Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Marine Shrimp Production in a Biofloc System With Artificial Salinization: A Technical and Financial Assessment of Production Viability

Fellipy Augusto Holanda Chaves[1]

fellipychaves@gmail.com

Federal University of Rio Grande - FURG

Victor Torres Rosas

Qatar University

Kilmer Coelho Campos[2]

Universidade Federal do Ceará

Geraldo Kipper Fóes[1]

Federal University of Rio Grande - FURG

Wilson Wasielesky

Federal University of Rio Grande - FURG

Luis Henrique Poersch[1]

Federal University of Rio Grande - FURG

Research Article

Keywords: Penaeus vannamei, ion balance, inland waters, economic indicators

Posted Date: March 4th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8853624/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Culturing marine shrimp in water with low salinity has been an inland culture tool. However, the difference in the ionic composition of these waters compared to marine waters generates technical and financial uncertainties. Closed systems, specifically the BFT system, have been associated with artificial salinization, due to the more efficient use of inputs. This work aims to report the zootechnical results and show the economic viability of this system. In addition, a scenario analysis was used to characterize possible production and price fluctuations. The zootechnical results of final weight, weekly weight gain, final biomass, feed conversion, survival, and productivity correspond to two production cycles carried out at a density of 210 shrimp.m^{-3}. Concerning viability indicators, cash flow was used for a 10-year period, with an APR of 13.75% per year to calculate NPV, IRR, IRRM, and PBD. The results showed that at the level of production achieved, there was no viability. However, when taking into account the positive variation in production (15%) and prices (30%), the system becomes viable with the capacity to return the capital invested in four years. Therefore, when considering an investment like this, it is important to consider price variations and the average cost of production, as well as the level of production that will maximize production and financial results.

INTRODUCTION

Worldwide cultivation in inland waters increased by 6.03% between 2016 and 2022, as countries that previously did not have significant production began to gain prominence with crustacean cultivation (FAO, 2024). In this sense, the *Penaeus vannamei* stands out for its ability to adapt to different environmental conditions.

According to Samocha (2019) and Wyk et al. (1999), penaeids are animals with excellent osmoregulatory capacity, capable of withstanding salinity variations ranging from 2 to 40 g.L^{-1} without harming zootechnical performance; this, along with other factors, has favored the internalization of shrimp farming worldwide.

According to Maicá et al. (2012), inland farming in waters with low salinity has proven to be technically and economically viable. In addition, the author pointed out that the reduction in the cost of land, less stringent criteria concerning legal requirements, and a reduction in environmental pressure in the coastal zone are some of the advantages that have allowed the activity to expand in these areas. Pinto et al. (2020) emphasized the issue of generating income and improving social and regional conditions. However, from an environmental point of view, Maicá et al. (2012) stated that the discharge of effluent (untreated from the cultivation of *P. vannamei* in traditional systems) and the constant water changes interfere with the sustainability of the activity. In addition, the animal's physiology is affected by the ionic composition of the water which, in the case of oligohaline waters, can have different characteristics to seawater, which affects the zootechnical results of productions (Boyd et al., 2009; Li et al., 2017).

Regarding the environmentally sustainable system, Moura et al. (2023) stated that it is technically possible to produce marine shrimp in low salinity waters and that bacteria from the BFT system could influence the ionic composition of water. For Moura et al. (2021), the biofloc system is characterized by the use of little or no water exchange, the reuse of the same water for several cycles, (Krummenauer et al., 2014a) and the rational use of inputs (Hargreaves, 2013; Samocha, 2019), which makes it suitable to be associated with artificial salinization.

In this sense, to make the growing environment suitable, water corrections, particularly at low salinity, are recommended (Fukura et al., 2024). For example, Boyd et al. (2002) identified the use of hypersaline concentrate, the result of evaporating seawater. Another strategy is to correct the ionic balance using commercial salts (Pinto et al., 2020). However, in both cases, the cost of transportation to more distant regions and acquisition time can make the use of these strategies unfeasible. The alternative of using chemical compounds to meet the ionic demand of the culture has been growing (a process known as salinization), since, through these corrections, it is possible to meet the ionic demands of *vannamei* with lower production costs and as inputs that can be acquired more easily.

On the other hand, Hanson et al. (2013) consider that, for the BFT system, special attention should be paid to economic information, specifically when it comes to operating costs, since this can become an obstacle to the system's attractiveness. In this sense, there is little economic information on the BFT system and/or BFT with salinization. For example, the pioneering study by Pinto et al. (2020) provided information on zootechnical and nutritional indicators and economic results. However, this information is on a laboratory scale.

Thus, the aim of this study is to evaluate and provide information on the financial and economic viability of the BFT system at a commercial level using artificial salinization with super-intensive density in the cultivation of marine shrimp in the southern region of Brazil.

METHODOLOGY

Data source

The production data with artificial salinization in a biofloc system and the costs are of primary origin collected from the technical manager of the production unit located in the city of Tapes, Rio Grande do Sul, Brazil.

The data relates to cultivations carried out between 2019 and 2020. The post-larvae used was acquired at the pl_{10} stage and acclimatized in two nurseries for 55 and 59 days. Afterwards when larvae reached an average weight of 1.19 g, the *P. vannamei* were considered juveniles and were transferred to grow-out ponds at a density of 210 shrimp.m^{-3} and remained there for 64 and 78 days, aiming to commercialize two different shrimp sizes. Sugar cane molasses was used to fertilize the tanks as a source of organic

carbon at a ratio of 20:1 (C:N) for three days (Avnimelech, 1999). After this period, new applications were made when the ammonia concentration reached 1.0 $mg.L^{-1}$ (Ebeling et al., 2006).

The enterprise's production system consisted of two 265 m^3 ponds covered with 0.8 mm thick HDPE geomembrane inside greenhouses. The aeration system consisted of rough hoses (Aerotube ®) and three-phase air compressors with a power of 5.0 HP (Model CR9,) as well as settling tanks to control total suspended solids (TSS). There was also a building with rooms for storing maintenance and operating equipment, a water quality laboratory, and a room for storing feed.

The shrimp were harvested at different times. The first pond (A) was harvested when the animals reached an average weight of 14.82 g. The second pond (B) was harvested at an average weight of 19.76 g.

Salinization

The water used in the cultivation was collected from the rain through the greenhouse gutters, then the water was chlorinated at $10mg.L^{-1}$ and then dechlorinated with aeration. After this process, the salts were added and homogenized (Table 1), aiming to reach a salinity of 20 $g.L^{-1}$. The salts used were purchased from specialized companies, the selection criteria being linked to the need for a correct ionic balance, cost optimization, as well as providing the same ionic ratios found in seawater.

Table 1
Description of the compounds and the quantity used in the water salinization process for each cubic meter (m³), as well as the costs for the quantity needed to raise the salinity to 20 $g.L^{-1}$.

Salinity	**Quantity ($kg.m^{-3}$)**	**Price* ($US\$.m^{-3}$)**	**Participation in relation to quantity (%)**
Sodium sulfate (Na_2SO_4)	2.28	0.72	11.35
Potassium chloride (KCl)	0.38	0.30	1.89
Sodium Bicarbonate ($NaHCO_3$)	0.11	0.06	0.55
Potassium bromide (kBr)	0.06	1.07	0.30
Boric acid (H_3BO_3)	0.02	0.02	0.10
Sodium Fluoride (NaF)	0.01	0.01	0.01
Magnesium Chloride ($MgCl_2$)	2.90	1.60	14.44
Calcium Chloride ($CaCL_2$)	0.64	0.30	3.19
Strontium Chloride ($Sr\ Cl_2$)	0.01	0.51	0.07
Sodium chloride (NaCl)	13.68	1.44	68.09
Total	20.09	6.03	100

*The price is for 2019.

December dollar rate/2019: US$ 1.00 = R$ 4.08

Economic analysis

The methodologies proposed by Bordeaux-Rêgo (2013) and Correia Neto (2019) were used. The data collected was used to define the total operating costs (TOC). The model suggested by Martin et al. (1998) was used to structure the costs. According to the authors, effective operating costs (EOC) are the costs actually disbursed (feed, energy, temporary labor, molasses, probiotics, and alkalizing agents) to produce in a given area. Other operating costs (OOC) take into account depreciation of machinery, equipment, and improvements to the production structure and taxes (CESSR equivalent to 2.70% of production and FGTS of 35.97% of payroll). Finally, the "total operating cost" (TOC), consists of the sum of the previous costs.

In relation to gross revenue (GR), this was the product of the average sales price practiced in Brazil by the expected average production (Martin et al., 1998). To determine the minimum volume of production

that will cover the TOC, the total operational leveling point was used. This indicator was described by Martin et al. (1998) and shows the relationship between the TOC and the price per kilogram (US$.kg^{-1}).

The cash flow was drawn up after surveying the costs and revenues generated by the system, and through this it was possible to carry out economic viability analyses. In addition, the cash flow was estimated for a period of 10 years.

As for the economic indices, it was first necessary to determine the value considered attractive or what risk the investor would be willing to tolerate in order to enter the business. This criterion is defined by the minimum rate of attractiveness (MRA). For this purpose, the basic Brazilian interest rate (Selic rate) for 2022 was used as a reference, which was 13.75%.

In the short term, the profitability of the enterprise was measured by Operating Profit (OP), i.e. the financial surplus after discounting the disbursements with the TOC (Martin et al., 1998).

$$\mathrm{OP} = \mathrm{GR} - \mathrm{TOC}$$

The profitability index (PI) is the function of the cash flow, the monetary return (or not) is a function of the amount disbursed. Thus, as a decision criterion, the investment is considered unviable when the value found is greater than 1 (Correia Neto, 2019).

$$\mathrm{PI}=\frac{\sum \mathrm{PV}_{\mathrm{positive}}}{\sum \mathrm{PV}_{\mathrm{negative}}}$$

The Net Present Value (NPV) used the future values estimated by the project adjusted to the MRA for the reference period for decision-making (Correia Neto, 2019), i.e. year zero. In addition, Bordeaux-Rêgo (2013) states that as a decision criterion, a positive NPV indicates recovery of the capital invested at the chosen APR and generation of wealth.

$$\mathrm{NPV} = \sum_{\mathrm{n}=1}^{\mathrm{t}} \frac{\mathrm{PV}_{\mathrm{n}}}{(1+\mathrm{r})^{\mathrm{n}}}$$

The Internal Rate of Return (IRR), which represents the project's potential return in percentage terms, is used in a similar way to the MRA. The result indicates whether the project can be accepted (IRR > MRA) or rejected (Correia Neto, 2019).

$$0 = \sum_{\mathrm{n}=1}^{\mathrm{t}} \frac{\mathrm{PV}_{\mathrm{n}}}{(1+\mathrm{IRR})^{\mathrm{n}}}$$

The Modified Internal Rate of Return (MIRR) reflects the expected return more realistically because it takes into account the different rates of reapplication of the amounts generated.

$$\mathrm{MIRR} = \sqrt[\mathrm{n}]{\frac{\mathrm{VF}}{\mathrm{VP}}} - 1$$

The Discounted Payback (DPB) corresponds to the return on investment, described in years, in relation to the cost of capital (Correia Neto, 2019).

Shrimp sales prices and production often vary between production cycles. For the entrepreneur, these fluctuations generate uncertainty. For Correia Neto (2019), uncertainty is the impossibility of accurately predicting results.

In order to measure uncertainties, Correia Neto (2019) described the methodology of scenario analysis with an approach based on the occurrence of variations in different situations. The scenario analysis works on the following premises: pessimistic, probable and optimistic. However, when analyzing the production results of other authors (Silveira et al., 2020; Silveira et al., 2022; Krummenauer et al., 2011; Samocha, 2019), it was observed that it would be possible to improve production results with the salinity adopted. Thus, with regard to production, the scenarios were set at 15% and 30% above the production obtained. With regard to prices, using the "CAMARADA" platform (an application used to monitor the sale prices of marine shrimp developed by the Brazilian Shrimp Breeders Association, ABCCAM), it was possible to observe that in relation to the sale price assumed in this study (corresponding to the variation occurring in the year 2022), the increase in price variation was positive, so the price scenarios were increases of 15% and 30%. The latter was drawn up in the event of a simultaneous increase in production (15%) and price (30%).

RESULTS

The costs and quantities of the compounds used are described in Table 1. A concentration of 20 $g.L^{-1}$ was adopted as the working value for salinization and US$ 6.03 was spent on each cubic meter of water.

The salts had different influences on the cost of the salinization process. The need for sodium chloride for salinization represents 68.09% of the total used. However, when related to the cost of acquisition, magnesium chloride ($MgCl_2$) represents the highest cost. The ratio between sodium sulfate (Na_2SO_4) and potassium bromide (KBr) show the difference between cost and quantity. The need for sodium sulphate was 38 times greater than for potassium bromide. However, in terms of cost, bromide is 49.66% more expensive than sodium sulphate. Therefore, potassium bromide is the third element with the greatest impact on cost, after sodium sulphate (Kester et al., 1967).

The data on water quality variables are summarized in Table 2. Temperature, dissolved oxygen, and settleable solids showed significant differences ($p < 0.05$) between the tanks. However, temperature and oxygen were within the optimum range for maximizing the zootechnical performance of marine shrimp and microbial activity (Hargreaves, 2013; Samocha, 2019).

Table 2
Results of the water quality parameters (mean ± standard deviation) throughout the production cycle of 64 and 78 days, respectively, in the grow-out tanks with salinized water with a saline concentration of 20 $g.L^{-1}$.

	Pond A	**Pond B**
Temperature (ºC)	29.21 ± 1.29[a]	28.49 ± 1.83[b]
Oxygen ($mg.L^{-1}$)	5.30 ± 0.51[a]	5.12 ± 0.58[b]
pH	7.76 ± 0.19	7.83 ± 0.27
TAN ($mg.L^{-1}$)	0.05 ± 0.05	0.08 ± 0.09
NO_2^- ($mg.L^{-1}$)	7.66 ± 9.03	9.06 ± 9.55
NO_3^- ($mg.L^{-1}$)	57.58 ± 35.91	73.23 ± 53.05
Alkalinity ($mg.L^{-1}$)	132.50 ± 16.69	131.21 ± 16.73
SS ($mg.L^{-1}$)	21.97 ± 6.95[a]	11.38 ± 2.85[b]

Different letters indicate a statistical difference between the means($p < 0.05$)

For nitrite, even though there was no significant difference ($p > 0.05$), values above the safe level were observed (Lin and Chen, 2003) which may have affected the zootechnical results in the two production tanks (Fig. 2).

In pond B, the higher final weight of the shrimp at harvest was responsible for the better results in terms of final biomass and productivity since the densities were the same and the survival of the shrimp in pond B was lower. Pond A showed better feed conversion and survival (Table 3).

Table 3
Results of the zootechnical variables of the production of *P. vannamei* in a BFT system in artificial salinization in the grow-out tanks throughout the 64- and 78-days production cycle.

	Pond A	**Pond B**
Initial weight(g)	1.19	1.19
Final weight (g)	14.82	19.76
Weekly weight gain (g)	1.50	1.77
Initial biomass(kg)	86.91	86.53
Final biomass(kg)	908.58	1,075.57
FCR	1.47	1.50
Productivity ($kg.m^{-3}$)	3.10	3.72
Survival (%)	84.62	83.06

The biggest expense was the construction of the grow-out tanks, followed by the purchase and installation of the geomembrane because this stage involves moving soil, building ponds and installing the geomembrane, which requires specialized people (Table 4).

Table 4
Description of the main disbursements for setting up the BFT system to operate with 210 shrimp.m^{-2} and the amount spent on the artificial salinization process (20 g.L^{-1}).

Description	Unit	Quantity	Total (US$)	Participation (%)
Construction			**25,502.25**	**60.75**
Geomembrane grow-out tanks	m²	795	13,639.71	32.49
Greenhouse	m²	1,113	11,394.61	27.14
Drainage system	Unit	1	467.93	1.11
Complementary Works			**1,852.70**	**4.41**
Pump room	m²	6	1,225.00	2.92
Electrical installation	Unit	1	627.70	1.50
Water analysis			**862.75**	**2.06**
Multiparameter probe	Unit	1	723.04	1.72
Refractometer	Unit	1	31.86	0.08
Imhoff cone	Unit	2	107.84	0.26
Aeration system			**6,776.93**	**16.14**
Radial compressor	Unit	3	4,490.17	10.70
Aerotube	M	466.5	2,286.77	5.45
Pumps			**1,984.56**	**4.73**
Generator	Unit	1	1,436.28	3.42
Motor pump	Unit	1	425.74	1.01
Electrical installation	Unit	1	122.55	0.29
Miscellaneous			**209.78**	**0.50**
Salinization			**4,789.49**	**11.41**
Total			**41,978.45**	**100.00**

The greenhouses and aeration system installation had strong influence on the investment value. For the greenhouses, in addition to purchasing the structure, it was necessary to hire specialized labor. For the installation of the aeration system, which had air compressors and microperforated hoses, the system required the purchase of pipes, fittings, and electrical installations for proper operation.

Among the items that made up the effective operating cost (EOC), feed represented the largest outlay, followed by labor; these two items accounted for 72.12% of the EOC. The cost of feed accounted for 37.95% of the total EOC. Labor costs included hiring a technical manager and a person responsible for managing and collecting water quality variables (Fig. 4).

*Others: Alkalizing agents (hydrated lime and bicarbonate), molasses, calcium hypochlorite.

The results showed that with approximately three cycles per year, it would be possible to obtain a production of 5,952.45 kg (Table 5). Revenue was influenced by sales prices. In this case, harvesting at different weights (14.82g and 19.76g) resulted in different selling prices (US$ 5.88 and US$ 7.11). Under these conditions, the cost of production was 19.05% higher than the gross revenue, which generated a negative operating profit (US$ -5,966.64). Concerning the return on invested capital, the profitability index (PI) showed that there was no return on invested capital (-1.47).

Table 5
Productive result of *P. vannamei* considering three production cycles per year in a BFT system with artificial salinization.

Variables	**Results**
Production (kg)	5,952.45
Average selling price (US$.kg^{-1})	6.55
Gross revenue (US$)	38,968.71
Total cost of production (US$)	44,935.36
Operating profit (US$)	-5,966.64
Profitability index	-1.47
Leveling point(kg)	6,918.35
Average cost of production (US$.kg^{-1})	7.55

The sales prices were taken from the CAMARADA shrimp sales price monitoring app.

In the condition evaluated, the leveling point showed that in order to equalize gross revenue with the total cost of production, it would be necessary to increase the scale of production (keeping all zootechnical results constant) by at least 16.23% or increase the selling price per kilogram of shrimp produced to US$7.55.

The profitability indicators show that, over the 10-year period, the return generated was influenced by the cost of production, production, and sale price. In this sense, the estimated NPV result identified that, concerning the minimum rate of attractiveness (i.e. the Selic rate of 13.75%), investing in the BFT system with artificial salinization would not generate wealth, because the rates generated by the venture (IRR

and MIRR are lower than the MTR. Furthermore, it was not possible to verify the return on the capital invested using the cash flow.

In the simulation of scenarios, it was possible to see an improvement in the profitability indicators, in the hypothesis of a simultaneous increase in production and price (15% and 30% respectively) the result showed viability with a positive NPV (US$ 20,930.14); IRR and MIRR (24.96% and 18.52%) higher than the MRA (13.75%) and a discounted payback of four years. The simultaneous increase in production and price produced the lowest ratio between how much must be produced to pay off the entire TCP. Under this condition, 79.73% of production would have to be used to pay off the TCP (Table 6).

Table 6
Scenario analysis considering a 15% and 30% increase in production and sales price per kilogram of shrimp; and a successive 15% increase in production and 30% increase in price on the indicators.

	15 Prod	**30 Prod**	**15 Price**	**30 Price**	**15 Prod e 30 Price**
NPV (US$)	-58,309.58	-13,788.3	-46,900.71	-7,954.91	20,930.14
IRR (%)	-	5.85	-16.33	9.26	24.96
MIRR (%)	-15.38	9.21	-11.89	11.33	18.52
DPB (years)	-	10	-	9	4
Prod (kg)	6,845.32	8,898.91	5,952.45	5,952.45	6,845.32
GR (US$)	44,814.02	58,258.23	44,814.02	52,412.92	60,274.86
TCP (US$)	47,259.12	52,251.11	45,093.18	45,298.35	47,676.56
OP (US$)	-2,445.10	6,007.12	-279.16	7,114.57	12,598.30
PI	-0.61	1.44	-0.08	1.71	3.04
LP (kg)	7,276.12	8,044.7	6,037.09	5,185.31	5,457.54
PN (US$)	6.90	5.87	7.58	7.61	6.97

Net Present Value (NPV); Internal Rate of Return (IRR); Modified Internal Rate of Return (MIRR); Discounted Payback (DPB); Production (Prod); Gross Revenue (GR); Total Cost of Production (TCP); Operating Profit (OP); Profitability Index (PI); Leveling Point (LP).

Isolated increases in production and price had an impact on improving the results of the venture's viability indicators compared to the deterministic condition. Increases of 30% in production and sales price (30%) had a positive impact on the IRR and MIRR. However, the quantity of shrimp produced in these circumstances and used to pay off the TCP is different. In this situation, the price increase (30%) did not generate an increase in expenditure (or new expenditure) and meant that the quantity used to pay off the TCP was smaller. However, when increasing production, it should be noted that this does not

happen in isolation, as it is also necessary to increase the use of inputs, particularly the use of feed and energy.

The value of PI showed a positive result and performed better when prices increased. The scenarios produced with isolated increases of 15% in production and 15% in price did not affect gross revenue (GR). In OP, the 15% increase in price caused an improvement, but by increasing production (15%) there is a need to increase other inputs (e.g. post-larvae and feed), thereby increasing TCP, so in this situation, the increase in production had a negative effect.

DISCUSSION

Salinity indicates more than the concentration of inorganic ions present in the water. This variable is related to the concentration of dissolved oxygen (Van Wyk and Scarpa, 1999), the toxicity of nitrogen compounds (Lin and Chen 2001, 2003b) and the nutritional requirements of L. vannamei (Li et al., 2017). In addition, ions can (separately or together) impact the physiological processes of marine shrimp. Moura et al. (2023) and Hernández et al. (2023) demonstrated that the variation of magnesium ions altered the growth and physiological response of the animals. In this sense, according to Boyd (2018) and Samocha, (2019) in addition to the concentration of ions, it is important to evaluate the ratio of the major ions (Na+:K+, 28:1; Mg2+:Ca2+, 3:1; and K+:Ca2+, 1:1) in order to establish, if necessary, the adequate ionic balance.

Regarding nitrogen, As Lin and Chen (2001, 2003) explain, the effect of ammonia toxicity is deeply related to salinity. In this sense, the results were in the appropriate range for cultivation. The cultivations carried out in a BFT system in salinized water by Maicá et al. (2012), Moura et al. (2021) and Pinto et al. (2020) presented similar results for ammonia with regard to the results of this study (within the range of 0.02 to 1.75 $mg.L^{-1}$).

In this study, in the first 15 days of cultivation, both tanks showed nitrite values that exceeded the safety limit. The nitrite values fluctuated, with peaks above 20 $mg.L^{-1}$. According to Lin and Chen, (2003) the LC_{50} for salinity between 15 and 25 $g.L^{-1}$ is 6.10 $mg.L^{-1}$ and 15.20 $mg.L^{-1}$, respectively. During the production cycle, although there was no mortality, the animals were under stress. Regarding strategies to control nitrite toxicity, Moura et al. (2021) adopted a strategy of fertilization with molasses and the addition of seawater. Pinto et al. (2020) reported a similar protocol, but with fertilization for 30 days before the start of the stand and to keep the ionic concentration constant they used commercial salts. However, Maicá et al. (2012) reported the difficulty of maintaining nitrite at a safe level in low salinity due to the shrimp low tolerance to the presence of this compound and that this can affect negatively the animals zootechnical performance.

Concerning the zootechnical results in this study, the grow-out stage began with shrimp weighing 1.19 g on average and at a density of 210 $shrimp.m^{-3}$. The values for average weekly weight gain (1.50 and 1.77 g), survival (84.62 and 83.06%) and feed conversion (1.47 and 1.50) were higher than those of Pinto

et al. (2020), who worked with a density of 250 shrimp.m^{-3}, starting the stocking at a weight of 1.10 g. The density adopted in this study possibly influenced the better zootechnical results compared to the aforementioned author. However, when comparing our results with cultivation in a BFT system with seawater, Krummenauer et al. (2011) reported that cultivation of marine shrimp at a density of 300 shrimp.m^{-2} showed lower GPS than that found in this research, and also showed a 12% reduction in FCR with a 9.94% increase in productivity compared to the best results in this study.

Regarding investment, the data showed that the highest costs were incurred in building the production unit. Rego et al. (2017) reported that the cost of this item represented 37.12%. Almeida et al. (2021) described that investing in the BFT system in the southern region of Brazil would require 89.04% of the total investment just to build the production unit.

The effective operating cost (EOC) as reported by Rego et al. (2017) when evaluating the cultivation of marine shrimp in a BFT system in the state of Pernambuco described that the feed had a result close to that found in this work (37.89%). However, Almeida et al. (2021) evaluated BFT production with 400 shrimp.m² and found that feed accounted for 57.54% of production costs. According to Hargreaves (2013), increasing density causes greater dependence on feed, in addition, increasing density increases feed conversion, thus increasing production costs. In the current work, the sum of feed and labor costs accounted for 74.60%.

The relationship between production and sales price affected the result of gross revenue (GR), even though the BFT system is characterized by high productivity (Silveira et al., 2020; Krummenauer et al., 2011). GR was affected by the high average cost of production (US$7.55/kg). In the system evaluated, the results showed that the selling price is below the average cost of production. In addition, the leveling point (LP) identified the need to be technically more efficient in the use of inputs, since there is a need to increase production to pay off the total cost of production (TCP), but without increasing costs. It is important to note that simply increasing density may not be enough to increase production, as there may be a negative effect on zootechnical results due to the increased level of stress caused to the animals by the increase in stocking density.

When it comes to profitability indicators, Almeida et al. (2021) and Rego et al. (2017) found results that attest that the BFT system presented favorable results as an investment option. The authors state that the NPV and IRR were higher than the MTR, with MTR values of 10.25% (Almeida et al., 2021) and 10% (Rego et al., 2017ª). For this study, the NPV, IRR, and MIRR results were lower than the decision-making criterion (MIR of 13.75%).

The scenarios evaluated indicate an improvement in economic indicators with a simultaneous increase in production and price. However, an increase in production can also lead to an increase in EOC, since this can generate an increase in demand for the inputs used (feed, energy). In addition, sales prices can vary according to size, time of year, and between regions.

The productivity results obtained in this study were higher than those reported by Pinto et al. (2020). However, the lack of correct management of nitrogen compounds, particularly nitrite, may have negatively affected the best productive performance of the system, specifically for pond A, which had the lowest average harvest weight. In addition, the longer cultivation time for pond B may have favored the animals' recovery from stress and achieved the best results in terms of final weight and GPS, as reported by Moura et al. (2021) a previous BFT maturation can be done to minimize the nitrite risks. Additionally, Gao et al. (2017), stated that the salinity of 20 $g.L^{-1}$ is the point that maximizes the physiological performance of *L. vannamei*, the same salinity as in the present study.

Krummenauer et al. (2011) reported that at a density of 300 $cam.m^{-2}$ it is possible to find the best productive results. However, the author emphasizes the role of artificial substrates for the fixation of nitrifying bacteria. In addition, the reuse of water from previous cultivations, i.e. matured water with an established bacterial community, are strategies that can be used to reduce the harmful effect of ammonia and nitrite.(Krummenauer et al., 2014b). It is important to note that in this study, the density adopted (210 $cam.m^{-2}$) without the adoption of consolidated strategies against nitrite, had a negative influence on the technical and economic results.

With regard to production strategies that increase productivity, Silveira et al. (2022) found that by adopting partial harvests in the production of marine shrimp there was an increase in productivity (between 5.85 and 6.22 $kg.m^{-2}$ with the adoption of one and two partial harvests), in addition, this strategy made it possible to achieve higher average harvest weights, which implies higher sales prices. However, the author opted for super-intensive cultivation with 500 $cam.m^{-2}$, which increased the FCA, a fact corroborated by Krummenauer et al. (2011) who found that increasing density increased feed conversion. In this sense, Weldon et al. (2021) stated that the feed management tool can be an important instrument in reducing FCR and, consequently, costs. According to the author, proper feed management must be accompanied by quality feed and knowledge of the correct biomass. When working with 160 $cam.m^{-2}$, the aforementioned author obtained a lower FCR result than Krummenauer et al. (2011) who worked with 150 $cam.m^{-2}$.

As a result, it is possible to improve zootechnical results and reduce costs. However, it is important to pay attention to water quality management (particularly when it comes to nitrogen control), feed management (since feed is the main way of obtaining the nutrients needed to maximize animal performance and the highest operating cost) and proper planning of the viability of the strategy adopted.

Lastly, the decision to invest is based on the attractiveness of the business. In this sense, reducing the MTR can lead to an improvement in the rates of return (IRR, MIRR, DPB and PI) of the aquaculture enterprise and these rates can vary between countries and, above all, due to political decisions. It is important to note that when investing in shrimp farming, it is necessary to be aware of price variations, particularly for the BFT system. The impact of price fluctuations can affect the viability of the venture, because, as Hanson et al. (2013) and Hargreaves (2013) state, the high cost of investing in and operating this system can be an obstacle to consolidating the system.

CONCLUSION

Production in a BFT system with artificial salinization reaching 20 $g.L^{-1}$ has shown that it is technically possible. However, it is important to master management strategies such as nitrogenate sub-product control, this can make the production system economically viable. Reaching high survival rates and a constant growth rate is necessary to improve BFT culture feasibility. In addition, the results indicate the need for a prior study of consumer willingness to pay sales prices and production costs, as well as a study of the viability of the different strategies that can be adopted.

Declarations

Acknowledgements: The authors are grateful for the financial support provided by the National Council for Scientific and Technological Development (CNPq), Coordination for the Improvement of Higher-Level Personnel (CAPES). Wasielesky, W. Jr. and Luís Poersch are a research fellow of CNPq under process number: 310652/2017-0 and process number: 312980/2020-5, respectively.

Data availability: Data will be made available on request.

Competing Interests: The authors declare that they have no known competing financial/personal interests.

Author contributions: Fellipy Augusto Holanda Chaves: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Kilmer Coelho Campos**: Writing – review & editing. **Victor Torres Rosas** – review & editing. **Geraldo Kipper Fóes: Writing** – review & editing. **Wilson Wasielesky Jr**: Writing – review & editing, Funding acquisition. **Luis Henrique Poersch:** Conceptualization, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

References

1. Avnimelech, Y. (1999). Carbon/nitrogen ratio as a control element in aquaculture systems. Aquaculture, 176(February),227–235.
2. Bordeaux-Rêgo, R. et al, 2013. Viabilidade econômico-financeira de projetos, 4º. ed. Rio de Janeiro.
3. Boyd, C.E., 2018. revisiting-ionic-imbalance-in-low-salinity-shrimp-aquaculture. Global Aquaculture Advocate.
4. Boyd, C.A., Chaney, P.L., Boyd, C.E., Rouse, D.B., 2009. Distribution of ground water suitable for use in saline-water aquaculture in central and west-central alabama. J. Appl. Aquac. 21, 228–240. https://doi.org/10.1080/10454430903114048.
5. Boyd, C.E., 2002. Dissolved Salts in Water for Inland , Low-Salinity Shrimp Culture 40–45.
6. Boyd, C.E., Thunjai, T., 2003. Concentrations of major ions in waters of inland shrimp farms in China, Ecuador, Thailand, and the United States. J. World Aquac. Soc. 34, 524–532.

https://doi.org/10.1111/j.1749-7345.2003.tb00092.x.

7. Boyd, C.E., Tucker, C.S., Somridhivej, B., 2016. Alkalinity and hardness: critical but elusive concepts in aquaculture. J. World Aquacult. Soc. 47, 6–41. https://doi.org/ 10.1111/jwas.12241.
8. Chen, S., Ling, J., Blancheton, J.P., 2006. Nitrification kinetics of biofilm as affected by water quality factors. Aquac. Eng. 34, 179–197. https://doi.org/10.1016/j.aquaeng.2005.09.004.
9. Correia Neto, J.F., 2019. Elaboração e Avaliação de Projetos de Investimento.
10. Kester, I. Duedall, D. Connors, R.P., 2011. Preparation of Artificial Seawater. Am. Soc. Limnol. Oceanogr. 12, 176–179.
11. Silveira, L.G.P., Krummenauer, D., Poersch, L.H., Fóes, G.K., Rosas, V.T., Wasielesky, W., 2022. The effect of partial harvest on production and growth performance of *Litopenaeus vannamei* reared in biofloc technologic system. Aquaculture 546. https://doi.org/10.1016/j.aquaculture.2021.737408.
12. Silveira, L.G.P., Krummenauer, D., Poersch, L.H., Rosas, V.T., Wasielesky, W., 2020. Hyperintensive stocking densities for *Litopenaeus vannamei* grow-out in biofloc technology culture system. J. World Aquac. Soc. 51, 1290–1300. https://doi.org/10.1111/jwas.12718.
13. Almeida, M.S., Carrijo-Mauad, J.R., Gimenes, R.M.T., Gaona, C.A.P., Furtado, P.S., Poersch, L.H., Wasielesky, W., Fóes, G.K., 2021. Bioeconomic analysis of the production of marine shrimp in greenhouses using the biofloc technology system. Aquac. Int. 29, 723–741. https://doi.org/10.1007/s10499-021-00653-1.
14. Ebeling, J.M., Timmons, M.B., Bisogni, J.J., 2006. Engineering analysis of the stoichiometry of photoautotrophic, autotrophic, and heterotrophic removal of ammonia-nitrogen in aquaculture systems. Aquaculture 257, 346–358. https://doi.org/10.1016/j.aquaculture.2006.03.019.
15. FAO, 2024. World Fisheries and Aquaculture, FAO:Rome,2024.
16. FAO, 2018. The state of world fisheries and aquaculture- meeting the sustainable development goals. ROMA.
17. Hanson, T., Ph, D., Morris, T., 2013. Economic Analyses Project Rising Returns For Intensive Biofloc Shrimp Systems. Glob. Aquac. Advocate 2011–2013.
18. Hargreaves, John A, 2013. Biofloc Production Systems for Aquaculture Southern regional aquaculture center. SRAC Publ. 1–12.
19. Hargreaves, J.A., 2006. Photosynthetic suspended-growth systems in aquaculture. Aquac. Eng. 34, 344–363. https://doi.org/10.1016/j.aquaeng.2005.08.009.
20. Hernández, D.P., Abdelrahman, H.A., Galkanda-Arachchige, H.S.C., Kelly, A.M., Butts, I.A.E., Davis, D.A., Beck, B.H., Roy, L.A., 2023. Evaluation of aqueous magnesium concentration on performance of Pacific white shrimp (Litopenaeus vannamei) cultured in low salinity water of West Alabama, USA. Aquaculture 565. https://doi.org/10.1016/j.aquaculture.2022.739133
21. Krummenauer, D., Peixoto, S., Cavalli, R.O., Poersch, L.H., Wasielesky, W., 2011. Superintensive culture of white shrimp, *Litopenaeus vannamei*, in a biofloc technology system in Southern Brazil at

different stocking densities. J. World Aquac. Soc. 42, 726–733. https://doi.org/10.1111/j.1749-7345.2011.00507.x.

22. Krummenauer, D., Samocha, T., Poersch, L., Lara, G., Wasielesky, W., 2014. The reuse of water on the culture of pacific white shrimp, *Litopenaeus vannamei*, in BFT system. J. World Aquac. Soc. 45, 3–14. https://doi.org/10.1111/jwas.12093.
23. Li, E., Wang, X., Chen, K., Xu, C., Qin, J.G., Chen, L., 2017. Physiological change and nutritional requirement of Pacific white shrimp *Litopenaeus vannamei* at low salinity. Rev. Aquac. 9, 57–75. https://doi.org/10.1111/raq.12104.
24. Lin, Y.-C., Chen, J.-C., 2001. Acute toxicity of ammonia on *Litopenaeus Vannamei* Boone juveniles at different salinity levels. J. Exp. Mar. Bio. Ecol. 259, 109–119.
25. Lin, Y.C., Chen, J.C., 2003. Acute toxicity of nitrite on *Litopenaeus vannamei* (Boone) juveniles at different salinity levels. Aquaculture 224, 193–201. https://doi.org/10.1016/S0044-8486(03)00220-5.
26. Maicá, P.F., de Borba, M.R., Wasielesky, W., 2012. Effect of low salinity on microbial floc composition and performance of *Litopenaeus vannamei* (Boone) juveniles reared in a zero-water-exchange super-intensive system. Aquac. Res. 43, 361–370. https://doi.org/10.1111/j.1365-2109.2011.02838.x.
27. Martin, N.B., Serra, R., Oliveira, M.D.M., Ângelo, J.A., Okawa, H., 1998. Sistema integrado de custos agropecuários - CUSTAGRI. Informações Econômicas v. 28, n.1 28, 7–28.
28. Miranda, F.R., Lima, R.N., Crisóstomo, L.A., Santana, M.G.S., 2008. Reuse of inland low-salinity shrimp farm effluent for melon irrigation. Aquac. Eng. 39, 1–5. https://doi.org/10.1016/j.aquaeng.2008.04.001.
29. Moura, P., Neto, I.A., Brandão, H., Furtado, P., Poersch, L. and Wasielesky Jr, W., 2023. Effects of magnesium reduction in artificial low-salinity water on the growth of Pacific white shrimp Litopenaeus vannamei in a biofloc system. Aquaculture, 577, p.739956. https://doi.org/10.1016/j.aquaculture.2023.739956
30. Moura, P.S. de, Wasielesky, W., Serra, F. da P., Braga, A., Poersch, L., 2021. Partial seawater inclusion to improve *Litopenaeus vannamei* performance in low salinity biofloc systems. Aquaculture 531, 735905. https://doi.org/10.1016/j.aquaculture.2020.735905.
31. Pinto, P.H.O., Rocha, J.L., do Vale Figueiredo, J.P., Carneiro, R.F.S., Damian, C., de Oliveira, L., Seiffert, W.Q., 2020. Culture of marine shrimp (*Litopenaeus vannamei*) in biofloc technology system using artificially salinized freshwater: Zootechnical performance, economics and nutritional quality. Aquaculture 520. https://doi.org/10.1016/j.aquaculture.2020.734960.
32. Rego, M.A.S., Sabbag, O.J., Soares, R., Peixoto, S., 2017a. Financial viability of inserting the biofloc technology in a marine shrimp *Litopenaeus vannamei* farm: a case study in the state of Pernambuco, Brazil. Aquac. Int. 25, 473–483. https://doi.org/10.1007/s10499-016-0044-7.
33. Rego, M.A.S., Sabbag, O.J., Soares, R., Peixoto, S., 2017b. Risk analysis of the insertion of biofloc technology in a marine shrimp *Litopenaeus vannamei* production in a farm in Pernambuco, Brazil: A case study. Aquaculture 469, 67–71. https://doi.org/10.1016/j.aquaculture.2016.12.006.

34. Samocha, T.M., 2019. Sustainable Biofloc Systems for, Sustainable Biofloc Systems for Marine Shrimp. https://doi.org/10.1016/C2018-0-02628-6.
35. Saoud, I.P., Davis, D.A., Rouse, D.B., 2003. Suitability studies of inland well waters for Litopenaeus vannamei culture. Aquaculture 217, 373–383. https://doi.org/10.1016/S0044-8486(02)00418-0.
36. Ueno Fukura, M., Collazos Lasso, L.F., Vinatea Arana, L.A. and Baldisserotto, B., 2024. Salinity/ionic balance interactions on the zootechnical performance and histology of Litopenaeus vannamei and water quality in a biofloc system. *Journal of the World Aquaculture Society*, p.e13093. https://doi.org/10.1111/jwas.13093
37. Valenti, W.C., Barros, H.P., Moraes-Valenti, P., Bueno, G.W., Cavalli, R.O., 2021. Aquaculture in Brazil: past, present and future. Aquac. Reports 19, 100611. https://doi.org/10.1016/j.aqrep.2021.100611.
38. Wyk, P. Van, Davis-Hodgkins, M., Laramore, R., Main, K.L., Mountain, J., Scarpa, J., 1999. Farming Marine Shrimp in Recirculating Freshwater Systems. Harb. Branch Oceanogr. Inst. 4520 pages.

Figures

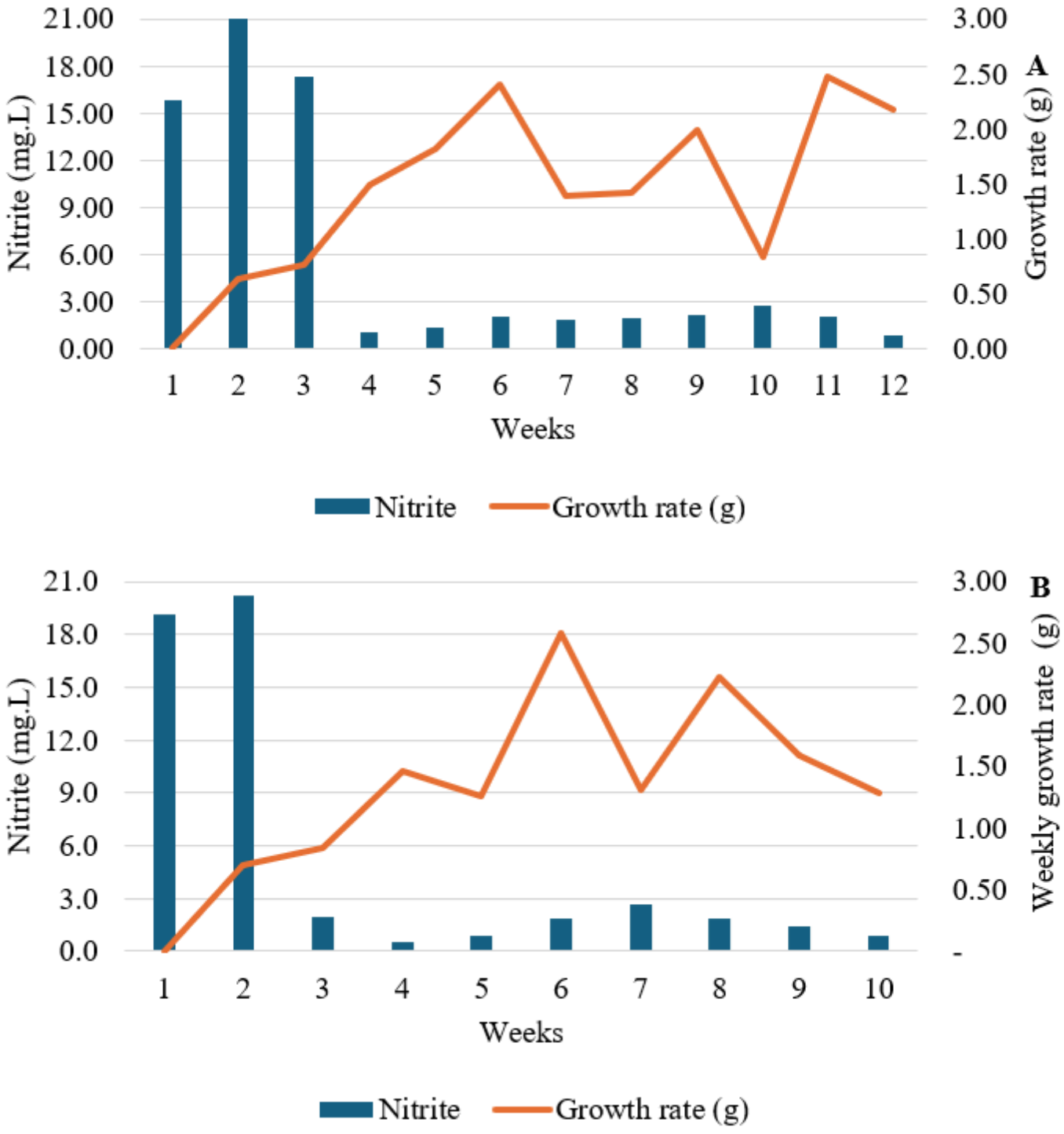


Figure 1

Nitrite and growth parameters of shrimps from pond A during 64 culture days. A) Relation between nitrite and final weight. B) relation between Nitrite and growth rate.

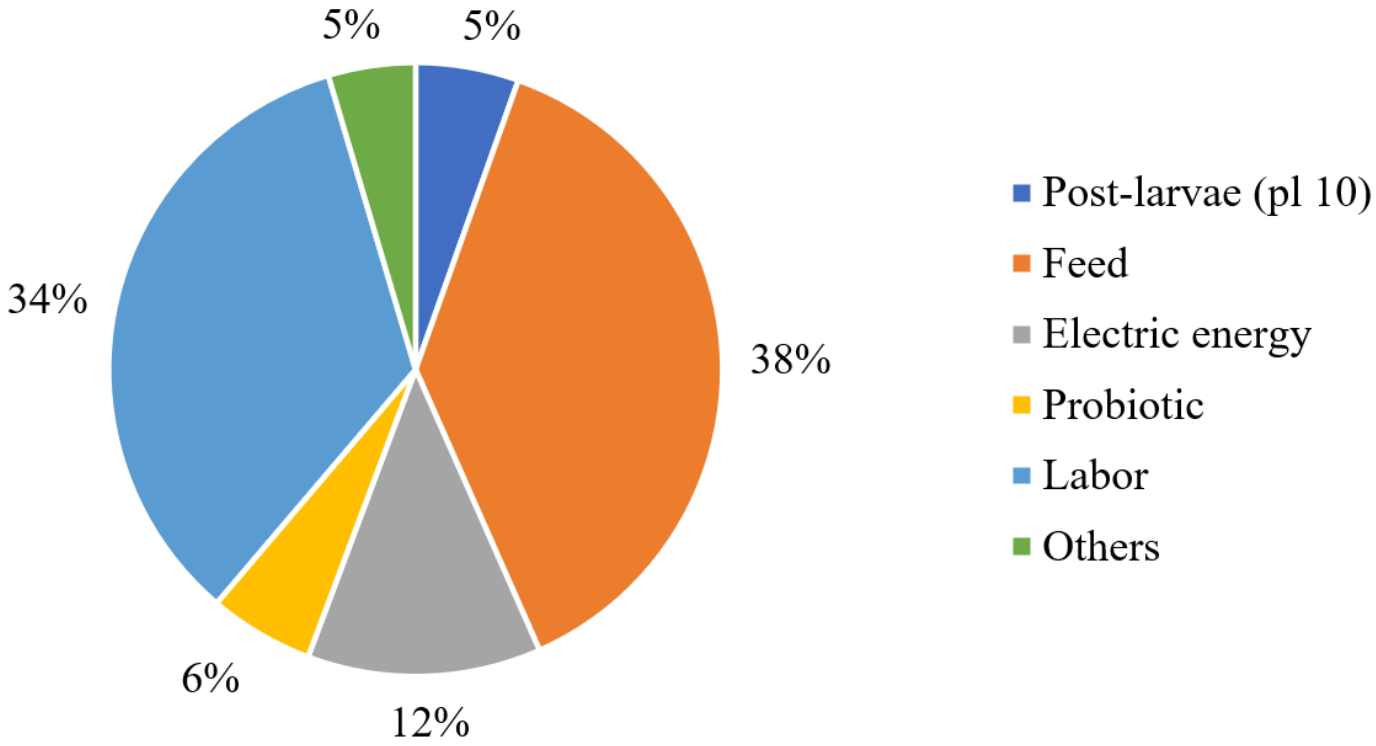


Figure 2

The effective operating cost of production encompasses all the inputs used along with labor without charges during the production cycle.

*Others: Alkalizing agents (hydrated lime and bicarbonate), molasses, calcium hypochlorite.