



RESEARCH ARTICLE

Economic viability of selected seaweed farming techniques in Coastal India

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Abstract

Seaweed farming is gaining importance in India's blue economy due to its potential to provide sustainable livelihoods and environmental benefits. The country's coastal waters, particularly in Tamil Nadu and Andhra Pradesh, are suitable for cultivating commercially important species such as *Kappaphycus alvarezii* and *Gracilaria edulis*. This study was undertaken to assess the economic performance of selected seaweed farming methods and identify the most profitable options for coastal communities. Primary data were collected from 180 farmers, 90 each from Mandapam taluk in Ramanathapuram district, Tamil Nadu and the Visakhapatnam coast of Andhra Pradesh covering establishment cost, operational expenses, yields and revenues. The analysis compared multiple cultivation systems, including raft-based bamboo, tube nets, monoline and high-density polyethylene (HDPE) rafts, using indicators such as net returns, benefit-cost ratio (BCR) and return on investment (ROI). Results showed that raft-based bamboo culture for *K. alvarezii* (BCR 3.60) and for *G. edulis* (BCR 3.48) were the most profitable, offering high returns with relatively low operational complexity. Species-specific differences in performance were influenced by environmental conditions, farming system suitability and no input requirements. Monoline methods were moderately profitable for *K. alvarezii* but less suitable for *G. edulis*, while HDPE rafts yielded lower returns due to high initial costs. The study concludes that matching species to appropriate cultivation systems can significantly enhance profitability. Expanding seaweed farming in India will require improved seed supply, targeted training and better market linkages to strengthen its role in coastal livelihood security and marine conservation.

Keywords: benefit-cost ratio; coastal livelihoods; economic analysis; *Gracilaria edulis*; *Kappaphycus alvarezii*; seaweed farming

Introduction

Seaweed cultivation has emerged as one of the most promising activities within India's evolving blue economy, providing a rare combination of environmental sustainability and livelihood enhancement (1). The country's extensive coastline, particularly along Tamil Nadu and Gujarat, offers favourable conditions for growing commercially valuable species such as *Kappaphycus alvarezii* and *Gracilaria edulis* (2). Farming these seaweeds demands minimal capital investment, does not require land or freshwater and fits well with the seasonal routines of coastal fishing communities, especially women-led self-help groups (3). At the same time, a growing global appetite for seaweed-derived products ranging from carrageenan and agar to biofertilizers, cosmetics and functional foods has created new opportunities for India to expand its production base (4).

Beyond its market value, seaweed farming supports marine ecosystem health. Seaweeds absorb excess nutrients, sequester carbon and help counter coastal eutrophication and acidification (5). The activity can also reduce fishing pressure by offering an alternative source of income, thereby contributing to both resource conservation and community resilience (6).

Despite these advantages, India's share in global farmed seaweed output remains small compared with major producers such as China, Indonesia and South Korea (7). A key constraint is the

lack of systematic economic assessments comparing the profitability of different cultivation systems under Indian conditions (8). While methods like floating bamboo rafts, tube nets, monolines and high-density polyethylene (HDPE) rafts are in use, they vary in terms of investment needs, operational ease and yield potential (9). Decisions on method adoption are often driven by tradition or local availability of materials rather than clear financial evidence (10).

This study seeks to fill that knowledge gap by analysing the economics of selected seaweed farming techniques currently practiced along the Indian coast. Using field data from active cultivators, the research evaluates costs, returns, benefit-cost ratios and profitability for each method (11). The findings are intended to help farmers, cooperatives, policymakers and investors choose systems that are not only biologically feasible but also financially rewarding, thereby laying the groundwork for scaling up seaweed farming as a sustainable coastal enterprise in India. Although several studies have documented the profitability of individual seaweed farming systems in India, most assessments remain method-specific or location-specific, with limited comparative analysis across species and cultivation techniques under similar economic conditions. Existing studies rarely apply statistical tests to determine whether observed differences in yield, cost, or profitability are statistically significant. This limits evidence-based decision-making by farmers, extension agencies and investors.

Accordingly, this study hypothesises that the economic performance of seaweed farming in coastal India varies across cultivation methods and species and that aligning suitable species with appropriate farming systems can enhance profitability and return on investment.

Materials and Methods

Study area and ecological conditions

The study was undertaken in two major seaweed-producing regions of India Mandapam taluk in Ramanathapuram district, Tamil Nadu and the Visakhapatnam coast of Andhra Pradesh. These locations were chosen for their favourable ecological conditions, such as stable salinity levels, moderate wave action and shallow nearshore waters, which are highly suitable for seaweed cultivation.

Sampling design

A purposive sampling approach was adopted to select a total of 180 farmers, comprising 90 from each state, with the condition that all participants had at least one year of practical experience in seaweed farming. The selected respondents were actively engaged in one or more of the major cultivation techniques currently in practice, including raft-based bamboo culture, tube net farming, monoline culture and HDPE raft-based culture.

Data collection

Primary data were collected using a structured, pre-tested questionnaire and through direct personal interviews. Data were recorded for six production cycles within a year, covering the size and specifications of farming units, seed material quantity and cost, crop duration, number of cycles per year, wet and dry yield per cycle and prevailing market prices for both fresh and dried seaweed. Detailed information on fixed and variable costs, total revenue, net returns and return on investment was also gathered to facilitate a comprehensive economic evaluation of each farming method.

Economic indicators

The economic performance of different systems was analysed using standard financial indicators.

The total cost of production was calculated as:

$$\text{Total cost} = \text{Fixed cost} + \text{Operational cost}$$

Gross revenue was obtained from:

$$\text{Gross revenue} = \text{Dry yield (kg)} \times \text{Price per kg}$$

Net revenue was determined by:

$$\text{Net revenue (₹)} = \text{Gross revenue} - \text{Total cost of production}$$

The benefit–cost ratio (B:C) was computed as:

$$\text{B:C ratio} = \frac{\text{Gross revenue}}{\text{Total cost of production}}$$

Break-even price was calculated to understand the minimum price required to cover costs:

$$\text{Break - even price (₹/kg)} = \frac{\text{Total cost of production}}{\text{Dry yield (kg)}}$$

Return on investment (ROI) was expressed as:

$$\text{ROI (\%)} = \frac{\text{Net revenue}}{\text{Total cost of production}} \times 100$$

Profit margin was measured as:

$$\text{Profit margin (\%)} = \frac{\text{Net revenue}}{\text{Gross revenue}} \times 100$$

Statistical analysis

The collected data were analysed separately for each cultivation method and seaweed species. Economic indicators such as yield, net returns, benefit-cost ratio, return on investment and profit margin were computed for each cultivation system. Where farmer-level observations were available, differences between *K. alvarezii* and *G. edulis* within a cultivation method were assessed using independent-sample t-tests. Statistical significance was evaluated at the 5 % probability level ($p < 0.05$). Comparative analysis was used to examine variations in yield, cost structure and profitability in order to identify the most economically viable seaweed farming systems.

Results

Economic performance of raft-based cultivation

The raft-based method, widely practiced along the Tamil Nadu and Andhra Pradesh coasts, showed strong economic viability for both *K. alvarezii* and *G. edulis* of per bamboo raft (Table 1) have the size of 12 square feet and the crop duration was 45 days with 5 cycles per year for *K. alvarezii* and 5 cycles per year for *G. edulis*. The average dry yield of *K. alvarezii*, was 4725 kg by single farmers who individually handles 45 rafts, with an annual cost of ₹104924.70. After accounting for a gross return of ₹378000.00, the net returns stood at ₹273075.30 and a return on investment (ROI) of 260.26 %. Profit margins were also high at 72.24 %, resulting in a high benefit-cost (B:C) ratio of 3.60.

In the *G. edulis*, dry yield was 5670 kg per year but commanded a price of ₹60 per kg, leading to gross annual returns of ₹340200. With an annual cost of ₹97724.79, the net revenue reached ₹242475.21. The profit margin, at 71.27 %, with corresponding to a B:C ratio of 3.48 and an ROI of 248.12 %, indicated that this method was highly profitable for both species, with *K. alvarezii* showing slightly better cost efficiency.

Economic performance of tube net cultivation

The tube net method (Table 2), although requiring a smaller seed quantity, showed mixed economic outcomes depending on the species. For *K. alvarezii*, annual dry yield was 1152 kg per year, generating gross returns of ₹92160. After covering a production cost of ₹29193.60, the net returns were ₹62966.40, with the B:C ratio of 3.16 and an ROI of 215.69 %. The profitability ratio stood at 68.32 % and break-even price at ₹25.34.

By contrast, *G. edulis* performed average under the tube net method. With a dry yield of 864 kg per year and a market price of ₹60 per kg, annual gross return reached ₹51840. Net returns of ₹22646.40 were achieved against a total cost of ₹29193.60, resulting in the B:C ratio of 1.78 and an ROI of 77.57 %. The profitability ratio was 43.69 % with break-even price at ₹33.79.

Economic performance of monoline cultivation

The monoline method yielded for *K. alvarezii*, with an annual dry yield of 960 kg per year and gross returns at ₹76800. With total

Table 1. Economics of raft-based cultivation

Sl. No.	Parameter	<i>Kappaphycus alvarezii</i>	<i>Gracilaria edulis</i>
1	Raft size (ft)	12 × 12	12 × 12
2	Crop duration (days)	45	45
3	Cycles/year	5	6
4	Seed requirement (kg)	2700.00	1800.00
5	Establishment cost (₹)	24374.25	24374.25
6	Fixed cost (₹)	6824.7	6824.79
7	Operating cost (₹)	98100.00	90900.00
8	Wet yield (kg)	47250.00	56700.00
9	Dry weight (%)	10.00	10.00
10	Dry yield (kg)	4725.00	5670.00
11	Price/kg (₹)	80.00	60.00
12	Total cost/year (₹)	104924.70	97724.79
13	Gross return (₹)	378000.00	340200.00
14	Net returns (₹)	273075.30	242475.21
15	Profitability ratio (%)	72.24	71.27
16	Break-even price (₹)	22.21	17.24
17	ROI (%)	260.26	248.12
18	B:C ratio	3.60	3.48

Table 2. Economics of tube net cultivation

Sl. No.	Parameter	<i>Kappaphycus alvarezii</i>	<i>Gracilaria edulis</i>
1	Tube net length (m)	6	6
2	Crop duration (days)	45	45
3	Cycles/year	5	6
4	Seed requirement (kg)	480.00	480.00
5	Establishment cost (₹)	39120.00	39120.00
6	Fixed cost (₹)	10953.60	10953.60
7	Operating cost (₹)	18240.00	18240.00
8	Wet yield (kg)	11520.00	8640.00
9	Dry weight (%)	10.00	10.00
10	Dry yield (kg)	1152.00	864.00
11	Price/kg (₹)	80.00	60.00
12	Total cost/year (₹)	29193.60	29193.60
13	Gross return (₹)	92160.00	51840.00
14	Net returns (₹)	62966.40	22646.40
15	Profitability ratio (%)	68.32	43.69
16	Break-even price (₹)	25.34	33.79
17	ROI (%)	215.69	77.57
18	B:C ratio	3.16	1.78

production costs of ₹19948.80, the net returns were ₹56851.20, producing a B:C ratio of 3.85 and an ROI of 284.99 %. The profitability ratio was 74.03 %, with break-even price of ₹20.78 (Table 3).

In *G. edulis* under the monoline method recorded lower profitability. Annual dry yield was 864 kg, generating gross returns of ₹51840, with the total production cost of ₹18748.80, net returns

was ₹33091.20, with a B:C ratio of 2.76 and an ROI of 176.50 %. The profitability ratio stood at 63.83 %, with break-even price at ₹21.70.

Economic performance of HDPE raft-based cultivation

The HDPE raft method (Table 4), designed for greater durability, presented economic outcomes. For *K. alvarezii*, annual dry yield

Table 3. Economics of monoline cultivation

Sl. No.	Parameter	<i>Kappaphycus alvarezii</i>	<i>Gracilaria edulis</i>
1	Monoline length (m)	24	24
2	Crop duration (days)	45	45
3	Cycles/year	5	6
4	Seed requirement (kg)	480.00	480.00
5	Establishment cost (₹)	3960.00	3960.00
6	Fixed cost (₹)	1108.80	1108.80
7	Operating cost (₹)	18840.00	17640.00
8	Wet yield (kg)	9600.00	8640.00
9	Dry weight (%)	10.00	10.00
10	Dry yield (kg)	960.00	864.00
11	Price/kg (₹)	80.00	60.00
12	Total cost/year (₹)	19948.80	18748.80
13	Gross return (₹)	76800.00	51840.00
14	Net returns (₹)	56851.20	33091.20
15	Profitability ratio (%)	74.03	63.83
16	Break-even price (₹)	20.78	21.70
17	ROI (%)	284.99	176.50
18	B:C ratio	3.85	2.76

was 1296 kg, generating gross returns of ₹103680. With production costs of ₹33710.40, the net returns were limited to ₹69969.60 resulting in a B:C ratio of 3.08 and an ROI of 207.56 %. The profitability ratio at 67.49 %, along with the break-even price of ₹26.01.

The HDPE raft method of *G. edulis*, annual dry yield reached 864 kg, leading to gross returns of ₹51840. Against total production costs of ₹32750.40, net returns stood at ₹19089.60, producing a B:C ratio of 1.58 and an ROI of 58.29 %. The profitability ratio was 36.82 %, with break-even price of ₹37.91

Species-wise performance comparison

The graphical representation of the results (Fig. 1–3) clearly illustrates the higher profitability of raft-based farming for *K. alvarezii* and tube net farming for *G. edulis*. Profitability ratio above 70 % were observed in these top-performing combinations, while the HDPE raft method consistently showed lower economic returns for both species. Across all methods, *K. alvarezii* generally achieved higher B:C ratios and ROI values compared to *G. edulis*,

except in the case of tube net farming, where *G. edulis* outperformed significantly.

Discussion

The present study highlights significant variations in economic performance among different seaweed cultivation systems, with raft-based bamboo method for *K. alvarezii* was the emerging with most profitable options, as the seaweed harvest durations was just around 45 days per harvest with four to six harvest cycles per year take place for the *K. alvarezii* and *G. edulis* species respectively which was found clear differences across the species along with the different cultivation methods. The high benefit–cost ratios is found across the species due to there is no inputs for the seaweed cultivation as it grows with naturally available resource as salinity and favourable sea surface temperature with perfectly climate conditions for seaweed cultivations and strong ROI values suggest that species-specific selection of farming methods can substantially improve farmer income (1). These results align with earlier reports

Table 4. Economics of high-density polyethylene (HDPE) raft-based cultivation

Sl. No.	Parameter	<i>Kappaphycus alvarezii</i>	<i>Gracilaria edulis</i>
1	Raft size (ft)	12 × 12	12 × 12
2	Crop duration (days)	45	50
3	Cycles/year	5	6
4	Seed requirement (kg)	600.00	600.00
5	Establishment cost (₹)	49680.00	49680.00
6	Fixed cost (₹)	13910.40	13910.40
7	Operating cost (₹)	19800.00	18840.00
8	Wet yield (kg)	12960.00	8640.00
9	Dry weight (%)	10.00	10.00
10	Dry yield (kg)	1296.00	864.00
11	Price/kg (₹)	80.00	60.00
12	Total cost/year (₹)	33710.40	32750.40
13	Gross return (₹)	103680.00	51840.00
14	Net returns (₹)	69969.60	19089.60
15	Profitability ratio (%)	67.49	36.82
16	Break-even price (₹)	26.01	37.91
17	ROI (%)	207.56	58.29
18	B:C ratio	3.08	1.58

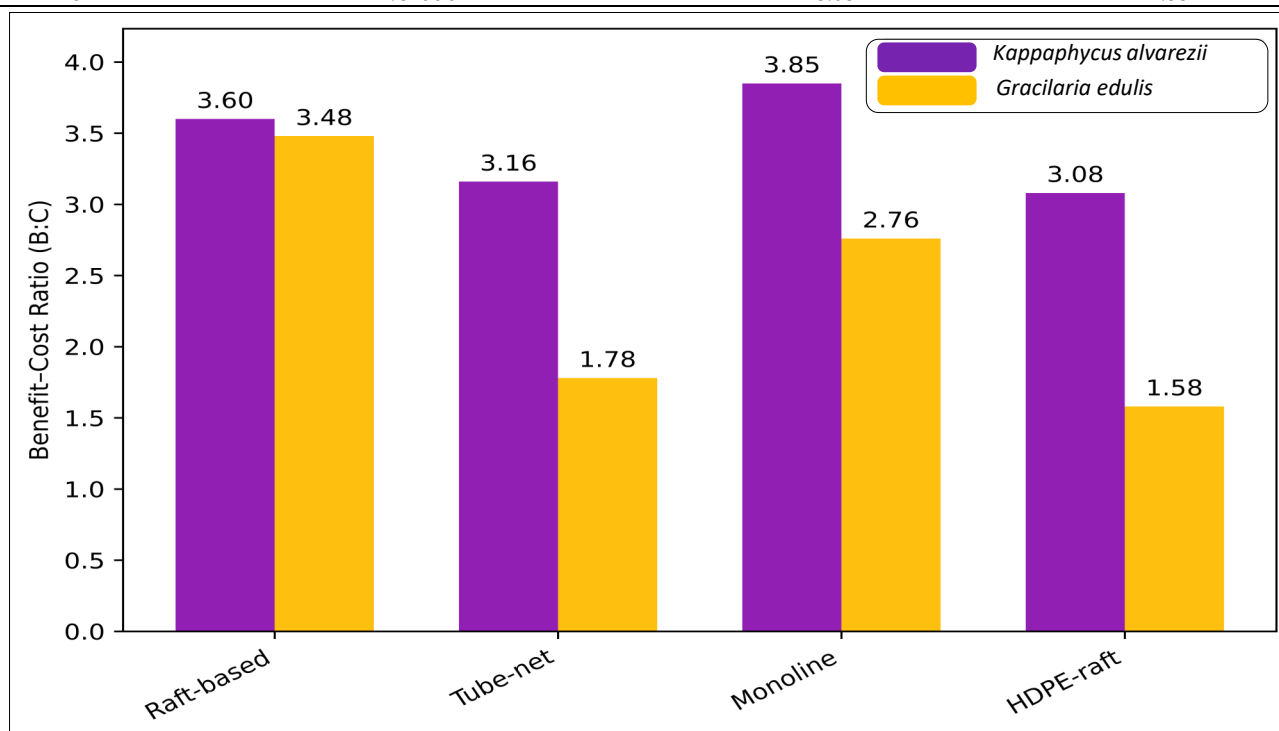


Fig. 1. Benefit–cost ratio and return on investment across cultivation methods for *Kappaphycus alvarezii* and *Gracilaria edulis*.

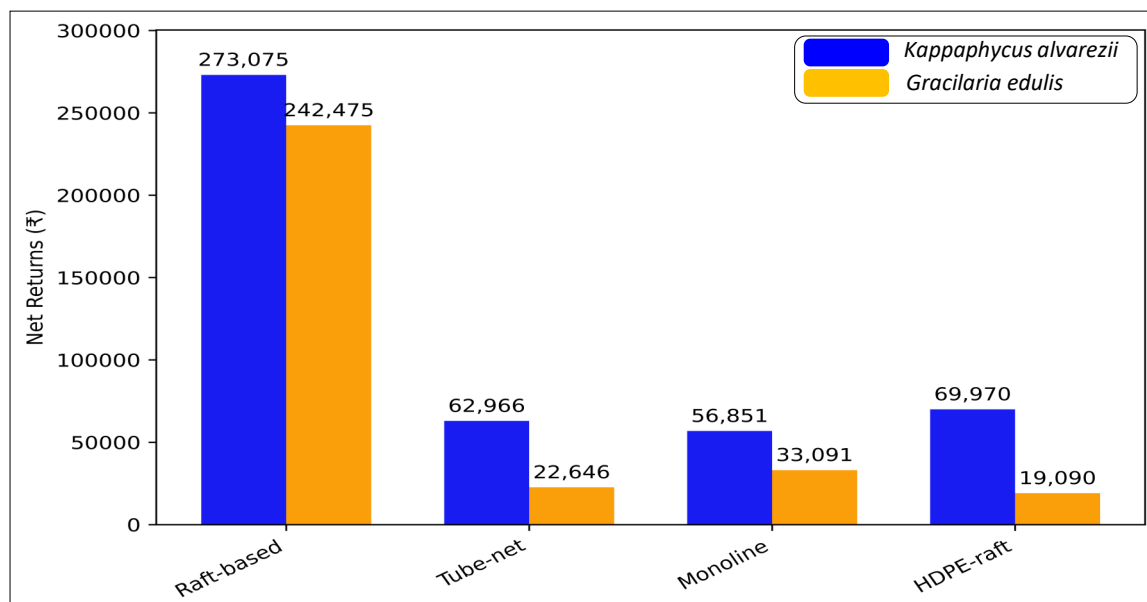


Fig. 2. Net revenue comparison for different seaweed cultivation methods.

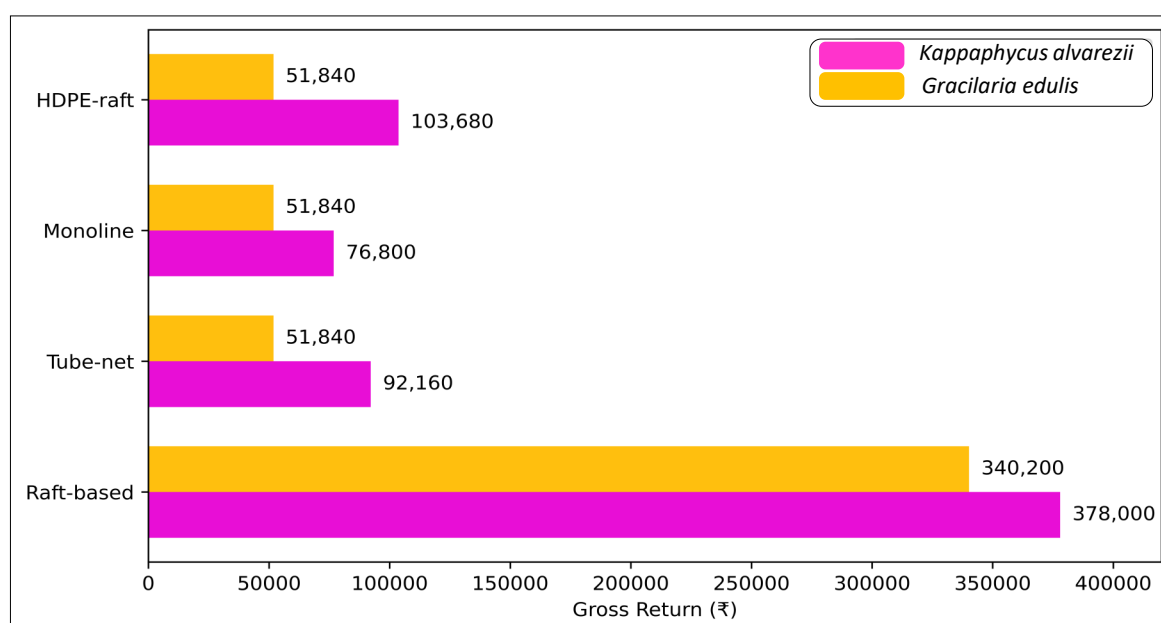


Fig. 3. Gross return comparison for different seaweed cultivation methods.

from Ramanathapuram district, where raft-based farming of *K. alvarezii* was shown to deliver net returns of over ₹70000 per annum with profit margins exceeding 60 % (12). The superior economic performance of raft-based systems for *K. alvarezii* can be attributed to their suitability for calm and shallow waters, ease of seed placement and relatively low maintenance costs (8). The *G. edulis* species has low growth rate and also the make price is less compared with the demand of *K. alvarezii* (13), where the bamboo raft method ensured consistent yields and offered quick turnover between cycles, making it a reliable source of supplementary income for coastal fishers. Conversely, for *G. edulis*, the tube net system outperformed other methods, likely due to its adaptability in slightly higher wave action zones and reduced seed losses from grazing (1). Experimental trials under the National Innovations in Climate Resilient Agriculture (NICRA) programme have also confirmed that tube net farming can deliver high biomass yields for *G. edulis* with limited capital inputs.

While monoline cultivation showed competitive results for *K. alvarezii*, it was less viable for *G. edulis*, largely due to higher operational costs and lower marketable yield (14). This species-

specific performance difference to site-specific environmental conditions and species morphology influences the effectiveness of a given farming technique (15). The HDPE raft-based method, although designed for durability in exposed sites, exhibited comparatively lower returns in this study as the long terms profitable is high. This explained by its higher initial investment and maintenance expenses observed, can outweigh benefits unless operated at scale or integrated with other mariculture activities (13).

The results further reinforce the broader livelihood potential of seaweed farming in India, which emphasised that well-supported cultivation initiatives can provide an alternative to fishing and contribute to reducing pressure on marine capture resources (16, 17). This is particularly relevant for women-led self-help groups, who have been active participants in seaweed farming value chains (13). The need of seaweed is growing demand across multiple sectors including agriculture, pharmaceutical industry, food industries, cosmetics industries and nutraceuticals and it is used along with direct food for human, livestock and fish. Despite high profitability in seaweed cultivation, there were practical constraints affect the economic stability of seaweed farming. The periodic

shortages of quality seed material, particularly after monsoon-related crop losses. Biofouling, grazing by herbivorous fish, disease outbreaks and damage during rough sea conditions were identified as recurring challenges that reduced effective yields and increased maintenance costs. These factors can introduce income variability, especially for systems such as HDPE rafts where recovery of high initial investment depends on uninterrupted production (18).

The findings indicate that economic viability in seaweed farming is highly dependent on the interplay between species, cultivation method and local environmental conditions. Policymakers and development agencies should therefore promote method-species combinations that maximise profitability under specific coastal settings. Ensuring access to quality seed material and providing targeted training can help farmers achieve consistent yields and returns, thereby strengthening India's contribution to the global seaweed sector.

Limitations

This study has certain limitations. The analysis relies on self-reported cost and yield data, which may be subject to recall bias. Long-term environmental parameters such as nutrient dynamics and climate variability were not continuously monitored. The geographical focus on two coastal states may limit the generalisability of results to other regions. The downstream value-chain components such as processing, storage and marketing margins were not included. Future studies integrating long-term environmental monitoring and value-chain economics would provide a more comprehensive assessment.

Conclusion

The economic evaluation of different seaweed cultivation methods in this study clearly shows that profitability in the sector is closely linked to the right combination of species, farming system and local environmental conditions. Raft-based bamboo culture for *Kappaphycus alvarezii* and tube net farming for *Gracilaria edulis* stood out as the most rewarding options, delivering high returns on investment with relatively low operational complexity. These findings reinforce the potential of seaweed farming to serve as a viable supplementary livelihood for coastal households, particularly for women's self-help groups, while also contributing to marine resource conservation and climate change mitigation. Expanding the sector will require more than simply promoting profitable methods. Consistent access to quality seed material, targeted skill development and support for market linkages are essential to ensure sustainable growth. In addition, region-specific extension services can help farmers match farming techniques to local conditions, reducing the risk of crop loss and improving income stability. By combining technical guidance with institutional support, India can significantly enhance its seaweed production, narrow the gap with global leaders and build a resilient coastal economy that benefits both people and the environment. The insights from this study provide a practical foundation for farmers, policymakers and investors to make informed decisions that align economic feasibility with ecological sustainability.

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Authors' contributions

KK carried out the field surveys, collected and compiled the primary data, performed the economic analysis and drafted the manuscript. S and RG conceived the study, supervised the research design and provided critical revisions to the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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