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PRODUCTION OF THE *Kappaphycus alvarezii* EXTRACT AS A LEAF BIOFERTILIZER: TECHNICAL AND ECONOMIC ANALYSIS FOR THE NORTH COAST OF SÃO PAULO-BRAZIL*

Valéria Cress GELLI[1,2]*

Marco Túlio Ospina PATINO[1]

Jansle Vieira ROCHA[1]

Edison BARBIERI[2]

Kleber Campos MIRANDA-FILHO[3]

Marcelo Barbosa HENRIQUES[2]

[1] Universidade Estadual de Campinas - Faculdade de Engenharia Agrícola (UNICAMP – FEAGRI). Av. Cândido Rondon, 501 - Cidade Universitária, CEP: 13083-875, Campinas, SP, Brazil.

[2] Instituto de Pesca - Agência Paulista Tecnológica dos Agronegócios (IP-APTA). Estrada Professor Joaquim Lauro Monte Claro, 2275, CEP: 11680-0000, Ubatuba, SP, Brazil. valeria.gelli@sp.gov.br (*corresponding author)

[3] Universidade Federal de Minas Gerais – UFMG, Departamento de Zootecnia, Av. Antônio Carlos, 6627, CEP: 31270-901, Belo Horizonte, MG, Brazil.

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ABSTRACT

The extract of the *Kappaphycus alvarezii* seaweed is used as a leaf biofertilizer and several studies had proven its efficiency in several crops. This study aimed to analyze the economic viability of fresh seaweed production and the chemically characterized seaweed extract cultivated as a technical-economic alternative for coastal communities. Yields of the solid and liquid fractions were quantified, the extract was characterized in its chemical composition of macronutrients and micronutrients and it was classified according to the criteria of the Brazilian legislation of agricultural fertilizers. For the study of economic feasibility, different sales price scenarios were considered and compared with the commercialization of fresh seaweed. The average yield obtained from the processing of the Brazilian adapted strains of the *K. alvarezii* for the liquid fraction or fresh seaweed extract was 0.71 ± 0.0080 L kg^{-1} and the moisture solid production was 295 ± 0.0126 g kg^{-1}. The production of fresh seaweed was unfeasible and for the handmade extract was economically viable for the scenario with the sale price of US$ 2.77 with a net present value of US$ 35,300.13 and an internal rate of return (IRR) of 38.99% over ten year.

Keywords: macroalgae; Seaweed Liquid Fertilizers (SLF); mariculture, economic feasibility

PRODUÇÃO DO EXTRATO DA MACROALGA *Kappaphycus alvarezii* COMO BIOFERTILIZANTE FOLIAR: ANÁLISE TÉCNICA E ECONÔMICA PARA O LITORAL NORTE DE SÃO PAULO-BRASIL

RESUMO

O extrato da alga marinha *Kappaphycus alvarezii* é utilizado como biofertilizante foliar e vários estudos comprovaram sua eficiência agronômica em diversas culturas agrícolas. Este estudo teve como objetivo analisar a viabilidade econômica do cultivo de algas marinhas frescas e seu extrato quimicamente caracterizado como alternativa técnico-econômica para comunidades costeiras. Os rendimentos das frações sólida e líquida foram quantificados, o extrato foi caracterizado em sua composição química de macronutrientes e micronutrientes e foi classificado de acordo com os critérios da legislação brasileira de fertilizantes agrícolas. Para o estudo de viabilidade econômica, diferentes cenários de preços de venda foram considerados e comparados com a comercialização das algas marinhas frescas. O rendimento médio obtido pelo processamento das linhagens brasileiras de *K. alvarezii* para a fração líquida ou extrato de alga marinha fresca foi de 0,71 ± 0,0080 L kg^{-1} e o rendimento da fração sólida foi de 295 ± 0,0126 g kg^{-1}. A produção de algas marinhas frescas foi inviável economicamente e, para o extrato artesanal, foi viável para o cenário com preço de venda de US$ 2,77, com valor presente líquido de US$ 35.300,13 e taxa interna de retorno (TIR) de 38,99% para um horizonte de dez anos.

Palavras-chave: macroalgas; Fertilizantes Líquidos de Algas (FLA); maricultura; viabilidade econômica.

INTRODUCTION

The seaweed *Kappaphycus alvarezii* is cultivated especially for extracting the hydrocolloid *kappa*-carrageenan (Hayashi et al., 2011). According to the Food and Agriculture Organization - FAO (2020), in 2018 about 1.5 million tonnes of this crop was produced, representing 4.7% of the total aquatic plants grown worldwide and a figure of US$ 214.8 million.

According to Valderrama et al. (2015), the market for *K. alvarezii* seaweed presents price volatility due to the great offer, speculation, and sectoral disorganization. The mean price for selling a kilogram of dry seaweed was US$ 0.18 in 2014, and reducing by nearly 39% in 2016 (FAO, 2020).

The development of *K. alvarezii* seaweed cultivation was stimulated by incentive programs that began in the mid-1960s in the Philippines (Mantri et al., 2017) as a consequence of the increasing demand of the *kappa*-carrageenan hydrocolloid by the food industry, cosmetics and pharmacological (Hayashi and Reis, 2012). In addition to the species being cultivated for the extraction of bioactives (Rajasulochana et al., 2012; Raman and Doble, 2015), seaweed can be produced as biofertilizers or agricultural stimulants (Zodape et al., 2012; Trivedi et al., 2017, 2018), bioethanol (Masarin et al., 2016; Roldán et al., 2017; Solorzano-Chavez et al., 2019), hydrogen (Fonseca et al., 2018) and consumed in human or animal nutrition (Suresh-Kumar et al., 2015; Qadri et al., 2019).

The cultivation system of this seaweed does not require advanced technology or large investments (Pickering, 2006); the species adapts easily since it reproduces through vegetative stems, besides it presents a growth rate of 4 to 8% per day and producing large amounts of biomass in a period of 30 to 60 days. These factors and others certainly have enabled the spread of its cultivation worldwide (Zuniga-Jara and Marin-Riffo, 2016).

In Brazil, the species was introduced in 1995 as a result of the domestication of more vigorous phenotypes from a selection program involving 23 wild strains from Malaysia and the Philippines (Paula et al., 1999; Paula and Pereira, 2001; Bulboa and Paula, 2005).

The Brazilian production of this seaweed was estimated at 700 tonnes in 2018 (FAO, 2020), however, this number might be overestimated given the lack of interest and the abandonment of commercial crops in Rio de Janeiro and São Paulo due to the restrictive environmental laws in these states (Gelli and Barbieri, 2015); the low prices paid by carrageenan extraction industries; management and infrastructural problems. Brazil imported around 2.4 tonnes of carrageenan in 2019, which represented approximately US$ 20.1 million (Brasil, 2020a).

Carrageenan processing requires an infrastructure with large investments in installation and equipment, intense workforce, energy, and water volume. Such costs are impractical for the local communities (Paula and Pereira, 2001). However, the processing of seaweed extract requires a simple homemade infrastructure and could be an alternative for the producers to benefit from a direct and profitable trade (Gelli and Barbieri, 2015). According to Craigie (2011), the prerequisite for creating industry is a constant supply of raw materials. The resource must be renewable and sustainable, and it requires efficient management of the seaweed harvest. These conditions are found in the production of seaweed by aquaculture.

In India, Mantri et al. (2017) noted that with the discovery of new applications for processing this seaweed, its dry production had been substantially increased from 21 tonnes in 2001 to 1490 tonnes in 2013. Thus, the country is rapidly emerging as an important production center of *K. alvarezii* in Southeast Asia, with an annual turnover of about US$ 27.8 million.

The extract of *K. alvarezii*, also known as Seaweed Liquid Fertilizers (SLF), can be extracted by milling and filtration processes (Eswaran et al., 2005). Studies have shown that this extract contains phytohormones, micro and macronutrients, vitamins, and amino acids. It is also considered to be biodegradable, may reduce agricultural diseases, increase productivity, and reduce the production time (Shah et al., 2013). These factors stimulate its environmental use, enabling the adaptation to practices of sustainable agriculture, as recommended by FAO (Babu and Rengasamy, 2012). Layek et al. (2015) stated that the extract was considered sustainable, with low carbon content, and can be used in horticulture and forestry.

The extract can be used as a biofertilizer or agricultural stimulant, when applied as foliar "spray" and its efficiency has been reported by many authors (Karthikeyan and Shanmugam, 2014; Mondal et al., 2015; Karthikeyan and Shanmugam, 2017; Layek et al., 2018; Vasantharaja et al., 2019).

In Brazil, studies related to the efficiency of seaweed extract are recent. Costa et al. (2017) used the extract of *K. alvarezii* to treat soybean seeds; however, according to the results obtained, the authors concluded that the extract may help increase growth parameters when used in seed treatments, where smaller doses were more efficient. Other studies with the extract regarding greenhouse gas emissions (N_2O and CH_4) were also developed for several crops and proved that its use can decrease such emissions (Sousa, 2017).

Thus, a way of encouraging the cultivation of seaweed, a non-existent activity in almost all of the Brazilian coast, is offering a value-added product such as handmade seaweed extract, which can be used directly in agriculture at specific concentrations and become an economic and sustainable alternative for coastal communities.

Therefore, this study aimed to analyze the economic viability of the production of fresh algae and the chemically characterized extract of the seaweed of *K. alvarezii* cultivated on the coast of São Paulo in the minimum family modules as an alternative Technical-economic income for coastal communities.

MATERIAL AND METHODS

Study Area

For the economic feasibility analysis, the Brazilian aquaculture legislation was considered, which is a relatively new instrument since the marine aquaculture is normally ruled by federal and state laws, decrees, and regulations. The Environmental Laws IBAMA, Normative Instruction nº. 1 (Brasil, 2020b), restricts the production of exotic seaweed to only part of the coastal states of Santa Catarina, São Paulo, and Rio de Janeiro. Thus, this study includes Ilhabela and Ubatuba municipalities, on the Northern coast of São Paulo state (Figure 1).

Cultivation System

The economic study considered the deployment of four rafts (3 x 50 m) and one working raft of 20 m^2, occupying a total of 0.2 ha. The material used for assembly of the raft (Figure 2) was described by Gelli and Barbieri (2015). The planting system was the tubular fishing net described by Reis et al. (2015) and adopted a productivity of 3 kg m^{-1}. For the calculations, was considered withdrawing 20% of the total production of fresh seaweed for the production of new seedlings. The cultivation time

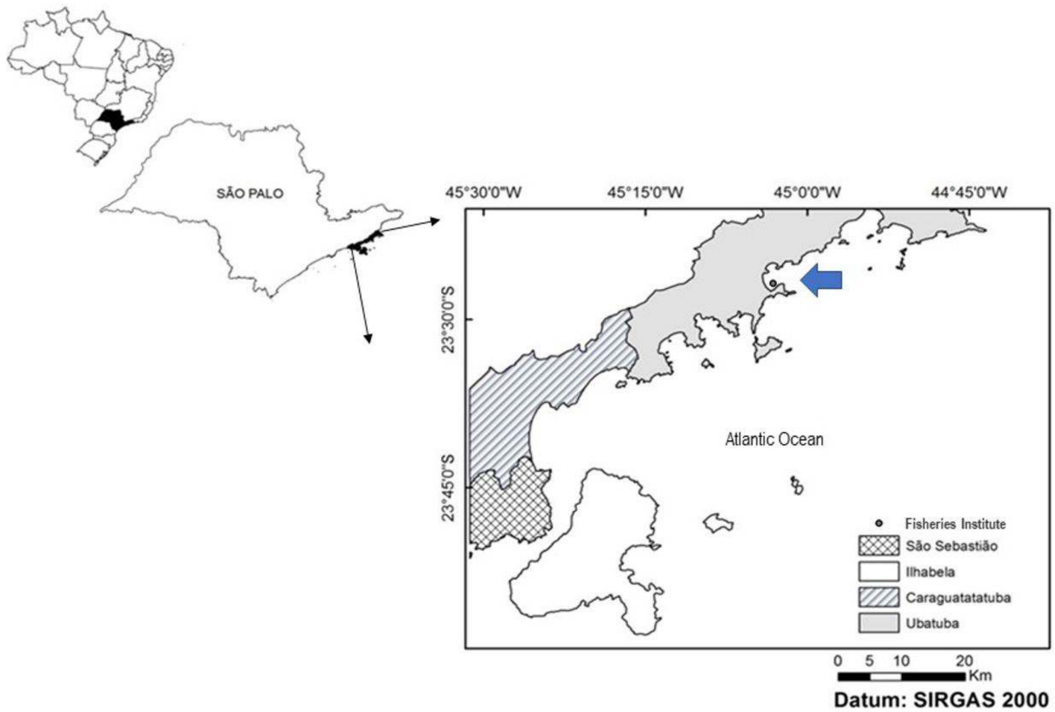

Figure 1. Study area in São Paulo state, Brazil, and marine farm of the Fisheries Institute of the Secretariat of Agriculture of the State of São Paulo.

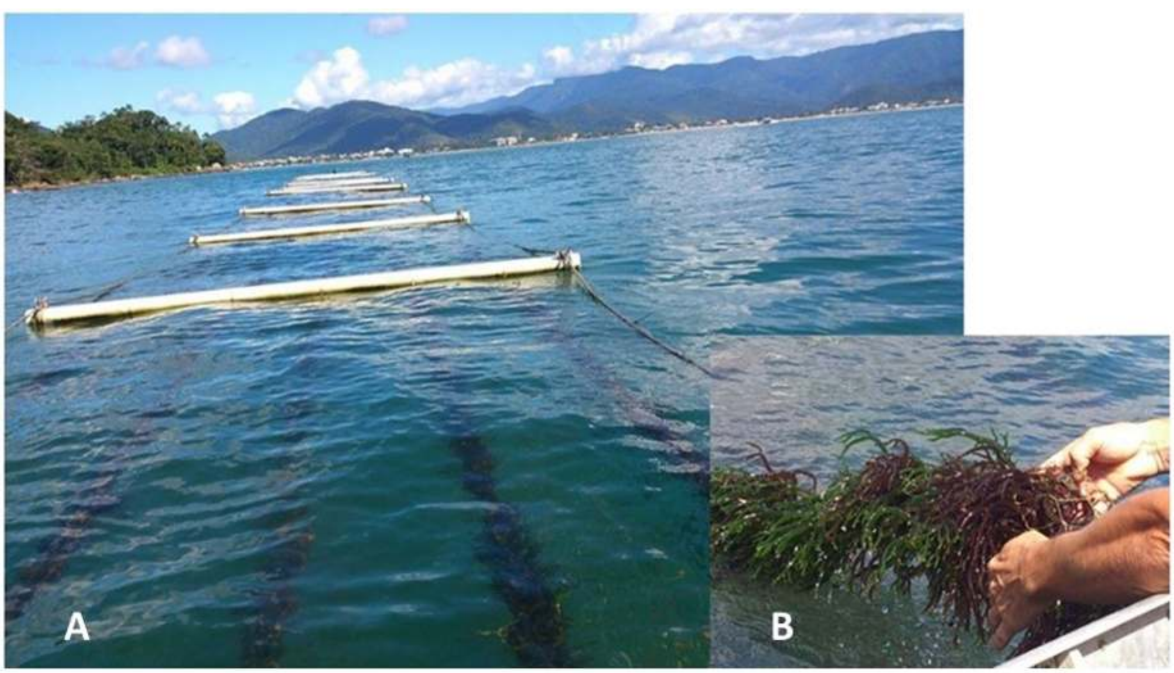

Figure 2. Cultivation system in raft (A) and planting in tubular nets of the seaweed (B).

of the algae was 45 days, totaling 8 annual cycles and 280 days of work, considering the family labor, composed by two people and one temporary worker.

The Aquafarmer's kitchen was considered as the family infrastructure to process the fresh seaweed, thus ignoring the investment in a site for processing and bottling of the extract of *K. alvarezii.*

The economic study considered a yield of the liquid fraction of 0.7 L kg^{-1} found in the previous phase of the seaweed processing.

Extraction and yield of the liquid fraction (extract) and the solid fraction (flour)

The sap of *K. alvarezii* was extracted following the methodology of Eswaran et al. (2005) and adapted for the Brazilian strains cultivated in the marine farm of the Fisheries Institute of the Secretariat of Agriculture of the State of São Paulo (45°2´49"W 23°27'8"S) (Figure 1). Equal parts of the four cultivated strains (original brown, original green, original red and Edison de Paula) were harvested after 45 days of cultivation, between June and July of 2016. After that, they were washed in running chlorinated fresh water to remove any fouling, weighed in equal parts, and mixed and broken to facilitate grinding. Grinding was performed by a 4-L industrial blender (high rotation, 60 HZ - 800W) for approximately 5 minutes. Then, this liquid was filtered in polyamide cloth, separating solid and liquid fractions (Gelli and Barbieri, 2015).

The mean yield of the liquid fraction and the solid fraction of five samples were calculated for each kilogram of seaweed. Graduated test tubes were used to measure the volume of the liquid extract. After removal of the liquid phase, the residue remaining in the filter was specified as a recent solid fraction, which was weighed on a digital scale.

The fraction of net primary productivity or extract was calculated as a ratio of the net fraction volume obtained and the initial weight of the seaweed used, according to Equation 1.

$$\text{Liquid Fraction} = \text{Total Volume} / \text{Initial Weight} \quad (1)$$

The total residue produced was calculated as a function of the total weight of the solid fraction retained in the filtration and the initial weight of the seaweed used (Equation 2).

$$\text{Solid Fraction} = \text{Total Residue} / \text{Initial Weight} \quad (2)$$

According to Shanmugam and Seth (2018), the solid fraction is a residue which contains semi-refined carrageenan and may have economic value. However, for these economic analyses, we considered only the liquid fraction.

Characterization of the chemical composition of the extract of the seaweed *Kappaphycus alvarezii* of macro and micronutrients and classification according to the Brazilian fertilizer legislation

No studies are characterizing the composition of the seaweed extract produced in Brazil, thus, the chemical composition was performed following the specific Brazilian laws for biofertilizer analysis.

The extract was sent to the official fertilizer laboratory of the University of São Paulo (Escola Luiz de Queiroz) which examined the chemicals composition of the following parameters: pH by direct-reading sample; organic matter ignition loss, according to Schulte et al. (1987); total nitrogen by sulfuric digestion; mineral waste ignition loss according to Schulte et al. (1987); Phosphorus (P_2O_5) by molybdenum vanadium colorimetry; Potassium (K_2O), Calcium (Ca), Magnesium (Mg), Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn) by atomic absorption spectrophotometry extracted with Nitric-Perchloric solution.

Afterward, the extract was classified according to the Brazilian legislation regulating agricultural fertilizers, Law no. 6,894, of December 16, 1980 (Brasil, 1980), which provides on the inspection and supervision of the production and trade of fertilizers, correctives, inoculants, or biofertilizers, remineralizers and substrates for plants destined for agriculture and their decrees and normative instructions that regulate it.

Economic Analysis

Currently, marine farmers occupy a marine area of up to 0.2 ha (Gelli, 2007) and were classified as small producers. Thus, this size was adopted for the calculations of this study and was denominated as a minimal family module (MFM). On the North coast of São Paulo, the activity of mariculture was limited in the size of the area of up to 2 hectares of water, by state Decree no. 62.913, of November 8, 2017 (São Paulo, 2017). To verify the economic feasibility of *K. alvarezii* seaweed cultivation in MFM (0.2 ha) we compared the fresh seaweed (FS) production and the seaweed extract (SE). A sensitivity analysis for the production of the extract was performed and considered different selling prices and having reference as the highest price of the product found in the Brazilian trade: A) lowest price (SE1), medium price (SE2) and commercial price of the extract applied in the Brazilian market (SE3). The costs, revenue, and profit obtained with the production and sale of the product were taken into account, using partial budget analyses to compare costs and revenue variation under the different scenarios proposed (Shang, 1990).

The average prices paid by the Brazilian industry for fresh seaweed (FS) were US\$ 0.18 kg^{-1} and US\$ 5.53 L^{-1} for the extract (SE3).

All specifications of these enterprises for cost and economic viability index calculations are described in Table 1.

Initial investment

To calculate the initial investment the values of the project elaboration, environmental licensing rate, and equipment (boat,

Table 1. Economic values for the production of fresh and extract seaweed in low-impact areas, on the Northern coast of São Paulo – Brazil (January 2019).

Seaweed	Fresh production	Extract production scenarios		
	FS	SE1	SE2	SE3
Productivity (kg tubular nets m^{-1})*	3.0	3.0	3.0	3.0
Total area (m^2)	2,000	2,000	2,000	2,000
Number of rafts (3 x 50 m)	4	4	4	4
Number of cycles year^{-1}	8	8	8	8
Production per cycle (kg)	3,600	3,600	3,600	3,600
Seedling production (kg)	720	720	720	720
Total production (kg)	2,880	2,880	2,880	2,880
Total annual production (L)	0	16,128	16,128	16,128
Sale price (US$ kg^{-1})* (US$ L^{-1})	0.14*	2.15	2.77	5.53
Total cycle production value (US$)	398.27	4,336.68	5,575.74	11,151.47
Total annual production value (US$)	3,186.13	34,693.46	44,605.88	89,211.76

*Source: (Gelli and Barbieri, 2015).

outboard, raft management, production rafts, worktable, signboards, anchors, scale electronics, industrial blender) were considered.

Operational costs

All technical data for the economic study were obtained from the Fisheries Institute of the Secretariat of Agriculture of the state of São Paulo.

Phases of cultivation (planting, harvesting, and processing), production cycles, infrastructures used, organizational indexes obtained, monetary disbursement, and marketing channels were identified, allowing the calculation of the cost of production and profitability indicators (Table 1).

The methods proposed by Matsunaga et al. (1976) and Martin et al. (1998) were adopted, which considered the expenses with transportation, inputs, fuel, water, electricity, permanent and daily labor for the Effective Operational Cost (EOC); the sum of EOC, social charges of 80% on the value of labor and interest on operating expenses and depreciation of equipment, vessels and crop structures for Total Operating Cost (TOC); the sum of the TOC with the value of the annual depreciation of the installations and the interest of the capital of the investment for the Total Cost of Production (TCP).

Profitability indices and feasibility analysis

The feasibility of the investment is analyzed through the Internal Rate of Return (IRR), which represents a certain source of annual income, after covering operating expenses, on the cost of investment (Shang, 1990; Martin et al.,1994). Economic feasibility is achieved when the IRR is higher than a certain attractiveness rate, in this study defined at 10% per year, higher than the interest earned on traditional Brazilian financial investments and the rates offered by the Brazilian government to subsidize this type of activity through a bank loan.

Through the cash flow, profitability ratios are calculated. Cash flow is the result, year by year, of the difference between Gross Revenue (GR) and Total Operating Cost (TOC). The Payback Period (PP) is the cost of the investment divided by the annual average balance obtained in the cash flow.

Payback Period (PP) is the time (years) required for recovering the capital invested in current values, using the attractiveness rate.

Net Present Value (NPV) was also estimated using cash flow, discounting the rates that represent capital costs of importance to the long-term investor (Shang, 1990; Martin et al., 1994).

The breakeven point (BP) representing the minimum production of seaweed needed to cover the cost was obtained by dividing the total operating cost by the sales price per kilogram of the product. The following economic indicators were determined for the study of economic viability analysis (Martin et al., 1998):

$$GR = Price \times Q \quad (3)$$

where, GR: Gross Revenue; Q: Quantity of seaweed produced;

$$NR = GR - TOC \quad (4)$$

where, NR: Net Revenue; TOC: Total Operational Cost;

$$BP = Fixed\ Costs / (SP - VC) \quad (5)$$

where, BP: Breakeven point; SP: Selling Price; VC: Variable Cost.

Since access to credit in this kind of production is difficult, the working capital of 85% of the total investment was considered according to Matsunaga et al. (1976) and Martin et al. (1998). The indicators were determined for a 10-year project horizon. The Minimum Attractiveness Rate (MAR) considered was 10% and also it was the discount rate used to calculate the Net Present Value (NPV). Economic viability is achieved when IRR is higher than this rate, which is superior to interests that could be received in financial applications (Selic Rate - Central Bank of Brazil, January 2019) and the available interests in bank loans funded by the Brazilian Government for this type of activity.

RESULTS

Yield and chemical composition of seaweed extract *Kappaphycus alvarezii* cultivated in Brazil

The average yield obtained from the extract of fresh seaweed was 0.71 ± 0.0080 L kg^{-1} and the moisture solid production was 295 ± 0.0126 g kg^{-1}.

The results of the chemical composition of the extract obtained in this study are listed in Table 2 as well as the results found in the works by Rathore et al. (2009), Layek et al. (2015), and Normative Instruction of the agriculture ministry no. 25, July 23, 2009 (Brasil, 2009).

Economic analysis of Fresh and Processed Seaweed Enterprises (extract): investments, costs, and profitability

Investment items for the cultivation of *K. alvarezii* seaweed in MFM production areas can be seen in Table 3. Initial investments for the economic study of fresh seaweed (FS) and its extract (SE, SE2, and SE3) were from US$ 16,580.11 to US$ 17,296.44, respectively. The major investment item in all enterprises is the working raft, with 26.75% and 25.64% of participation, respectively.

All operational expenses of fresh seaweed production were calculated and are shown in Table 4. In the production, inputs were considered: 720 kg of seedlings, 10,560 m of 4-mm mesh tubular fishing net, 120 fishing net protection units of 3 x 5 m, 20 plastic boxes, 12 boxes of surgical gloves, 20 trays, 5 filters, 6 EPI sets, 10 knives, 1,600 liters of fuel, 3 rolls of 4-mm polypropylene cables, 80 L of 2T oil and 3,226 plastic flasks.

The labor force and the respective social charges represent 63.48, 49.22, 48.37, and 45.34% of the operating cost of the crop for FS, SE1, SE2, and SE3, respectively. These values differ according to the contribution of social security, which is 2.3% of gross revenue.

Acquisition of propagating material (seedlings) for the first cycle of production was considered as an operational cost, even though its cost of US$ 22.13 is insignificant due to the restrictions of the Brazilian environmental legislation that determine the origin of the seedlings.

Costs' results for the monoculture proposed for fresh seaweed in MFM areas recommended by the current environmental laws can be observed in Table 5 and values presented in Tables 5 and 6 to produce fresh seaweed for carrageenan extraction are unviable for Minimum Module areas. Even with a total operating cost of US$ 3,374.79, the results of economic indices such as net revenue, profitability index, NPV, IRR, and CRP were negative. The minimum amount that must be produced at a marketing price of US$ 0.14 for the profitability to achieve zero was calculated in 244,404 kg. This amount is 9.4 times greater than the production capacity of low-impact regions per year, which makes the enterprise impractical on the coast of São Paulo.

Table 2. Physical and Chemical composition of the extract of *Kappaphycus alvarezii* seaweed on the Northern coast of São Paulo - SP, Brazil.

Variables	This study	Rathore et al., 2009	Layek et al., 2015	Brazilian Legislation*
pH	5.97			
Density (g mL^{-1})	0.95			
Residue 110 (g L^{-1})	43.43			
Organic matter (g L^{-1})	6.89			
Soluble mineral residue (g L^{-1})	36.53			
Total Carbon (g L^{-1})	3.83			
Total Mineral Residue (g L^{-1})	36.57			
Mineral Insoluble Residue (g L^{-1})	0.036			
Potassium (K_2O) (g L^{-1})	20.17	19.70	33.65	
Total Nitrogen	0.42	0.30		
Phosphorus (P_2O_5) (g L^{-1})	0.090	0.0340	0.0175	
Sulphur (S) (g L^{-1})	0.35	0.60		3
Calcium (Ca) (g L^{-1})	0.25	0.46	0.32	3
Magnesium (Mg) (g L^{-1})	0.2367	0.58	1.11	3
Iron (Fe) (g L^{-1})	0.0037	0.0106	0.0861	0.2
Zinc (Zn) (g L^{-1})	0.0010	0.0006	0.0047	0.5
Manganese (Mn) (g L^{-1})	0.0003	0.0025	0.0021	0.2
Copper (Cu) (g L^{-1})	0.0	0.0003	0.0006	0.5

* Normative Instruction of the Ministry of Agriculture no. 25 of July 23, 2009 (Brasil, 2009).

Table 3. Investment items for implementing the production of fresh seaweed (FS) and extract (SE) from *Kappaphycus alvarezii*, cultivated on the Northern coast of São Paulo (January 2019). Project Horizon = 10 years.

Investment	Quantity	Lifespan (years)	Unit value (US$)	Fresh (FS)	Extract (SE)*
				Total (US$)	Total (US$)
Project design	0.05	10	445.21	426.77	445.21
Environmental Licensing	1	10	0.00	0.00	0.00
Aluminum boat 4 m	1	10	1,229.22	1,229.22	1,229.22
Outboard motor - 5 HP	1	10	1,198.49	1,198.49	1,198.49
Working Raft 5 x 4 m	1	10	2,396.98	2,396.98	2,396.98
Cultivation Raft	4	5	430.23	1,720.91	1,720.91
Worktable 1.5 x 1.5 m	1	5	92.19	92.19	92.19
Signaling buoys	4	5	48.80	195.20	195.20
70-kg anchors	12	20	82.97	995.67	995.67
Electronic scale 30 kg	1	5	245.84	245.84	245.84
High-pressure washer	1	5	460.96	460.96	460.96
Industrial blender 10 L	2	5	184.38	0	368.77
Partial value				**8,962.22**	**9,349.42**
Working capital	0.85			7,617.89	7,947.01
Total (US$)				**16,580.11**	**17,296.44**

* For all the three extract price scenarios.

Table 4. Operating expenses to produce fresh algae (FS) and extract (SE) of *Kappaphycus alvarezii* seaweeds, grown on the Northern coast of São Paulo (January 2019), including the workforce.

Items	Fresh (FS) (US$)	Extract (SE) Scenarios (US$)		
	FS	SE1	SE2	SE3
Algae Seedlings	22.40	22.40	22.40	22.40
Production inputs	5,929.48	9,696.66	9,696.66	9,696.66
Transport	-	737.53	737.53	737.53
Water and Electricity	1,475.06	3,318.89	3,318.89	3,318.89
Staff – algae producer + 80% charge	9,956.67	9,956.67	9,956.67	9,956.67
Staff – family member + 80% charge	6,637.78	6,637.78	6,637.78	6,637.78
Staff - maintenance support	1,475.06	1,475.06	1,475.06	1,475.06
Membership fee	36.88	36.88	36.88	36.88
Social Security fee	146.56	1,835.28	2,359.65	4,719.30
Total US$	**26,137.77**	**33,717.16**	**34,241.52**	**36,601.17**

The results of the economic indicators in the proposed scenarios are presented in Table 6. The interested in the activity could invest in the seaweed cultivation according to the scenario (SE2), but these analyses would need to be observed with caution since the activity depends directly on the oceanographic and climatic conditions.

Another point observed in this work was that the production of the handmade extract would be linked to the demand for the product by the agricultural sector. According to the sale price survey, it was observed that this extract was currently elaborated and commercialized nationally by only one industry located in the state of Rio de Janeiro at the sale price per liter of US$ and corresponded to the study (SE3) of the analysis of the sensitivity of this study. According to the results for the artisan production, the profit margin would be about 57.93%, however, an industrial establishment composes other investments and costs.

The economic analysis profitability showed that, in the conditions established and based on family work, were positive only in scenarios SE2 and SE3.

Table 5. Economic indexes of the scenarios for the commercialization of fresh seaweed (FS) and its extracts (SE), grown on the Northern coast of São Paulo (January 2019).

Items	Fresh	Extract (SE) scenarios		
	FS	SE1	SE2	SE3
Production inputs (US$ cycle^{-1})*	982.84	1,719.17	1,719.17	1,719.17
Workforce - Daily Maintenance fee (US$)	184.38	184.38	184.38	184.38
Fees and Taxes (US$ cycle^{-1})	22.93	234.02	299.57	594.52
Effective Operational Cost	**1,190.15**	**2,137.57**	**2,203.12**	**2,498.07**
Other costs				
Depreciation (US$ cycle^{-1})	110.33	118.62	118.62	118.62
Family workforce (US$ cycle^{-1})	2,074.31	2,074.31	2,074.31	2,074.31
SUB-TOTAL (US$ cycle^{-1})	**2,184.64**	**2,192.93**	**2,192.93**	**2,192.93**
Total Operational Cost (TOC) (US$ cycle^{-1})	**3,374.79**	**4,330.50**	**4,396.05**	**4,691.00**
Production (kg; FS) (L; SE)	2,880	2,016	2,016	2,016
Average TOC (US$ kg^{-1}; FS) (US$ L^{-1}; SE)	1.17	2.15	2.18	2.33
Selling price (US$ kg^{-1}; FS) (US$ L^{-1}; SE)	0.14	2.15	2.77	5.53
Gross Revenue (US$ cycle^{-1})	398.27	4,336.38	4,396.05	4,691.01
Net Revenue (US$ cycle^{-1})	-2,976.52	6.18	1,179.69	6,460.46
Breakeven Point (kg; FS) (L; SE)	244,404	2,013	1,589	848
Profit (US$)	-2,976.52	6.18	1,179.69	6,450.46
Operating Profit (US$)	-3,395.52	-566.09	596.64	5,830.01

*Cycle of 45 days.

Table 6. Economic viability indicators of *Kappaphycus alvarezii* seaweed production in Minimum Family Modules for fresh algae (FS) and extract (SE) production on the Northern coast of São Paulo (January 2019).

Seaweeds	Fresh (FS)	Extract (SE) Scenarios		
	FS	SE1	SE2	SE3
Sale Price* (US$ kg^{-1}; FS) (US$ L^{-1}; SE)	0.14*	2.15	2.77	5.53
Payback (years)	- 0.76	25.68	2.74	0.75
Net Present Value - NPV (US$)	- 158,990.45	- 18,887.74	35,300.13	284,809.09
Internal Rate of Return - IRR (%)	n.r.	-16.55	38.99	215.98

* CRP in current values, using the attractiveness rate.

DISCUSSION

Results of extract yield for the strains of seaweed corroborated the data achieved by Gelli and Barbieri (2015) that obtained an average yield of 0.741 L kg^{-1} of the extract.

Micronutrient and macronutrient concentrations of the extract of *K. alvarezii* seaweed varied compared with the results observed in the studies by Rathore et al. (2009) and Layek et al. (2015).

The highest concentration of the macronutrients found in this work was for potassium (K) and the lowest was for the micronutrient copper (Cu). These results corroborate with the studies by Rathore et al. (2009) and Layek et al. (2015). However, according to the results of the macronutrients in the work of Layek et al. (2015), the K concentration was 66.9% higher for K and null for Cu compared to the present study. The concentration of K, according to the works of Mantri et al. (2017) was the main factor that promoted a new pathway for the increase of biomass through the production of liquid fertilizer, generating energy through the gasification of the granules and new technological innovations.

Nitrogen concentration data were 28.57% higher than those found in the work by Rathore et al. (2009). Phosphorus was also found in small amounts of 0.09 g. However, it is three times greater than the amount found in the extracts of India

Given the results of concentrations of secondary macronutrients and micronutrients in this study and, following the normative instruction of the Ministry of Agriculture no. 25 of July 23, 2009 (Brasil, 2009), the seaweed extract cannot be classified as a fluid foliar organic fertilizer, because it does not present the organic carbon concentrations in 8% and also because it does not meet the established requirements of minimum concentrations of secondary macronutrients that have been calcium (0.3%), magnesium (0.3%), and sulfur (0.3%), and also of micronutrients: iron (0.02%), zinc (0.05%), manganese (0.02%), and copper (0.05%).

This study was carried out in the winter seasons. According Solorzano-Chavez et al. (2019) the productivity and growth rates of different strains of *K. alvarezii* were more pronounced in the seasons of summer-autumn, in this same location. Shanmugam and Seth (2018) found values of average yield of biofertilizer of same species that varied with the harvest and planting seasons of macroalgae. We suggest new seasonal economic studies to observe these variations and different scenarios based on the seasonal floatability of seaweed strains productivity and mineral contents.

The extract analyzed (Table 2) could be classified as stimulant or biofertilizer, according to the fertilizer legislation, Decree no. 4,954, of January 14, 2004 (Brasil, 2004), (though for its registration with the Ministry of Agriculture, further studies to identify its active ingredient or organic agent are necessary.

The extract of *K. alvarezii* when applied as foliar "spray" is considered as a biofertilizer or agricultural stimulant and its efficiency has been reported by many authors. Zodape et al. (2008) studied the use of different extract concentrations in the cultivation of Okra (*Albemos chusesculentus*) finding 2.5% of extract concentration was more efficient, with a productivity increase of 20.47%. Rathore et al. (2009) applied the extract for growing soybeans (*Glycine max*) and the highest grain yield was recorded with the application of 15% seaweed extract which resulted in an increase of 57% compared to the control. Zodape et al. (2012) applied it in wheat cultivation (*Triticum aestivum*) and found a significant difference in the growth of this cereal when using 1% *K. alvarezii* extract, with a productivity increase of 80.44%, data not achieved by Shah et al. (2013), who only found an increase of 19.74% for extracts with 7.5% concentration. Zodape et al. (2010) stated that the use of 1% seaweed extract led to a greater yield and quality in green bean (*Phaseolus radiata L.*) crops. Zodape et al. (2011) used the seaweed extract in tomatoes (*Lycopersicon esculentum*), achieving better results with a 5% concentration, generating a productivity increase of 60.89% in comparison to the control. Babu and Rengasamy (2012) observed that with the addition of the extract of the seaweed to 2% per paddy (*Orysa sativa* L.) and chilli (*Caspicum annum*), there was a significant yield increase of 27% and 23%, respectively. The extract used at 1% concentration in culture peanut (*Arachis hypogea* L.) resulted in an increased yield of 30.6% %. Karthikeyan and Shanmugam (2014) observed that banana varieties of hills and foothills viz. Robusta (AAA), Njali poovan (AB), Red banana (AAA), and Nendran (AAB) had responded well to biostimulant of seaweed *K. alvarezii* to 5% with average yields increase of 56.58%, 19.08%, 39.35%, and 11.46%, respectively. Karthikeyan and Shanmugam (2017) applied a 1% biostimulant on cane (sugarcane variety Co 86032) and the results yielded an increase of 24.90, 28.79, 20.47, and 26.16% in the plantation crop, 1st ratoon, 2nd ratoon, and 3rd ratoon, respectively, with statistically significant yields and juice quality.

Economic analysis

Considering that the seaweed extract is an efficient agricultural stimulant, the economic study was carried out for a minimum production area of 0.2 ha. This study showed that it was possible to produce 1,200 m of productive lines per cycle for US$ 0.14 and with a production cost of US$ 1.4, which demonstrates that this is impractical. Valderrama et al. (2015) compared the activity of *K. alvarezii* seaweed cultivation in six countries (India, Solomon Islands, Mexico, Tanzania, Philippines, and Indonesia), and concluded that at least 2,000 m of seaweeds cultivation line and marketed at a price of at least US$ 0.80 kg^{-1} and with a production cost of about US$ 0.25 kg^{-1} would be necessary for small producers to guarantee the turnover of economic business.

Mantri et al. (2017) claim that the successful implementation of the commercial cultivation of *K. alvarezii* showed that scientific innovation can benefit rural coastal areas that lack alternative economic opportunities. Moreover, this scenario was found almost 10 years ago in India and today this country is rapidly emerging as an important commercialization and production center of value-added products of *K. alvarezii* in Southeast Asia, generating work and an annual turnover of about US$ 27.57 million.

The working raft is also a factor that impacts the value of the investment; 27.08 for the company SF and 25.96% for the companies (SE1, SE2, and SE3). This value may be reduced by encouraging cooperation among producers to share it, or by improving purchasing power, and using alternative materials. In some Pacific islands, there was the possibility of receiving a support vessel through incentive programs to attract fishermen to enter the activity (Pickering, 2006). Any economic incentive for investment and operating expenses would be a positive factor to encourage the development of this activity in Brazil.

An economic study performed by Santos (2014), in the state of Santa Catarina, Brazil, compared the potential for producing *K. alvarezii* seaweed with the already established cultivation of oysters and mussels in Southern. The results of economic index estimates were feasible for three categories: monoculture, joint cultivation with oysters, and joint cultivation with mussels. For seaweed monoculture in areas up to one hectare, the results were positive for dry seaweed, with an IRR of 30.67% and a recovery rate of 3.8 years.

Unlike São Paulo state, other states in Brazil do not have the restriction of a 2 ha area of water surface for growth and can expand their production, but the Brazilian environmental legislation limits the production of the exotic seaweed *Kappaphycus alvarezii* to only the states of São Paulo and Rio de Janeiro. A possible alternative being studied would be implementing the integrated multitrophic aquaculture (IMTA) as a possible alternative of economically viable production, or, such as in the studies of Mantri et al. (2017) commercializing processed products which could lead to the development of a productive chain of seaweed in the state of São Paulo.

Profitability indicators for extract production enterprises show that in the conditions established and based on a familiar workforce, only scenarios SE3 and SE4 were positive.

CONCLUSION

According to the concentrations of the secondary macronutrients and micronutrients analyzed, the extract of the seaweed *K. alvarezii* cultivated on the North coast of São Paulo cannot be considered an organic foliar fertilizer because it does not present the minimum concentrations established by Brazilian legislation. So, it can be considered a biofertilizer or an agricultural biostimulant.

Results showed that the production of the handmade extract was economically feasible in this study for seaweed extracts from the selling price of US$ 2.77. The minimum family modules are not feasible for the production of fresh seaweed.

Further studies should be encouraged in Brazil on the application of this extract as an agricultural biostimulant for the improvement of the productive chain, in addition to investigations with new alternative products from seaweeds. We also emphasize that economic studies in areas larger than 0.2 hectares should be encouraged, in addition to studies with integrated multitrophic aquaculture already established in the region, such as fish, scallops, and mussels.

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