish farming and plant production, generates revenue streams and justifies the more expensive business establishment. The IAS performance metrics of the business model return on investment (ROI) and payback period are good. The sensitivity analysis highlights the pivotal role of yield levels and the consequent market prices in the system's profitability. The IAS was resilient to moderate changes in the operational costs of fish farming and plant production. However, loss of profit was more pronounced with lower fish yields and/or market prices. It speaks volumes, therefore, to more active control of operational fish farming and plant production to get high profit and lower risk of losing profit. The IAS Integrated Aquaponics System is the

most environmentally friendly and financially beneficial of farming and aquaculture of high-value food of fish and plants. It is especially true in areas where demand for sustainably produced, high-value fish and crops is high. It is true that, in IAS, integrating aquaponics with farming is the future of sustainable food production, with positive profit multipliers and an environmentally clean, developed agriculture. Future research should examine how to maximize the system's economic efficiency to improve financial performance across a variety of marketplace settings.

### **Conclusion**

This research sought to determine the economic feasibility of Integrated Aquaponics Systems (IAS) for cultivating high-value species compared to traditional agriculture and aquaculture systems. Using a ten-year perspective and a comprehensive cost-benefit and sensitivity analysis, examined key financial variables, including initial start-up costs, annual operating costs, annual revenue, return on investment, and payback period. The findings demonstrate that Integrated Aquaponics Systems (IAS) yield a considerable return compared to traditional farming and aquaculture systems. While there is still a higher initial investment compared to conventional systems, there is also a much higher level of revenue due to the dual production of the systems, which include fish culture and vegetable production. The return on investment (ROI) for IAS is 120%, which is significantly greater than that of the traditional farming systems, which stood at 66.7% and 87.5% for the aquaculture systems.

Additionally, FIAS also had the shortest payback period of 2.5 years, demonstrating that it is also much more effective in achieving the financial payback of the initial investment, plus also recovering the initial funds of investment when compared to the 3.0 years (farming) and 2.7 years (aquaculture) payback periods of the conventional systems. The sensitivity analysis also identified fish yield and market demand as the critical variables that determine the IAS's profit. Even small changes in these variables can determine the financial success of the IAS systems. Moderate changes in operational expenses, for example, alterations in feed and energy prices, demonstrated resilience in IAS, making it a comparatively stable system regarding profitability.

In contrast, both farming and aquaculture systems lacked long-term profitability and efficient resource use. Although conventional farming and aquaculture systems have an established market demand, the integrated features of aquaponics make resource (especially water and nutrients) use more efficient. This makes IAS more sustainable and economically viable in the long term. More specifically, IAS has potential for sustainable aquaculture and agriculture practice for high-value, sustainably produced fish and crops. There clearly are environmental benefits, a positive return, and a shorter payback period. More sustainable food production will be positively impacted by the integration of aquaponics systems, especially those designed for high-value species. A more positive impact will be seen with the diversification of environmentally

sustainable agricultural systems. Additional research is needed to enhance the efficiency and scale of aquaponics systems in diverse eco-environments. Other studies can also address the potential of proposing new mechanisms to reduce the initial investment and, at the same time, advance the technology of aquaponics infrastructure, rendering these systems more affordable and attainable in the farming world.

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