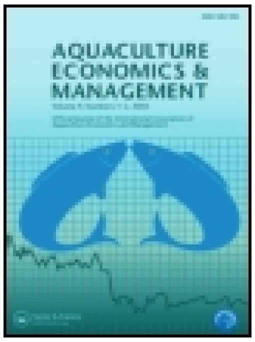

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A bioeconomic analysis of the potential of seaweed *Hypnea pseudomusciformis* farming to different targeted markets

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ABSTRACT

Simulations were performed to evaluate the economic potential of farming the seaweed *Hypnea pseudomusciformis* in two production scales for the carrageenan, human food, and glycolic extract markets in Brazil. The initial investment was low in all scenarios (US$25,579 in 7.5 ha and US$71,202 in 22.5 ha farms). Labor and taxes were the major production costs for production commercialized for the carrageenan and human food markets, respectively. Liquid glycerin and bottles were the main costs when the productions were marketed for glycolic extract. The carrageenan market showed no economic feasibility. On the other hand, the human consumption market was shown as very profitable, resilient, and highly attractive (IRR was ∼100%). Marketing the glycolic extract is also feasible and attractive (IRR was ∼25%) but had lower economic indicators and low resilience when compared to the human food market scenario. Upscaling the production optimized investments and reduced production costs, improving profitability. The plasticity of seaweed enables entrepreneurs to explore different markets simultaneously to increase farm resilience.

KEYWORDS
Macroalgae; carrageenan; functional food; nutraceuticals; cosmetics

Introduction

The global production of seaweeds grew from 10.6 million tonnes in 2010 to ∼32.4 million tonnes in 2018 reaching a value of ∼US$13.3 billion (FAO, 2020) and currently representing the largest component of mariculture output by quantity (Chopin, 2018). Seaweed farming has short growing cycles and requires simple technology and low initial investment when compared to the aquaculture of other organisms.[1] Furthermore, the activity shows high profitability and short payback periods in some supply chains, and provides opportunities for coastal communities (Coastal Resources

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Center, 2002; FAO, 2013; Rebours et al., 2014; Valderrama et al., 2015) and can provide ecosystem services if suitably managed (Campbell et al., 2019).

Macroalgae production has wide range applications, including its integration in food for human consumption, as a food additive for animal feeds, agricultural fertilizers, biofuels, medicines, cosmetics, and as a source of hydrocolloids (FAO, 2018; Mazarrasa et al., 2014; McHugh, 2003; Valderrama et al., 2015; White & Wilson, 2015). The majority of harvested seaweed biomass is used for obtaining hydrocolloids, which are sourced from the red algae *Eucheuma* sp., *Kappaphycus* sp., and *Gracilaria* sp. (FAO, 2018). In 2016, globally exports of seaweed commodities to the top 35 importing countries were valued at ∼ US$985 million for agar-agar and carrageenan and ∼ US$648 million for edible seaweed products (FAO, 2018). The introduction of ingredients obtained from macroalgae in cosmetics is increasing, as it may improve health and well-being (Bedoux et al., 2014; Fernando et al., 2019; Ferrara, 2020; Pereira, 2018). Algal glycolic extracts have been used as an ingredient in the manufacturing of shampoos, soaps, moisturizers, among other cosmetics.

Seaweed mariculture has a high potential for expansion throughout South America given the vast coastlines and good climate conditions. Currently, seaweed production is carried out mainly in Chile and is extractive, whereas seaweed mariculture is limited in the Atlantic coast countries (FAO, 2018). Attempts have been carried out in Brazil to cultivate the exotic species *Kappaphycus alvarezii* in the sea, however, this species presents environmental risks for having rapid propagation and competing with native algae species, and shading coral reefs (Castelar et al., 2015; Chandrasekaran et al., 2008). Hence, the aquaculture of this species has suffered restrictions throughout most of the South American Atlantic coast. Thus, studies regarding seaweed mariculture in this region should focus on native species for economic development.

Seaweeds of the genera *Hypnea* can be destined for human consumption (Pereira, 2016; White & Wilson, 2015), to produce carrageenan (Greer et al., 1984; Guist et al., 1982), and glycolic extract for the cosmetic, pharmaceutical and nutraceutical industry (Chakraborty et al., 2016; Shareef et al., 2012; Xu et al., 2015). *Hypnea musciformis* are epiphytic macroalgae that are naturally distributed around the world and occur in shallow tropical and subtropical marine areas (Berchez et al., 1993; Castelar et al., 2016; Guist et al., 1982; Nauer et al., 2015). The species was recently redescribed in South America as *Hypnea pseudomusciformis* (Nauer et al., 2015). The high commercial potential and natural occurrence worldwide of this macroalgae make it a suitable candidate for research with the purpose of understanding its cultivation technology and bioeconomics.

The purpose of the present study was to evaluate the economic potential of producing *H. pseudomusciformis* in small and medium-scale farms using

Brazilian data when commercializing the harvested biomass for carrageenan, human consumption, and glycolic extract. A budget analysis was carried out to evaluate the economics of producing *H. pseudomusciformis* with two farming scales for commercialization to different markets. The budget analysis included cost-return, cash flow, and economic feasibility, and the cash flow considered a project life of 20 years (Engle, 2010; Shang, 1990).

Materials and methods

The technology to cultivate *H. pseudomusciformis* was developed recently, and a patent has been claimed on the Brazilian National Industrial Property Institute (INPI) (Valenti et al., 2019). The culture of this macroalgae was performed using a modified module system of long-lines (Pereira et al., 2020). Each module consists of a main polypropylene braid rope with a length of 1 m and with a diameter of 1 cm and is laced with a shredded rope of 30 cm for fixing seedlings of the macroalgae. This farming system obtains productivity of ~0.10 kg of dry algal mass per meter of line with a production cycle of 45 days and a yield of 5 L of glycolic extract per kg of dry mass. These data were used to simulate two hypothetical farming scenarios that differed by production scale (Table 1). The smaller farm occupied 7.5 ha and consisted of 150 long-lines while the medium-sized farm has an area of 22.5 ha and has 450 long-lines. The long-lines are 10 m apart, and each has 50 modules. Therefore, the small and medium farms have 7.5 km and 22.5 km of long-lines, respectively. Both farm scenarios conducted eight production cycles of 45 days per year. The harvested biomass was marketed for the carrageenan industry (CM), for human consumption (HC) and the production of glycolic extract on-site for the cosmetic industry (GE).

All costs and prices were acquired in the Brazilian market in the first quarter of 2018 and converted to US$ dollars (US$1.00 = R$3.42). The farmers' price of the seaweed biomass for carrageenan was US$0.60/kg, which was the value paid by a hydrocolloid refinery in Brazil (AgarGel). This price is derived from the international seaweed market to carrageenan.

Table 1. Seaweed production data for different farming scales.

Variable	Small	Medium
Total farm area (ha)	7.5	22.5
Cycle time (days)	45	45
Cycle/year	8	8
Long-lines/cycle	150	450
Seaweed productivity (kg/m)	0.10	0.10
Seaweed productivity (kg/year)	6,000	18,000
Glycolic extract productivity (L/year)	30,000	90,000

Productivity data corresponds to the dried seaweed biomass.

Commercialization of *H. pseudomusciformis* for human consumption is non-existent in Brazil, so the present study surveyed 794 persons in March 2019 regarding this market potential. The results showed that 89% are interested in consuming this seaweed, and more than 59% are willing to pay US$14.63/kg or higher. This price was used to simulate the marketing of products for human consumption. The price of the glycolic extract was set at US$14.33/L, which was the mean value of 10 different producers that commercialize the product on the internet. The value of the glycolic extract was maintained for one year with no variation in price.

Fixed costs (FC) included employee salaries, vehicle property tax, maintenance of equipment and facilities, depreciation of assets, and opportunity costs. The depreciation was calculated by the straight-line method (Engle, 2010). Opportunity costs were the interests of the fixed capital and remuneration of the entrepreneur. Variable costs (VC) consisted of expenses with plastic raffia ribbon, cotton yarn, fuel, plastic raffia bag, manual labor, and taxes. The VC for producing the glycolic extract included liquid glycerin, cereal alcohol, plastic bottles, and paper filters. Cost and revenue data were used to determine gross revenue (GR), net revenue (NR), and profit (P) as described below:

$$\text{GR} = \text{Production} \times \text{Selling price} \tag{1}$$

$$\text{NR} = \text{Gross revenue} - \text{Total operation costs} \tag{2}$$

$$\text{P} = \text{Net revenue} - \text{Opportunity costs} \tag{3}$$

The cash flow analysis considered 20 years of operation. Year zero included the initial investments and working capital. Production was assumed to be 40 and 20% lower than the predicted values for the first and second years, respectively, to compensate for potential difficulties at the beginning of the venture such as technological adjustments, personnel training, and insertion of the product into markets.

Internal rate of return (IRR), net present value (NPV), benefit-cost ratio (BCR), and discounted payback period (DPP) were used to determine the financial feasibility. The four indicators were determined based on annual inputs and outputs according to calculations described in Engle (2010), Jolly and Clonts (1993) and Shang (1990):

$$\sum_{t=1}^{n} \text{NCF}_t/(1+\text{IRR})^t - \text{NCF}_0 = 0 \tag{4}$$

$$\text{NPV} = \sum_{t=1}^{n} \text{NCF}_t/(1+i)^t - \text{NCF}_0 \tag{5}$$

$$\text{BCR} = \sum_{t=1}^{n} (\text{NCF}_t/(1+i)^t)/\text{NCF}_0 \tag{6}$$

Table 2. Distributions and values of the stochastic input variables established for the Monte Carlo sensitivity analysis.

Market scenario	Stochastic input variables	Unit	Distribution	Mean value	Minimum value	Maximum value
CM*	Price CM	US$/kg	Triangular	1.25	0.50	2.50
HC	Price HC	US$/kg	Triangular	37.54	14.62	80.00
GE	Price GE	US$/L	Triangular	14.33	11.70	16.08
CM; HC; GE	Seaweed yield	kg/m	Triangular	0.10	0.00	0.20
GE	Liquid glycerin	US$/L	Triangular	5.21	2.60	7.81
GE	100 mL bottle	US$	Triangular	0.26	0.13	0.39

*CM: sale for carrageenan market; HC: sale for direct consumption; GE: Production and sale of the glycolic extract.

DPP is the time t discounted at a given interest rate (MARR), where:

$$\sum_{t=0}^{n} (\mathrm{NCF})^{\mathrm{MARR}} = 0 \tag{7}$$

NCF is the net cash flow; i is the discount rate; n is the number of years in operation (0, 1, 2, 3 … n) and t is the year. The minimum attractive rate of return (MARR) and the discount rate were both set at 11% per year, which was an average of the interest on initial capital in Brazil in the past 5 years.

A Monte Carlo simulation was conducted using the @RISK software to mitigate the risks associated with developing and managing the farms and commercialization of the products. The simulation considered farm uncertainties as variations in production efficiency, market prices, and operating costs. The simulation generated probability distributions for the IRR, NPV, BCR, and DPP using 10,000 iterations (Engle, 2010). The sensitivity analysis considered the inputs that had a substantial impact on the IRR, NPV, BCR, and DPP. For all scenarios, the stochastic input variables were seaweed productivity and prices. The GE scenario included the prices of liquid glycerin and bottle as input variables as well. All input variables were described by triangular distribution (Table 2). A variation of 100% was used for seaweed productivity to consider a total loss of the cultivation and the increase in production. The price of the seaweed biomass for carrageenan varied between 0.50 and 2.50 US$/kg as described in Campbell and Hotchkiss (2017). The price of seaweed marketed for human consumption ranged from 14.62 to 80.00 US$/kg (van den Burg et al., 2016). The glycolic extract was assumed to have a variation of 20% in price. A price variation of 50% was used for liquid glycerin and 100 mL bottles since the values of these items vary widely.

Results

Sale to carrageenan market (CM)

Investments for the facilities include building a shed, handling, and drying tables. Expense with equipment were long-line cables, braided ropes, anchors, buoy, 500 L tank, PET bottles, commercial weight scale, fisherman knife, boat, motors, life jacket, and motorcycle (Supplement Appendix A). The initial investments were US$25,579 for the small-scale farm and US$68,253 for the medium-scale farm when marketing the seaweed biomass for carrageenan. The long-lines and anchors represented the majority of costs at ∼45 to 51% and ∼24 to 27%, respectively. The investment costs per hectare decreased from US$3,406 to US$3,033 with an increased scale of production. The total production cost was US$30,025 for the small-scale farm and US$72,000 for the medium-scale farm (Supplement Appendix B). Variable costs were US$13,922 and US$43,241, and the fixed costs were US$16,103 and US$28,759 for the small and medium farms, respectively. Paid labor showed the highest proportion of operating costs at 84 to 86% (Figure 1A). The cash flow analysis did not show liquidity over the lifetime of the project (Figure 2A). Furthermore, the medium-scale farm showed negative financial indicators for this market scenario (Table 3).

Sale to direct human consumption (HC)

The initial investment costs for the HC scenario were similar to those of the CM. Total costs were US$49,298 and US$129,819 for the small-scale and medium-scale farms, respectively. Variable costs were US$32,191 and US$98,046 and the fixed costs were US$17,108 and US$31,773 for the small and medium-scale farms, respectively. Taxes showed the highest proportion of operating costs at ∼47 to 51% followed by labor at ∼40 to 44% (Figure 1B). The annual profit was US$38,452 and US$133,431 for the small and medium farms, respectively (Table 4).

Cash flow analysis showed liquidity over the lifetime of the project (Figure 2B). The indicators of financial feasibility were positive (Figure 3). The internal rate of return (IRR) was 97.5% to the small-scale and 119.1% for the medium-scale farm. The net present value (NPV) showed a substantial interval between the small-scale farm (US$296,613) and the medium farm (US$977,186). The benefit-cost ratio (BCR) was US$3.71 and US$4.50 for the small and medium-scale farms, respectively. The return of invested capital was 1.6 years for the medium-scale farm and 1.7 years for the small-scale farm.

Production and sale of glycolic extract (GE)

Investments in facilities for the GE scenario were similar to those of the other two markets with the exception of requiring amber bottles (5 L wine bottle), cereal mill, and a plastic funnel. The initial investments were US$26,036 and US$71,025 for the small and medium-scale farms,

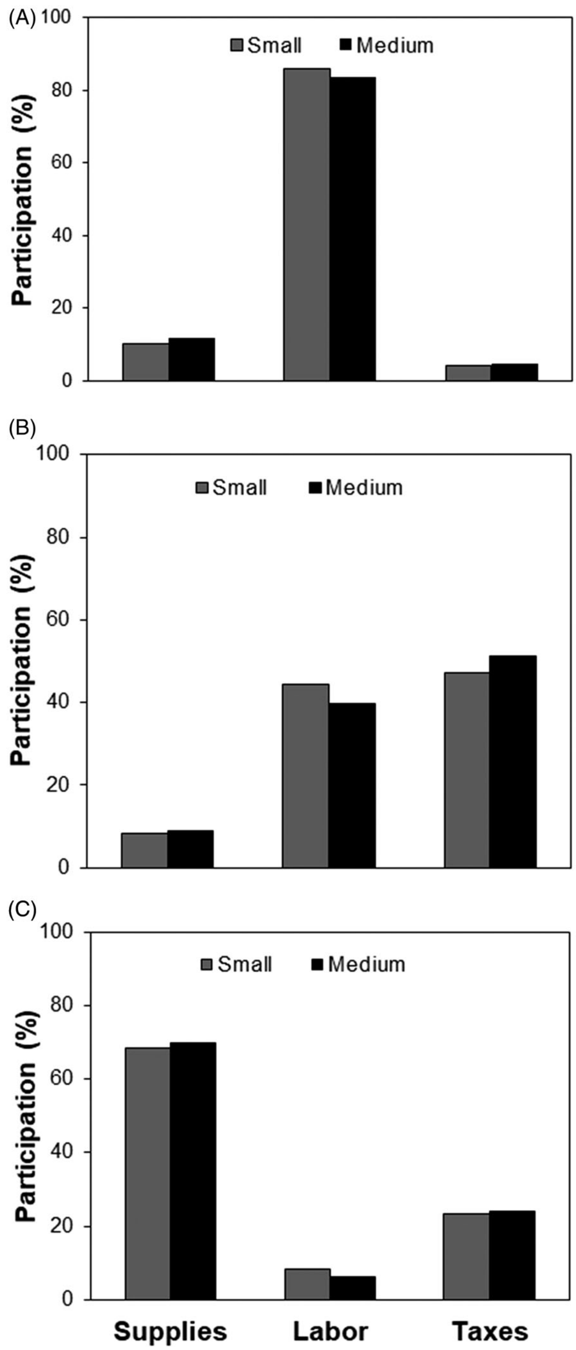

Figure 1. Participation percentages (%) of supplies, labor, and taxes of the operating costs. (A) Sales directed to the carrageen market; (B) for direct human consumption; (C) and production and sale of the glycolic extract.

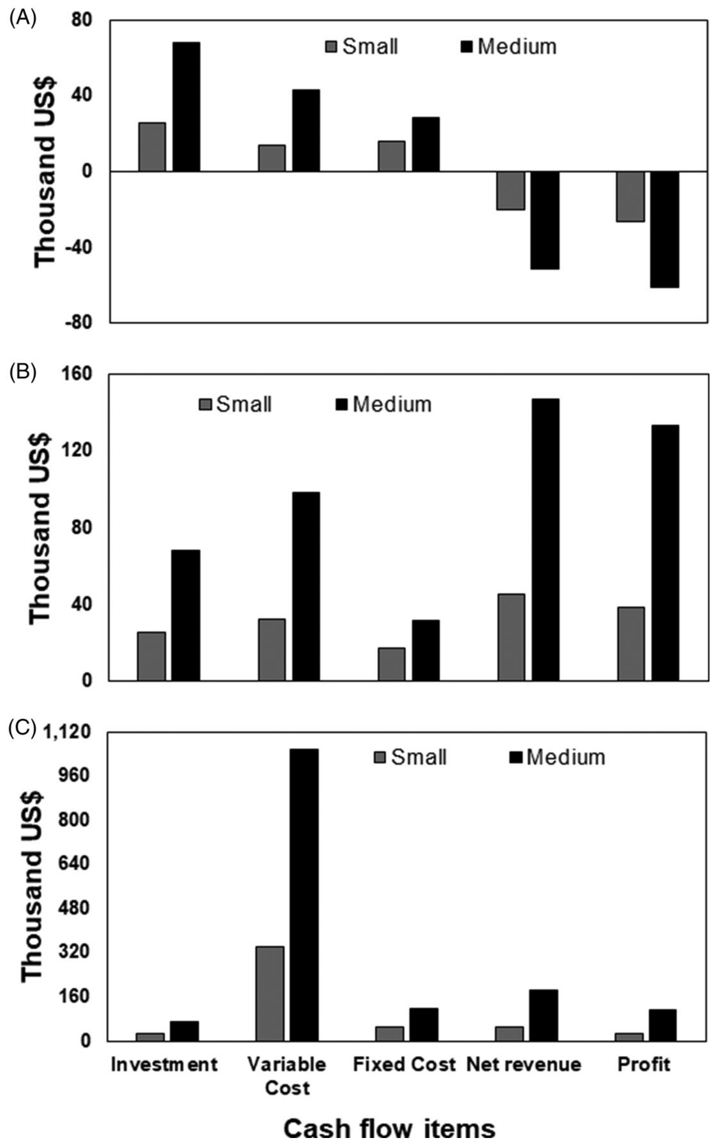

Figure 2. Cash flow for the different markets: (A) Sales to the carrageen market; (B) for human consumption; (C) and production and sale of the glycolic extract. (US$1.00 = R$3.42).

respectively, and the items with the highest proportion of initial costs were the long-lines (44–49%) and anchors (24–26%). The total production costs were US$393,887 and US$1,175,583 for the small and medium farm scales, respectively. The variable costs were US$342,776 and US$1,057,945 and the fixed costs were US$51,111 and US$117,639 for the small and medium-scale farms, respectively. Supplies were the highest operating cost (68–70%), and labor was the lowest (6–8%) for this marketing scenario (Figure 1C). The most expensive items were the liquid glycerin and 100 mL

Table 3. Cost-return analysis and indicators of financial feasibility of seaweed farming commercialized for the carrageen market using different hypothetical farm scales.

Item	Small	Medium
Price (US$/kg)	0.60	0.60
Production yield (kg/year)	6,000	18,000
Production cost (US$/year)	30,025	72,000
Initial investment (US$/ha)	3,406	3,033
Gross revenue (US$)	3,600	10,800
Net revenue (US$)	−20,311	−51,081
Break-even price (US$/kg)	5.00	4.00
Profit (US$)	−26,425	−61,200
IRR (%/aa)	–	–
NPV (US$)	−182,941	−462,577
BCR (US$)	−1.78	−1.68
DPP (years)	–	–
Break-even production (%)	−132	−74

IRR: internal rate of return; NPV: net present value; BCR: benefit-cost ratio; DPP: discounted payback period.

Table 4. Cost-return analysis and indicators of the financial feasibility of seaweed farming to direct human consumption in different hypothetical farm scales.

Item	Small	Medium
Price (US$/kg)	14.63	14.63
Production yield (kg/year)	6,000	18,000
Production cost (US$/year)	49,298	129,819
Initial investment (US$/ha)	3,406	3,033
Gross revenue (US$)	87,750	263,250
Net revenue (US$)	45,571	146,564
Break-even price (US$/kg)	8.22	7.21
Profit (US$)	38,452	133,431
IRR (%/aa)	97.5	119.1
NPV (US$)	296,613	977,186
BCR (US$)	3.71	4.50
DPP (years)	1.69	1.56
Break-even production (%)	28	16

IRR: internal rate of return; NPV: net present value; BCR: benefit-cost ratio; DPP: discounted payback period.

bottles. The annual profit was US$26,216 for the small-scale farm and nearly four times higher (US$114,343) for the medium-scale farm (Table 5).

The cash flow analyses exhibited liquidity over the lifetime of the project (Figure 2C) and positive financial feasibility indicators for both scales of production. The internal rate of return (IRR) was 20.6% for the small-scale farm and 27.1% for the medium-scale farm. The net present value (NPV) was US$147,080 and US$682,030 and the benefit-cost ratio (BCR) was US$2.23 and US$3.31 for the small and medium-scale farms, respectively. The discounted payback period (DPP) increased from 4.9 to 6.4 years with the farm-scale decrease.

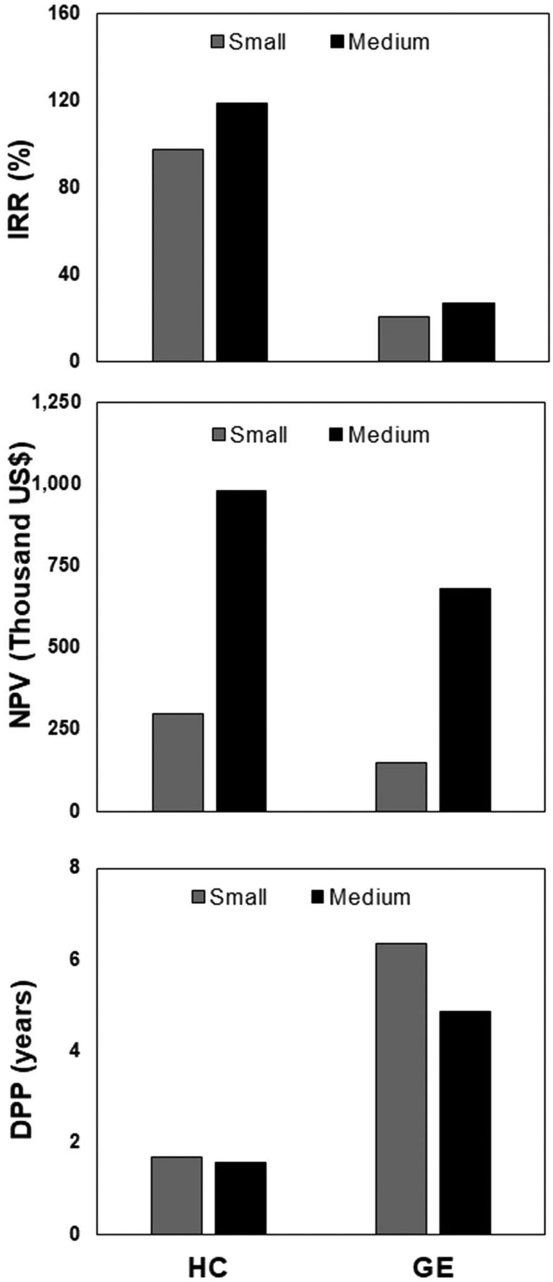

Figure 3. Indicators of economic feasibility for human consumption and glycolic extract as marketed from the different farm scales.

Monte Carlo sensitivity analysis

The Monte Carlo sensitivity analysis showed all economic indicators to be negative for the carrageenan market scenario with variations in the seaweed productivity and price. The simulation of seaweed productivity and price for the HC scenario showed an IRR mean value of 268 and 319%, and NPV means of US$1,084,573 and US$3,337,638 to small and medium farm, respectively (Table 6). The sensitivity analysis of the GE scenario varied seaweed productivity, price, price of liquid glycerin and 100 mL bottles, and showed an IRR means of 27 and 32%, and NPV means of US$106,452 and US$560,217 to the small and medium-scale, respectively.

Discussion and conclusions

The initial investment per unit of area to set up seaweed farming operations decreased when upscaling production, with US$3,033 ha^{-1} for the medium-scale farm and US$3,469 ha^{-1} for the small-scale farm. This variable was low when compared to the aquaculture of other organisms such as finfish. Total initial investment values for seaweed farming show high variation, ranging from 166 to 138,000 US$/ha (FAO, 2013; Hurtado et al., 2001; Shanmugam et al., 2017; van den Burg et al., 2016). The wide range of investment values may be due to differences in production systems, currency conversion, and local opportunities. Seaweed farms in developing countries in Southeast Asia and the Pacific have reduced investment costs by borrowing, sharing, or renting costly items from other farms (FAO, 2013). Farming operations located in the Pacific Islands receive materials from the government and social projects, and thus, these items were omitted in the economic analysis (Kronen et al., 2010; Namudu & Pickering, 2006). Nevertheless, the present study shows investment values that can be used worldwide by accounting for all of the required items to establish seaweed farms.

Fish and shrimp farms require higher investments for facilities and supplies, such as ponds and tanks, diet, and electricity, which are unnecessary for seaweed farming. Commercial diets generally account for ∼70% of production costs in fish and shrimp farming, whereas in seaweed farming, no investment is made for this item. In the present study, labor has been shown as a major production cost (higher than 40%) for seaweed production when marketing the product for carrageenan and human consumption, while accounting for a lower proportion of costs (less than 8%) for the glycolic extract market (GE). This difference is in reason of the increasing expenses with supplies to manufacturing the extract. High costs with labor are positive, once farms that have a higher production cost in paying wages are more socially sustainable (Valenti et al., 2018). Small aquaculture farms generate higher rural income than larger farms by demanding more physical labor rather than investing in technologies that reduce labor costs (Filipski & Belton, 2018).

Table 5. Cost-return analysis and indicators of financial feasibility of seaweed farming for the production and sale of glycolic extract using different hypothetical farm scales.

Item	Small	Medium
Price (US$/kg)	14.33	14.33
Production yield (kg/year)	30,000	90,000
Production cost (US$/year)	393,887	1,175,583
Initial investment (US$/ha)	3,469	3,156
Gross revenue (US$)	429,975	1,289,926
Net revenue (US$)	51,836	182,126
Break-even price (US$/kg)	13.46	13.06
Profit (US$)	26,216	114,343
IRR (%/aa)	20.6	27.1
NPV (US$)	147,080	682,030
BCR (US$)	2.23	3.31
DPP (years)	6.36	4.88
Break-even production (%)	54	33

IRR: internal rate of return; NPV: net present value; BCR: benefit-cost ratio; DPP: discounted payback period.

Table 6. Results of the Monte Carlo sensitivity analysis for both farm scales using 10,000 interactions for the different markets, based on the IRR, NPV, BCR, and DPP.

	HC		GE	
Item	Small	Medium	Small	Medium
IRR (%)				
5th percentile	64.0	77.0	0.0	2.0
95th percentile	550.0	663.0	67.0	80.0
Mean	268.0	319.0	27.0	32.0
Standard deviation	149.0	179.0	21.0	25.0
NPV (US$)				
5th percentile	122,449	452,586	−395,077	−977,474
95th percentile	2,591,213	7,865,970	831,492	2,704,002
Mean	1,084,573	3,337,638	106,452	560,217
Standard deviation	765,430	2,295,927	385,703	1,156,398
BCR (US$)				
5th percentile	1.72	2.25	−3.85	−3.50
95th percentile	30.02	34.07	10.02	11.73
Mean	12.75	14.63	1.77	2.80
Standard deviation	8.77	9.86	4.36	4.78
DPP (years)				
5th percentile	1.10	1.08	−3.01	−0.91
95th percentile	2.13	1.93	12.61	11.18
Mean	1.34	1.35	5.24	5.51
Standard deviation	2.66	3.67	21.79	20.94

IRR: internal rate of return; NPV: net present value; BCR: benefit-cost ratio; DPP: discounted payback period.

In the present study, taxes were the largest cost (47–51%) for the HC market, overpassing labor. The income tax rates were based on the tax system in Brazil and may vary for other countries with different government policies. Nevertheless, governments can encourage the production of seaweed for human consumption by legislating a favorable tributary policy for the sector. The production of glycolic extract on-site requires a high amount of liquid glycerin and bottles, which increase costs. These items are usually produced in large cities located far from the farms. As such, a noteworthy portion of the money is spent outside the community where the activity is carried out. Thus, marketing the seaweed culture for carrageenan and human consumption brings more social development since more capital is spent and received in the local community (Valenti et al., 2018).

The cost of production in the present study decreased when upscaling the farm size for all market scenarios. The break-even price for the activity ranged between US$4.00/kg and US$13.46/kg. These results are similar to the values obtained for production in the United States, where the break-even price for seaweed farming varied between US$6.84/kg and US$11.42/kg (Ladner et al., 2018). These values are much higher than the ones estimated by Valderrama et al. (2015) for the production of *Kappaphycus* carried out in Asia, Africa, and Central America, varying from US$0.06/kg to US$0.70/kg. Differences in production values are due to variations in labor costs between countries, of which the present study (Brazil) and the USA are higher. Seaweed farms in some countries show no costs for wages because the activity is subsidized. Family farms in Asia and Africa often divide the profit between family members rather than pay for labor (FAO, 2013; Valderrama et al., 2015). In other countries, labor is compensated with household food items instead of currency (Kronen et al., 2010). Thus, farms in western countries are unable to compete with Asian producers in international markets.

The results in this study indicated that the seaweed production based on marketing to the carrageenan industry is unfeasible due to the low price. The carrageenan market is directly affected by Asian seaweed farms that produce on a large scale with low labor costs. Furthermore, the global hydrocolloid market shows a high variation in prices, creating further uncertainty for the activity (Coastal Resources Center, 2002; FAO, 2013; Kronen et al., 2010; Valderrama et al., 2015; van den Burg et al., 2016). Some studies have shown that farming seaweed for the carrageenan market was profitable in different developing countries due to low investment and a short return period of the invested capital (Coastal Resources Center, 2002; FAO, 2013; Valderrama et al., 2015). Low production cost in many countries is due to the low salaries paid for workers, thereby permitting low trading prices. Kronen et al. (2010) suggested that the high output of seaweed biomass from large farms allows for competitive prices to the hydrocolloid industries. However, all economic indicators in the present study showed a financial loss, even when upscaling production. This result suggests that the current price does not cover the production costs in western countries despite the high demand for carrageenan. On the other hand, the carrageenan extracted from *H. pseudomusciformis* is of higher quality than that of *Kappaphycus sp.* (Greer et al., 1984), which is the most common macroalgae destined for this market in South America. The *H. pseudomusciformis* carrageenan has antibacterial, antifungal, anti-inflammatory, anticancer, antioxidant and neuroprotective activities, which are attractive to the pharmaceutical industry (Brito et al., 2016; Chakraborty et al., 2016;

Souza et al., 2018). Thus, farmers may sell their products for higher prices to a premium market.

The marketing of seaweed production for human consumption showed high prices and positive economic indicators. The IRR was higher than 97%, and the return of invested capital was ∼1.6 years. These values are attractive to investors that have capital available to raise the scale of farming or for startups. Marketing the product for human consumption was also attractive for small or rural farms, and profitability increased substantially with larger farms. The sensitivity analysis suggested that *H. pseudomusciformis* farming for human consumption is a resilient activity and financially feasible. Prices of seaweed around the world for consumption vary from US$18/kg (*Laminaria*) to US$800/kg ("wakame") and according to the species and region where the product is sold (van den Burg et al., 2016). Most consumption occurs in Asian countries, where seaweed is a traditional food. However, in spite of seaweed being a nontraditional food outside Asia, the demand for seaweed food products consumption is increasing in Europe (Birch et al., 2019; Mouritsen et al., 2019; van den Burg et al., 2016). Veganism, vegetarianism, and a healthier lifestyle are expanding worldwide in a growing global population (Jones-Evans, 2018), creating a consistent market for algae farmers. It is relevant to notice that this growing demand for seaweeds as food in the Western society represents a niche market at the moment, thus still may be structured (Birch et al., 2019; Ferrara, 2020; Lucas et al., 2019; Mouritsen et al., 2019). Thus, actions to expand the demand is necessary to sustain the high prices assumed in the present work. McHugh (2003) suggests that improving the labels of seaweed products and the creation of new products such as "sea farina" for culinary purposes may facilitate the commercialization of seaweed. No applications of fertilizers and chemical compounds occur in the production process, and thus, algae may be sold at high prices for the organic market. In addition, *H. musciformis* can be marketed as a functional food or as a nutraceutical ingredient when considering its composition of amino and fatty acids (Shareef et al., 2012).

The production of the glycolic extract showed economic indicators with promising values for financial feasibility. The IRR between 21–27% was higher than the MARR; the NPV upper US$147,080 and BCR higher than US$2.23; and the return of invested capital was less than 6.5 years. The sensitivity analysis shows that the enterprise is attractive but has a medium risk investment once it is affected by variations in the price of supplies, mainly liquid glycerin. Nevertheless, the marine algae extract has a commercial appeal as an organic food product (Hitton et al., 2007), since consumer interests have shifted toward natural, vegan and "cruelty-free" products, and its use in the cosmetic industry is growing (Mazarrasa et al., 2014). Seaweeds have emollient, anti-inflammatory, and antioxidant properties (Hitton et al., 2007; Nurjanah et al., 2016). Xu et al. (2015) indicated that *H. musciformis* can be used as an anti-aging component of cosmetics. This species also provides beneficial antioxidants that are used in the pharmaceutical and food industries (Chakraborty et al., 2016). Thus, the trade of *H. pseudomusciformis* for glycolic extract is attractive for farmers and investors.

In conclusion, the present study revealed the potential economic feasibility for the farming of *H. pseudomusciformis* seaweed in small and medium-scale productions when marketed for human consumption and the artisanal production of glycolic extract. The production for human consumption is profitable, resilient, and attractive, showing high potential to promote social development and contribute to food security. The marketing of *H. pseudomusciformis* as an organic food product has the potential to be developed in South American countries, once consumers search for food more healthy and plant-based protein. Increasing the scale of production can decrease investments and operating costs, thereby increasing profitability. However, marketing the seaweed biomass for carrageenan showed no feasibility for both scales of production. Farmers should explore different seaweed markets simultaneously and invest in strategies that strengthen the resilience of the activity.

Ethical approval

This article was authorized by the ethics committee for research involving traditional knowledge (CAAE: 91801118.0.0000.5466). This article does not contain any studies with animals performed by any of the authors.

Note

1. Access to capital has been shown to be a major impediment for aquaculture (Mitra et al., 2019).

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Disclosure statement

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