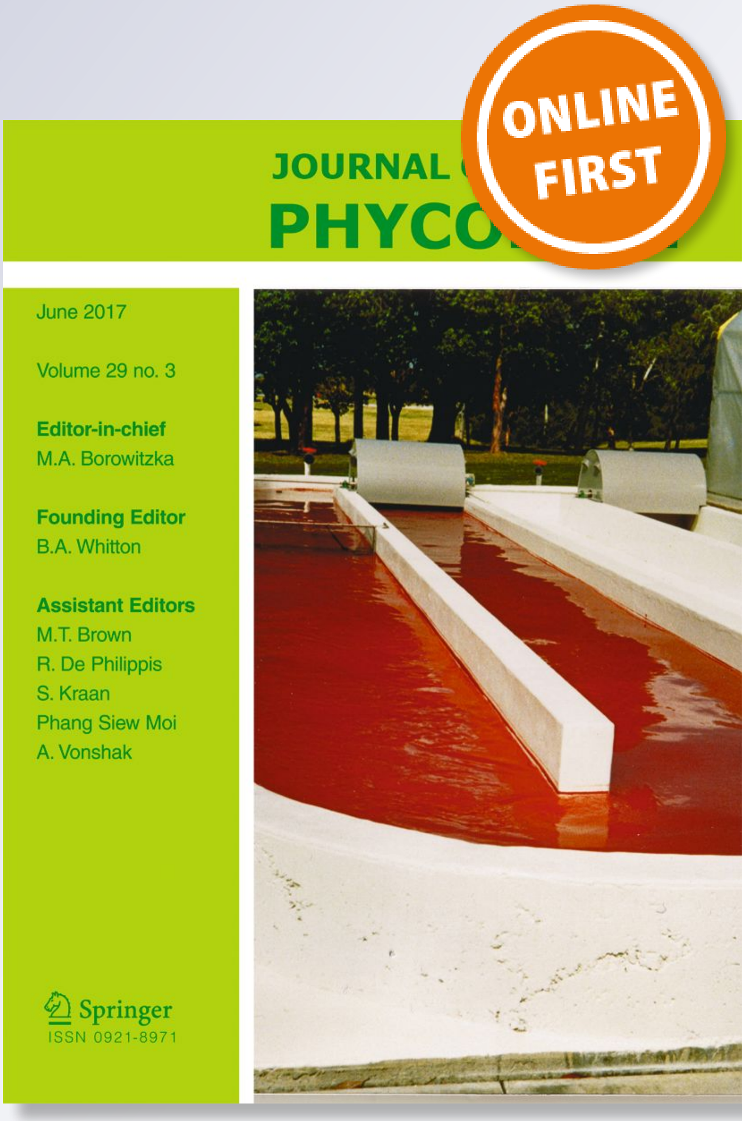
Successful establishment of commercial farming of carrageenophyte Kappaphycus alvarezii *Doty (Doty) in Sri Lanka: Economics of farming and quality of dry seaweed*

M. Shanmugam, K. Sivaram, E. Rajeev, V. Pahalawattaarachchi, P. N. Chandraratne, J. M. Asoka & Abhiram Seth

Journal of Applied Phycology

ISSN 0921-8971

J Appl Phycol
DOI 10.1007/s10811-017-1161-z



J Appl Phycol
DOI 10.1007/s10811-017-1161-z

Successful establishment of commercial farming of carrageenophyte *Kappaphycus alvarezii* Doty (Doty) in Sri Lanka: Economics of farming and quality of dry seaweed

M. Shanmugam[1] · K. Sivaram[2] · E. Rajeev[2] · V. Pahalawattaarachchi[3] · P. N. Chandraratne[4] · J. M. Asoka[4] · Abhiram Seth[1]

Received: 18 October 2016 / Revised and accepted: 1 May 2017

Abstract *Kappaphycus alvarezii* seed material was brought from Malaysia in 2011 to initiate cultivation in Sri Lanka. After conducting trial cultivation, the results were found encouraging and commercial farming was started in mid-2012 at Valaipadu village. The average daily growth rates (ADGRs) using bamboo raft method were varied from 3.44 ± 0.12 to 4.45 ± 0.85% in 2014 and 3.47 ± 0.33 to 4.51 ± 0.58% in 2015, whereas using the monoline method, the same were 2.99 ± 71 to 3.95 ± 0.55% in 2014 and 2.44 ± 1.14 to 4.22 ± 0.37% in 2015. ADGR% decreased with increasing seawater temperature ($p = -788$, $r = 0.01$) and was positively correlated with water motion ($p = 820$, $r = 0.001$). The average monthly production of dry seaweed of a family of three members was 1359 to 1800 kg, and their monthly income ranged between US$465 and 615. The qualities of dry weed produced in 2014 in terms of moisture, clean anhydrous weed, soluble salt, impurities, and C/s ratio were 34.20 ± 3.47, 40.18 ± 3.77, 25.04 ± 2.39, 0.56 ± 0.46, and 1.42 ± 0.35, respectively, whereas in 2015, the values were 34.08 ± 1.81, 39.20 ± 3.62, 25.24 ± 1.90, 1.44 ± 0.50, and 1.46 ± 0.37%. The yield of SRC manufactured at commercial level was 34.64 ± 2.36% and its water and KCl gel strengths were 430 ± 147.88 and 871 ± 166.30 g cm^{-2}, respectively. The absorbance of SRC sample at 1257, 1074, 929, and 846 cm^{-1} in IR spectrum confirms that it was a *kappa* kind of carrageenan. Results of commercial cultivation of *K. alvarezii* in the present investigation showed that Sri Lanka has good potential to create additional income for coastal people through its farming and produce quality dry weed for the carrageenan industries.

Keywords Seaweed · *Kappaphycus alvarezii* · Farming economics · Dry weed quality · SRC · Sri Lanka · Growth rate

✉ M. Shanmugam
m.shanmugam@aquagri.in

[1] AquAgri Processing Private Limited, SIPCOT Industrial Complex, Manamadurai 630606, India

[2] Hayleys AquAgri Private Limited, 25 Foster Lane, Colombo-10, Colombo, Sri Lanka

[3] National Aquatic Resources Research and Development Agency, NARA Road, Colombo-15, Colombo, Sri Lanka

[4] National Aquaculture Development Authority of Sri Lanka, New Parliament Road, Palawatta, Battaramulla, Sri Lanka

Introduction

The global production of the carrageenophytes *Kappaphycus* and *Eucheuma* through farming rose from 0.94 Mt. (fresh) in 2000 to 5.6 Mt. (fresh) in 2010 (63% increase) (Cai et al. 2013); therefore, the productions of raw material increases every year to meet the world demand of carrageenan. Commercial farming of *K. alvarezii* was developed in the Philippines in the late 1960s, jointly by Marine Colloids Corporation and Dr. Maxwell Doty of the University of Hawaii using local wild varieties (Parker 1974, Porse and Rudolph 2017). It was subsequently introduced to over 31 countries over the last 40 years, but only a few countries produce around 1000 dry t year^{-1} for the carrageenan industry today (Mollin and Braud 1993; Hurtado et al. 2001, 2014). Seaweed farming is a supplementary activity to existing fishing for fisher-folks, and it could transform into an additional monthly income of about US$450 to an individual cultivator (Vaibhav et al. 2017). The most important socio-economic benefit of seaweed farming is that it can provide employment opportunities for women, thereby providing them a source of income (Bindu 2011; Periyasamy 2014). Given the numerous environmental, social, economic, and political benefits

Published online: 23 May 2017

of farming *K. alvarezii* (Luxton et al. 1987; Lirasan and Twide 1993; Ask and Azanza 2002; Bindu 2011), it is considered to be one of the few successful aquaculture species for benefits of coastal villagers.

Kappaphycus alvarezii (formerly known as *Eucheuma cottonii*) is a major source of carrageenan, a thickening agent used in more than 250 applications, and its compound annual growth rate in volume is about 8.0% (Abhiram and Shanmugam 2016). The world's geographical area for *Kappaphycus* farming lies within ±10° latitude, particularly from southeast Asian countries extending to east Africa and Brazil. However, the southeast Asian region, primarily the Brunei–Indonesia–Malaysia–Philippines (East Association of Southeast Asian Nations (ASEAN) Growth Area–BIMP-EAGA-integrated countries), has the greatest potential for expanded tropical seaweed farming, consisting 60% of the sites in the world (Hurtado et al. 2014).

Indonesia and Philippines are the major producers of *K. alvarezii* and contribute more than 90% of the total annual production. Indonesian annual seaweed volume rose from less than 0.04 Mt. dry year^{-1} to over 0.30 Mt. dry year^{-1} from 2000 to 2010 and, in the Philippines, the production doubled (from 0.09 to 0.18 Mt. dry) during this period (Hurtado et al. 2014). In India, the commercial farming of *K. alvarezii* was started in 2000, and the developments made so far in the farming and production of value added products like carrageenan and agricultural biostimulants have been summarized by Abhiram and Shanmugm (2016). About 0.2 Mt. of dry *K. alvarezii* is produced annually worldwide with total carrageenan production of about 50,000 t year^{-1} (personal communication).

In Sri Lanka, the National Aquatic Resources Research and Development Agency (NARA) had imported about 100 kg of *K. alvarezii* seed material on 29 July 2011 from Malaysia and the same was acclimatized in Valaipadu, Vidathalaitivu, and other locations in Sri Lanka. Pilot scale trials were carried out by Pahalawattaarachchi in different locations of Jaffana, Mannar, and Kilinochi provinces, and encouraging results were obtained (Personal communication). Then, a thorough feasibility study was carried out by Shanmugam et al. in January 2012 (personal communication) in the north and Mannar provinces to check the suitability of sites for establishing commercial farming of *K. alvarezii* in Sri Lankan waters. Large-scale cultivation was initiated at Valaipadu (9.3378°N, 80.0528°E) and Nainativu (9.6071°N, 79.7652°E) in June 2012 and generated enough biomass for expansion in other locations and to study the quality of dry weed produced on commercial level (Personal communication).

The present study describes the successful establishment of commercial farming of *K. alvarezii* in Sri Lanka for the first time. The results obtained during 2014 to 2015 from the village Valaipadu (9.3378°N, 80.0528°E) in terms of ADGR%; farming operations; and its economics to seaweed growers, quality of dry weed, and yield and quality of semi-refined carrageenan manufactured on a commercial scale are described in the present investigation.

Materials and methods

Seaweed farmers and cultivation techniques

Three families (3 members in each family) were involved in the present investigation. Among them, two families were growing *Kappaphycus* using bamboo raft method and one family used the off bottom monoline method.

Floating bamboo raft method

The size of the floating bamboo raft used was 3.0 m × 3.0 m and consisted of four main bamboo poles (3.6 m each) tied together with four diagonal bamboos (1.2 m each) in a square shape, and fishing net (0.75 mm thickness with 35-mm mesh) was mounted underneath to avoid fish-grazing. In each raft, there were 20 planting lines (3 mm polypropylene (PP) rope) with length of 3 m each and each line consisted of 20 seedlings weighing approximately 200 g per seed; therefore, each raft was planted with 60 kg of seed material (Abhiram and Shanmugam 2016; Vaibhav et al. 2017). The raft with seed was anchored at the farming site using an iron anchor (20 kg), and each anchor held a cluster of five rafts. Total numbers of rafts maintained by a person was 45 so that each family operated 135 rafts. The entire biomass from raft was harvested after 45 days and the average daily growth rate percentage (ADGR %) was calculated (Fig. 1a, b).

Off-bottom monoline plots

Monoline plot (30 m × 20 m) was constructed using casuarina and bamboo poles (1.5 m length with 25–8 cm diameter), and a polypropylene rope was securely tied to the stakes at a distance of 0.5 m from the bottom (Hurtado et al. 1996). Approximately 200 g of seed was inserted into a loop with seed spacing of 20 cm in 30 m PP (3 mm) rope and line space of 1.0 m. A total of 15 plots were made for three members of a family and each member has operated a total of 2700 m of culture line (equivalent to 45 rafts) on the basis of 60-m operation per day, and biomass harvested from 60 m was used for calculating ADGR% (Fig. 1c, d).

Farming operation

The daily farming operation carried out by farmers included seedling preparation where 60 kg seed per raft or 60 m in monoline culture method was planted. Farm maintenance done by farmers during the study period included fixing up of loose knots, removing the debris and other seaweeds from their farm, relocating the farm if plants were not healthy, etc. The harvest was made after 45 days of the plantation, the grown rafts or monolines were fully harvested, and the total biomass was weighed. A family of 3 persons harvested 3 rafts

Fig. 1 **a** Floating bamboo raft. **b** Biomass produce from raft culture method. **c** Off-bottom monoline culture method. **d** Biomass produce from monoline culture method. **e** View of fresh *K. alvarezii* seaweed. **f** View of *K. alvarezii* dry seaweed

or 6 × 30 m monolines per day and replanted the same number of rafts or monolines on the same day. Healthy and well-branched material (Fig. 1e) was used as a seed, and the biomass left after re-plantation was sun-dried for 2–3 days on elevated platforms to a moisture level of about 35% (Fig. 1f). The dry material was cleaned from dirt and sand and packed in jute sacs and stored under a thatched roof till sold. Procurement of dry weed was by local seaweed processor, and payment was made to the farmers on a weekly basis.

Environmental parameters

Seawater temperature, salinity, and water motion were recorded every 3 days during the study period, and mean monthly average was calculated. A float was tied with a 5-m PP rope and placed on the water surface, and the time required to travel 5 m by float was measured to calculate the water motion.

Average daily growth rate (%)

The ADGR% was calculated based on total biomass obtained from a raft or 60-m monoline culture against its initial weight of 60 kg by using the following formula of Yong et al. (2013):

$$\%\text{daily growth} = \frac{\ln(\mathrm{Mf}) - \ln(\mathrm{Mi}) \times 100}{\text{No. of days}}$$

where M_f = final weight and M_i = initial weight.

A total of six rafts were operated by two families in a day, and readings of two rafts were taken randomly for every 3 days and the ADGR% calculated. The mean of ADGR% of 20 rafts

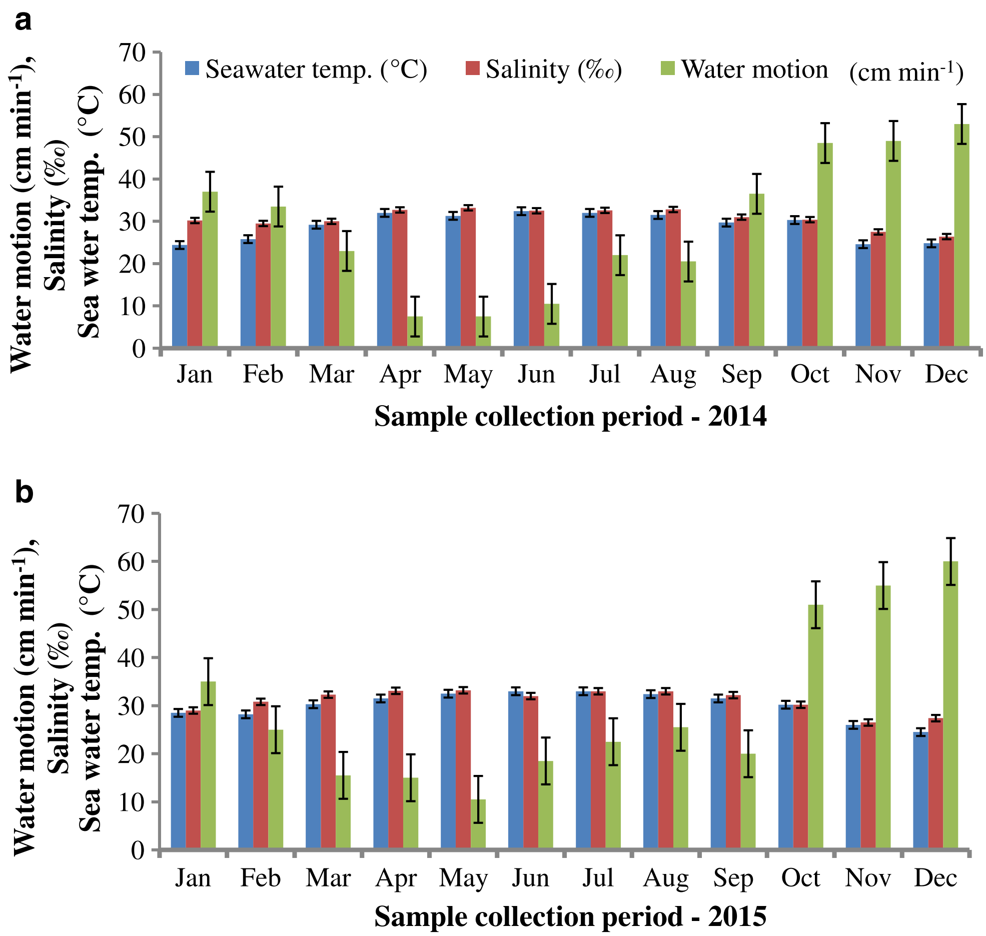


Fig. 2 **a** Seawater temperature, salinity, and water motion in Valaipadu village during 2014. **b** Seawater temperature, salinity, and water motion in Valaipadu village during 2015

in a month was considered the monthly average ADGR%. Similarly, readings of 10 monolines were taken for calculating monthly ADGR%. The ratio of fresh-weed to dry weed was calculated from dry wt. obtained from the fresh biomass of 20 rafts which was used for calculating the mean monthly ADGR%, whereas in the case of the monoline method, readings of 10 monolines were taken to calculate the monthly fresh-dry ratio. Plant loss per raft or monoline was observed at the time of harvesting and recorded as the values of 15 rafts (10 monolines in the case of monoline method) to calculate the average monthly plant loss percentage. Occurrence of grazing was observed during farm maintenance and at the time of harvest and the results recorded.

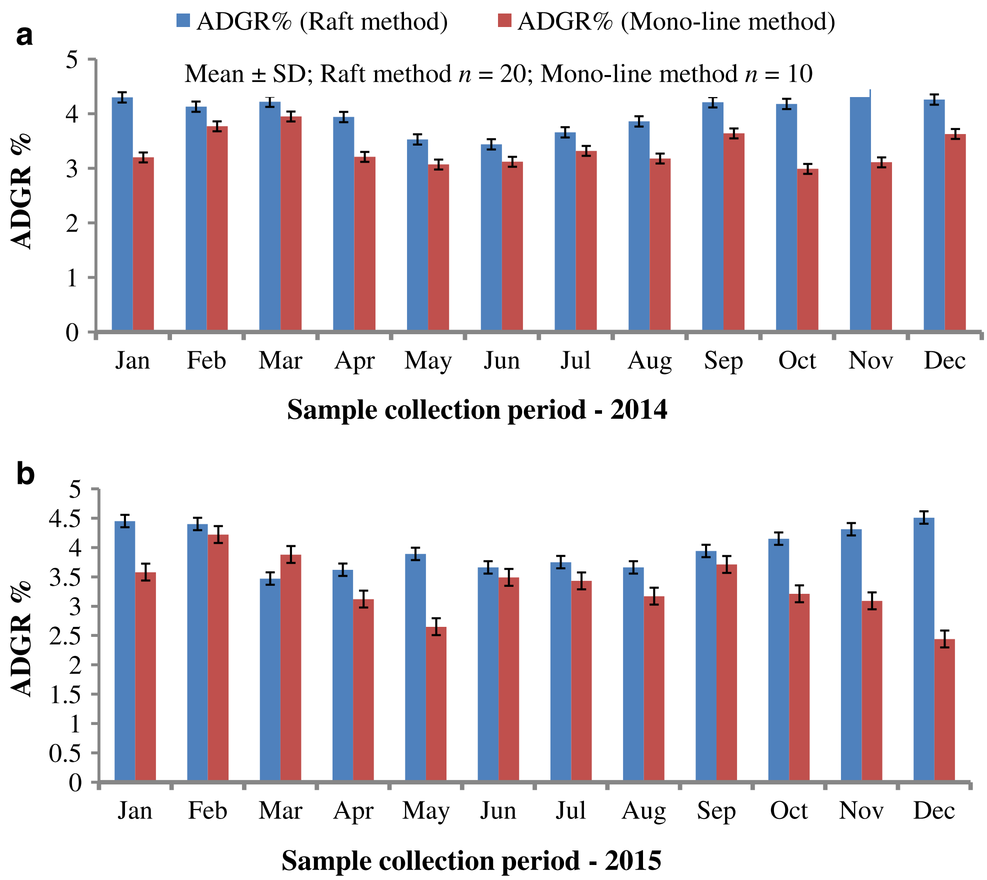
Analysis of dry seaweed

Quality parameters such as moisture content, soluble salt, clean anhydrous seaweed (CAW), and impurities of composite mixture of dry weed produced using both culture methods were estimated as follows: A sample 50 ± 2 g of the dry seaweed was cut into about 30 to 50 mm length and oven dried at 85 ± 2 °C for 16 h to calculate the moisture content. A sample of 50 ± 2 g was mixed evenly with 1 L of water and soaked for 30 min, and the washed material was oven dried at 85 ± 2 °C for 16 h and calculated the percentage of CAW. Impurities were estimated by filtering out the washed liquid left from CAW estimation through pre-weighed muslin cloth. The C/s was the ratio between CAW and soluble salt (SS) (Neish 2003; Moses et al. 2015). Each year, 48 samples were analyzed and their average values for 2014 and 2015 are presented.

Production of SRC

Commercial-scale semi-refined carrageenan (SRC) was produced at the facility of AquAgri Processing Private Limited, India. The composite mixture of dry weed produced using both floating bamboo raft and monoline culture method from Valaipadu village during 2014 and 2015 (118.15 t) was exported to India, and the same was used for producing SRC. The size of the batch processed was 1000 ± 10 kg. The raw material was stuffed into perforated basket and prewashed with water for 30 min and cooked with 8% KOH at 80 ± 2 °C for 2 h. The cooked material was then washed

Fig. 3 **a** Average daily growth rate of *K. alvarezii* by floating bamboo raft and monoline method during 2014. **b** Average daily growth rate of *K. alvarezii* by floating bamboo raft and monoline method during 2015



with water to remove excess KOH, chopped into 2- to 5-mm bits, and sun-dried followed by a fluidized bed drier. The dried SRC chips were ground and sieved through 80 mesh (180 A.S.T.M) to obtain SRC samples for further testing (Mehta et al. 2008). A total of 10 batches were run in the present investigation and their average value is reported.

Analysis of SRC quality

The moisture-free SRC sample was incinerated in a muffle furnace at 550 °C for 4 h and the ash content determined gravimetrically (Moses et al. 2015). Ester sulfate content was determined using sulfate hydrolysis followed by precipitation of sulfate as $BaSO_4$ (Moses et al. 2015). A known quantity of SRC (W_1, g) was hydrolyzed with 50 mL of HCl (1.0 N) at boiling temperature for 30 min, and 10 mL of 0.25 M $BaCl_2$ was added drop-wise. After 5 h at room temperature, the barium sulfate precipitate was filtered out through ashless filter paper and incinerated for 1 h at 700 °C and ash was weighed as W_2 and sulfate content was calculated using the equation below:

$$\%\text{sulfate} = \left(W_2 / W_1\right) \times 100 \times 0.4116$$

The acid-insoluble matter was determined by using 0.1% sulfuric acid as described by Mehta et al. (2008). Viscosity was measured at 1.5% in water at 75 °C, 30 rpm, and spindle no. 62 using Brookfield LVDV-II + pro. KCl gel strength was determined at 1.5% of SRC in 0.2% KCl solution using a Brookfield Texture Analyzer (Model CT3 4500), and water gel strength was measured in the same way but in plain water without KCl (Ohno et al. 1996; Wakibia et al. 2006; Villanueva et al. 2011). The FT-IR spectrum of the SRC sample was analyzed in KBr pellets using an FT-IR spectrophotometer (Perkin-Elmer Spectrophotometer GX). The 3,6-anhydrogalactose of SRC samples was estimated by an improved phenol-resorcinol method using fructose as standard (Yaphe and Arsenault, 1965). The microbial load of the SRC samples was carried out by inoculating 0.1 mL of 1% SRC solution into nutrient media, followed by incubation for 48 h and the calculation of the colony forming unit (CFU) per gram of SRC and other pathogenic bacteria (Cruchaga et al. 2001).

Statistical analysis

Statistical analyses such as analysis of variance (ANOVA, SYSTAT version 7), correlation, and regression were applied to

Table 1 Investment cost for a family of three persons by using floating bamboo raft method (3 m × 3 m)

Items	Unit	Qty. required for a raft (3 m × m^3)	Unit price (LKR)	Total cost per raft (LKR)	Total cost for 135 rafts for 3 persons of a family at 45 rafts per person (LKR)	Total cost for 135 rafts for 3 persons of a family at 45 rafts per person (US$) (1 US$ = 146.1 LKR)
(a) Infrastructure cost						
HDPE Fishing Net (75 mm thickness; 350 mm mesh)	kg	1.0	1350.00	1350.00	182,250.00	1247.43
1.5 mm HDPE rope	kg	0.5	230.00	115.00	15,525.00	106.26
3 mm PP rope	kg	1.5	230.00	345.00	46,575.00	318.79
5 mm PP rope	kg	1.0	300.00	300.00	40,500.00	277.21
6 mm PP rope	kg	0.2	350.00	70.00	9450.00	64.68
10 mm PP rope	kg	0.1	370.00	37.00	4995.00	34.19
12 ft. bamboo	No	6	160.00	960.00	129,600.00	887.06
Iron anchor (20 kg)	No	1/5 raft	1000.00	200.00	27,000.00	184.80
Seed cost	kg	66	8.00	528.00	71,280.00	487.89
Transportation cost	Unit	1	4500.00	100.00	13,500.00	92.92
Total cost for a raft of 60 m culture line				4005.00	459,035.00	3141.92
Total cost for 45 rafts per person				180,225.00		
Total cost for a family of 3 persons					540,675.00	3700.72
Total cost per meter of culture line					66.75	0.45
(b) Operational cost						
Cost of thatched roof for Storage for dry-seaweed) (10 m × 5 m)					25,000.00	171.12
Cost of drying bed (300m^2)					30,000.00	205.34
Cost of boat / Catamaran (for material shifting)					100,000.00	684.46
Maintenance of farm and infrastructure (10% of total infrastructure cost)					54,067.50	370.07
Total operational cost					209,067.50	1430.99
Grand total of infrastructure and operational costs (a + b)					749,742.50	5131.71

analyze the data of ADGR% and environmental parameters, and results were considered statistically significant when $p < 0.05$. Tukey's HSD test was applied for post hoc comparison studies.

Results

Average daily growth rate and physicochemical properties of seawater

The seawater temperatures, salinity, and water motion for 2014 and 2015 are shown in Fig. 2a, b. In 2014, the ADGR % of *K. alvarezii* using bamboo raft method ranged between 3.44 ± 0.12 and 4.45 ± 0.85 and from 2.99 ± 0.71 to 3.95 ± 0.55 for the monoline method (Fig. 3). In 2015, the ADGR% using bamboo raft method ranged between 3.47 ± 0.33 and 4.51 ± 0.58 and between 2.44 ± 1.14 and 4.22 ± 0.37 for the monoline method (Fig. 3b). The plant loss in monoline method during monsoon months were 17.5 ± 2.22 and 20.0 ± 3.17% in 2014 and 2015, respectively, and they were 1.55 ± 0.75 (2014) and 2.70 ± 0.1.2% (2015) for the raft method.

Cost of infrastructure

The total rafts operated by a farmer on the basis of a 45-day harvest cycle were 45; therefore, the total rafts maintained by a family of 3 members were 135. The total cost of a raft including seed material was LKR 4005 (US$27.41) (conversion factor 1 US$ = 146.1 LKR) and for 135 rafts, it was LKR 540,675 (US$3700.72). Operational cost which included erection of thatched roof (6 m × 9 m), boat, drying bed, and plot

Table 2 Investment cost for a family of three persons by using off-bottom monoline culture plots

Items	Unit	Qty. required for a plot of 600 m culture line	Unit price (LKR) per plot of 20 m × 30 m	Total cost per plot (LRK)	Total cost for 15 plots for 3 persons of a family at 5 plots per person (LKR)	Total cost for 15 plots for 3 persons of a family at 5 plots per person (USD) (1US$ = 146.1 LKR)
(a) Infrastructure cost						
1.5 mm HDPE rope	kg	0.5	230.00	115.00	1725.00	11.81
3 mm PP rope	kg	9	230.00	2070.00	31,050.00	212.53
10 mm PP rope	kg	5	370.00	1850.00	27,750.00	189.94
Floats	No	174	5.00	870.00	13,050.00	89.32
HDPE fishing net 0.50 × 22mm × 300 mm	kg	10	1350.00	13,500.00	202,500.00	1386.04
Anchors (50 kg each)	No	4	100.00	400.00	6000.00	41.07
Anchors (25 kg each)	No	40	50.00	2000.00	30,000.00	205.34
Seed cost	kg	66	8.00	528.00	7920.00	54.21
Transportation cost			90.00	450.00	6750.00	46.20
Total cost/plot of 600 m of culture line				21,783.00		149.10
Total cost for a family of 3 persons					326,745.00	2236.45
Total cost per meter of culture line					40.34	0.27
(b) Operational cost						
Cost of thatched roof for storage for dry seaweed (10 m × 5 m)					25,000.00	171.12
Cost of drying bed (300m^2)					30,000.00	205.34
Cost of boat / Catamaran (for material shifting)					100,000.00	684.46
Maintenance of farm and infrastructure (10% of total infrastructure cost)					32,674.50	223.64
Total operational cost					187,674.50	1284.56
Grand total of infrastructure and operational costs (a + b)					514,419.50	3521.01

maintenance charge was LKR 209,067.50 (US$1430.99) (Table 1). Cost of erecting one monoline plot (600 m) was LKR 21,783.0 (US$149.10), and total cost of 15 plots for 3 persons at 5 plots per person (45 rafts equivalent culture line) was LKR 326,745.0 (US$2236.45) with an operational cost of LKR 187,674.50 (US$1284.56). Therefore, total cost per meter of culture line was US$0.45 and US$0.27 in raft and monoline methods, respectively (Tables 1 and 2).

Dry weed production and income generation

Average dry material obtained per raft day^{-1} was 20 ± 1.8 kg. The fresh and dry weed conversion ratio was 9:1, i.e., 9.0 kg of fresh material yielded 1.0 ± 0.15 kg dry material (mean of 20 readings per month). The dry weed production and income model for a family of 3 persons is given in Table 3. The total production of dry seaweed from 12 months of operation during 2014 and 2015 by 9 farmers of 3 families from Valaipadu village was 118.15 t (Table 4).

Quality of dry weed and semi-refined carrageenan

The texture of dry weed produced through both the raft and monoline methods was pinkish in color with good elasticity (Fig. 1f). The moisture content, CAW, and soluble salt of dry weed produced in 2014 ranged from 27.47 ± 3.19 to 38.08 ± 3.88% (mean 34.20 ± 3.47%), from 34.56 ± 4.07 to 42.44 ± 3.66% (mean 40.18 ± 3.77%), and from 22.87 ± 3.10 to 34.09 ± 2.78% (mean 25.04 ± 2.39%), respectively

Table 3 Farming operation and monthly income model of a family of three persons through farming of *K. alvarerzii*

Descriptions	
Total culture line for a family of three persons at 2700 m (45 rafts)/person (m)	8100
Harvest cycle (day)	45
Total culture line handled per day by 3 persons at 60 m/person (m)	180
Total yield of fresh seaweed from 180 m/day at 275 kg/60 m of a raft (kg)	825
Net produce from 180 m of culture line or 3 rafts / day after re-plantation at 60 kg/60 m	645
Dry produce from 645 kg fresh weed at 9:1 ratio (kg)	72
Dry produce available in a month (72 × 25 days operation) (kg)	1800
Sale price of one kg dry weed (LKR)	50
Gross monthly income for a family of 3 persons (LKR)	90,000
Less 10% maintenance and operation cost (LKR)	9000
Net monthly net income by a family of 3 persons (LKR)	81,000
Net monthly net income by a family of 3 persons in US$	**555**
Annual income of a 3 persons of a family (US$)	**6660**

(Fig. 4a). Impurities were between 0.18 ± 0.29 and 2.12 ± 0.71% (mean 0.56 ± 0.46%), and C/s ratio ranged from 1.12 ± 0.26 to 1.58 ± 0.30 with an average of 1.42 ± 0.35 (Fig. 4b). The quality of dry weed produced in 2015 was moisture ranged from 30.42 ± 1.71 to 36.14 ± 1.99% with mean 34.08 ± 1.81% and mean CAW was 39.20 ± 3.62% (36.42 ± 3.38 to 42.50 ± 3.06%). Values from 24.40 ± 2.29 to 30.31 ± 1.92% with an average of 25.24 ± 1.90% and from 0.48 ± 1.22 to 2.38 ± 0.41% (mean 1.44 ± 0.50%) corresponded to soluble salt and impurity levels, respectively. C/s ratio of dry weed ranged between 1.25 ± 0.31 and 1.61 ± 0.45 (mean 1.46 ± 0.37) (Fig. 5a, b).

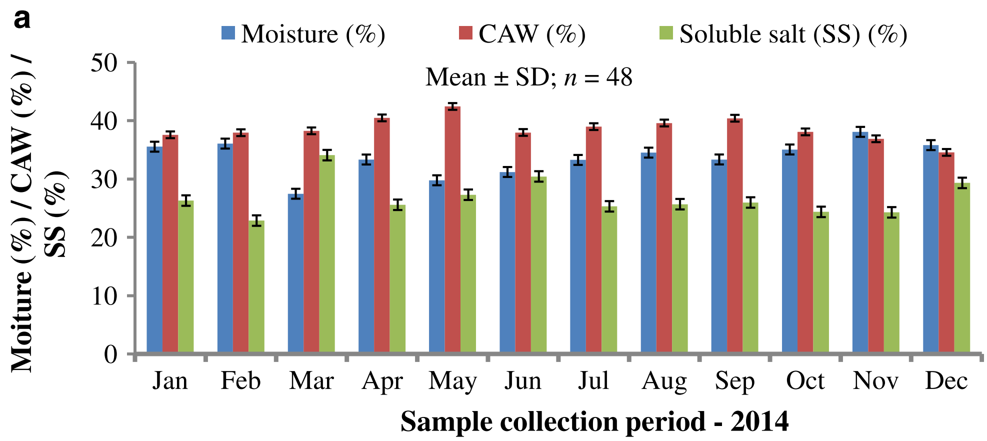
The quality of composite mixture of dry weed produced through the raft and monoline methods during 2014 and 2015 is given in Table 5. The yield of SRC varied between 32.20 and 39.0% (mean 34.64 ± 2.36%) with an average moisture level of 6.29 ± 0.70%. The average ash and sulfate contents were 20.61 ± 1.60% (18.75 to 22.87%) and 13.68 ± 0.64% (12.82 to 14.92%), respectively. The contents of 3,6-anhydrogalactose varied from 26.50 to 29.80% (mean

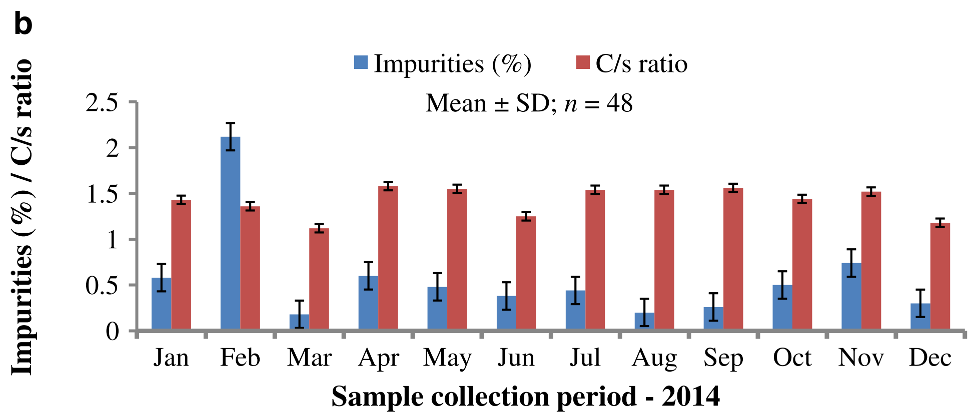
Table 4 Actual dry weed production and monthly income of three families during 2014 and 2015 at Valaipadu village

2014[a]	Family 1 (raft method)	Family 2 (Raft method)	Family 3 (monoline method)
Total dry weed produced (kg)	20,142	21,598	16,310
Average monthly production (kg)	1679	1800	1359
Sale price of per kg dry weed (LKR)	50	50	50
Total income per year (LKR)	1,007,100	1,079,900	815,500
Total income per year (US$) (146.1/US$)	6893.22	7391.51	5581.79
Average monthly income (US$)	574.44	615.96	465.15
Average monthly income/person(US$)	191.48	205.32	155.05
2015[a]			
Total dry weed produced (t)	21,166	20,885	18,049
Average monthly production (kg)	1764	1740	1504
Sale price (LKR 50/kg)	50	50	50
Total income per year (LKR)	1,058,300	1,044,250	902,450
Total income per year (US$) (146.1/US$)	7243.67	7147.50	6176.93
Average monthly income (US$)	603.64	595.63	514.74
Average monthly income/person(US$)	201.21	198.54	171.58

[a] Total dry weed production was 58.05 and 60.10 t in 2014 and 2015, respectively

Fig. 4 **a** Moisture, clean anhydrous weed, and soluble salt content of dry weed produced during 2014. **b** Impurity level and C/s ratio of dry weed produced during 2014



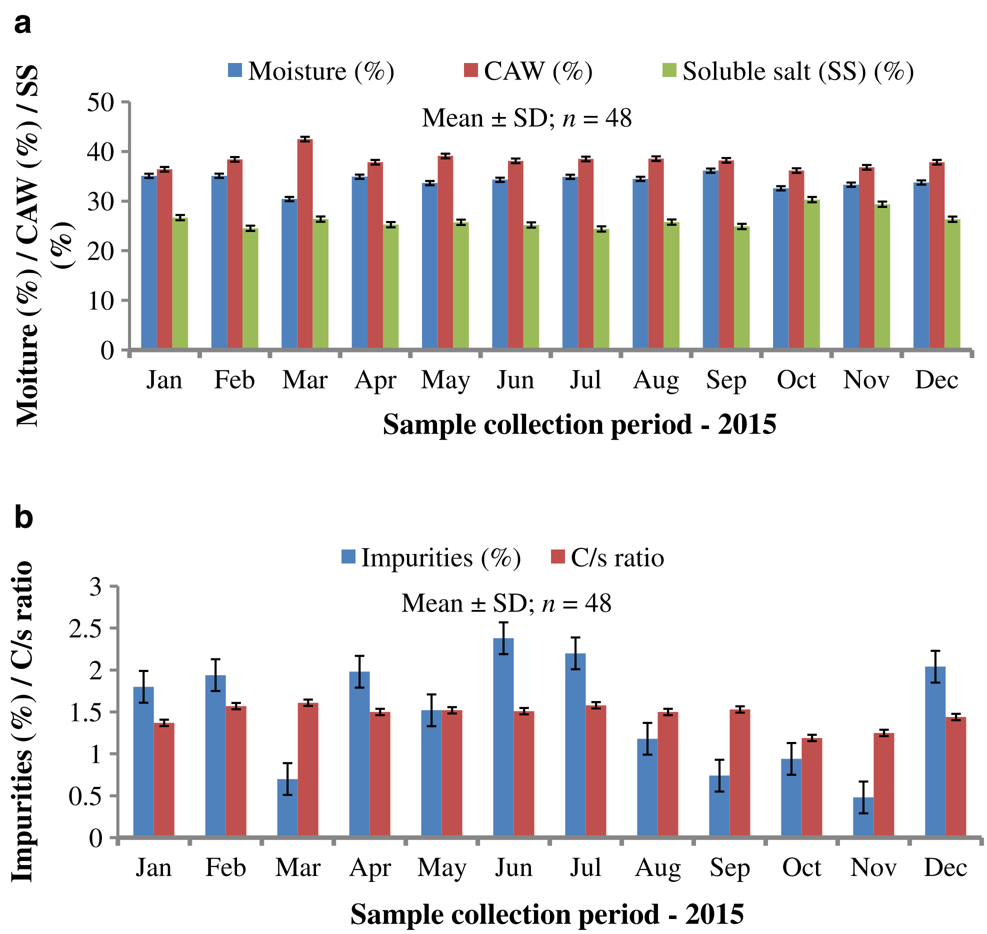


28.42 ± 1.01). Water and KCl gel strength of SRC were 430 ± 147.88 g cm^{-1} (245 to 770 g cm^{-1}) and 871 ± 166.30 g cm^{-1} (1050 to 600 g cm^{-1}), respectively (Table 5), and viscosity ranged between 27 and 72 cP with an average of 49 cP. In the FT-IR spectrum of the SRC sample (Fig. 6), absorbance at 1257 cm^{-1} referred to ester sulfate and 1074 cm^{-1} for glycosidic linkage; the presence of 3,6 anhydrogalactose was characterized by absorbance at 930 cm^{-1} and 846 cm^{-1} was assigned to galactose-4-sulfate (Moses et al. 2015). The total plate count of the SRC samples was 2500 and yeast and molds were less than 100 (1 g); no pathogenic microbes like *Shigella*, *Salmonella*, and *Escherichia coli* were found (25 g).

Discussion

In the study location, the lowest seawater temperatures of 24.4 to 24.8 °C with high water motion (53 to 60 cm s^{-1}) were recorded during rainy months (October to January), whereas they were reverse in summer months (March to May), i.e., seawater temperatures of 32.4 to 33.0 °C with water motion of 7.5 to 23 cm s^{-1}. Overall, the ADGR% of *K. alvarezii* using the raft method was 3.98 ± 0.36 and 4.01 ± 0.32% in 2014 and 2015, respectively, but varied by months. Samples from rainy months demonstrated good ADGR% for two study seasons, i.e., 4.45 to 4.51% and 4.18 to 4.45% in 2014 and 2015, respectively, as compared to 3.47 to 3.89% and 3.53 to 3.94% in summer months, and these observations are in agreement with literature reports. Kumar et al. (2016) reported higher ADGR% of 6.29 ± 0.0% during winter than summer months (ADGR% 5.43 ± 0.02) in the northwest coast of India for the same alga, and Ateweberhan et al. (2015) recorded higher ADGR% of 5.04 ± 0.31% in winter months against 3.90 ± 0.28% in summer season in the south-west of Madagascar. The ADGR% found decreased as seawater temperature increased ($p = -788$, $r = 0.01$) and also positively correlated to water motion ($p = 820$, $r = 0.001$). However, in the monoline method, low ADGR% of 2.99 to 3.63% was recorded during the winter months than during the summer months (3.77 to 3.95%) in 2014, and a similar trend was observed in 2015. The low ADGR% in the monoline method could be due to plant loss of 17.5 to 20% recorded in rainy months whereas it was only 1.0 to 2.7% in the bamboo raft method. There was also evidence of fish grazing in the monoline plots by Siganid and Scarus fishes observed in

Fig. 5 **a** Moisture, clean anhydrous weed, and soluble salt content of dry weed produced during 2015. **b** Impurity level and C/s ratio of dry weed produced during 2015



January to February in both 2014 and 2015. The ADGR% of *K. alvarezii* observed in the present investigation from Sri Lanka are similar to those reported elsewhere for the same seaweed. In the Philippines, ADGR% of 4.5% by Gerung and Ohno (1997), 2.3 to 4.2% by Hurtado et al. (2001), and 2.2 ± 0.6 to 4.0 ± 0.8 (Hurtado et al. 2015) were reported for the same seaweed. The DGRs obtained in this study were also comparable to the DGRs of *Eucheuma cottonii* (=*K. alvarezii*) cultured in Indonesia (2.5 to 3.5%) by Adnan and Porse (1987), Madagascar (3 to 4%) by Mollin and Braud (1993), Fiji (3.5 to 3.7%) by Luxton et al. (1987), Zanzibar (1.7–6.8%) by Msuya (2013), Tamil Nadu coast of India (3.02 to 4.04%) by Periyasamy et al. (2014), and from 1.96 ± 0.08 to 2.29 ± 0.11 and from 2.25 ± 0.06 to 2.96 ± 0.02 for *K. alvarezii* and *K. striatum* cultured in a customized tank in Malaysia by Zuldin et al. (2016).

The cost per meter of culture line was US\$0.45 and US\$0.27 using the raft and monoline culture methods, respectively (Tables 1 and 2), and this is comparable to the cost of culturing the same alga elsewhere. The total investment per meter of culture line is approximately at US\$0.27 m^{-1} in Indonesia, Tanzania (floating), and India despite differences in the operations. The Philippine and off-bottom Mexican systems were around US\$1.00 m^{-1} line. The most economical investment corresponded to the off-bottom system in Tanzania (US\$0.15 m^{-1}), and the most expensive systems were found in Mexico in floating method and the Solomon Islands at around US\$1.40 m^{-1} (Valderrama et al. 2015).

The seaweed cultivators involved in the present study were paid for the dry weed they produced through their bank accounts on a weekly basis. The seaweed cultivators in Sri Lanka are supported by the government, non-government organizations, bankers, and private companies by providing them financial assistance for infrastructure and other necessary permissions.

A family of a three persons had produced 1359 to 1800 kg per month, and the average monthly income of a family ranged between US\$465 and US\$615 and total annual income to a family was US\$7391 to US\$5581 (Table 4), which is comparable to income of *K. alvarezii* farmers in the largest producing countries like the Philippines and Indonesia. Abhiram and Shanmugam (2016) reported that the monthly income of an individual

Table 5 Yield and quality of SRC manufactured from *K. alvarezii* on commercial scale

Batch	Dry weed quality[a]				SRC yield			SRC quality						
	Moisture (%)	Impurities (%)	Soluble salt (%)	CAW (%)	RM input (kg)	SRC output (kg)	SRC Yield (%)	Moisture content (%)	Water gel strength (g cm^{-2})	KCl gel strength (g cm^{-2})	Viscosity (cP)	Ash (%)	Sulfate (%)	3,6-AG (%)
1	28.40	0.7	26.40	44.50	1000	345	34.50	6.23	530	1050	48	19.65	12.82	29.14
2	34.40	0.16	21.14	44.30	1000	338	33.80	5.88	400	1000	45	18.93	13.50	29.25
3	38.11	0.17	20.11	41.62	1000	344	34.40	5.90	500	950	72	22.87	14.45	28.55
4	37.59	0.48	18.09	43.84	1000	346	34.60	7.10	770	1010	55	21.16	13.76	29.80
5	32.18	0.12	18.28	49.42	1000	322	32.20	5.12	380	1000	52	22.80	13.50	28.09
6	36.42	0.94	18.30	44.34	1000	343	34.30	6.75	460	750	27	18.75	13.44	27.10
7	29.68	0.74	25.54	44.04	1000	361	36.10	5.56	320	600	60	21.08	14.53	28.65
8	37.52	0.48	17.28	44.72	1000	371	37.10	6.15	320	700	43	22.10	14.92	28.33
9	39.15	0.41	18.58	42.13	1000	343	34.30	7.11	245	690	35	19.18	13.89	26.50
10	37.1	0.7	18.36	43.84	1000	390	39.00	7.08	370	960	53	19.54	13.00	28.71
Mean	35.06	0.49	19.21	45.28		340	34.64	6.29	430	871	49	20.61	13.68	28.41
STD	3.75	0.28	2.59	3.85		8	2.36	0.70	147.88	166.30	12.66	1.60	0.64	1.01

[a] Composite mixture dry *K. alvarezii* produced using bamboo raft and off-bottom monoline method during 2014 and 2015.

farmer through farming of *K. alvarezii* in India was US\$220 to US\$300. The farm-gate price of dry *K. alvarezii* in the present study was US\$0.34 kg^{-1} (per kg price LKR 50; conversion factor 1 US\$ = 146.1 LKR), and it is US\$0.33, US\$0.27, and US\$0.38 in India, Tanzania, and Solomon Islands, respectively (Valderrama et al. 2015). However, the farm gate price in Philippines (US\$1.09 kg^{-1}) and Indonesia (US\$1.09 kg^{-1}) are a little higher due to less logistic cost (Valderrama et al. 2015).

Quality of dry weed and semi-refined carrageenan

The moisture (34.08 to 34.20%), CAW (39.20 to 40.18%), SS (25.04 to 25.24%), and C/s ratio (1.3) are in accordance with international values for this seaweed as per the standard specification, i.e., moisture content less than 42%, CAW/salt ratio from 0.92 to 1.40, and minimum SRC yield of 27% (Neish 2003). The moisture content of dry *K. alvarezii* produced in the Philippines is 36–42; in Indonesia it is 35–45% with CAW of more than 35% (Darmawan et al. 2013). The C/s of *K. alvarezii* of Philippine origin varies between 1.1 and 1.3 whereas Indonesian material has 0.9 to 1.2 (personal communication). The SRC yield ranged between 32.2 and 39.0% with an average of 35.06 ± 3.75, and these are comparable with those reported elsewhere for the same seaweed, viz. 24.52 to 31.10% in India (Periyasamy et al. 2014), 17.1 to 56.31% (Iskandar et al. 2013) and 45% (Ohno et al. 1996) in Indonesia, 31 to 43% (Hayashi et al. 2007) and 41.16% (Goés and Reis 2012) in Brazil, 34.5 to 45.30% in Vietnam (Ohno et al. 1996), and 54.5% in the Philippines (Ohno et al. 1996). The KCl gel strength of SRC obtained in the present study ranged between 600 and 1050 g cm^{-2} with an average of 871 ± 166.30, and water gel was 245 to 770 g cm^{-2} (average 430 ± 147.88 g cm^{-2}), and these readings are comparable to gel strength of SRC of *K. alvarezii* farmed off-shore of Vietnam by raft method, i.e., water gel strength and KCl gel strength were 245 to 557 and 1190 to 1712 g cm^{-2}, respectively (Ohno et al. 1996), in India 526 ± 26.55 to 650 ± 1 g cm^{-2} (Moses et al. 2015), 1022 to 1140 g cm^{-2} in Indonesia, and 1005 to 1224 g cm^{-2} in Philippines (Ohno et al. 1996). Viscosity of the SRC samples manufactured in the present study was 27 to 72 cP, and Ohno et al. (1996) reported the viscosity ranging from 16 to 97 cP for carrageenan samples from similar seaweed farmed in Vietnam.

In the FT-IR spectrum (Fig. 5), absorbance at 1272 cm^{-1} referred to ester sulfate, 1080 cm^{-1} for glycosidic linkage (C–O–C), the presence of 3,6 anhydrogalactose was characterized by absorbance at 930 and 851 cm^{-1} assigned to galactose-4-sulfate (Moses et al. 2015). The total plate count of the SRC samples were 2500, and yeast and molds were less than 100

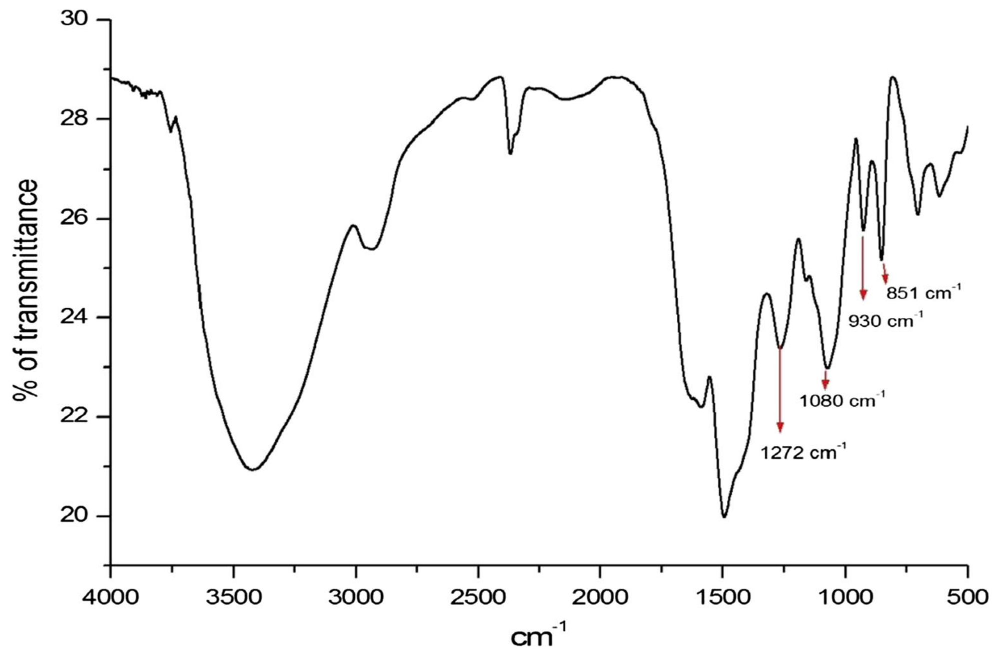


Fig. 6 FT-IR spectrum of SRC sample prepared from *K. alvarezii* farmed in Sri Lankan waters

and no pathogenic microbes like *Shigella*, *Salmonella*, and *E. coli* were found.

The growth rate, economics of farming, quality of dry weed, and carrageenan of *K. alvarezii* farmed in Sri Lanka are comparable to commercially established farms of the Philippines, Indonesia, Malaysia, and other countries. Sri Lanka has good potential for growing *K. alvarezii* and produce quality raw material for carrageenan industries which will provide socioeconomic benefits to the coastal people.

Acknowledgements The authors are very grateful to Mr.Arun Patnaik, CEO, and Mr. Prem Patnaik of AquAgri Processing Private Limited; Mr. Mohan Pandithage, Chairman; Mr. Sayeed Rizvi, Director; and Mr. Ruwan Rajapakse, Director of Hayleys AquAgri, Sri Lanka, for their constant encouragement and support to the present investigation. The Govt. of Sri Lanka, Fisheries Dept., NGOs, Bankers, Fishermen Associations, the first generation of *Kappaphycus* farmers in Sri Lanka, and field technicians are gratefully acknowledged for their contribution for paving a path for the commercial cultivation of seaweed for the first time in Sri Lanka.

References

Abhiram S, Shanmugam M (2016) Seaweeds as agricultural crops in India: new vistas. In: Dagar JC, Sharma PC, Sharma DK, Singh AK (eds) Innovative saline agriculture. Springer India, New Delhi

Adnan H, Porse H (1987) Culture of *Eucheuma cottonii* and *Eucheuma spinosum* in Indonesia. Hydrobiologia 151/152:355–358

Ask EI, Azanza RV (2002) Advances in cultivation of commercial eucheumatoid species: a review with suggestions for future research. Aquaculture 206:257–277

Ateweberhan M, Rougier A, Rakotomahazo C (2015) Influence of environmental factors and farming technique on growth and health of farmed *Kappaphycus alvarezii* (cottonii) in south-west Madagascar. J Appl Phycol 27:923–934

Bindu MS (2011) Empowerment of coastal communities in cultivation and processing of *Kappaphycus alvarezii*—a case study at Vizhinjam village, Kerala, India. J Appl Phycol 23:789–796

Cai J, Hishamunda N, Ridler N (2013) Social and economic dimensions of carrageenan seaweed farming: a global synthesis. In: Valderrama D, Cai J, Hishamunda N, Ridler N (eds) Social and economic dimensions of carrageenan seaweed farming, fisheries and aquaculture technical paper no. 580. FAO, Rome, pp 5–59

Cruchaga S, Echeita SA, Aladuena A, Garciapena J, Frias N, Usera MA (2001) Antimicrobial resistance in salmonella from human, food and animals in Spain in 1998. Antimicrob Chemother 47:315–321

Darmawan M, Utomo BSB, Raekal AYM (2013) The quality of alkali treated cottonii (ATC) made from *Eucheuma cottonii* collected from different regions in Indonesia. Squalen Bulletin of MarFish Postharvest Biotechnology 8:117–127

Gerung GS, Ohno M (1997) Growth rates of *Eucheuma denticulatum* (Burman) Collins et Harvey and *Kappaphycus striatum* (Schmitz) Doty under different conditions in warm waters of southern Japan. J Appl Phycol 9:413–415

Goés HG, Reis RP (2012) Temporal variation of the growth, carrageenan yield and quality of *Kappaphycus alvarezii* (Rhodophyta, Gigartinales) cultivated at Sepetiba Bay, southeastern Brazilian coast. J Appl Phycol 24:173–180

Hayashi L, Paula EJD, Chow F (2007) Growth rate and carrageenan analyses in four strains of *Kappaphycus alvarezii* (Rhodophyta, Gigartinales) farmed in the subtropical waters of Sao Paulo state, Brazil. J Appl Phycol 19:505–511

Hurtado AQ, Agbayani RF, Chavoso EAJ (1996) Economics of cultivating *Kappaphycus alvarezii* using the fixed-bottom line and hanging-long line methods in Panagatan Cays, Caluya, Antique, Philippines. J Appl Phycol 105:105–109

Hurtado AQ, Agbayani RF, Sanares R, Castro-Mallare MTR (2001) The seasonality and economic feasibility of cultivating *Kappaphycus alvarezii* in Panagatan Cays, Caluya, Antique, Philippines. Aquaculture 199:295–310

Hurtado AQ, Gerung GS, Yasir S, Critchley AT (2014) Cultivation of tropical red seaweeds in the BIMP-EAGA region. J Appl Phycol 26: 707–718

Hurtado AQ, Neish IC, Critchley AT (2015) Developments in production technology of *Kappaphycus* in the Philippines: more than four decades of farming. J Appl Phycol 27:1945–1961

Iskandar A, Syam R, Trijuno DD, Rahmi D (2013) Content of carrageenan, chlorophyll a and carotenoid of *Kappaphycus alvarezii* cultivated in different seawater depth Laikang Village, district of Mangarabombang, Takalkar Regency. J Appl Biotechnol 2:1–9

Kumar KS, Ganesan K, Subba Rao PV, Thakur MC (2016) Seasonal studies on field cultivation of *Kappaphycus alvarezii* (Doty) Doty on the northwest coast of India. J Appl Phycol 28:1193–1205

Lirasan T, Twide P (1993) Farming *Eucheuma* in Zanzibar, Tanzania. Hydrobiologia 260/261:353–355

Luxton IM, Robertson M, Kindley MJ (1987) Farming of *Eucheuma* in the South Pacific Islands, Central Pacific. Hydrobiologia 151/152: 359–262

Mehta AS, Mody KH, Anita I, Ghosh PK (2008) Preparation of semi-refined carrageenan: recycling of alkali from spent liquor. Ind J Chem Tech 15:45–52

Mollin J, Braud JPA (1993) *Eucheuma* (Solieriaceae, Rhodophyta) cultivation test on the south west coast of Madagascar. Hydrobiologia 260/261:373–378

Moses J, Anandhakumar R, Shanmugam M (2015) Effect of alkaline treatment on the sulfate content and quality of semi-refined carrageenan prepared from seaweed *Kappaphycus alvarezii* Doty (Doty) farmed in Indian waters. Afr J Biotech 14:1584–1589

Msuya FE (2013) Effects of stocking density and additional nutrients on growth of the commercially farmed seaweeds *Eucheuma denticulatum* and *Kappaphycus alvarezii* in Zanzibar Tanzania. Tanz J Nat Appl Sci 4:605–612

Neish IC (2003) ABC of *Eucheuma* seaplant production. Monograph 1–0703, Suriya Link, 1–80; https://www.scribd.com/doc/152281638/The-ABC-of-Eucheuma-Seaplant-Production

Ohno M, Nang HO, Hirase S (1996) Cultivation and carrageenan yield and quality of *Kappaphycus alvarezii* in the waters of Vietnam. J Appl Phycol 8:431–437

Parker HS (1974) The culture of the red algal genus *Eucheuma* in the Philippines. Aquaculture 3:425–439

Periyasamy C, Anantharaman P, Balasubramanian T, Subba Rao PV (2014) Seasonal variation in growth and carrageenan yield in cultivated *Kappaphycus alvarezii* (Doty) Doty on the coastal waters of Ramanathapuram District, Tamil Nadu. J Appl Phycol 26:803–810

Porse H, Rudolph B (2017) The seaweed hydrocolloid industry: 2016 updates, requirements, and outlook. J Appl Phycol. doi:10.1007/s10811-017-1144-0

Vaibhav AV, Eswaran K, Shanmugam M, Ganesan M, Veeragurunathan V, Thiruppathi S, Reddy CRK, Seth A (2017) An appraisal on commercial farming of *Kappaphycus alvarezii* in India: success in diversification of livelihood and prospects. J Appl Phycol 29:335–357

Valderrama D, Cai J, Hishamunda N, Ridler N, Neish IC, Hurtado AQ, Msuya FE, Krishnan M, Narayanakumar R, Kronen M, Robledo D, Gasca-Leyva E, Fraga J (2015) The economics of *Kappaphycus* seaweed cultivation in developing countries: a comparative analysis of farming system. Aquacult Econ Manage 19:251–277

Villanueva RD, Romero JB, Montaño MNE, de la Peña PO (2011) Harvest optimization of four *Kappaphycus* species from the Philippines. Biomass Bioenergy 35:1311–1316

Wakibia JG, Bolton JJ, Keats DW, Raitt LM (2006) Seasonal changes in carrageenan yield and gel properties in three commercial eucheumoids grown in southern Kenya. Bot Mar 49:208–215

Yaphe W, Arsenault GP (1965) Improved resorcinol reagent for the determination of fructose and 3,6-anhydrogalactose in polysaccharide. Anal Biochem 13:143–148

Yong YS, Yong WTL, Anton A (2013) Analysis of formulae for determination of seaweed growth rate. J Appl Phycol 25:1831–1834

Zuldin WH, Yassir S, Shapawi R (2016) Growth and biochemical composition of *Kappaphycus* (Rhodophyta) in customized tank culture system. J Appl Phycol 28:2453–2458