

TECHNICAL AND ECONOMIC ANALYSIS OF WHITE SHRIMP (*Penaeus vannamei*) CULTURE IN THREE DIFFERENT SYSTEMS BASED ON STOCKING DENSITY

Sergio Gustavo Castillo-Vargasmachuca¹, Delia Rodríguez-Olague¹, Raúl Claro-de los Santos¹, Enrique Valenzuela-Wood², Eulalio Arámbul-Muñoz^{2*}

¹Universidad Autónoma de Nayarit. Programa de Doctorado en Ciencias Biológico-Agropecuarias. Carretera Tepic-Compostela km 9, Xalisco, Nayarit, Mexico. C. P. 63780.

²Universidad Autónoma de Baja California. Instituto de Investigaciones Oceanológicas. Carretera Transpeninsular 3917, Ensenada, Baja California, Mexico. C. P. 22860.

* Author for correspondence: eulalio.arambul@uabc.edu.mx

ABSTRACT

Given the increasing global demand for aquaculture products and the necessity to enhance production systems, it is important to produce comparative evidence to inform decision-making in aquaculture investments. This is particularly relevant in contexts such as Nayarit, Mexico, where aquaculture is a key activity for local economic development. This study evaluated the technical and economic variables of three white shrimp (*Penaeus vannamei*) production systems in the San Blas region of Nayarit. The hypothesis was that the hyper-intensive (HI) system would have a higher benefit-cost ratio and better yields per unit area due to its high level of technology and stocking density, compared to the semi-intensive (SI) and intensive (I) systems. Using principal component analysis with VARIMAX rotation, 14 key variables were identified that reflected significant differences in production intensity, with yields ranging from 1124 kg ha⁻¹ (SI) to 36 409 kg ha⁻¹ (HI) per cycle. Results showed that the HI system had the highest total costs (USD 54 419.28 year⁻¹) but also the highest net income (USD 14 857.36 year⁻¹) due to its high stocking density and technification. However, the SI system stood out with the best benefit-cost ratio (B:C) (1.51) and an internal rate of return (IRR) of 30 %, surpassing HI (1.21 B:C, 11.56 % IRR) and I (1.66 B:C, 7.53 % IRR). Despite requiring a higher break-even point (588.89 kg cycle⁻¹), HI demonstrated greater efficiency in resource utilization per kilogram of shrimp produced, reducing the environmental impact. Although hyperintensive systems require higher initial investments, their profitability improves over time due to cost amortization and higher yields per unit area.

Keywords: shrimp farming, cost-benefit ratio, break-even point.

INTRODUCTION

Aquaculture is experiencing rapid growth in a highly versatile and uncertain environment due to climate change and the globalization of trade. This growth is driven by demand, improvements in technologies available to fish farmers, diversification

Citation: Castillo-Vargasmachuca SG, Rodríguez-Olague D, Claro-de los Santos R, Valenzuela-Wood E, Arámbul-Muñoz E. 2025. Technical and economic analysis of white shrimp (*Penaeus vannamei*) culture in three different systems based on stocking density.

Agrociencia. <https://doi.org/10.47163/agrociencia.v60i3.3377>

Editor in Chief:
Dr. Fernando C. Gómez Merino

Received: October 13, 2025.

Approved: April 10, 2026.

Published in Agrociencia:
April 17, 2026.

This work is licensed under a Creative Commons Attribution-Non-Commercial 4.0 International license.



of farmed species, intensification of production, and the expansion of aquaculture farms (Ottinger *et al.*, 2016). The success of an aquaculture business depends not only on production techniques but also on cost control and cash flow analysis. Efficient production management and administration are key factors in increasing productivity and reducing costs. Simulating decision scenarios and training staff working on shrimp farms are crucial strategies for improving operational economic performance (Dávila-López *et al.*, 2020), while also analyzing cash flow using specialized tools that facilitate the visualization of prospective economic returns (Buarque, 1984).

Companies that provide a product or service rely on cost analysis to assess the profitability of their operations and recoup investments. Additionally, it helps identify the profit, which represents the excess of revenue over expenses incurred during operations or upon the liquidation of a company. The general criterion for defining the relevant costs and benefits of a project involves considering those that will occur if the project is undertaken and those that will not occur if it is not (Dávila-López *et al.*, 2020).

The growing global demand for seafood has made aquaculture a continuously expanding activity (Hamilton *et al.*, 2018). The largest single market for seafood imports is the European Union, whose purchases amounted to EUR 20.6 billion in 2014 and EUR 22.2 billion in 2016. Of these values, 56.1 % came from developing countries (Zhang and Tveterås, 2019). However, environmental constraints continue to hinder productivity, and therefore, development models adopted must not only increase the efficiency of companies but also mitigate environmental impacts (Drabo, 2017). Furthermore, farming intensification driven by high market demand has increased the associated risk of disease. Although researchers tend to agree that shrimp farming is highly risky and considered a gamble by many (Flaherty *et al.*, 2009), it remains a widely adopted production system, raising questions about how aquaculturists perceive and manage these risks.

Models for predicting risks in aquaculture, specifically shrimp farming, are complex, given the industry's diverse operational practices and cultural strategies (Little *et al.*, 2016), making it difficult to design a model that encompasses all aspects. In this context, risk categories have been identified and classified into two main groups: external (market, reputational, regulatory, technological, and production-related) and internal (financial, strategic, and operational) (Llorente and Luna, 2013). Ecological risk is related to environmental degradation resulting from aquaculture activities, such as the introduction of genetically modified or exotic species (Tidbury *et al.*, 2016), as well as the effects of new production systems.

Risk research in aquaculture has primarily focused on assessing ecological risks (Tidbury *et al.*, 2016) or economic approaches that analyze production at the farm level (Araneda *et al.*, 2011; Piamsomboon *et al.*, 2015). Some studies have evaluated fish farmers' perceptions of risks related to climate or disease (Chitmanat *et al.*, 2016; Kabir *et al.*, 2017), while others have adopted more analytical approaches using bioeconomic models, which allowed them to identify, through sensitivity analyses, the most

appropriate ways to improve farming and determine risk levels associated with shrimp diseases (Estrada-Pérez *et al.*, 2020). Luna *et al.* (2023) classify risks into four main categories: market, production, technological, and regulatory risks. Furthermore, Posadas and Hanson (2006) pointed out that many proposals continue to be evaluated using a deterministic approach, in which all biological, technological, and economic inputs are considered stable and without variance. Finally, other research has focused on the study of production and operational risks, as well as market risks (Asche, 2008; Llorente and Luna, 2013; Gobillon *et al.*, 2016; Khan *et al.*, 2018).

Based on previous studies highlighting the productive efficiency of hyper-intensive aquaculture systems (Chatvijitkul *et al.*, 2017; Junge *et al.*, 2017), this study hypothesized that the hyper-intensive (HI) system not only offers a better benefit-cost ratio but also higher yields per unit area and per kilogram produced compared to semi-intensive (SI) and intensive (I) systems in commercial production taking place in the municipality of San Blas, Nayarit, Mexico. Therefore, the objective of this study was to comparatively evaluate technical variables (production, survival) and economic variables (benefit-cost ratio, internal rate of return (IRR), and break-even point) using principal component and profitability analyses to identify the most sustainable and viable system in productive and financial terms.

MATERIALS AND METHODS

The analysis of the technical and economic variables of three commercial farms dedicated to the production of white shrimp (*Penaeus vannamei*), cultivated under three cultivation systems, was carried out in the municipality of San Blas, in Nayarit, Mexico. The study variables were the cultured hectares (ha), annual cycles, stocking density (org m^{-2} and/or org m^{-3}), survival (%), final size (g), production ($\text{kg ha}^{-1} \text{ cycle}^{-1}$), selling price in 2023 (USD), equipment and services used (motor, pump, pump filters, water intake, ponds, aerators, greenhouse, pipe, post-larvae, drugs, electricity, labor, feed, diesel, pond preparation, molasses, harvest, probiotic, silica sand), fixed costs (USD year^{-1}), variable costs (USD year^{-1}), total costs (USD year^{-1}), net income (USD year^{-1}), break-even point (BEP, kg cycle^{-1} ; USD cycle^{-1}), benefit-cost (B:C), and internal rate of return (IRR).

Technical variables

Semi-intensive system (SI)

Production data from the shrimp farm "Oro Azul" were analyzed. The farm has a surface area of 13 000 m^2 of water, where 15.4 organisms per square meter (org m^{-2}) are regularly stocked, with an average survival rate of 73 %. Four cycles are carried out during the year. This farm produces 5800 kg year^{-1} , with an average shrimp size of 10 g, which are sold locally at an average price of USD 4 per kg^{-1} .

Intensive system (I)

Production data from the “Natanael López” farm was analyzed. This farm has a water surface area of 20 000 m², where 28 org m⁻² are regularly stocked, with an average survival rate of 69 %. Three cycles are carried out per year. At this facility, 20 336 kg of fish are obtained per year, with an average size of 13 g, which are sold locally at an average price of USD 4.36 per kg⁻¹.

Hyper-intensive (HI) system

Production data from a shrimp farm belonging to the Coastal Bioengineering Laboratory of the Autonomous University of Nayarit was analyzed. This farm has a water surface area of 315 m², where 500 org m⁻³ are regularly stocked in circular geomembrane ponds, with an average survival rate of 78.3 % over four cycles per year. These facilities yield 4587.59 kg year⁻¹ with an average size of 9.3 g, which are sold locally at an average price of USD 5.89 kg⁻¹.

The information was obtained through direct interviews with farm owners and production managers. The collected data were verified against the daily logbooks kept by the farms for monitoring purposes.

Economic variables

Total cost

The costs considered for culture over one year (C_t) were considered according to Horngren *et al.* (2012):

$$C_t = C_f - C_v$$

where C_t is the total annual cost, C_f are the annual fixed costs, and C_v are the annual variable costs. The net income (nr) was determined as a function of time:

$$nr_t = i_t - c_t$$

where the total income (i_t) is the product of the total shrimp biomass (kg) multiplied by its market price.

Break-even point

The break-even point (BEP) was calculated according to Shawon *et al.* (2018):

$$BEP = \frac{C_f}{I_s - C_v}$$

where C_f are the fixed costs, I_s is the income per kilogram of shrimp (USD), and C_v are the variable costs needed to produce one kilogram of shrimp.

Cost-benefit ratio

To calculate the benefit-cost ratio ($B:C$), the total revenue (I_T) was evaluated in relation to the total costs (C_t).

$$B:C = \frac{I_T}{C_t}$$

Internal rate of return

For the calculation of the internal rate of return (IRR), a five-year period was estimated. The present value (PV/VP) was calculated using a cash flow for the same period of time, considering the net present value (NPV/VPN).

Profitability analysis

To determine how profitable the culture systems are over time, a direct profitability analysis was carried out with projections to 1, 5, and 10 years, based on technical-economic factors as well as financial profitability (Hornngren *et al.*, 2012) with the following formula:

$$\text{Profitability (\%)} = (\text{Net income} / \text{Total costs}) * 100$$

Principal component analysis

A total of 35 technical and economic variables were evaluated using principal component analysis. The variables were normalized and subsequently analyzed and rotated using VARIMAX with Kaiser normalization, using an orthogonal rotation procedure to improve their interpretability (Milstein *et al.*, 2005), with the SPSS v26 software (IBM SPSS Statistics, Armonk, NY, USA).

RESULTS AND DISCUSSION

There is a marked trend toward intensifying global shrimp production systems to reduce confinement space, avoid overexploitation of land, and decrease the impact of wastewater discharges on systems adjacent to farming units. However, production intensification presents several limitations, such as the need for trained personnel, operating equipment, cultivation techniques, market knowledge, initial capital, risk of disease, and facilities, among other factors. It also offers advantages such as smaller cultivation areas, better control of the physicochemical variables of water quality, use of *in situ* analysis equipment, higher yields per hectare, better product quality, and consistent production cycles throughout the year. However, much of the literature on sustainability lacks a systematic, data-driven approach that would allow for the identification of the most sustainable production systems or species (Engle and D'Abramo, 2016).

Technical variables

To determine the costs of the cultivation systems and to infer which offers the highest yields, the costs associated with the technical and economic variables were tallied (Table 1) and compared (Table 2). Although the HI system uses higher stocking densities compared to the other systems, the final production per hectare was also higher. System I incurred the highest costs, particularly in labor, post-larvae, and feed. This disparity is attributed to the fact that intensive systems operate over relatively large cultivation areas while primarily adjusting the stocking density, which consequently raises the expenses for these variables (Ahsan, 2011). This pattern aligns with the limitations typically associated with intensified systems (Le and Cheong, 2010). Survival rates were higher in system HI. However, system I recorded the smallest final size, surpassing system HI in this aspect. These results suggest that, in addition to being associated with the level of confinement of the organisms, whether due to lack of space or competition for food, other factors influence this variable, such as the genetic line of the postlarvae, weather conditions, and the overall management practices of the farm.

Table 1. Technical variables of the three culture systems evaluated in the municipality of San Blas, in Nayarit, Mexico.

Variable	Amount		
	Semi-intensive (SI)	Intensive (I)	Hyperintensive (HI)
Hectares	1.3	2.0	0.0315
Annual cycles	4	3	4
Stocking density (m ⁻² , m ⁻³)	15.4	28.0	500
Survival (%)	73.0	69.0	78.3
Final weight (g)	10.0	13.0	9.3
Production (kg ha ⁻¹ cycle ⁻¹)	1124.33	2511.60	36 409.20
Sale price (USD)	4.00	4.36	5.90
Pump (parts)	1	1	0
Pump filters (parts)	1	1	2
Water inlet (parts)	0	0	1
Tanks (parts)	1	4	9
Aerators (parts)	0	5	1
Greenhouse (parts)	0	0	1
Polyvinyl chloride (PVC) accessories	0	0	Several
Postlarvae (organisms)	800 800	1 680 000	630 000
Drugs (part)	0	0	2
Electricity (kW h ⁻¹)	0	81 176.47	30 545
Labor force (employees)	2.00	3.00	2.00
Food (kg)	5903.13	18 648.64	2810.84
Diesel (L)	4700	5800	0
Pond preparations	4	4	1
Molasses (L)	106	213	248
Harvest (people employed)	4	1	0
Probiotic (L)	0	20	15
Silica sand (kg)	0	0	300

Table 2. Cost of the technical variables in the three culture systems evaluated in the municipality of San Blas, in Nayarit, Mexico.

Variable	Cost (USD)*		
	Semi-intensive (SI)	Intensive (I)	Hyperintensive (HI)
Production (kg ha ⁻¹ cycle ⁻¹)	4496.80	7534.80	145 636.80
Sale price	4.00	4.36	5.90
Engines	2051.28	2051.28	422.82
Pumps	4102.56	4102.56	0
Pump filters	82.05	82.05	3610.56
Water inlets	1025.64	1025.64	1897.44
Tanks	8717.95	13 333.33	12 406.15
Aerators	0	2769.23	1205.13
Greenhouse	0	0	24 079.79
Polyvinyl chloride (PVC) accessories	0	0	519.85
Postlarvae	3285.33	6892.31	2584.62
Drugs	0	0	511.38
Electricity	0	3538.46	1331.49
Labor force	2461.54	3461.54	2531.08
Food	5600.41	17 692.31	2666.67
Diesel	2461.54	6923.08	0
Pond preparations	615.38	707.69	0
Molasses	30.77	61.54	71.79
Harvest	1554.62	517.95	0
Probiotic	0	461.54	215.38
Silica sand	0	0	12.21

*Costs are expressed in USD, based on an exchange rate of 19.8 MXN/USD for the year 2023.

Economic variables

In terms of costs (Table 3), System I had the highest expenses for labor, postlarvae, and feed, in addition to harvesting costs due to poor pond design that hindered gravity harvesting. Although system HI incurred the highest fixed and total costs, it also generated the highest net income. This distinction is due to the direct relationship between stocking density and economic returns (Chatvijitkul *et al.*, 2017). However, this same system required a higher break-even point (BEP) (588.89 kg cycle⁻¹), which implies that it needs approximately 50 % of its usual production to avoid losses, in contrast to the 5.64 and 18.92 % observed in systems I and SI, respectively (Figure 1). The IRR results show that system I achieved 30.18 %, surpassing system HI by 18 % and system SI by 22 %. This indicates that for every USD invested, an annual return of 30 % is expected, reflecting that system I generates greater value per unit of investment. Although system HI presents a lower return percentage, it compensates with higher absolute income but requires a longer time to recover the initial investment.

Table 3. Economic variables of the three culture systems evaluated in the municipality of San Blas, in Nayarit, Mexico.

Variable	Production system		
	Semi-intensive (SI)	Intensive (I)	Hyperintensive (HI)
Fixed costs (USD year ⁻¹)	15 979.49	23 364.10	44 422.87
Variable costs (USD year ⁻¹)	16 009.59	40 256.41	7688.72
Total costs (USD)	16 522.41	41 037.59	54 419.28
Net income (USD year ⁻¹)	7914.54	26 212.77	14 857.36
BEP (kg cycle ⁻¹)	365.89	282.14	588.89
BEP (USD cycle ⁻¹)	1463.57	1229.86	3472.94
Cost-benefit analysis (B:C)	1.51	1.66	1.21
IRR (%)	7.53	30.18	11.56

BEP: break-even point; IRR: internal rate of return.

These results are consistent with previous studies (Junge *et al.*, 2017), which indicate that initial investments increase operating costs during the first cycles; however, these costs tend to decrease over time, favoring long-term economic sustainability (Rego *et al.*, 2017). Barros *et al.* (2018) reported that the largest investment (43.18 %) is concentrated in the acquisition of the cultivation system equipment, while only 11.9 % corresponds directly to shrimp farming. The present study confirmed this pattern, identifying even higher percentage values. Furthermore, Rego *et al.* (2017) indicate that, in biofloc systems, expenses can be 10 times higher compared to conventional systems due to the use of more extensive equipment to maintain adequate oxygen levels. According to Junge *et al.* (2017), the highest costs occur in systems with artificial bottoms, as they require more technology and skilled labor, which increases production costs.

The HI system recorded the highest total costs in this study, primarily because of the initial investment. Most of these costs were concentrated in greenhouse construction, geomembrane installation, pumps, blowers, piping, acquisition of reagents for measuring the water's physicochemical variables, labor, periodic pumping, molasses application for nitrogen regulation, and constant aeration, which resulted in higher electricity consumption. In contrast, the costs for the other systems were primarily related to the ponds. However, these initial costs gradually amortize over time, thereby reducing operating costs in future cycles and allowing for a gradual increase in net income.

Despite the high initial costs, the HI system generates higher revenues due to its greater production and selling price, with potential for improved profitability as the investment is amortized. These results are consistent with Chatvijitkul *et al.* (2017) regarding the positive relationship between stocking density and economic yields (Table 4).

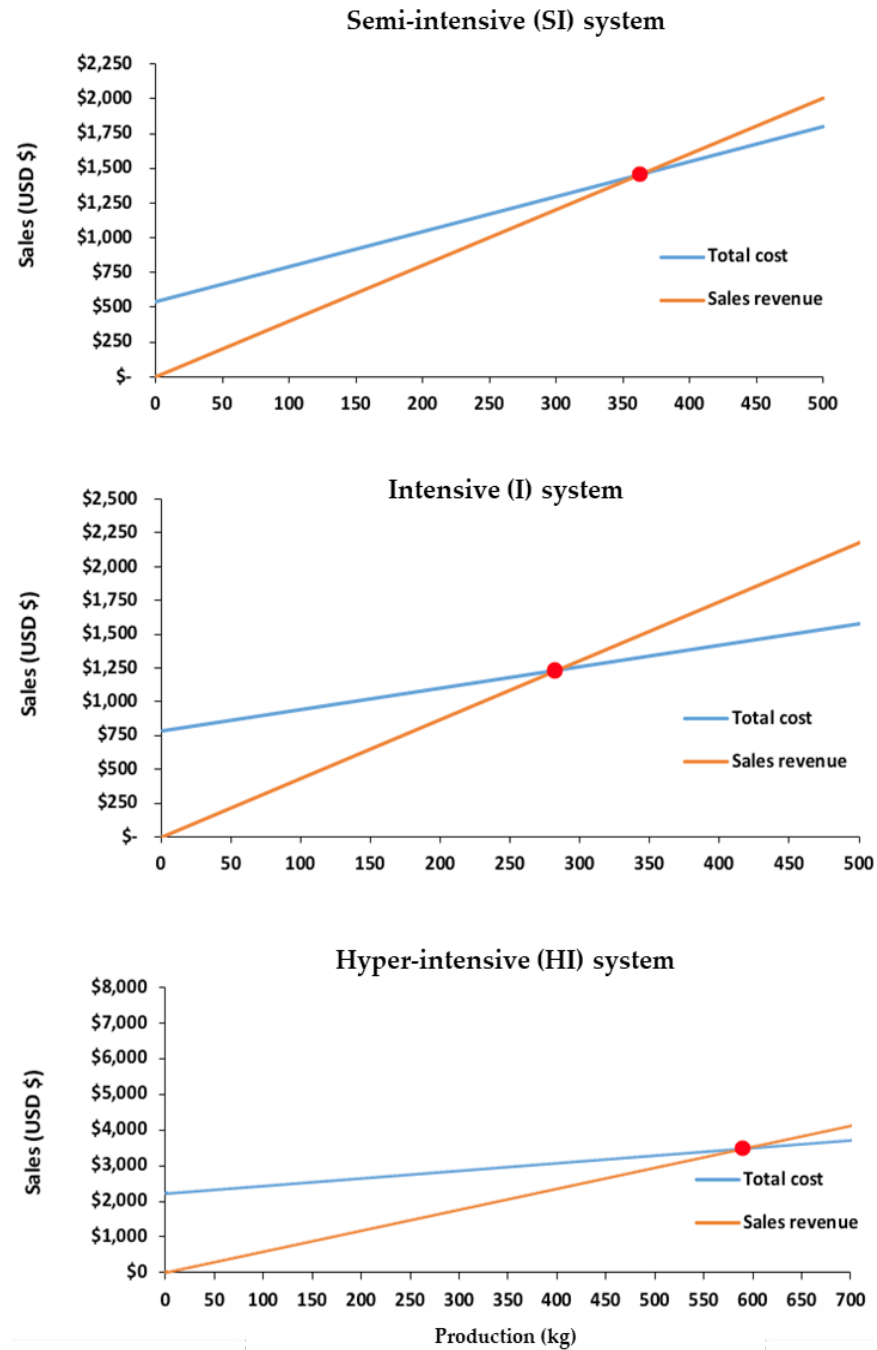


Figure 1. Break-even points resulting from the analysis of total costs (green line) in relation to net income (orange line) per crop cycle in the three production systems evaluated.

Table 4. Time horizon of profitability (%) by system at different years of operation (1, 5, and 10 years).

System	1 year	5 years	10 years
Semi-intensive (SI)	47.9 %	~50 %*	~52 %*
Intensive (I)	63.9 %	~65 %*	~68 %*
Hyperintensive (HI)	27.3 %	40–45 % (after amortization)	50–55 % (optimum)

*Projections based on the reduction of fixed costs through amortization and operational efficiency.

Principal component analysis

The component matrix showed that the highest costs were concentrated in initial expenses, not in post-larvae or feed, which contrasts with the findings of Ponce-Palafox *et al.* (2011). However, revenues increased with higher stocking densities and levels of technology (Chatvijitkul *et al.*, 2017), contrary to the findings of Boyd *et al.* (2016) and Engle *et al.* (2017). Furthermore, the principal component analysis clearly identified two orthogonal linear combinations derived from the 35 original variables (Table 5, Figure 2), which explained 62.25 % of the total variation.

Table 5. Rotated factor matrix derived from principal component analysis applied to 35 variables in the three evaluated farming systems (semi-intensive, intensive, and hyperintensive).

Variable	Component	
	1	2
Hectares	-0.869	0.495
Cycles	0.356	-0.934**
Planting density (m ²)	0.991**	-0.136
Survival (%)	0.824	-0.567
Weight(g)	-0.517	0.856
Production (kg ha ⁻¹ cycle ⁻¹)	0.992**	-0.124
Production (kg ha ⁻¹ year ⁻¹)	0.990**	-0.140
Sale price (USD)	0.999**	0.020
Fixed costs (USD)	0.995**	0.093
Variable costs (USD)	-0.575	0.818
Total costs (USD)	0.862	0.508
Net income (USD)	0.021	0.999**
BEP (kg cycle ⁻¹)	0.910**	-0.414
BEP (\$ cycle ⁻¹)	0.968	-0.251
Benefit-cost (B:C)	-0.881	0.473
IRR	-0.196	0.980**
Engines	-0.987**	0.159
Pumps	-0.987**	0.159

Table 5. Continued.

Variable	Component	
	1	2
Filters	0.987**	-0.159
Water inlets	0.987**	-0.159
Tanks	0.472	0.881
Aerators	0.084	0.996**
Greenhouse	0.987**	-0.159
Pipelines	0.987**	-0.159
Postlarvae	-0.494	0.870
Drugs	0.987**	-0.159
Electricity	0.017	0.999**
Labor	-0.297	0.955**
Food	-0.522	0.853
Diesel	-0.661	0.750
Pond preparation	-0.961**	0.276
Molasses	0.799	0.601
Harvest	-0.850	-0.527
Probiotics	0.121	0.992**
Silica sand	0.987**	-0.159

BEP: break-even point; IRR: internal rate of return. **Significant parameter ($p < 0.05$).

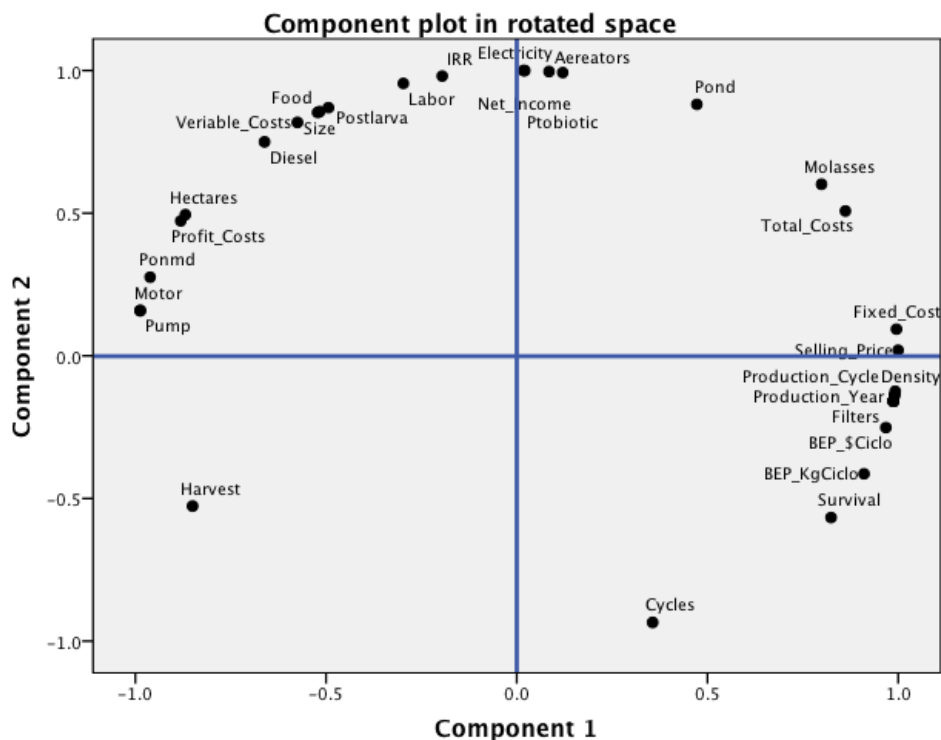


Figure 2. Principal component graph comparing the technical and economic aspects of shrimp farming production in the municipality of San Blas, Nayarit, Mexico.

In the first component, 16 main variables were identified (loads with absolute values ≥ 0.9): three with a negative sign (two related to fixed costs: engine and pump) and 13 with a positive sign. Among the latter, five are related to net income (production $\text{kg ha}^{-1} \text{ cycle}^{-1}$, production $\text{kg ha}^{-1} \text{ year}^{-1}$, selling price, BEP kg cycle^{-1} , and BEP USD cycle^{-1}), four correspond to total costs (fixed costs, water inlets, greenhouse, and piping), and three are associated with variable costs (filters, drugs, and silica sand). All these variables represent essential expenses for the operation of the system, which increase as stocking densities rise and the cultivated area is expanded.

The second component showed seven main variables (loads with absolute values ≥ 0.9). Five were positive, two of which are related to net income based on annual production, while three correspond to variable costs directly associated with increased stocking density (aerators, electricity, and probiotics), whose demand increases to meet the organism's requirements as density rises. One variable had a negative sign (culture cycles). These patterns support the idea that more technologically advanced systems require higher initial expenses but generate better returns per unit area (Hernández-Llamas *et al.*, 2013; Estrada-Pérez *et al.*, 2015).

Hierarchical cluster analysis (Figure 3) revealed two distinct groups: one comprised of systems SI and I, characterized by similar techniques and costs, and another

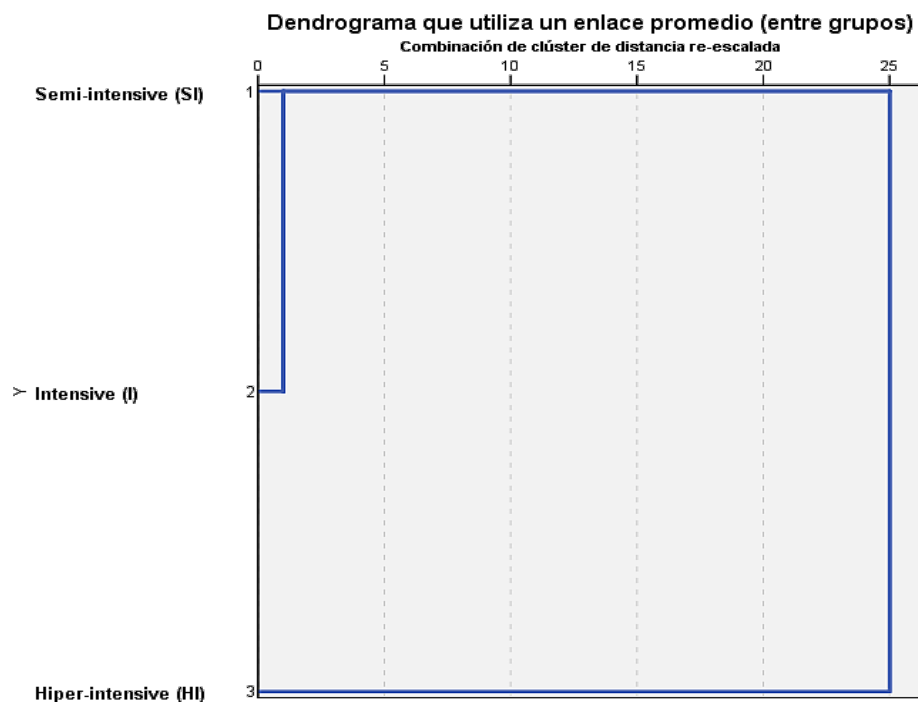


Figure 3. Dendrogram of farming system groups (semi-intensive, intensive, hyperintensive), comparing the technical and economic aspects of shrimp production in the municipality of San Blas Nayarit, Mexico.

corresponding to system HI, which exhibited significant disparities in total costs and final production. These differences reflect the potential of hyperintensive systems to maximize production in a smaller area, albeit at a considerably higher initial cost. It is worth noting that the potential of hyperintensive shrimp farming is remarkable, as it can generate equal or greater yields ($\text{kg ha}^{-1} \text{ cycle}^{-1}$) in a smaller area, and not necessarily at a higher operating cost.

CONCLUSIONS

The results of the technical and economic analyses showed improvements as stocking density increased, reflected in higher yields. These increases allowed fixed costs to be spread over time through amortization, maintaining favorable economic results, since the burden of initial expenses ceases to have an impact as the operation progresses. Within the range of yields and systems evaluated, the more intensive system proved to be more economical in the long term. The analysis showed that higher-intensity systems use fewer resources per unit of shrimp produced. It is recommended to continue evaluating groups of farming systems based on sets of management practices identified through multivariate analysis, rather than relying solely on a single variable such as stocking density.

ACKNOWLEDGEMENTS

We thank the production units “Oro azul”, owned by Mr. Felipe Ramos; Natanael López, owned by Mr. Natanael López; and the Coastal Bioengineering Laboratory of the Autonomous University of Nayarit.

REFERENCES

- Ahsan DA. 2011. Farmers’ motivations, risk perceptions and risk management strategies in a developing economy: Bangladesh experience. *Journal of Risk Research* 14 (3): 325–349. <https://doi.org/10.1080/13669877.2010.541558>
- Araneda M, Hernández JM, Gasca E. 2011. Optimal harvesting time of farmed aquatic populations with nonlinear size-heterogeneous growth. *Natural Resource Modeling* 24 (4): 477–513. <https://doi.org/10.1111/j.1939-7445.2011.00099.x>
- Asche F. 2008. Farming the sea. *Marine Resource Economics* 23 (4): 527–547. <https://doi.org/10.1086/mre.23.4.42629678>
- Barros LC, Almeida FH, Henriques MB, Seiffert WQ. 2018. Economic evaluation of the commercial production between Brazilian samphire and whiteleg shrimp in an aquaponics system. *Aquaculture International* 26 (5): 1187–1206. <https://doi.org/10.1007/s10499-018-0277-8>
- Boyd CE, McNevin AA, Racine P, Tinh HQ, Minh HN, Viriyatum R, Paungkaew D, Engle C. 2016. Resource use of shrimp *Litopenaeus vannamei* and *Penaeus monodon* production in Thailand and Vietnam. *Journal of the World Aquaculture Society* 48 (2): 201–226. <https://doi.org/10.1111/jwas.12394>

- Buarque C. 1984. Avaliação econômica de projetos: uma apresentação didática. Elsevier Campus: Rio de Janeiro, Brasil.
- Chatvijitkul S, Boyd CE, Davis DA, McNevin AA. 2017. Embodied resources in shrimp and fish feeds. *Journal of the World Aquaculture Society* 48 (1): 7–19. <https://doi.org/10.1111/jwas.12360>
- Chitmanat C, Lebel P, Whangchai N, Promya J, Lebel L. 2016. Tilapia diseases and management in river-based cage aquaculture in northern Thailand. *Journal of Applied Aquaculture* 28 (1): 9–16. <https://doi.org/10.1080/10454438.2015.1104950>
- Dávila-López KM, Carvajal-Romero HR, Vite-Cevallos HA. 2020. Análisis de rentabilidad económica del camarón (*Litopenaeus vannamei*) en el sitio Balao Chico, provincia del Guayas. *Polo del Conocimiento* 5 (1): 450–476.
- Drabo A. 2017. Climate change mitigation and agricultural development models: Primary commodity exports or local consumption production. *Ecological Economics* 137: 110–125. <https://doi.org/10.1016/j.ecolecon.2017.03.014>
- Engle CR, D'Abramo L. 2016. Showcasing research focusing on sustainability of aquaculture enterprises and global food security. *Journal of the World Aquaculture Society* 47 (3): 311–313. <https://doi.org/10.1111/jwas.12296>
- Engle CR, McNevin A, Racine P, Boyd CE, Paungkaew D, Viriyatum R, Minh HN. 2017. Economics of sustainable intensification of aquaculture: Evidence from shrimp farms in Vietnam and Thailand. *Journal of the World Aquaculture Society* 48 (2): 227–239. <https://doi.org/10.1111/jwas.12423>
- Estrada-Pérez M, Ruiz-Velazco JM, Hernández-Llamas A, Zavala-Leal I. 2015. A bio-economic approach to analyze the role of alternative seeding-harvesting schedules, water quality, stocking density and duration of cultivation in semi-intensive production of shrimp in Mexico. *Latin American Journal of Aquatic Research* 43 (3): 466–472. <https://doi.org/10.3856/vol43-issue3-fulltext-8>
- Estrada-Pérez N, Ruiz-Velazco JM, Hernández-Llamas A. 2020. Economic risk scenarios for semi-intensive production of *Litopenaeus (Penaeus) vannamei* shrimp affected by acute hepatopancreatic necrosis disease. *Aquaculture Reports* 18: 100442. <https://doi.org/10.1016/j.aqrep.2020.100442>
- Flaherty M, Samal KC, Pradhan D, Ray S. 2009. Coastal aquaculture in India: Poverty, environment and rural livelihood. Concept Publishing Company: New Delhi, India. 296 p.
- Gobillon L, Wolff FC, Guillotreau P. 2016. The effect of buyers and sellers on fish market prices. The effect of buyers and sellers on fish market prices. *European Review of Agricultural Economics* 44 (1): 149–176. <https://doi.org/10.1093/erae/jbw006>
- Hamilton K, Chen A, de-Graft E, Gitter A, Kozak S, Niquice C, Gurian P. 2018. *Salmonella* risks due to consumption of aquaculture-produced shrimp. *Microbial Risk Analysis* 9: 22–32. <https://doi.org/10.1016/j.mran.2018.04.001>
- Hernández-Llamas A, Ruiz-Velazco JM, Gómez-Muñoz VM. 2013. Economic risk associated with white spot disease and stochastic variability in economic, zootechnical and water quality parameters for intensive production of *Litopenaeus vannamei*. *Reviews in Aquaculture* 5 (2): 121–131. <https://doi.org/10.1111/raq.12008>
- Horngren CT, Datar SM, Rajan MV. 2012. Cost accounting: A managerial emphasis (14th edition). Prentice Hall: Hoboken, NJ, USA. 730 p.
- Junge R, König B, Villarroel M, Komives T, Jijakli MH. 2017. Strategic points in aquaponics. *Water* 9 (3): 182. <https://doi.org/10.3390/w9030182>

- Kabir MJ, Cramb R, Alauddin M, Roth C, Crimp S. 2017. Farmers' perceptions of and responses to environmental change in southwest coastal Bangladesh. *Asia Pacific Viewpoint* 58 (3): 362–378. <https://doi.org/10.1111/apv.12165>
- Khan A, Guttormsen A, Roll KH. 2018. Production risk of pangas (*Pangasius hypophthalmus*) fish farming. *Aquaculture Economics and Management* 22 (2): 192–208. <https://doi.org/10.1080/13657305.2017.1284941>
- Le TC, Cheong F. 2010. Perceptions of risk and risk management in Vietnamese catfish farming: an empirical study. *Aquaculture Economics and Management* 14 (4): 288–314. <https://doi.org/10.1080/13657305.2010.526019>
- Little DC, Newton RW, Beveridge MCM. 2016. Aquaculture: A rapidly growing and significant source of sustainable food? Status, transitions and potential. *Proceedings of the Nutrition Society* 75 (3): 274–286. <https://doi.org/10.1017/S0029665116000665>
- Llorente I, Luna L. 2013. The competitive advantages arising from different environmental conditions in seabream, *Sparus aurata*, production in the Mediterranean Sea. *Journal of the World Aquaculture Society* 44 (5): 611–627. <https://doi.org/10.1111/jwas.12069>
- Luna M, Llorente I, Luna L. 2023. A conceptual framework for risk management in aquaculture. *Marine Policy* 147: 105377. <https://doi.org/10.1016/j.marpol.2022.105377>
- Milstein A, Islam MS, Wahab MA, Kamal AHM, Dewan S. 2005. Characterization of water quality in shrimp ponds of different sizes and with different management regimes using multivariate statistical analysis. *Aquaculture International* 13 (6): 501–518. <https://doi.org/10.1007/s10499-005-9001-6>
- Ottinger M, Clauss K, Kuenzer C. 2016. Aquaculture: Relevance, distribution, impacts and spatial assessments – A review. *Ocean and Coastal Management* 119: 244–266. <https://doi.org/10.1016/j.ocecoaman.2015.10.015>
- Piamsomboon P, Inchaosri C, Wongtavatchai J. 2015. White spot disease risk factors associated with shrimp farming practices and geographical location in Chanthaburi province, Thailand. *Diseases of Aquatic Organisms* 117 (2): 145–153. <https://doi.org/10.3354/dao02929>
- Ponce-Palafox JT, Ruiz-Luna A, Castillo-Vargasmachuca S, García-Ulloa M, Arredondo-Figueroa JL. 2011. Technical, economics and environmental analysis of semi-intensive shrimp (*Litopenaeus vannamei*) farming in Sonora, Sinaloa and Nayarit states, at the east coast of the Gulf of California, México. *Ocean and Coastal Management* 54 (7): 507–513. <https://doi.org/10.1016/j.ocecoaman.2011.03.008>
- Posadas BC, Hanson TR. 2006. Economics of integrating nursery systems into indoor biosecure recirculating saltwater shrimp grow-out systems. In *Shrimp Culture: Economics, Market, and Trade*. Wiley: Hoboken, NJ, USA, pp: 279–289. <https://doi.org/10.1002/9780470277850.ch18>
- Rego MAS, Sabbag OJ, Soares R, Peixoto S. 2017. Financial viability of inserting the biofloc technology in a marine shrimp *Litopenaeus vannamei* farm: A case study in the state of Pernambuco, Brazil. *Aquaculture International* 25 (1): 473–483. <https://doi.org/10.1007/s10499-016-0044-7>
- Shawon NAA, Prodhan MMH, Khan MA, Mitra S. 2018. Financial profitability of small scale shrimp farming in a coastal area of Bangladesh. *Journal of the Bangladesh Agricultural University* 16 (1): 104–110. <https://doi.org/10.3329/jbau.v16i1.36490>
- Tidbury HJ, Taylor NGH, Copp GH, Garnacho E, Stebbing PD. 2016. Predicting and mapping the risk of introduction of marine non-indigenous species into Great Britain and Ireland. *Biological Invasions* 18 (11): 3277–3292. <https://doi.org/10.1007/s10530-016-1219-x>

Zhang D, Tveterås R. 2019. A fish out of water? Survival of seafood products from developing countries in the EU market. *Marine Policy* 103: 50–58. <https://doi.org/10.1016/j.marpol.2019.02.030>

Agrociencia