The prospects and feasibility of seaweed (*Kappaphycus alvarezii*) culture in the cage farming sites of Asian seabass (*Lates calcarifer*) in Central Kerala, India

Sunithakumari K[1, 3], Dr. Shoji Joseph[2*], Smina MS[1, 3] and Dr. Reeta Jayasankar[2]

[1] Research Scholar, ICAR-Central Marine Fisheries Research Institute, Post Box No. 1603, Ernakulam North (PO), Kochi, Kerala, India

[2] Principal Scientist, Mariculture Division, ICAR- Central Marine Fisheries Research Institute, Post Box No. 1603, Ernakulam North (PO), Kochi, Kerala, India

[3] Cochin University of Science and Technology, Kochi, Kerala, India

*Corresponding author: Dr. Shoji Joseph

Received 1 Dec 2025; Accepted 5 Jan 2025; Published 22 Jan 2026

DOI: https://doi.org/10.64171/IJPR.2026.6.1.10-17

Abstract

Seaweeds are primitive, photosynthetic, non-angiospermic macrophytes in tidal zones of oceans. The red algae *Kappaphycus alvarezii* was cultured in the present study for a period of 60 days (January – March 2021) in three stations: Malippuram (Station I), Chettuva (Station II), and Moothakunnam (Station III). Seedlings of *K. alvarezii* were collected from Mandapam, Tamil Nadu. Seedlings of *K. alvarezii* weighing 6.069 ± 0.069 g stocked in fruit net bags and floating bamboo raft; finally harvested 55.415 ± 0.018 g per fruit net bag from station I and 57.913 ± 0.068 g per fruit net from station II. Growth parameters of seaweed and water quality parameters of stations were analysed. The present study revealed good prospects for seaweed farming in Malippuram & Chettuva. Integration of seaweed culture with cage farming resulted in good growth of *K. alvarezii* in the open sea of Kerala. The objective of the study was to find out the feasibility of seaweed farming along with cage farming in Central Kerala using the fruit net bag tube method and the floating raft method.

Keywords: Bamboo Raft Culture, Fruit Net Bag Tube, Seaweed, Growth Parameters

Introduction

Seaweeds are macroalgae, primitive non-flowering plants, and commercially important marine living renewable resources. Ecologically, algae are primary producers, they can improve the water quality by utilizing the excess nutrients for photosynthesis and also act as breeding grounds for fish, and other marine organisms. Seaweeds are the major sources of production of phytochemicals such as agar, carrageenan, algin etc., and are widely used in various industries such as food, agriculture, cosmetics, and pharmacy [1]. Seaweeds occur in estuaries, backwaters, and intertidal areas from shallow to 180 m depth.

Based on the presence of pigments and some other characteristics the seaweeds are divided into three; Red (Rhodophyceae), Brown (Pheophyceae), and Green (Chlorophyceae). The red algae *K. alvarezii* is widely cultivated as the primary raw material for the phycocolloid industry. *K. alvarezii* has high demand in the world market as it is a major source of kappa-carrageenan which has strong gel properties and is used as a gelling, emulsifying, thickening, and stabilizing agent in pharmaceutical and nutraceutical products [2]. *K. alvarezii* powder is also used in spice adjuncts in India [3].

In India, seaweeds have been collected from natural beds, or wild populations and are exploited mainly for phycocolloids such as agar and algin. Fishermen also harvest seaweed from the wild for their livelihoods along with the fishing. Due to the over-exploitation, these resources are being depleted. Kaladharan & Kaliaperumal [4] observed scarcity of raw materials and poor quality of the products due to over-exploitation of seaweeds. The seaweeds collected from Indian coastal waters are inadequate to meet the growing demands for raw materials for the seaweed industries. Thus, it is important to promote the cultivation of commercially valuable seaweeds to meet the foreseeing demands of the industries. Once the seaweed culture and production are carried out on a large scale, natural seaweed beds can be conserved for seed materials. Today, seaweed cultivation techniques are standardized, routine, and economical in India and India is quickly developing as an important production centre for *K. alvarezii* in Southeast India[5]. The Central Salt and Marine Chemicals Research Institute (CSMCRI) was the first institute in India experimented on *Kappaphycus* farming [6, 7] in 1984and also investigated the feasibility of its cultivation along the Northwest coast of Gujarat [8] in 1990 and Southeast coast of Tamil Nadu [6] during 1995-1997. The commercial cultivation of *K. alvarezii* has been conducted in the Mandapam region of Tamil Nadu since 2000, and expanding to other parts of Tamil Nadu and other states such as Gujarat, Andhra Pradesh, Maharashtra, and Kerala in the western Indian Ocean [9, 10]. Experimental culture trials were conducted to assess the feasibility of cultivating *K. alvarezii* using the floating bamboo raft method in Gujarat [11, 12], Maharashtra [13], Tamil Nadu [14], and Kerala [15]. In 2005, the Science & Society Division of the Department of Science & Technology, Government of India approved a project under the Women Scientist Programme (DST WOS-B) to empower Kerala's coastal communities by developing technologies for the cultivation of high-value seaweeds [16,17] . Seaweed farming has already been recognized as a sustainable economic activity in many coastal communities in many parts of the world and as a tool for the economic empowerment of women in underdeveloped nations [18, 20].

The new cage designs and efforts of CMFRI increased the popularity of fish farming in cages in Kerala during the last decade and cage aquaculture became a trending activity here. The integration of seaweed culture along with the cages provides an opportunity to expand its culture throughout Kerala. ICAR – CMFRI attempted and examined the net-tube method for *K. alvarezii* cultivation, with open sea cages in Gujarat as an opportunity for additional income generation [21]. Studies were also conducted for the development of Integrated Multi-Trophic Aquaculture (IMTA) by combining seaweed (*K. alvarezii)* with pearl oyster (*Pinctada fucata*) and Asian seabass (*Lates calcarifer*) in open sea floating cages along the coasts of Andhra Pradesh [22]. In IMTA systems, seaweeds extract inorganic nutrients from their environment [23, 25] and minimize aquaculture wastes [25, 29]. Trials of IMTA with seaweeds in offshore and coastal areas of India were done by Ingale et al [30].

Recently CMFRI initiated seaweed farming with fish farming in cages to reduce the wastes from cages while increasing the production of seaweeds and doubling the farmer's income, the present study was done as a pilot study. The objective of the study was to ascertain the prospects and feasibility of seaweed culture (*K. alvarezii)* using the fruit bag net method and floating bamboo raft method along with the cage farming in different stations, provided two in the open coastal marine conditions (Malippuram and Chettuva) and the other one in a high saline backwater area (near bar mouth of the Periyar delta at Moothakunnam).

Materials and methods

Study site

K. alvarezii culture was conducted from 11th January 2021 to 13th March 2021, using fruit- net bags and floating bamboo raft method at three different locations on the central coast of Kerala. Initially, the cages were moored in the respective places, and started cage fish farming with *Lates calcarifer* (Asian seabass). Seaweed culture is also initiated followed by this near the cages while the fish culture is progressing.

Station I

The open sea of Malippuram beach is located in a village of Vypin block in Ernakulam district (N10^{0}0.1'03E076^{0}12'28.8" ± 4m). The cages for fish farming were moored in the Arabian sea at a distance of 1 km from the shore. The depth of the site varied between 5 to 6 m.

Station II

This fish farm is near by a pulimuttu located at Chettuva (N10030.468' E076002.511 ± 4m), Thrissur district in Kerala and it is a part of Arabian sea. The cages were moored at a distance of 200 m from the shore and here the depth varied from 5 to 6 m depending on the tides.

Station III

Moothakunnam is located in a small coastal village of Paravur block in Ernakulam district near to the Arabian Sea (N10^{0}11.478'E076^{0}11.901'± 4m). It is one of the coastal villages of Vadakkekkara panchayat, situated on the bank of the estuarine delta formed by the river Periyar. The cage was set at a distance of 10 m from the river bank. The depth of the site varied from 4 to 5 m depending on tides.

Collection of seedlings

In the present study, vegetative seedlings were used for the experimental culture. The seedlings of *K. alvarezii* were collected from Mandapam, Rameswaram district, Tamil Nadu. Live, healthy materials free from necrotic tissue and epiphytic algae were collected as seedlings and packed in wet jut bags soaked in seawater. To prevent the desiccation of the live material during transportation, the seawater was continuously sprayed over the jute bags at intervals of 2 hours. After acclimatization in the CMFRI lab, the seaweeds were packed in wet jute bags and immediately transferred to the respective stations.

Preparation of floating raft

Nine floating bamboo rafts of 1.5 x 1.5 m^2 were set for three stations for the triplicate studies. Four nylon ropes were tied to each raft at an interval of 25 cm. Seedlings of *Kappaphycus* (weighing 5.5 – 6.5 g) were placed inside fruit net bag tubes of length 15 cm each knotted on both ends with nylon threads (Fig: 1).

Fig 1: Seedlings of *Kappaphycus alvarezii* weighing 6.069 ± 0.069 g stocked in fruit net bag and tied at proximal end of tube net with nylon twines

Nylone twines were tied to each bag tube net on its proximal end, and the bags with the seedlings were hung on the nylon ropes of the raft frame at intervals of 10 cm using the twines. Each monoline contained 61.042 ± 1.062 g of *Kappaphycus* seed materials and the whole raft contained 244.167 ± 2.62 g of *Kappaphycus* seed material (Fig: 2).

Fig 2: A floating bamboo raft with fruit net bags stocked at Malippuram near to the fish cage

Each raft was anchored by poles at the stations to avoid displacement. The rafts were tied to the cages with coir to provide additional support to the rafts.

Analysis of water quality parameters

Water samples from the three stations were collected intermittently from the culture sites and reference sites (5 m away from the culture sites) at an interval of 15 days. Temperature, salinity, and pH were tested *in situ* using a digital thermometer, hand refractometer, and pH meter. Water transparency (light penetration) was estimated using a standard Secchi Disc. Valuations of orthophosphate, nitrite, nitrate, and ammonia were done by standard spectrophotometric methods following APHA [31] Dissolved oxygen content was determined using Winkler's titrimetric method.

Analysis of growth parameters

Sampling was done monthly; 25 fruit bag nets were taken from each raft, weighed with an electronic precision balance (accuracy 0.01 g) (ACZET - CG 1202), and returned to the same places. Before weighing, the seaweeds were wrapped with tissue paper to remove the water. The following growth parameters of seaweed were studied.

- Absolute growth (AG) (g) = Final weight of seaweed – Initial weight of seaweed
- Daily growth rate (DGR) [32, 35] (% day^{-1}) = [(ln final weight / initial weight) / culture days] × 100.
- Specific growth rate (SGR) (% day $^{-1}$) = (ln final weight – ln initial weight) / culture days [36].
- Relative growth rate (RGR) (g g^{-1} day^{-1}) = (ln final weight – ln initial weight) / culture days [37].
- Growth rate (GR) (% day^{-1}) = [(Mean final weight / Mean initial weight) – 1] × 100 / culture days [38].
- Net yield (g) = Final weight of seaweed harvested – Initial weight of seaweed stocked
- Seaweed production yield (kg m^{-2}) = [(Final weight of seaweed (g) – Initial weight of seaweed (g)) × Number of points of planting] / Length of rope (m) [39].

Statistical analysis

The statistical analysis was performed using the SPSS software program ver.23. One- way ANOVA was used to analyse the growth parameters of *Kappaphycus* and the water quality parameters of stations. Further, multivariant ANOVA followed by Tukey's HSD test was done to compare water quality parameters. The *p*-value < 0.05 was set to represent a significant difference in all the analysis.

Results and discussion

The study showed that *K. alvarezii* could be successfully cultured using fruit net bags and the floating bamboo raft method in the coastal waters of Malippuram (Station- 1) and Chettuva (Station II). However, it is observed that *K. alvarezii* did not survive or grow in the estuarine waters of Moothakunnam (Station- III). The water quality parameters are listed in Table 1.

Table 1: Physico-chemical characteristics of water collected monthly from stations I, II & III between 7.00 and 8.00 hrs during the study period (from January 2021 to March 2021)

Parameters	Malippuram (Station I)		Chettuva (Station II)		Moothakunnam (Station III)	
	Reference	Integrated	Reference	Integrated	Reference	Integrated
Temperature (ºC)	27.99 ± 1.392	28.03 ± 1.386	28.24 ± 1.102	28.28 ± 1.101	26.71 ± 1.97	26.4 ± 1.028
Salinity (ppt)	32.4 ± 1.51	32.4 ± 1.51	32.4 ± 1.87	32.4 ± 1.87	24.8 ± 3.574	24.8 ± 3.574
pH	6.99 ± 0.254	7.003 ± 0.249	7.449 ± 0.09	7.458 ± 0.07	7.41 ± 0.094	7.514 ± 0.052
Light penetration (cm)	166.98 ± 17.423	166.4 ± 17.432	77.771 ± 17.66	77.237± 18.042	116.072 ± 1.883	115.285 ± 11.86
Dissolved Oxygen (Mg L^{-1})	5.557 ± 0.412	5.562 ± 0.435	4.902 ± 0.259	5.007 ± 0.38	5.888 ± 0.146	5.739 ± 0.213
Nitrate (Mg L^{-1})	3.259 ± 0.939	3.18 ± 0.852	2.628 ± 0.765	2.493 ± 0.729	0.472 ± 0.183	1.45 ± 0.601
Nitrite (Mg L^{-1})	0.025 ± 0.011	0.024 ± 0.011	0.10 ± 0.077	0.841 ± 0.059	0.033 ± 0.016	0.265 ± 0.216
Orthophosphate (Mg L^{-1})	0.125 ± 0.063	0.123 ± 0.06	0.119 ± 0.061	0.101 ± 0.055	0.0201 ± 0.007	0.051 ± 0.008
Ammonia (Mg L^{-1})	0.0257 ± 0.0138	0.025 ± 0.014	0.0336 ± 0.02	0.028 ± 0.0155	0.0005 ± 0.0006	0.0184 ± 0.007

Values given represent mean ± SD, n = 60

The nitrate, nitrite, orthophosphate, and ammonia in stations I & II were slightly lower (not significant) in the integrated sites than in the reference site due to the culture of *Kappaphycus*. In station III except temperature, salinity, and light penetration other parameters in cage sites were significantly higher than the reference sites. The excreta of fish and unconsumed feed increased the nutrient load in the cage site.

The salinity ranged from 32.4 ± 1.51 ppt in station I, 32.4 ± 1.87 ppt in station II, and 24.8 ± 3.574 ppt in station III. The optimum salinity for the growth of *K. alvarezii* is found > 21 ppt. In station III the salinity was 28 ppt at the time of stocking and it survived for one week but the salinity lowered during the successive days due to rain. Due to the low salinity level, *K. alvarezii* has remained there only for one more week. The colour and nature of *Kappaphycus* changed, becoming pale and fragile to broken. The studies reveal that salinity is one of the key factors influencing the growth and distribution of algae in the marine environment[40] and the low salinity disturbs the continuity of seaweed metabolism and decreases the growth rate[41]. The temperature, light intensity, and nutrients [42, 44] and all other factors were optimum in stations I & II for *Kappaphycus* growth.

Bamboo an eco-friendly construction material used for floating rafts brought down the costs and made maintenance easy. The rural coastal population benefits by adopting this method as the initial amount required for the raft is low. The experimental studies done by Johnson & Gopakumar [45] and Gavino, C. & Trono, Jr.[46] proved that the bamboo raft technique is the most commercially viable technology for *Kappaphycus* farming. The floating raft method to cultivate *K. alvarezii* has been established effectively throughout Mumbai [13], the Gulf of Mannar and Palk Bay coasts of Tamil Nadu [6], the Saurashtra coast in Gujarat [11], and southwest coast of Kerala [15]. Floating raft cages, whether in polyculture or monoculture, are an excellent approach to increase *Kappaphycus* production [47]. In the present study, the fruit bag method was applied and it prevented grazers such as herbivorous fish, and polychaetes, attachment of epiphytic algae, loss of seedlings, and allowed easy harvest [6]. Farming of *K. alvarezii* by tube net method in Gujarat and Andhra Pradesh led to improved farming [48].

In the present study, the *Kappaphycus* farming was done by integrating with the cage fish farming of seabass. ICAR-CMFRI cultivated successfully *K. alvarezii* in open sea cages in Gujarat using the net- tube method for doubling the income [21] and polyculture of seaweed with crustaceans such as shrimps [49] or fish [50, 51] led to increased production, indicating a promising future for seaweed production when raw material demand is high. CMFRI developed IMTA by integrating seaweed (*Kappaphycus alvarezii*) and pearl oyster (*Pinctada fucata*) with Asian seabass (*Lates calcarifer*) and observed that the excretions (NO_3 and PO_4) of the fingerlings (*Lates calcarifer)* inside the cage help in nutrient provision for seaweed cultivation [22]. It is an improved technique to promote mariculture activities economically by recycling waste nutrients through seaweed with the finfish culture.

The growth parameters and yields of seaweed farmed in the present study are listed in Table 2.

Table 2: Growth performance and yield characteristics of seaweed *Kappaphycus alvarezii* from Station I & II. Values given represent mean ± SD, n = 3

Growth parameters	**Station**			
	Malippuram		**Chettuva**	
	30 Days	**60 Days**	**30 Days**	**60 Days**
Initial weight (g)	6.096 ± 0.069	6.096 ± 0.069	6.113 ± 0.076	6.113 ± 0.076
Final weight (g)	27.183 ± 0.033	55.415 ± 0.0176	28.653 ± 0.025	57.913 ± 0.068
Growth rate (% day^{-1})	345.964 ± 5.453	809.139 ± 10.472	368.807 ± 6.116	847.555 ± 12.726
Relative Growth Rate ($g\ g^{-1}\ day^{-1}$)	0.102 ± 0.0002	0.065 ± 0.00003	0.1038 ± 0.0001	0.0658 ± 0.0001
Specific Growth Rate (% day^{-1})	10.162 ± 0.0154	6.497 ± 0.003	10.384 ± 0.014	6.579 ± 0.0045
Daily Growth Rate (% day^{-1})	4.983 ± 0.041	3.679 ± 0.019	5.15 ± 0.044	3.747 ± 0.024
Absolute Growth (g)	21.087 ± 0.098	49.319 ± 0.085	22.54 ± 0.097	51.8 ± 0.141
Yield of *Kappaphycus* harvested				
Net yield (g)	843.475 ± 3.905	1972.76 ± 3.42	901.61 ± 3.881	2027.015 ± 5.648
Seaweed production Yield ($kg\ m^{-2}$)	8.435 ± 0.039	19.728 ± 0.034	9.016 ± 0.039	20.72 ± 0.056
Initial weight per monoline (g m-1)	60.958 ± 1.076	60.958 ± 1.076	61.125 ± 1.09	61.125 ± 1.09
Final weight per monoline (g m-1)	271.827 ± 18.873	554.18 ± 29.237	284.5 ± 3.041	579.129 ± 27.274
Initial weight per raft (g)	243.833 ± 2.754	243.833 ± 2.754	244.5 ± 3.041	244.5 ± 3.041
Final weight per raft (g)	1087.31 ± 1.328	2216.593 ± 0.702	1146.11 ± 1.004	2316.515 ± 2.733

The present study showed that fruit net tubes were better than other methods for supporting the growth of *K. alvarezii* in the raft culture. Seedlings were placed at an interval of 10 cm in the rope and the monoline/ropes at a distance of 25 cm. The growth of seaweed is highly influenced by the planting distance and the wider distance will help seaweed to utilize the sunlight for photosynthesis and nutrients from the water current effectively into their tissue to promote optimum growth rate [52, 54].

Seedlings weighing 6.069 ± 0.069 g (5.5 – 6.5 g) stocked in fruit net bags and after 60 days *Kappaphycus* attained a weight of 55.415 ± 0.018 g (ranging 41.62 – 72.208 g) in station I and 57.913 ± 0.068 g (ranging 42.076 – 71.887 g) in station II. The growth rate of *Kappaphycus* was 809.139 ±10.472 % day^{-1} in station I and 847.555 ± 12.726 % day^{-1} in station II. In this study seedling density was low. The seedling density has an important effect on growth rate [55]. High seedling density causes competition for space, and nutrients, resulting in stress on seaweeds reducing growth rate [56]. Msuya [57] reported that lower seedling density significantly enhanced the growth rates of *K. alvarezii;* also, low-density seedlings of *Porphyra dioica* resulted in a high growth rate [58]. Small thallus of seaweed for seedlings improves the capability of seaweed to perform self-propagation [59]. In the present study low seedling density and planting distance helped to get better growth.

Seaweeds harvested after 60 days of the experiments, as revealed by earlier researchers that harvesting of *Kappaphycus* after 45 to 60 days of cultivation would give a good yield [6, 60, 62]. The seaweed harvest at the proper time and their recultivation are important to ensure a better scrubbing process for more efficient utilization of inorganic nutrients from the fed aquaculture [25, 63]. The monoline weighing 61.042 ± 1.062 g of *Kappaphycus* seed materials became 554.148 ± 29.237 g in station I and 579.129 ± 27.274 g in station II. The net yield obtained from the raft in station I was 1972.759 ± 3.42 g and from station II was 2072.015 ± 5.649 g. The seaweed production yield obtained from stations I & II was 19.728 ± 0.034 kg m^{-2} and 20.72 ± 0.056 kg m^{-2} respectively. Experiments proved that the seaweeds cultivated near the fish farm showed significantly high growth rates [22, 64, 65]. Fish feed introduces more nutrients to the farm which enhances the seaweed production. The unconsumed feed and fish waste from cages provided additional nutrients to seaweed growth and production [66, 68]. Many researchers have reported that *K. alvarezii* can be cultured with fish or other aquatic animals and showed an increase in the biomass of all organisms cultured in different parts of the world [49, 51]. Integrating seaweed into an IMTA system in proximity to a fish farm within a distance of less than 1000 m has been reported beneficial [65, 69, 72]. A significant advantage of using seaweed in bioremediation is that it reduces the nutrient concentration of water by converting it into biomass production. It can be conveniently harvested with mesh, nets, or ropes.

The daily growth rate of *Kappaphycus* after 30 days in station I was 4.983 0.041 % day^{-1} and the specific growth rate was 10.162 0.015% day^{-1}. After 60 days the daily growth rate and specific growth rate became 3.679 ± 0.019 % day^{-1} & 6.497 ± 0.003% day^{-1} respectively. The daily growth rate and specific growth rate of *Kappaphycus* after 30 days in station II was 5.15 ± 0.0437 % day^{-1} and 10.384 ± 0.0144 % day^{-1} and after 60 days were 3.747 ± 0.0237 % day^{-1} & 6.579 ± 0.005 % day^{-1} respectively.

A daily growth rate (DGR) above 3.5 % day^{-1} is considered significant growth, for the commercial cultivation of *K. alvarezii* [42,73]. In the experimental study, DGR obtained from station I ranged from 3.679 ± 0.019 % d$^{-1,}$ and in station II ranged from 3.747 ± 0.0237 % d^{-1}. Similar observations of growth rates were obtained from the field cultivation of *K. alvarezii* using raft method on the Northwest and southwest coast of India – Gujarat (3.97± 0.08 % d^{-1}) [74] & Tamil Nadu (3.76 ± 0.07, 3.69 ± 0.11 & 3.76 ± 0.08 % day^{-1}) [75, 77]. Whereas, the experimental cultivation of *K. alvarezii* by off-bottom method at Mandapam region, Tamil Nadu showed lower values (0.39 to 3.15 % d^{-1}) compared to the present study [6]. The DGR of seaweed commercially cultivated in Hawaii (2.3 to 5.34% d^{-1}) [78], Indonesia (3.81 ± 1.80% day^{-1}) [79] and the experimental study in Panagatan Cays, Philippines (2.3% to 4.2% d^{-1})[80] showed a similar pattern of observation. The results are also comparable to the DGR of the seaweed cultured by off-bottom farming in Indonesia (3 to 4 % d^{-1})[81] and in the south-Pacific Islands of Fiji (3.5–3.7% d^{-1}) [82]. However, the DGR (5.79 - 7.76 % d^{-1}) was higher for the experimental cultivation of *K. alvarezii* using net-tube method in the Saurashtra coast of Gujarat[21] when compared with the present observations. The maximum DGR (15.76 to 21.6 % d^{-1}) of *Kappaphycus* was reported at Okha and Diu, Gujarat [83].

The specific growth rate (SGR) of *Kappaphycus* in station I ranged from 5. 904 to 6.988 and in station II it ranged from 5.989 to 6.967. The DGR and SGR were high for seaweeds using the net tube method [21, 83]. The SGR (6.87– 8.31% d^{-1}) was also high for the experimental cultivation of *K. alvarezii* on the Saurashtra coast of Gujarat [21] done using the net tube method. The SGR of seaweed cultured using a floating bamboo raft on the East coast of India varied from 1.49 to 4.12% d^{-1} [84] which was lower than the present study.

The present study indicated that acclimatization and culture of *Kappaphycus alvarezii* in the coastal waters of Malippuram and Chettva can be done successfully, as it is in the high saline area and it opened the possibilities of the seaweed culture along with cage farming on a large scale. Since the coastal seas in Kerala are prone to salinity fluctuations it is essential to conduct experiments for preserving the seedlings during the monsoon period. Otherwise, seed material has to be brought from other areas in every culture. The farmers have to depend on other states for the seed materials which will become another hurdle in seaweed farming.

Conclusion

The present study proved the prospects and feasibility of seaweed culture in Kerala. Farming of economically valuable seaweeds integrated with cage aquaculture enhances the economic profitability of the farmers without much investment. To meet the increased needs of raw materials for the seaweed-related industries in our country increased seaweed production is needed. Farming of commercially important seaweeds can be easily done with cages and its production can be increased according to the needs; again, it helps to conserve the natural seaweed resources of Indian waters apart from its bioremediation and carbon sequencing advantages. Seaweed farming can also provide socio-economic benefits to the cage farmers. Commercially important seaweed cultures can be promoted along with cage farming by providing proper awareness programs and training to the coastal people.

Acknowledgments

The authors are grateful to Dr. A. Gopalakrishnan, former Director of CMFRI, for providing all the facilities for this study. Thanks, are also due to Grinson George, Director CMFRI for all the help. We would like to thank the HOD, staff, and scholars in the Mariculture Division for their help and support. The Council of Scientific and Industrial Research (CSIR) is also acknowledged for its financial support.

References

1. Abdan ARR. Effect of planting distance on growth and carrageenan content of *Eucheuma spinosum* using the long-line technique. J Mina Laut Indones. 2013;3:132–133.
2. Abreu MH, Varela DA, Henríquez L, Villarroel A, Yarish C, Sousa-Pinto I, et al. Traditional vs integrated multi-trophic aquaculture of *Gracilaria chilensis*: productivity and physiological performance. Aquaculture. 2009;293(3–4):211–220.
3. Adnan H, Porse H. Culture of *Eucheuma cottonii* and *Eucheuma spinosum* in Indonesia. Hydrobiologia. 1987;151-152:355-358.
4. Ak I, Cirik S. Distribution of *Gracilaria verrucosa* (Hudson) Papenfuss (Rhodophyta) in Izmir Bay (Eastern Aegean Sea). Pak J Biol Sci. 2004;7:2022–2023.
5. Alifatri L. Growth rate and agar content of *Gracilaria verrucosa* with seaweed seedling weight on planting distance in an earthen pond, Karawang, West Java [thesis]. Bogor: Institut Pertanian Bogor, 2012.
6. APHA. Standard methods for the examination of water and wastewater. 21st ed. Washington (DC): American Public Health Association, 2005.
7. Aquaculture Foundation of India. Seaweed farming to rehabilitate tsunami affected coastal communities in Tamil Nadu. Final report of the DBT project. New Delhi: Department of Biotechnology, Ministry of Science and Technology, 2008, p41.
8. Ask EI, Batibasaga A, Zertuche-Gonzalez JA. Three decades of *Kappaphycus alvarezii* introduction to non-endemic locations. In: Chapman ARO, Anderson RJ, Vreeland VJ, Davison IR, editors. Proceedings of the 17th International Seaweed Symposium. Oxford: Oxford University Press, 2003, p49-57.
9. Athithan S. Growth performance of *Kappaphycus alvarezii* under lined earthen pond conditions at Thoothukudi coast, India. Res J Anim Vet Fish Sci. 2014;2(1):6–10.
10. Bergqvist J, Gunnarsson S. Finfish aquaculture: animal welfare, the environment, and ethical implications. J Agric Environ Ethics. 2013;26(1):75–99.
11. Bhatt NA, Sharma BK, Vaghela DT, Divu D. Trends in rural livelihood practice of raft culture of *Kappaphycus alvarezii* in Gujarat, India. Int J Bio-resour Stress Manag. 2018;9(3):441–444.
12. Bindu MS. Success in the pilot scale cultivation of *Kappaphycus alvarezii* in Vizhinjam Bay, India. In: Training manual—National Workshop on Seaweed Farming and Processing for Food. India; 2006. p. 54–60.
13. Bindu MS, Kumaraswamy AGP. Experimental field cultivation of *Kappaphycus alvarezii* at Vizhinjam Bay, Kerala. In: International Conference on Applied Phycology. New Delhi; 2006. p. 58.
14. Bindu MS. Empowerment of coastal communities through cultivation of *Kappaphycus alvarezii*. J Appl Phycol. 2011;23:157–163.
15. Bindu MS, Levine IA. Commercial red seaweed *Kappaphycus alvarezii*: farming and environment. J Appl Phycol. 2011;23:789–796.
16. Borlongan IAG, Tibubos KR, Yunque DAT, Hurtado AQ, Critchley AT. Impact of AMPEP on *Kappaphycus alvarezii*. J Appl Phycol. 2011;23:615–621.
17. Bryceson I. Coastal aquaculture developments in Tanzania. West Indian Ocean J Mar Sci. 2002;1(1):1–10.
18. Buschmann AH, Troell M, Kautsky N, Kautsky L. Integrated tank cultivation of salmonids and *Gracilaria chilensis*. Hydrobiologia. 1996;326–327:75-82.
19. Buschmann AH, Varela DA, Hernandez-Gonzalez MC, Huovinen P. Integrated seaweed-based aquaculture in Chile. J Appl Phycol. 2008;20:571–577.
20. Chopin T, Buschmann AH, Halling C, Troell M, Kautsky N, Neori A, et al. Integrating seaweeds into marine aquaculture systems. J Phycol. 2001;37(6):975–986.
21. Chopin T, Robinson SMC, Troell M, Neori A, Buschmann AH, Fang J. Multitrophic integration for sustainable marine aquaculture. In: Jørgensen SE, Fath BD, editors. Encyclopedia of Ecology. Vol 3. Oxford: Elsevier; 2008. p. 2463–2475.
22. Cole KM, Sheath RG. Biology of red algae. New York: Cambridge University Press; 1990. p. 385–390.
23. Cubillo AM, Ferreira JG, Robinson SMC, Pearce CM, Corner RA, Johansen J. Role of deposit feeders in IMTA. Aquaculture. 2016;453:54–66.
24. Dash B, Kumar SM, Rao GS. Integration of seaweed and pearl oyster with seabass. In: National Training on Cage Culture of Seabass. Kochi: CMFRI; 2009. p. 57–59.
25. Diana JS, Egna HS, Chopin T, Peterson MS, Cao L, Pomeroy R, et al. Responsible aquaculture in 2050. Bioscience. 2013;63(4):255–262.
26. Doty MS. Production and use of *Eucheuma*. FAO Fish Tech Pap. 1987;281:123–161.
27. Eswaran K, Ghosh PK, Mairh OP. Field cultivation of *Kappaphycus alvarezii* at Mandapam. Seaweed Res Util. 2002;24(1):67–72.
28. Eswaran K, Jha B. Commercial cultivation of *Kappaphycus alvarezii* in India. India; 2006. p. 40–46.
29. FAO. The state of world fisheries and aquaculture 2020. Rome: FAO; 2020.
30. Gavino C, Trono GC Jr. *Eucheuma* and *Kappaphycus*: taxonomy and cultivation. Bull Mar Sci Fish. 1992;12:51–65.
31. Glenn EP, Doty MS. Photosynthesis and respiration of tropical red seaweeds. Aquat Bot. 1981;10:353–364.

32. Glenn EP, Doty MS. Growth of *Kappaphycus alvarezii* affected by environment. Aquaculture. 1990;84:245–255.
33. Glenn EP, Doty MS. Water motion effects on growth rates. Aquaculture. 1992;108:233–246.
34. Góes HG, Reis RP. Growth and carrageenan yield of *Kappaphycus alvarezii*. J Appl Phycol. 2012;24:173–180.
35. Gunalan B, Kotiya AS, Jetani KL. Growth comparison of *Kappaphycus alvarezii*. Eur J Appl Sci. 2010;2:10–12.
36. Harrison PJ, Hurd CL. Nutrient physiology of seaweeds. Cah Biol Mar. 2001;42:71–82.
37. Hayashi L, Yokoya NS, Ostini S, Pereira RTL, Braga ES, Oliveira EC. Nutrient removal by *Kappaphycus alvarezii*. Aquaculture. 2008;277:185–191.
38. Hughes AD, Black KD. Trade-offs in IMTA development. Aquac Environ Interact. 2016;8:191–199.
39. Hurtado AQ, Agbayani RF, Sanares R, Castro-Mallare MTR. Seasonality of *Kappaphycus alvarezii*. Aquaculture. 2001;199:295–310.
40. Hurtado-Ponce AQ. Cage culture of *Kappaphycus alvarezii*. J Appl Phycol. 1992;4:311–313.
41. Ingle KN, Polikovsky M, Fenta MC, Ingle AS, Golberg A. Multitrophic aquaculture with marine energy. Ecol Eng. 2022;176:106525.
42. Johnson B, Gopakumar G. Farming of *Kappaphycus alvarezii* in Tamil Nadu. Mar Fish Inf Serv T&E Ser. 2011;208:1–5.
43. Kaladharan P, Kaliaperumal N. Seaweed industry in India. Naga ICLARM Q. 1999;22(1):11–14.
44. Kaliaperumal N, Ramalingam JR, Sulochanan B. Growth of *Kappaphycus alvarezii*. Seaweed Res Util. 2008;30(1–2):57–66.
45. Kapil SS, Mohammed KK, Divu D, et al. Experimental cultivation of *Kappaphycus alvarezii*. Mar Fish Inf Serv T&E Ser. 2017;231.
46. Kasim M, Mustafa A, Ishak E, et al. Environmental status of *Kappaphycus alvarezii* cultivation. AACL Bioflux. 2019;12(4):1102–1113.
47. Kavale MG, Sreenadhan N, Singh VV. Cultivation of *Kappaphycus alvarezii* in Maharashtra. Indian J Geo-Mar Sci. 2016;45(5):666–670.
48. Kerrigan D, Suckling CC. Meta-analysis of IMTA. Rev Aquac. 2018;10(3):560–572.
49. La Ode MA, Rahmad SP, Ruslaini, et al. Seasonal variation of *Kappaphycus alvarezii*. IOP Conf Ser Earth Environ Sci. 2019;370:012060.
50. Lombardi JV, Marques HLA, Pereira RTL, Barreto OJS, Paula EJ. Cage polyculture of shrimp and seaweed. Aquaculture. 2006;258:412–415.
51. Loureiro RR, Reis RP, Critchley AT. In vitro cultivation of *Kappaphycus alvarezii*. J Appl Phycol. 2010;22:101–104.
52. Loureiro RR, Reis RP, Berrogain FD, Critchley AT. AMPEP effects on *Kappaphycus alvarezii*. J Appl Phycol. 2012;24:427–432.
53. Luhan MRJ, Sollesta H. Carpospore cultivation of *Kappaphycus striatum*. J Appl Phycol. 2010;22:579–585.
54. Luxton DM, Robertson M, Kindley MJ. Farming of *Eucheuma* in Fiji. Hydrobiologia. 1987;151–152:359–362.
55. Mairh OP, Zodape ST, Tewari A, Rajyaguru MR. Culture of *Kappaphycus striatum*. Indian J Mar Sci. 1995;24:24–31.
56. Makwana NP. Growth comparison of *Kappaphycus alvarezii* in Gujarat. Adv Appl Sci Res. 2011;2:99–106.
57. Mandal SK, Mantri VA, Haldar S, Eswaran K, Ganesan M. Invasive potential of *Kappaphycus alvarezii*. Algae. 2010;25:205–216.
58. Mantri VA, Eswaran K, Shanmugam M, et al. Commercial farming of *Kappaphycus alvarezii* in India. J Appl Phycol. 2017;29:335–357.
59. Msuya FE. Impact of seaweed farming in Zanzibar. In: World Seaweed Resources. 2006. p. 27.
60. Msuya FE. Stocking density effects on *Kappaphycus alvarezii*. Tanz J Nat Appl Sci. 2013;4(1):605–612.
61. Neori A, Krom MD, Ellner SP, Boyd CE, Popper D, Rabinovitch R. Seaweed biofilters. Aquaculture. 1996;141:183–199.
62. Neori A, Chopin T, Troell M, Buschmann AH, Halling C, Shpigel M, et al. Integrated aquaculture. Aquaculture. 2004;231(1):361–391.
63. Neveux N, Bolton JJ, Bruhn A, Roberts DA, Ras M. Bioremediation potential of seaweeds. In: Production and Use of Marine Molecules. Wiley-VCH; 2018. p. 217–241.
64. Nur M, Tamaruddin A, Jabbar FBA, Tambaru R. Growth performance of *Kappaphycus alvarezii*. IOP Conf Ser Earth Environ Sci. 2020;575:012097.
65. Pereira R, Yarish C, Sousa-Pinto I. Growth and nutrient removal of *Porphyra dioica*. Aquaculture. 2006;252:66–78.
66. Periyasamy C, Anantharaman P, Balasubramanian T. Social upliftment through seaweed farming. J Appl Phycol. 2014;26:775–781.
67. Periyasamy C, Anantharaman P, Rao PVS. Experimental farming of *Kappaphycus alvarezii*. J Appl Phycol. 2015;27:935–944.
68. Periyasamy C, Rao PVS, Anantharaman P. Harvest optimization of *Kappaphycus alvarezii*. J Appl Phycol. 2019;31:587–597.
69. Pickering TD, Skelton P, Sulu RJ. Alien seaweed introductions. Bot Mar. 2007;50:338–350.
70. Quiñonez NB. Seaweed farming and improved livelihoods. Philippines; 2000.
71. Rodrigueza MRC, Montaño MNE. Bioremediation by carrageenophytes. J Appl Phycol. 2007;19:755–762.
72. Santelices B. Conceptual framework for marine agronomy. Hydrobiologia. 1999;398–399:15–23.
73. Schmidt EC, Nunes BG, Maraschin M, Bouzon ZL. UV-B effects on *Kappaphycus alvarezii*. Photosynthetica. 2010;48:161–172.
74. Senthil A, Mamatha BS, Vishwanath P, Bhat KK, Ravishankar GA. Seaweed-based spice mix. J Food Sci Technol. 2011;48:712–717.

75. Serdiati N, Widiastuti IM. Growth of *Eucheuma cottonii*. Media Litbang Sulteng. 2010;3(1):21–26.
76. Suresh KK, Ganesan K, Subba Rao PV, Thakur MC. Seasonal cultivation of *Kappaphycus alvarezii*. J Appl Phycol. 2016;28:1193–1205.
77. Thirumaran G, Anantharaman P. Growth rate of *Kappaphycus alvarezii*. World J Fish Mar Sci. 2009;1:144–153.
78. Troell M, Halling C, Neori A, Chopin T, Buschmann AH, Kautsky N, Yarish C. Integrated mariculture. Aquaculture. 2003;226:69–90.
79. Troell M, Halling C, Nilsson A, Buschmann AH, Kautsky N, Kautsky L. Integrated cultivation of *Gracilaria chilensis*. Aquaculture. 1997;156:45–61.
80. Troell M, Joyce A, Chopin T, Neori A, Buschmann AH, Fang JG. Ecological engineering in aquaculture. Aquaculture. 2009;297:1–9.
81. Veeragurunathan V, Eswaran K, Malarvizhi J, Gobalakrishnan M. Cultivation of *Gracilaria dura*. J Appl Phycol. 2015;27:2353–2365.
82. Wakibia JG, Bolton JJ, Keats DW, Raitt LM. Growth rates of eucheumoids in Kenya. J Appl Phycol. 2006;18:565–573.
83. Widiastuti I. *Gracilaria verrucosa* production in earthen ponds. J Agri Sains. 2011;12:57–62.
84. Xu J, Gao K. Growth and agar yield of *Gracilaria lemaneiformis*. J Appl Phycol. 2008;20:681–686.