Economic analysis of intensive and super-intensive *Litopenaeus vannamei* shrimp production in a Biofloc Technology system

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ABSTRACT

In recent decades, new aquaculture technologies have been developed and improved, such as the Biofloc Technology system, which is considered an alternative to the conventional aquaculture model. This study compared the bioeconomic viability of intensive production in nurseries and super-intensive production of shrimp *Litopenaeus vannamei* bioflocs greenhouses. The investment for implementing the project was US$ 767,190.18 for intensive production and US$ 807,669.16 for super-intensive production. The analyses showed Net Present Value of US$ 363,718.21 and US$ 385,477.42, Equivalent annual value of US$ 59,830.66 and US$ 63,410.00, Net future value of US$ 965,052.69 and US$ 1,022,786.35, Payback Period 4.12 and 4.11, Discounted payback period 5.64 and 5.63, Profitability Index 1.47 and 1.48, Internal Rate of Return 20.49 and 20.55%, and Modified Internal Rate of Return 14.61 and 14.64%. The investment analysis used in this study showed that super-intensive production in a greenhouse is the best investment option. The development of a new scenario simulating the super-intensive production of shrimp in a Biofloc Technology system, considering land use as a premise, made it possible to observe the possibility of obtaining financial gains in scale, both in the reduction of production costs and in the economic performance of the enterprise. However, the financial contribution for the implementation and operation of the project increased substantially.

Keywords: biofloc technology; investment analysis; sensitivity analysis; aquaculture management; modern aquaculture.

Análise econômica da produção intensiva e superintensiva de camarão Litopenaeus Vannamei em sistema de bioflocos

RESUMO

Nas últimas décadas, novas tecnologias aquícolas têm sido desenvolvidas e aprimoradas, como o sistema de bioflocos, considerado uma alternativa ao modelo convencional aquícola. O presente estudo compara a viabilidade bioeconômica da produção intensiva em viveiros com a da produção superintensiva em estufas do camarão *Litopenaeus vannamei* em bioflocos. O investimento para implantação do projeto foi de US$ 767.190,18 para produção intensiva e US$ 807.669,16 para superintensiva. As análises apresentaram valor presente líquido de US$ 363.718,21 e US$ 385.477,42, valor anual equivalente de US$ 59.830,66 e US$ 63.410,00, valor futuro líquido de US$ 965.052,69 e US$ 1.022.786,35, período de payback 4,12 e 4,11, payback descontado 5,64 e 5,63, índice de lucratividade 1,47 e 1,48, taxa interna de retorno 20,49 e 20,55% e taxa interna de retorno modificada 14,61 e 14,64%. As análises de investimentos neste estudo mostraram que a produção superintensiva em estufas é a melhor opção. O desenvolvimento de um novo cenário simulando a produção superintensiva de camarões em sistema de bioflocos, considerando o uso da terra como premissa, permitiu observar a possibilidade de ganhos financeiros em escala tanto na redução dos custos de produção quanto no desempenho econômico do empreendimento. No entanto, a contribuição financeira para implantar e operar o projeto aumentou substancialmente.

Palavras-chave: tecnologia de bioflocos; análise de investimentos; análise de sensibilidade; gestão aquícola; aquicultura moderna.

INTRODUCTION

With a projected increase in the world's population of another two billion people by 2050, global pressure on natural resources will intensify (Godfray et al., 2010; UN, 2019). Meanwhile, there is increasing demand from public policy makers and consumers for the implementation of sustainable practices in the agricultural sector (Bartolini et al., 2016; Soto, 2021). In this context, the development of global

agribusiness faces two major challenges. The first is to increase food production to ensure food security[1], and the second is to mitigate the environmental impacts generated by this increase in production (Godfray et al., 2010).

According to data from the Food and Agricultural Organization of the United Nations (FAO, 2020a), between 2001 and 2018 aquaculture production grew on average by 5.3% per year. Among the various aquaculture sectors, shrimp farming is particularly notable (Almeida et al., 2021) as it is a commercially significant enterprise that includes a group of high market value species (FAO, 2010b), making it one of the most important activities in the sector (FAO, 2016, 2018, 2020a). However, despite the positive growth in aquaculture in recent decades, the FAO (2020b) warns that the COVID-19 pandemic will continue to have a significant impact on the sector, especially the production of shrimp and salmon.

The production of farmed shrimp in Brazil is mainly focused on the Pacific whiteleg shrimp, *Litopenaeus vannamei* (FAO, 2020a). The species has excellent zootechnical performance, rusticity and closed technological package, and well-defined technological practices, factors that make it one of the most commonly produced shrimp species in the world (Cuzon et al., 2004; FAO, 2018, 2020a).

The installation of conventional shrimp production systems requires large areas, proximity to the ocean or estuaries, and the use of large volumes of water to maintain pond water quality within acceptable levels for the species (Silva et al. 2015; Almeida et al., 2021). These semi-intensive systems use low stocking densities, from 5 to 45 animals/m², and obtain average yields of approximately 4.5 ton/ha/year (Ostrensky et al., 2008).

However, modern aquaculture practices must develop and evolve toward sustainability, finding a balance between environmental, economic, and social concerns (FAO, 2018; Siqueira, 2018). As opposed to the conventional model of shrimp production, modern shrimp farming seeks to be both environmentally sustainable and economically viable. As such, researchers, companies, and producers have engaged in efforts to develop more efficient production systems in terms of both environment and productivity. New aquaculture technologies have been established and improved, such as the Biofloc Technology (BFT) system, which is an alternative to the conventional aquaculture model (Panigrahi et al., 2018; Ren et al., 2019; Yu et al., 2020).

BFT is based on the conversion of organic waste from the cultivation environment into microbial biomass, which can be used as a feed supplement in the nutritional management of the organisms (Avnimelech, 2007; Gaona et al., 2017; Panigrahi et al., 2018). It is particularly noteworthy due to improved biosecurity (Wasielesky et al., 2006; Krummenauer et al.,

2011) and the use of smaller areas and less water compared to the conventional system (Krummenauer et al., 2012; Vieira et al., 2019). However, due to the high stocking densities that the system supports, it requires constant monitoring and maintenance of water quality parameters (Wasielesky et al., 2006; Krummenauer et al., 2011; Costa et al., 2018; Nguyen et al., 2019). In terms of nutrition, bioflocs offer significant potential as feed supplements for the produced organisms, resulting in better feed conversion rates and, consequently, reduced production costs (Wasielesky et al., 2006; Panigrahi et al., 2018).

The BFT system makes it possible to optimize the use of production factors, as it allows intensive and super-intensive shrimp production in small areas, with stocking densities that can vary from 100 to 450 shrimp/m³. According to Taw (2010), the most used densities in intensive cultivation are in nurseries, at the biofloc system, is 130–150 shrimp per m². Wasielesky et al. (2016) added that the system allows the use of high stocking densities in intensive grow-out ponds, from 100 to 200/m², and in raceways, with the possibility of carrying out stocking with 300–600 shrimp/m² in a super-intensive system.

The possibility of using high stocking densities in the BFT system converges in greater production using smaller spaces, thus overcoming not only the problem of the lack of areas for the aquaculture projects implementation (Krummenauer et al., 2011) and also the possibility of better financial results for the business (Almeida et al., 2021).

Factors such as intensification, species diversification, as well as the introduction of innovations and technologies have contributed to the growth of aquaculture (FAO, 2016). In this context, stocking density is an important factor to consider, since it has a direct influence on production (Jackson and Wang, 1998), and the consequent profitability of an enterprise (Almeida et al., 2021). Despite the environmental, sanitary, and economic advantages (Krummenauer et al., 2012; Rego et al., 2017a; Nguyen et al., 2019; Shinji et al., 2019; Vieira et al., 2019), implementing and operating BFT systems requires significant investment (Poersch et al., 2012). As with other economic activities, production costs in aquaculture are directly related to the profitability of the business (Di Trapani et al., 2014). Although this is an important issue, there are few studies that have examined the costs and benefits of shrimp production in BFT systems (Shinji et al., 2019).

Thus, the present study aimed to analyze and compare the bioeconomic viability of intensive and super-intensive production of *L. vannamei* in a BFT system located on the south coast of the state of Rio Grande do Sul, Brazil. For this, the costs of implementing and operating two enterprises with distinct production strategies were calculated: intensive shrimp production in a BFT system with rearing ponds, and super-intensive shrimp production in a BFT system with greenhouses. After data collection, a feasibility analysis of the investments was applied.

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[1]"Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 2010a).

MATERIALS AND METHODS

Investment analysis methods and criteria

The investment analysis includes tools that enable decision-making under conditions of uncertainty, seeking to eliminate or minimize risk. An investment is accepted or rejected based on predefined and widely tested criteria.

In this study, the following investment analysis criteria were applied: Net Present Value (NPV), Equivalent Annual Value (EAV), Payback Period (PP), Discounted Payback Period (DPP), Profitability Index (PI), Internal Rate of Return (IRR), and Modified Internal Rate of Return (MIRR). The mathematical equations and decision-making criteria can be found in the studies by Gollier (2010), Blank and Tarquin (2011), Blank et al. (2014), Gitman and Zutter (2018), Ruiz Campo and Zuniga-Jara (2018), Mazzarol and Reboud (2020), Mejía-Ramírez et al. (2020), Sarsour and Sabri (2020), and Almeida et al. (2021).

Production systems

Intensive production in rearing ponds (intensive system) consists of four ponds with a useful volume of 3,350 m³ (Appendix 1). The super-intensive production system in greenhouses (super-intensive system) consists of 10 greenhouses with 600 m³ tanks (Appendix 2). The total annual production for both systems is 69,120 kg of shrimp *in natura.*

The evaluated systems are characterized by being mutually exclusive projects. Despite the different characteristics existing between the production of white shrimp *L. vannamei*, in an intensive and super-intensive BFT system, the same production volume was adopted as the main parameter for the elaboration of the projects of the two production strategies (23.040 kg per harvest), in order to facilitate the comparison between the results of the economic feasibility analyses of the evaluated investment projects.

The first production cycle considered the formation of the biofloc from the manipulation of the carbon and nitrogen ratio (C:N) in the environment. For this, fertilization was carried out by adding sugarcane molasses and wheat bran to the cultivation water. In the other cycles, the water with biofloc obtained from the previous cycles was used. Biofloc maintenance is carried out with the addition of sugarcane molasses and wheat bran, along with the feed, maintaining a C: N ratio of 20: 1 (Avnimelech, 1999).

Data on the costs of implementation were budgeted based on quotes from specialized companies in local currency (Real) and converted into U.S. dollars (exchange rate on October 16, 2021). Data related to productivity, zootechnical performance, and production costs were obtained over eight cycles for both the intensive system with rearing ponds and the super-intensive system with greenhouses, installed at the Aquaculture Marine Station, Oceanography Institute of the Federal University of Rio Grande (FURG), in the state of Rio Grande do Sul, Brazil. For the study, the average cost of land in the region was considered.

In the economic analyses of super-intensive production, we also used data obtained by Almeida et al. (2021). Due to the exchange variation of the Brazilian currency (Real) against the U.S. dollar that occurred in the period between the studies, it was necessary to update these data.

Intensive system

The fixed investment corresponds to the construction of four excavated ponds with a useful area of 3,350 m³ each, for a total of 13,400 m³ of total useful production area. This amount includes costs related to excavation and earthmoving services for pond construction, geomembrane lining (HDPE), bird-proof mesh covering to avoid shrimp predation, a 7.5-HP water pump, hydraulic and electrical networks, aerators, a 55-kVA generator, parameter monitoring equipment, nets, maintenance equipment, fixed costs, variable costs, and working capital. Other budgeted costs include the acquisition of a 3 ha area to establish the enterprise, the construction of a footbath and shower arch at the entrance of the PUs to disinfect vehicles entering the vicinity (biosecurity), and the construction of an 80 m² building that serves as a feed and supply storage area, guard house, and employee break area.

The stocking density used was 179.11 shrimp/m³ and the survival rate was 80%, resulting in a production of 23,040 kg/shrimp/cycle and 69,120 kg/shrimp/year (3 cycles/year) (Table 1).

Table 1. Summary of zootechnical variables, production unit (PU) characteristics, and production strategies used in the bioeconomic analysis of intensive production and super-intensive production BFT systems of whiteleg shrimp, *Litopenaeus vannamei.*

	Quantity
Stocking density intensive production (shrimp/m³)	179.11
Stocking density super-intensive production (shrimp/m³)	400
Average weight (kg)	0.012
Survival (%)	80
FCR	1.6
Useful volume of PUs intensive production (m³)[2]	13,400
Useful volume of PUs super-intensive production (m³)[1]	6,000
Production per harvest (kg)	23,040
Harvests (per year)	3
Total production (kg/year)	69,120
Productivity intensive production (kg/m³/year)	5.16
Productivity super-intensive production (kg/m³/year)	11.52

FCR: feed conversion ratio. [1]The intensive system includes four rearing ponds each with a useful volume of 3,350 m³; the super-intensive system consists of 10 greenhouses, each with 2 adjoined tanks, for a total useful volume of 600 m³.

Harvesting and commercialization is based on live animals with an average weight of 12 g.

For the formation and maintenance of bioflocs in the BFT system, 6,699.80 and 2,999.81 kg of sugarcane molasses and 669.77 and 299.98 kg of wheat bran were used in the intensive production and super-intensive, respectively.

Table 1 provides a summary of the zootechnical variables, production unit (PU) characteristics, and production strategies used in the bioeconomic analysis.

Table 2 is a summary of the fixed investments and working capital for intensive production of *L. vannamei* in rearing ponds in a BFT system.

Super-intensive system

The fixed investment for the super-intensive system considers 10 PUs, with a total individual useful volume of 600 m³. Each PU consists of a greenhouse constructed with galvanized steel arches and covered in plastic sheeting, two wooden boxes covered with PEAD geomembrane (1.0 mm) with a sand bottom (tanks), and a footbath. The hydraulic network includes water inlet pipes (60 mm), drainage pipes (150 mm), a 4.0 HP aerator, primary (60 mm) and secondary (20 mm) aeration pipes, and diffusers.

The following costs were also considered: acquisition of an area of 2 ha to establish the enterprise; equipment for monitoring water quality parameters, maintenance, and shrimp management; fixed costs; variable costs; and working capital. As with the intensive system, the construction of an 80 m² building was also included in the budget (Table 3).

For the super-intensive system, the zootechnical variables used in the simulations were as follows: stocking density of 400 shrimp/m³, survival rate of 80%, and production of 23,040 kg/cycle and 69,120 kg/year (3 cycles/year) (Table 1). Harvesting and commercialization is based on live animals with an average weight of 12 g. Based on land use, a new scenario was drawn up comparing the economic performance of super-intensive production in greenhouses, in an area of the same size, in which the economic feasibility analyses of intensive production in nurseries were carried out (total area of 3.0 ha and structures of production with a total useful volume of 13,400 m³). The zootechnical variables were maintained (stock density 400 shrimp/m³, FCA 1.6 and 80% survival, and average final weight of 12 g).

RESULTS

For the intensive system, the fixed investment for the implementation of the enterprise was US$ 252,326.84 (Table 2)

Table 2. Summary of fixed investments and working capital for intensive production of *Litopenaeus vannamei* in a BFT system.

	Quantity	Unit value (US$)	Total (US$)
Fixed investment			252,326.84
Land (ha)	3	4,140.71	12,422.13
Production structure*	4	32,110.35	128,441.41
Paddlewheel aerators 1.0 CV	48	982.25	47,147.93
Edifications (80 m²)	1	40,525.25	40,525.25
Equipment of parameters measurement	–	–	3,337.64
Networks and equipment of maintenance	–	–	1,668.81
Generator (55 Kva)	1	17,218.91	17,218.91
Catchment pump (7.5 HP)	1	1,564.76	1,564.76
Working capital			198,496.80
TOTAL			450,823.64

*Excavated nurseries with HDPE geomembrane coating (1.0 mm), anti-bird mesh, footbath/whirlpool, hydraulic network, and electrical network. U.S. dollar quotation on October 16, 2021: 5.4504 Brazil Real.

Table 3. Summary of fixed investment and working capital for the super-intensive production of *Litopenaeus vannamei* in a BFT system[1].

	Quantity	Unitary value (US$)	Total (US$)
Fixed investment			292,571.75
Land (ha)	2	4,140.71	8,281.42
Production structure[2]	10	21,997.49	219,974.96
Edifications (80 m²)	1	40,525.25	40,525.25
Equipment of parameters measurement	–	–	3,337.64
Networks and equipment of maintenance	–	–	1,668.81
Generator (55 Kva)	1	17,218.91	17,218.91
Catchment pump (7.5 HP)	1	1,564.76	1,564.76
Working capital			208,947.35
Total			501,519.09

[1]Updated data from Almeida et al. (2021). [2]Production structure (greenhouse): galvanized arches, plastic film, wooden box with geomembrane coating (1.0 mm) and sand bottom, clarifiers, hydraulic network, electrical network, 4.0 HP blower, aeration pipe primary (60 mm) and secondary (20 mm). and air diffusers. U.S. dollar quotation on October 16, 2021: 5.4504 Brazil Real.

and the total capital contribution[2] was US$ 767,190.18; for the super-intensive system, the fixed investment was US$ 292,571.75 (Table 3) and total capital contribution was US$ 807,669.16.

The most significant cost in the implementation of the enterprises were the PUs, which represents 50.90% of the fixed investment (US$ 128,441.41) (Table 2) and 16.74% of the total investment in the intensive system, and 75.19% of the initial investment (US$ 219,974.96) (Table 3) and 27.23% of the total investment in the super-intensive system. This difference is mainly due to the greater number of PUs in the super-intensive system and the fact that the greenhouses require more investment in infrastructure and equipment (i.e., aerators, aeration pipes, and covered structures) compared to the intensive system (see note in Tables 2 and 3).

The working capital for both projects corresponds to 34.90% of the sum of the total amount of fixed investment, fixed costs, and variable costs of each enterprise, corresponding to US$ 198,475.27 for the intensive system (Table 2) and US$ 208,947,35 for the super-intensive system (Table 3).

To implement the super-intensive production system in greenhouses, the cost was US$ 48.76/m³, a value 2.59 times greater than that obtained for the rearing ponds (US$ 18.83/m³). This significantly higher value is related to the costs associated with the greenhouses.

Among the fixed costs of the intensive and super-intensive enterprises, salaries and taxes were the most significant, corresponding to US$ 45,532.61 (Table 4).

The fixed costs of both BFT system projects are listed in Table 4.

Table 4. Fixed costs of intensive production in rearing ponds and super-intensive production in greenhouses of *Litopenaeus vannamei* in a BFT system.

Item	Value (US$)
Employees salary (/year)	13,912.45
Manager salary (/year)	19,323.03
Charges (37% upon the payroll) (/year)	12,297.33
Accountant (/year)	5,106.60
Electrical energy building and security (/year)	2,898.45
Tap water (/year)	1,501.93
RLT intensive production (/year)	750.89
RLT super-intensive production (/year)	500.64
Maintenance (/year)	2,649.75
TOTAL INTENSIVE PRODUCTION (US$)	58,440.22
TOTAL SUPER-INTENSIVE PRODUCTION (US$)	58,189.27

RLT: Rural land tax. U.S. dollar quotation on October 16, 2021: 5.4504 Brazil Real.

Feed, electricity, post-larvae acquisition, sugar cane molasses, and wheat bran are the main variable costs for the intensive and super-intensive production systems of *L. vannamei* (Table 5). Among the variable costs, nutrition (commercial feed) was the most significant, representing 59.73% of total production costs (fixed and variable costs) in the intensive system and 61.74% in the super-intensive system, followed by electricity at 11.80 and 9.34%, and the cost of post-larvae acquisition at 8.83 and 9.13%, respectively. Salaries and taxes represent 14.39% of the total production cost in the intensive enterprise and 14.87% in the super-intensive system. The inputs used in the formation and maintenance of the biofloc, although essential for the BFT system, were the items that were less relevant in terms of production costs. Sugar cane molasses and wheat bran represented 1.55 and 0.04% of the total production costs in intensive production and 0.72 and 0.02% in super-intensive production, respectively (Figure 1).

The relative participation of each item (%) in the total costs for intensive production and super-intensive production of *L. vannamei* in a BFT system can be seen in Figure 1.

The commercialization of 69,120 kg of live shrimp at a sale price of US$ 8.26 generates a gross revenue of US$ 570,931.20 for each enterprise. From this value, we subtracted US$ 384,899.82 for the intensive system and US$ 374,661.81 for the super-intensive system, which corresponds to fees and fixed and variable costs. Net profits were US$ 185,969.68 for the intensive system and US$ 196,269.39 for the super-intensive production system (Table 6).

The net profit generated per m³ of the PUs was US$ 13.88 for the intensive system (total useful volume of 13,400 m³ and shrimp with an average weight of 12.00 g/unit) and US$ 32.71 for the super-intensive system (total useful volume of 6,000 m³ and shrimp with average weight of 12.0 g).

Table 5. Variable costs for intensive production in rearing ponds and super-intensive in greenhouses of *Litopenaeus vannamei* in a BFT system.

Item	Value (US$)
Post-larvae (thousand)	27,949.25
Commercial feed	189,011.43
Sugar cane molasses intensive production	4,890.86
Wheat bran intensive production	120.56
Sugar cane molasses super-intensive production[2]	2,189.86
Wheat bran super-intensive production[2]	54.00
Electrical energy intensive production	34,453.14
Electrical energy super-intensive production[2]	27,232.94
Several[1]	1,522.32
TOTAL INTENSIVE PRODUCTION	257,947.85
TOTAL SUPER-INTENSIVE PRODUCTION	247,960.09

[1]Compounds for the correction of the pH and alkalinity, probiotic, sodium hypochlorite, and structure maintenance. U.S. dollar quotation on October 16, 2021: 5.4504 Brazil Real. [2]Updated data from Almeida et al. (2021).

A second scenario was designed to evaluate super-intensive production considering the same area used in intensive production in nurseries, presented a fixed investment for the implementation of the project of US$ 607,162.36 and the total capital contribution was US$ 1,633,710.34. The estimated annual production was 154,368 kg (51,456 kg per harvest, 3 harvests/year), generating the value of US$ 1,275,079.68 as gross incomes. Total production costs amounted to US$ 756,909.93 (taxes US$ 153,009.56, fixed cost US$ 83,715.20, and variable cost US$ 520,185.17). The amount referring to depreciation was US$ 55,826.75/year. Net income was US$ 518,169.75.

The super-intensive production in scenario 2 provided an increase of 123.33% in production (going from 69.120 to 154,368 kg). The enterprise's net profit in this new context was US$ 38.67/m³, 178.60% higher than the intensive system (US$ 13.88) and 18.24% higher than the same system operating in a smaller area (US$ 32.71).

The projection of cash flow, payback, and discounted payback of intensive production in rearing ponds and super-intensive production in greenhouses of Litopenaeus vannamei in a BFT system are presented in Tables 7 and 8.

Among the applied methods, the intensive system obtained better results in five of them (PB, DPP, PI, IRR and MIRR), while the super-intensive system presented better results in three (NPV, EAV and NFV). The results of the economic analyses showed no significant differences in any of the methods and criteria used to compare the economic viability of the two production systems assessed herein. The results of these analyses can be seen in Table 9.

DISCUSSION

Teixeira and Guerrelhas (2011) found that when adapting commercial shrimp ponds (7,800 m²) from semi-intensive to intensive production using a BFT system, the result was a cost of US$ 7.56/m². In this study, a cost of US$ 18.83/m³ was found for the implementation of an intensive production enterprise with rearing ponds. This value is higher than that obtained by Rego et al. (2017a, 2017b) of US$ 14.83/

Table 6. Simplified cash flow for intensive production in rearing ponds and super-intensive production in greenhouses of *Litopenaeus vannamei* in a Biofloc Technology system.

Item	Value/quantity
Production (kg)	69,120
Sale price (US$/kg)	8.26
Gross revenue (US$)	570,931.20
Tax, fixed, and variable costs intensive production (US$)	-384,899.82
Tax, fixed, and variable costs super-intensive production (US$)	-374,661.81
NET PROFIT INTENSIVE PRODUCTION (US$)	186,031.38
NET PROFIT SUPER-INTENSIVE PRODUCTION (US$)	196,269.39

U.S. dollar quotation on October 16, 2021: 5.4504 Brazil Real.
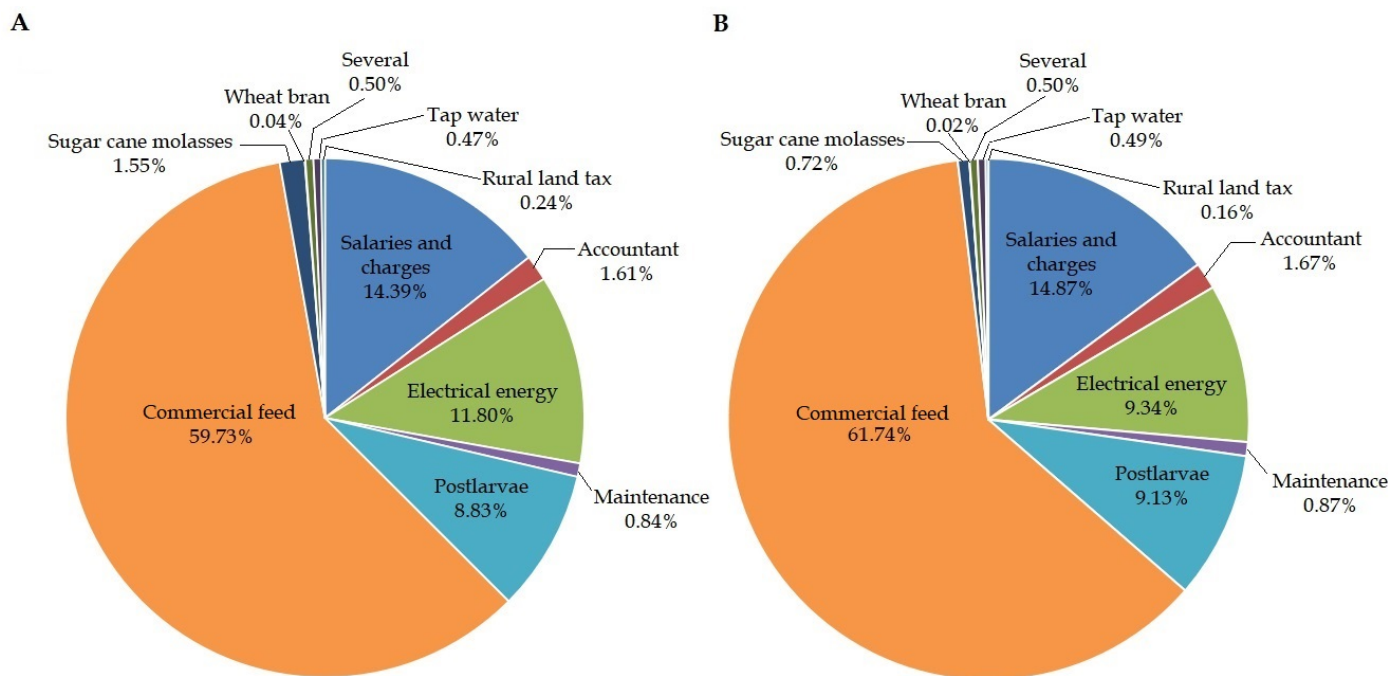
Figure 1. Relative participation of each item (%) in the total cost of intensive production in rearing ponds (A) and super-intensive production in greenhouses (B) of Litopenaeus vannamei in a BFT system.

m² when adapting conventional rearing ponds in the state of Pernambuco, Northeast Brazil, to an intensive BFT production system. This difference is partly related to the U.S. dollar quotation in November 2014, when the study was carried out (US\$ 1.00=R\$ 2.49). Similarly, Mauladani et al. (2020) reported a cost of US\$ 16.23/m² for the implementation of intensive production ponds in a BFT system while testing the influence of nanobubbles on *L. vannamei* survival in a super-intensive system in Indonesia.

The use of greenhouses for shrimp production has attracted the attention of researchers and producers in several countries, as they offer the possibility of producing shrimp in subtropical and temperate climate regions. Greenhouses are used to maintain a consistent water temperature, avoiding fluctuations and abrupt temperature drops, which can be harmful, or even lethal, to shrimp (Castilho-Barros et al., 2018; Van Wyk and Scarpa, 1999; Ponce-Palafox et al., 1997). However, their use has some disadvantages, including higher installation costs,

Table 7. Projection of cash flow, payback, and discounted payback of intensive production in rearing ponds of *Litopenaeus vannamei* in a Biofloc Technology system, with an average final weight of 12 g, a 10-year horizon, and a Minimum Attractive Rate of Return of 10.25%.

Period (year)	Production (kg)	SP (US$)	Revenue (US$)	PT (US$)	Fixed costs (US$)	Variable costs (US$)	Balance (US$)	Payback period (US$)	Discounted payback (US$)
0	0						-767,190.18	-767,190.18	-767,190.18
1	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	-581,158.80	-598,454.24
2	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	-395,127.42	-445,405.76
3	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	-209,096.04	-306,586.28
4	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	-23,064.66	-180,672.92
5	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	162,966.72	-66,465.79
6	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	348,998.11	37,123.45
7	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	535,029.49	131,081.94
8	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	721,060.87	216,305.06
9	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	907,092.25	293,604.94
10	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	1,093,123.63	363,718.21

SP: sale price; PT: production tax.

Table 8. Projection of cash flow, payback, and discounted payback of super-intensive production in greenhouses of *Litopenaeus vannamei* in a Biofloc Technology system, with an average final weight of 12 g, a 10-year horizon, and a Minimum Attractive Rate of Return (MARR) of 10.25%.

Period (year)	Production (kg)	SP (US$)	Revenue (US$)	PT (US$)	Fixed costs (US$)	Variable costs (US$)	Balance (US$)	Payback period (US$)	Discounted payback (US$)
0	0	–	–	–	–	–	-807,669.16	-807,669.16	-807,669.16
1	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	-611,399.76	-629,647.03
2	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	-415,130.37	-468,175.71
3	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	-218,860.97	-321,716.47
4	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	-22,591.58	-188,873.62
5	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	173,677.82	-68,381.24
6	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	369,947.21	40,908.91
7	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	566,216.60	140,038.29
8	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	762,486.00	229,951.56
9	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	958,755.39	311,505.55
10	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	1,155,024.79	385,477.42

SP: sale price; PT: production tax.

greater electricity consumption due to the need for intensive aeration and removal of suspended solids in the water column, and increased operating costs, among others (Krummenauer et al., 2012; Gaona et al., 2017). Furthermore, these structures have higher maintenance costs when compared to other systems, along with a greater risk of structural damage as they are more exposed to extreme weather conditions, such as windstorms and hurricanes.

Our results are similar to those obtained in similar studies for labor costs of 17.16% (Teixeira and Guerrelhas, 2011), 13.66%

Table 9. Results of bioeconomic analyses of intensive production in rearing ponds and super-intensive production in greenhouses of *Litopenaeus vannamei* in a Biofloc Technology system.

Indicators	Results		
	Intensive	Super-intensive	Super-intensive (scenario 2)
Net present value (US$)	363,718.21	385,477.42	1,516,309.37
Equivalent annual value (US$)	59,830.66	63,410.00	249,428.80
Net future value (US$)	965,052.69	1,022,786.35	4,023,220.18
Payback	4.12	4.11	3.18
Discounted payback period	5.64	5.63	4.0
Profitability index	1.47	1.48	1.93
Internal rate of return (%)	20.49	20.55	29.29
Modified internal rate of return (%)	14.61	14.64	17.73

(Rego et al., 2017a, 2017b), and 21.52% (Mauladani et al., 2020) in relation to the total cost of production.

The results of this study are similar to those reported in previous studies on the economic performance of aquaculture production in BFT systems, with feed representing between 54.00 and 66.11% of total production costs. The proportion is lower for post-larvae acquisition, being between 13.71 and 17.63% (Teixeira and Guerrelhas, 2011; Poersch et al. 2012; Yuan et al. 2017; Rego et al. 2017a, 2017b; Cang et al. 2019; Mauladani et al. 2020.

In terms of feed provision, our results were superior to those obtained by Rego et al. (2017a, 2017b) and Mauladani et al. (2020) in intensive and super-intensive productions of *L. vannamei*, which were 54 and 53.17%, respectively. The impact of the amount spent on feed on total costs is also similar to the values found by Poersch et al. (2012), with 62.22%, and by Teixeira and Guerrelhas (2011), with 62%, but higher than those obtained by Hanson et al. (2009) of approximately 37.10% (Table 10).

The stocking density significantly influences production levels, enabling greater productivity in a smaller cultivation area. Consequently, it offers more efficient use of production factors and improves profitability of the enterprise (Jackson and Wang, 1998; Krummenauer et al., 2011; Almeida et al., 2021). Furthermore, the sale price used by Rego et al. (2017a) was considerably lower than the one used herein (US$ 5.91 compared to US$ 8.26), which is related to the different markets considered in each study and the influence of supply and demand on the sale price of shrimp.

Rego et al. (2017a) studied intensive shrimp production in a BFT system in Northeast Brazil and projected a net profit of US$ 5.19 per m². The difference between the study by Rego et al. (2017a) and this study is mainly related to stocking densities (113 shrimp/m² vs. 179.11 shrimp/m³) and the consequential difference in production (2.90 kg/m² vs. 5.15 kg/m³). We obtained a net profit of US$ 14.25 per m³, with a sale price of US$ 8.26 per kg. Such divergent results are likely

Table 10. Summary of the results found in the literature of the proportion (%) of the most relevant costs in terms of total production costs of aquaculture enterprises using a Biofloc Technology system.

Items	Authors						Present study	
	Teixeira and Guerrelhas (2011)[1]	Poersch et al. (2012)[2]	Yuan et al. (2017)[3]	Rego et al. (2017a, 2017b)[1]	Cang et al. (2019)[4]	Mauladani et al. (2020)[2]	IS[a]	SS[b]
Implementation (US$/m² or m³)	7.56	8.79	–	14.83	–	16.23	18.83	48.76
Labor (%/total costs)	17.16	3.68	–	13.66	–	21.52	14.39	14.87
Electrical energy (%/total costs)	–	7.45	–	14.46	–	6.39	11.80	9.34
Commercial feed (%/total costs)	62.00	62.22	66.11	54.00	65.00	53.17	59.73	61.74
Post-larvae (%/total costs)	15.00	13.71	–	17.63*	–	14.71	8.83	9.13

IS: intensive system; SS: super-intensive system.
[1]Adaptation of conventional semi-intensive to intensive Biofloc Technology system; [2]Implementation of a project to operate in the Biofloc Technology system; [3]Analysis of the profitability of carp production using the Biofloc Technology system; [4]Analysis of tilapia profitability in Biofloc Technology system.
*Value considered with other entries not detailed by the authors.

related to the difference in sale price of shrimp as well as the time between the two studies (8 years difference). Nevertheless, the productivity was similar between both studies (5.48 kg/m² vs. 5.16 kg/m³). Poersch et al. (2012) obtained a net profit of US$ 3.32 per m² for intensive shrimp production (sale price of US$ 2.67 per kg), with stocking densities and survival rates similar to those used herein.Mauladani et al. (2020), when testing the influence of nanobubbles on survival in a super-intensive BFT production system, using a density of 400 shrimp/m² and considering an average final weight of 10.10 g, obtained a net profit of US$ 13.81 per m². It is important to highlight that their study produced smaller shrimp than those considered in this study, which resulted in a lower sale price.

Our results demonstrate that, under the analyzed conditions, intensive production in rearing ponds and super-intensive production in greenhouses of *L. vannamei* in a BFT system are feasible and present positive economic results. However, the super-intensive system showed better results in the eight economic analysis methods used.

Methodologies to assess the environmental impacts of products and production systems have the potential to complement, from an environmental perspective, the decision-making process in aquaculture and agribusiness. To ensure the economic and environmental efficiency of the enterprise, methods that compare the impact of the enterprise on the environment can inform investor decision-making. For this, we suggest the methodology Life Cycle Assessment (LCA) that can be used to identify the critical points of the system in order to reduce its environmental impacts or compare different systems to determine which alternative results in the least impact on the environment (Bohnes et al., 2019).

CONCLUSION

The implementation of intensive production systems in rearing ponds and super-intensive production in greenhouses in a BFT system of whiteleg shrimp, *L. vannamei*, requires a considerable capital input. However, our results show that, from a bioeconomic perspective, these projects are viable.

The investment analysis used in this study showed that super-intensive production in a greenhouse is the best investment option. The development of a new scenario simulating the super-intensive production of shrimp in a BFT system, considering land use as a premise, made it possible to observe the possibility of obtaining financial gains in scale, both in the reduction of production costs and in the economic performance of the enterprise. However, the financial contribution for the implementation and operation of the project increased substantially.

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CONFLICT OF INTERESTS

Nothing to declare.

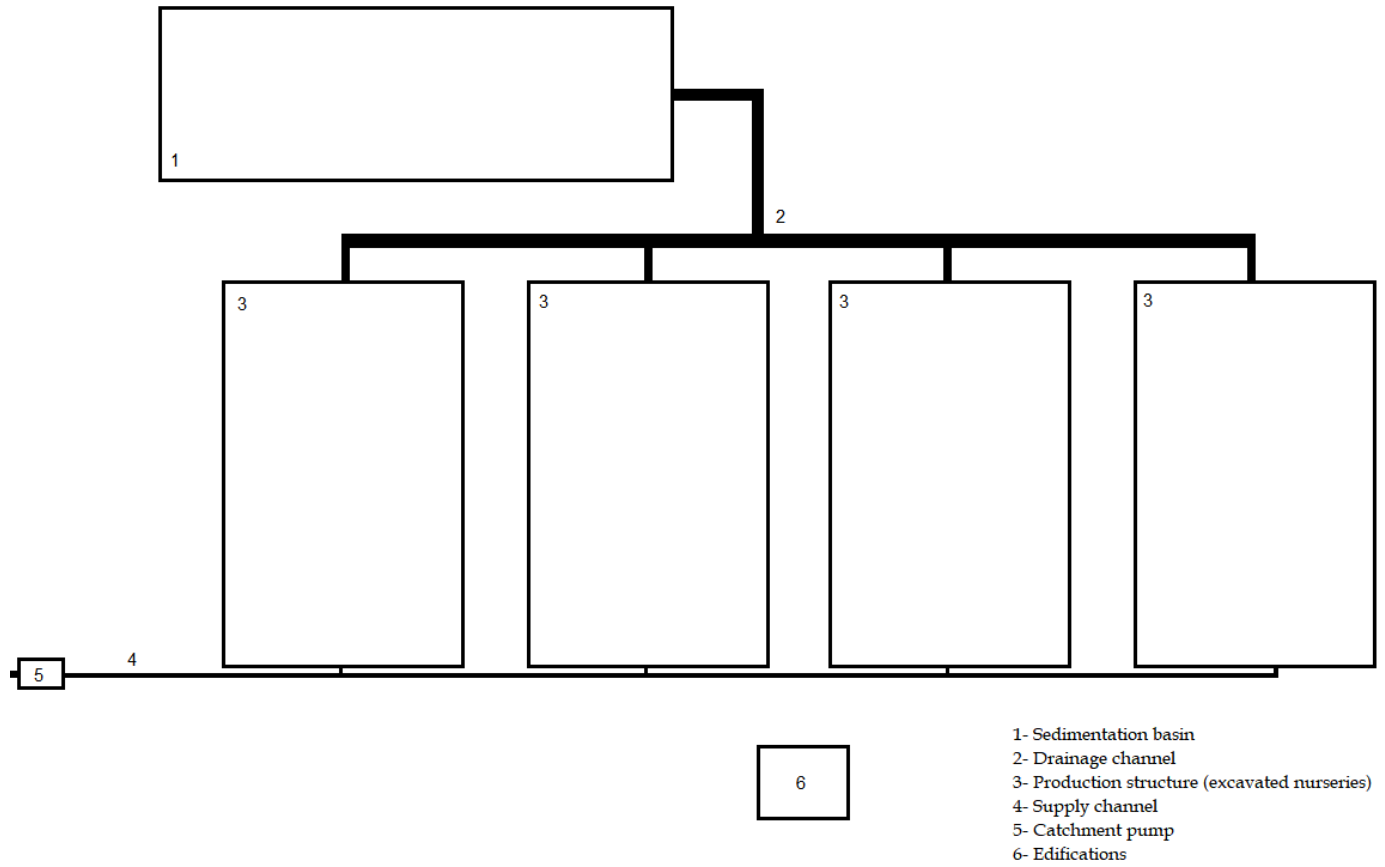## FINANCIAL SUPPORT

AUTHORS' CONTRIBUTIONS

Almeida, M.S.: conceptualization, data curation, funding acquisition, investigation, project administration, resources, writing - original draft, writing – review & editing. Gimenes, R.M.T.: conceptualization, data curation, formal data, analysis, methodology, supervision, validation, writing - original draft, writing – review & editing. Furtado, P.S.: conceptualization, data curation, formal data analysis, methodology. Poersch, L.H.: conceptualization, methodology, supervision, validation,Visualization, Writing – review & editing. Wasielesky Júnior, W.: conceptualization, funding acquisition, methodology, supervision, validation, visualization, writing - review & editing. Fóes, G.K.: conceptualization, methodology, supervision, validation, visualization, writing – review & editing. Mauad, J.R.C.: conceptualization; project administration; resources; data curation; supervision; visualization; writing – original draft; writing – review & editing.
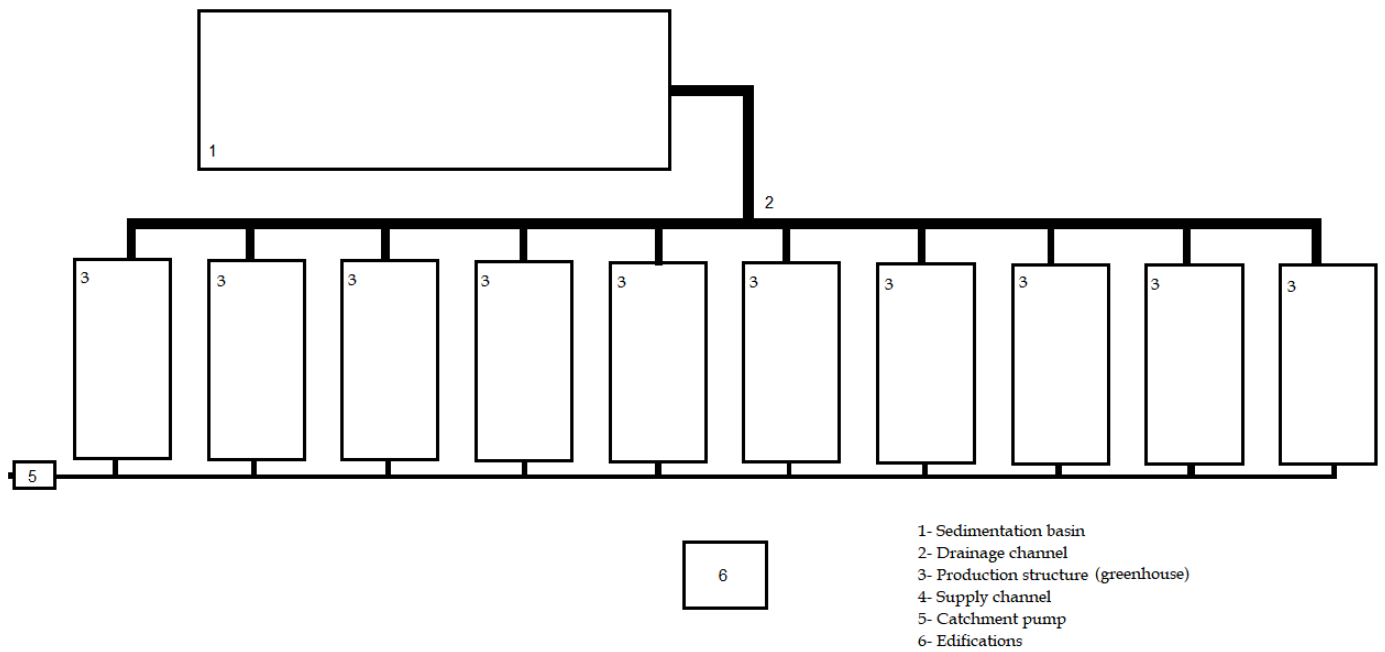
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1- Sedimentation basin
2- Drainage channel
3- Production structure (excavated nurseries)
4- Supply channel
5- Catchment pump
6- Edifications

Appendix 1. Basic sketch of the enterprise for the intensive production of *Litopenaeus vannamei* shrimp in Biofloc Technology system.

1- Sedimentation basin
2- Drainage channel
3- Production structure (greenhouse)
4- Supply channel
5- Catchment pump
6- Edifications

Appendix 2. Basic sketch of the enterprise for the super-intensive production of *Litopenaeus vannamei* shrimp in Biofloc Technology system.