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Cultivation of *Gracilaria verrucosa* (Huds) Papenfuss in Chilika Lake for livelihood generation in coastal areas of Orissa State

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Abstract The agarophyte red alga *Gracilaria verrucosa* occurs widely in Chilika Lake, one of the RAMSAR wetland sites in India. The lake is situated in the extreme southeast corner of Orissa between latitudes 19°28′ and 19°54′ N and longitudes 85°06′ and 85°35′ E. The natural biomass production is not sufficient for the agar industry, and the only alternative is to maximize the production of the seaweed through mass cultivation by seaweed farming. To elucidate important aspects of the growth and development of *G. verrucosa*, experimental field cultivation was undertaken at Langaleswar and Samal sites of Chilika Lake using ropes and raft methods during March to August, 2009. After 30 days of cultivation a maximum 15- and 13.8-fold increase in biomass in raft culture and rope culture, respectively, was observed at Langaleswar and an 11.6- and 11.0-fold increase in biomass at Samal. Environmental parameters such as temperature, salinity, pH, transparency, DO, conductivity, nitrate, and phosphate were monitored at both stations, and the influence of environmental parameters is discussed.

Keywords Chilika Lake · Farming · Gracilaria · Langaleswar · Samala · Seaweed

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Introduction

The red algal genus *Gracilaria* is a source of the phycocolloid agar and is among the most important commercial seaweeds (Santelices and Doty 1989). This genus is widely distributed in tropical and temperate seas with more than a hundred species. In terms of the production of economically valuable phycocolloids, the most important genera of macroalgae are *Gracilaria*, *Eucheuma*, and *Hypnea* (Dawes 1998). Since 1972, the Central Marine Fishery Research Institute has been involved in the experimental field cultivation of agar yielding *Gracilaria verrucosa* and *Gracilaria edulis* in near-shore areas of the Gulf of Mannar and Palk Bay through vegetative propagation methods by inserting the fragments of the mother material into the twist of coir rope nets (Chennubhotla et al. 1977; Chennubhotla and Kaliaperumal 1987; Rao 1973, 1974; Krishnamurthy et al. 1975). More studies probably have been carried out on *Gracilaria* in regard to culture and agar production than any other red algal genus. This interest is in part due to the rapid growth rates, broad tolerances of many forms, and diversity of species that occur in tropical and warm temperate waters of the world (Bird 1995). *Gracilaria* now accounts for more than 53% of all agar produced worldwide (McHugh 1991), with a large portion of the 1,000-t agar produced each year being imported into the USA (Jensen 1993). Chilika Lake, a highly productive lagoon ecosystem with rich fishery resources, sustains the livelihood of more than 0.2 million fisher folk and 0.8 million people who live in the catchments of the lagoon. It is the largest lagoon system in Asia, and *G. verrucosa* grows in different sectors of the Lake. The pear-shaped brackish water lagoon is situated on the east coast of Indian peninsula between latitudes 19° 28′ and 19° 54′ N and longitudes 85° 06′ and 85° 35′ E in the districts of Puri, Ganjam, and Khurda in Orissa, India. The entire area influenced by Chilika covers about 2,343 km^2, and the water area varies between 1,165 km^2 during the monsoon and 906 km^2 during summer. The wider northern sector is fed by the rivers Daya and Bhargavi and is 15–18 km in width and has a muddy bottom.

Submerged rocks and rocky shores offer a very good substrate for the luxuriant growth of various forms of marine algae, and *G. verrucosa* is the most conspicuous component of the flora in summer months. The lake offers a favorable environment for mass cultivation of the seaweeds.

The present work was designed to investigate the growth pattern in terms of biomass and growth rate of *G. verrucosa* cultured using long-line coir rope and floating raft methods at Langaleswar and Samal sites of Chilika Lake during March to August 2009, with a view to study the possibility of large-scale cultivation in Chilika Lake which could provide sustainable livelihood generation for the coastal fisher women.

Material and methods

Gracilaria verrucosa was collected from the Kalijai area of Chilika Lake. Plant materials and water samples were collected monthly from March to August 2009. The freshly collected seaweed samples were thoroughly cleaned and washed in Chilika water. They were then placed in plastic bags. Two types of cultivation methods, namely rope (Chennubhotla and Kaliaperumal 1987) and floating raft (Eswaran et al. 2002), were adopted for cultivation. The rafts were prepared with different measurement such as 3.5×3.5 and 4.0×4.0 m. The seed samples were fixed in different ways by the help of the ropes within the rafts. In the rope method, two sets each of 20-m-long rope were anchored with four bamboo stakes. In both methods, the algae were tied in such manner that they were 30 cm under the water surface. These rafts and rope cultivation methods were located at two different sites of Chilika Lake, namely Langaleswar and Samala. The growth in terms of biomass (g wet weight), length (cm), and specific growth rate (SGR) (% d^{-1}) was measured after 30 days of growth in each month following the methods of Premila and Rao (1997). The SGR was estimated from the expression SGR (% d^{-1}): Specific Growth Rate (SGR) (% d^{-1}) = $\frac{\ln(m_1/m_0)}{t} \times 100$, where m_0 = initial weight, m_1 = final weight, and t = time of culture in days

Samples for water chemistry analysis were collected in acid-washed 1-L plastic bottles from a depth of 15 to 30 cm. The plastic bags containing plant samples and the plastic bottle containing water samples were brought to the laboratory in a cool box. Water temperature, water transparency, salinity, pH, DO, conductivity, nitrate, and phosphate were determined

Table 1 Physicochemical properties of water at Langaleswar and Samal sites in Chilika Lake (March–August 2009)

Water Parameters	Months											
	March		April		May		June		July		August	
	L	S	L	S	L	S	L	S	L	S	L	S
Temperature (°C)	30.4±0.26	29.2±0.25	33.5±0.27	31.4±0.27	33.8±0.27	32.8±0.26	31.7±0.27	30.9±0.26	29.8±0.251	28.4±0.25	28.2±0.25	28.2±0.24
Salinity (ppt)	14.1±0.43	12.2±0.39	16.2±0.45	14.3±0.44	18.9±0.46	16.4±0.42	15.8±0.45	13.5±0.38	14.2±0.438	12.1±0.42	13.8±0.43	11.9±0.42
Transparency (cm)	93.5±1.82	91.8±1.71	94.8±1.82	92.3±1.74	94.2±1.73	89.9±1.81	81.3±1.74	79.1±1.79	85.4±1.831	82.3±1.82	73.2±1.63	71.1±1.69
DO (mg L^{-1})	3.6±0.22	3.2±0.21	3.9±0.23	3.7±0.23	4.2±0.23	4.1±0.21	2.9±0.21	2.8±0.19	3.2±0.211	3.1±0.22	4.1±0.24	3.9±0.23
Conductivity (mho cm^{-2})	12.2±0.73	11.9±0.69	8.9±0.69	9.5±0.67	10.1±0.71	11.2±0.70	18.4±0.74	17.3±0.73	29.0±0.683	28.4±0.69	42.1±0.79	41.3±0.68
Nitrate (mg L^{-1})	1.23±0.13	1.19±0.12	1.29±0.13	1.18±0.13	1.32±0.14	1.29±0.13	1.38±0.14	1.34±0.14	1.48±0.142	1.38±0.14	2.10±0.14	2.0±0.14
Phosphate (mg L^{-1})	1.48±0.21	1.28±0.20	1.65±0.20	1.42±0.21	1.58±0.23	1.38±0.21	1.90±0.31	1.70±0.30	2.20±0.333	2.10±0.31	2.80±0.39	2.60±0.29
pH	7.3±0.14	7.1±0.13	8.1±0.16	8.2±0.14	8.6±0.17	7.9±0.17	8.2±0.15	8.4±0.14	7.4±0.148	7.8±0.14	6.8±0.13	6.9±0.133

All values are mean ± SD of three replicates

L Langaleswar, *S* Samal, *DO* dissolved oxygen

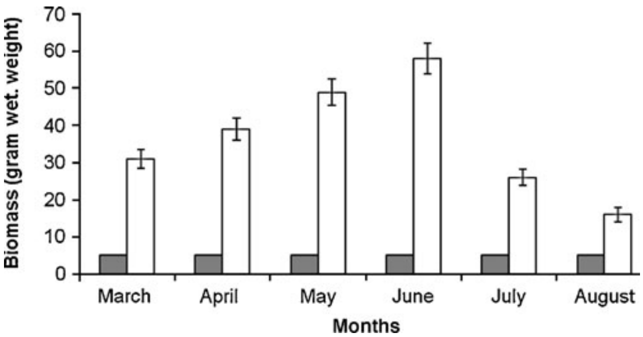

Fig. 1 Biomass production of *G. verrucosa* at Langaleswar in raft culture (March–August 2009). *Black bar* represents initial weight and *open bar* represents final weight. Mean ± SD, $n=3$

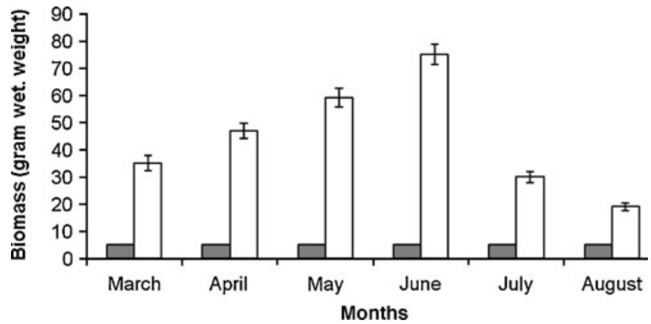

Fig. 3 Biomass production of *G. verrucosa* at Samal site in raft culture (March–August 2009). *Black bar* represents initial weight and *open bar* represents final weight. Mean ± SD, $n=3$

monthly. Transparency and temperature were measured by Secchi Disk and a thermometer. Dissolved oxygen was measured by the Winkler method and salinity by measuring refractive index (Atago), and pH and conductivity were measured on the site using portable Systronic pH and conductivity meter. Nitrate and phosphate were estimated following Strickland and Parsons (1972). Water analyses were done in triplicate and mean values are reported.

Results

The physicochemical characteristics of water at both sites are presented in Table 1. During the field experiment from March to August 2009, the water temperature reached its maximum in May at both Langaleswar (33.8±0.27°C) and Samal (32.8±0.26°C) sites followed by a gradual decrease to 28.02±0.25°C (Langaleswar) and 28.20±0.24°C (Samal) in August. Salinity was lowest in August (13.8±0.429 ppt, Langaleswar; 11.9±0.418 ppt, Samal) and highest in May (18.9±0.46 ppt, Langaleswar; 16.4±0.42 ppt, Samal). These seasonal fluctuations are related directly to the flow of freshwater due to heavy rainfall. Transparency (Secci depth) was highest in April (94.8±1.82 cm, Langaleswar; 92.3±1.74 cm, Samal) and lowest during August (73.2±1.63 cm, Langaleswar; 71.1±1.69 cm, Samal). The content of dissolved oxygen was lowest in June at 2.9±0.21 and 2.8±0.19 mg L^{-1} at Langaleswar and Samal, respectively, and the maximum was reached in May at 4.2±0.23 and 4.1±0.21 mg L^{-1} at Langaleswar and Samal, respectively. Conductivity varied from 42.1±0.79 to 8.9±0.69 mho cm^{-2} at Langalewar and 41.3±0.68 to 9.5±0.67 mho cm^{-2} at Samal between August and April. Maximum dissolved nitrate at Langalewar ranged from 2.10±0.14 to 1.23±0.13 µg L^{-1} at Langaleswar between August and March and from 2.0±0.14 to 1.18±0.13 µg L^{-1} between August and April at Samal. Maximum phosphate values of 2.8±0.39 and 2.6±0.29 µg L^{-1} were observed in August, and minimum values of 1.48±0.21 and 1.28±0.20 µg L^{-1} were observed in March at Langaleswar and Samal, respectively. pH varied from a maximum of pH 8.6±0.17 in May at Langaleswar and pH 8.4±0.14 in June at Samal to a minimum of pH 6.8±0.13 and pH 6.9±0.13 in August at Langaleswar and Samal, respectively.

Figures 1, 2, 3, and 4 show the biomass of *G. verrucosa* obtained at the two culture sites. The biomass reached a maximum value 75±4.13 g wet wt., which is a 15-fold increase from the 5-g inoculums in June by raft culture at Langaleswar. The biomass ranged from 17±1.84 to 69±4.21 g wet wt. in rope culture at the same site. The maximum biomass obtained by raft culture at Samal was 58±3.69 g wet

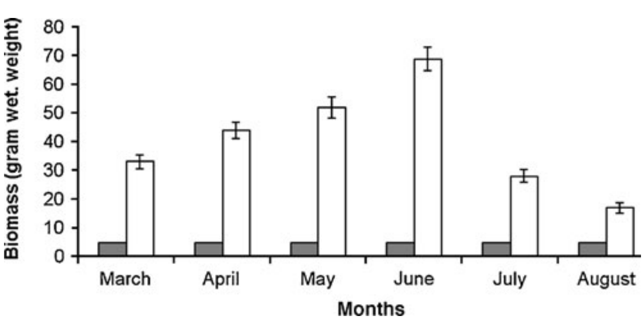

Fig. 2 Biomass production of *G. verrucosa* at Langaleswar in rope culture (March–August 2009). *Black bar* represents initial weight and *open bar* represents final weight. Mean ± SD, $n=3$

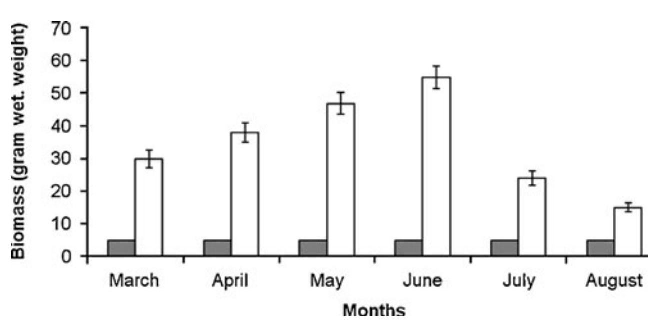

Fig. 4 Biomass production of *G. verrucosa* at Samal site in rope culture (March–August 2009). *Black bar* represents initial weight and *open bar* represents final weight. Mean ± SD, $n=3$

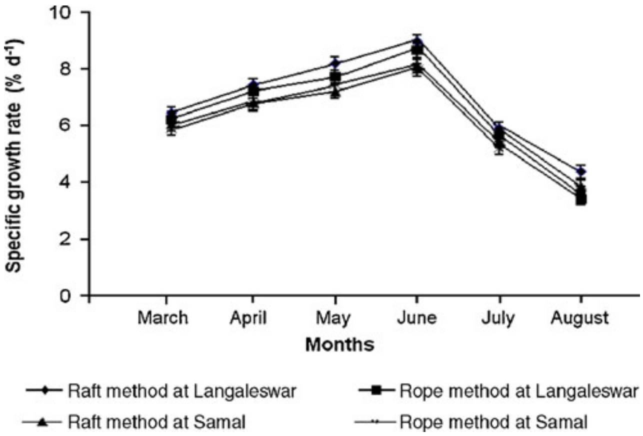

Fig. 5 Specific growth rate (% d^{-1}) of *G. verrucosa* at Langaleswar and Samal site in raft and rope culture (March–August 2009) on the 30th day of incubation. Langaleswar: *diamonds* = raft method, *squares* = rope method; Samal: *triangles* = raft method, *x marks* = rope method. Mean ± SD, *n*=3

wt. which is an 11.6-fold increase. In rope culture, it ranged from 15±1.28 to 55±3.48 g wet wt. in the same site.

The length of *G. verrucosa* presented in Table 2 reached maximum values of 29.0±2.84 cm in June by raft culture at Langaleswar, and in rope culture the length varied from 9.8±1.14 cm in August to 27.2±2.32 cm in June. The maximum length obtained by raft culture at Samal site was 25.0±2.45 cm in June, and by rope culture, the length ranged from 8.9±0.89 to 24.0±2.43 cm (Table 1).

The specific growth rate (% d^{-1}) of *G. verrucosa* at the two sites at 1.5-m depth shows that the specific rate was slightly higher at Langaleswar using raft culture technique (Fig. 5). Maximum specific growth rate (8.96±0.24% and 8.65±0.24% d^{-1}) was observed in June at Langaleswar by the raft and rope culture methods, respectively.

Discussion

Seaweed is a natural, renewable resource, and India has not gone for seaweed farming with selected species which commands a price and demand. In India, seaweeds are used as raw material for the production of agar, alginate, and liquid seaweed fertilizer. There are about 30 seaweed industries situated at different places in Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, and Gujrat (Kaliaperumal and Kalimuthu 1997; Kaladharan and Kaliaperumal 1999; Ramalingam et al. 2000). The quantity of seaweeds harvested, particularly agarophytes, is inadequate to meet the raw material requirement. To augment the supply of raw materials to Indian seaweed industries, seaweed cultivation has to be taken up on large scale by vegetative and reproductive methods (Kaliaperumal 1993). *G, verrucosa* is the most conspicuous component of the flora of Chilika Lake in summer. At times, industrialists encourage the local people to resort to indiscriminate harvesting for raw material supply to their industry. Since the natural growth cannot supply adequate amount of raw material to the industries, cultivation of the seaweed has become an imperative.

The biomass of *G. verrucosa* showed marked variation during the period of study. The biomass production increased from March until June when the temperature, salinity, and pH were high. This pattern was similar to that described for *Gracilaria* species in temperate zones by others (Bird et al. 1977; Penniman et al. 1986; Chirapart and Ohno 1993) who recorded high biomass during the summer. During the period of cultivation, the biomass obtained in July and August was comparatively low at both the sites. Low pH and low salinity prevailed during this period which might have an impact on the productivity of *G. verrucosa*. However, nitrate and phosphate concentrations were high during August, indicating that nutrients have less impact on the productivity of the microalgae than light and temperature as has been observed in temperate waters (Lapointe 1989)

The plants reached harvestable size after 30 days. The higher growth rate observed at Langaleswar may be attributed to the clarity of water, low sedimentation, and less epiphytic growth. Also, the nutrient enrichment due to surface runoff into the lake might be contributing factor. Culture experiments using rope and raft culture technique at 1.5-m depth have revealed that *G. verrucosa* cultivated

Table 2 Growth of *G. verrucosa* in raft and rope culture at Langaleswar and Samal sites of Chilika Lake (March–August 2009)

Month	Final length (cm) in raft method		Final length (cm) in rope method	
	Langaleswar	Samal	Langaleswar	Samal
March	15.2±1.98	12.8±1.43	14.6±1.48	11.9±1.21
April	18.4±2.43	16.4±1.98	17.7±2.13	16.0±1.46
May	22.1±2.67	18.7±2.13	20.9±2.41	17.8±2.12
June	29.0±2.84	25.0±2.45	27.2±2.32	24.0±2.43
July	14.1±1.43	11.9±1.21	12.8±1.38	11.8±1.11
August	10.1±1.21	9.0±0.98	9.8±1.14	8.9±0.89

using raft culture technique grow faster at Langaleswar. This may be attributed to high photosynthetic rate due to optimum light and presumably faster nutrient uptake and constant motion of the rafts due to wind and associated water currents. These short-time observations indicate that Chilika Lake is suitable for cultivation of *G. verrucosa* using rope and raft culture techniques, but throughout-the-year cultivation in Chilika Lake is required in order to find out the best period for maximum biomass production.

Seaweed farming in India is presently gaining momentum, and the activity is encouraged by the Department of Science and Technology (DST), Government of India. The experimental results from this study could be used as field demonstration units for popularizing and disseminating the idea that the seaweed *G. verrucosa* could be cultivated as a new cash crop in coastal villages. In order to facilitate the diffusions of the seaweed farming idea and the associated technology, various training programs have been initiated by DST (Science and Society Division), Government of India, in different states of India. The coastal women have acquired some basic knowledge about the cultivation and uses of *G. verrucosa* and handling of the harvested crop. These activities will definitely improve the socioeconomic standard of the coastal villages, and through their involvement in seaweed farming, they have come to a better understanding about the great value of the natural resources. Presently, 90% of the workers are women. With the significant monetary earning from the sales of the farmed seaweed, their standard of living will be improved, and there is no doubt that the cultivation of this seaweed, by growing into a major economic activity, can diversify the state's economy, can meet the requirement of state, and can fit well into the strategy of the integrated rural development.

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