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Does orientation of raft helps in augmenting yield during lean period?: A case study of *Gracilaria edulis* cultivation in open sea by vertical raft alignment along the south-eastern coast of India

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ABSTRACT

The food grade agar in India has been almost exclusively obtained from *Gracilaria edulis*, but the industrial production overwhelmingly relies on exploitation of natural resources. United Nations efforts through Food and Agriculture Organization under Bay of Bengal Program highlighted the necessity of undertaking commercial farming of this species along Indian coast for socio-economic benefits. The pilot-scale experiments established viability of large-scale cultivation by floating raft method. Nevertheless, drastic reduction in yield and quality during summer months due to enhanced sedimentation and severe epiphytism is found to be a major hindrance. Altering the positioning of rafts from horizontal to vertical alignment improved the growth and yield under open sea condition at two different locations along south east coast of India. The average yield in horizontal raft was found to be 3.08 ± 0.61 kg fr wt raft^{-1} with corresponding DGR of 1.87 ± 0.63% day^{-1} while same in case of vertical rafts was 13.76 ± 3.86 kg fr wt raft^{-1} and 5.00 ± 0.5% day^{-1} in Gulf of Mannar under 45 days growth cycle. The corresponding values along Palk Bay were 2.98 ± 0.52 g fr wt raft^{-1} and 1.38 ± 0.42% day^{-1} for horizontal raft and 13.02 ± 6.06 kg fr wt raft^{-1} and 4.14 ± 1.18% day^{-1} for vertical raft. ANOVA clearly indicated that raft position significantly influenced the biomass yield and DGR at Palk Bay ($F = 75.77$; $F = 112.81$) as well as Gulf of Mannar ($F = 27.21$; $F = 59.16$) at $p = 0.001$. The increment of 1.9–2.6% in fresh weight of individual frond was reported in vertically aligned rafts. The computational fluid dynamics (CFD) based unsteady numerical simulations have confirmed that vertical alignment of raft facilitates relatively free movement of water due to which sedimentation and epiphytism are either minimised or eliminated. Thus these studies can help us to deduce important conclusions pertaining to management of sustained commercial cultivation of this alga in Indian waters.

1. Introduction

An estimated 80% of world's total agar is obtained from genus *Gracilaria*; while Chile, Malaysia, Thailand, New Zealand, Philippines, Indonesia, China, Taiwan and South Africa are the major producers (c.f. Veeragurunathan et al., 2015a). In terms of global value, *Gracilaria* stands fourth, having US$ 342 million trade corresponding to eight percent market share (Nayar and Bott, 2014). Nevertheless, unlike carrageenan seaweed industry – where *Kappaphycus* and *Eucheuma* are the primary source – several species dominate agar business, contributing immensely to the regional economy. The industrial exploitation of *Gracilaria lemaneiformis* is being carried out in China (Yang et al., 2006); *G. chilensis* in Chile (Buschmann et al., 2001); *G. gracilis* in Argentina (Michetti et al., 2013), *G. tikvahiae* in USA (Samocha et al., 2015); *G. tenuistipitata* in Malaysia (Yu et al., 2013) and *G. edulis* (Ganesan et al., 2011) as well as *G. verrucosa* (Padhi et al., 2011) in India.

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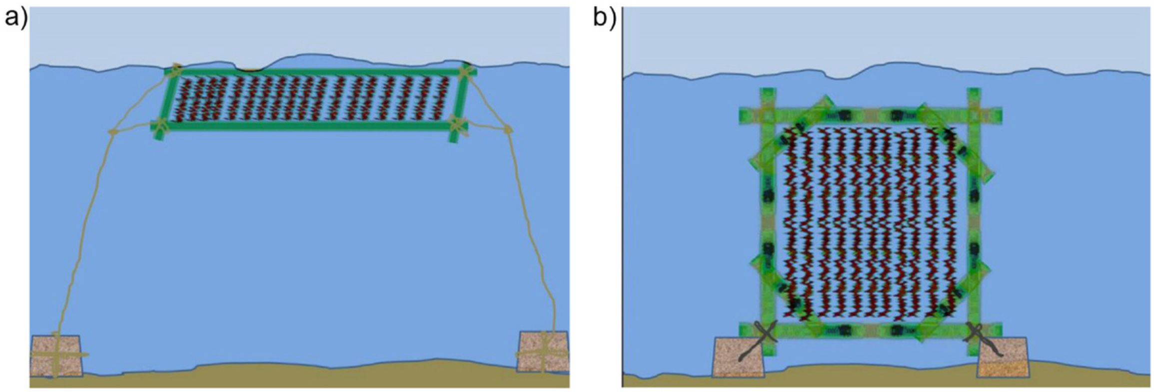

Fig. 1. Diagrammatic representation of raft arrangement.

In India, food grade agar (450–490 g cm^2), is being prepared from *Gracilaria edulis* (Ganesan et al., 2011). Besides, industrial agar production, this alga has spectrum of applications in pharmaceutical sector (Ravikumar et al., 2011; Patra and Muthuraman, 2013). Furthermore our research group has developed integrated method for simultaneous recovery of multiple value added products through green processing of biomass (Baghel et al., 2015). However, in recent years steady depletion of the natural beds of this alga has raised serious doubts about long term sustainability of wild stocks.

To cater to the demand of over twenty agar industries, it is necessary to establish and implement an agriculture-like protocol. The cultivation practices so far have employed long-line rope, net-culture, bottom planting, cage culture, single floating rope technique, etc. (Chennubhotla et al., 1978; Kaladharan et al., 1996; Kaliaperumal et al., 2003; Raju and Thomas, 1971; Subbaramaiah and Thomas, 1990; Umamaheswara Rao, 1974). Ganesan et al. (2011) have reported supremacy of floating bamboo raft method over the others in obtaining higher yield of *G. edulis*. Although, horizontally placed rafts provide ease in maintenance and harvesting; enhanced epiphytic infestation (Supplementary material Fig. 1a–c), siltation and breakage during summer, cumulatively accounts for about 15–20% crop loss [author's personal observation]. The seedlings at centre of the raft are more susceptible to the epiphytic infestation during initial growth phase (10–15 days). The over-growth of epiphytes typically reduces the seedling density on planting rope by basal necrosis. In *Gracilaria*, where 30% of the harvest is being re-used as a seed material for subsequent planting (Hurtado-Ponce et al., 1992), the additional crop loss exerts stern economic constrains on viability of aquaculture.

In present communication, we report that change in raft alignment to vertical position during elevated temperatures fetches higher yield. This position shift will enable commercial seaweed farmer to sustain the growth rates for accomplishing year-round farming. The parameters studied include daily growth rate (DGR), average biomass of an individual plant and distribution of biomass range of an individual plant. We also tested the hypothesis through computational fluids dynamics (CFD) based unsteady numerical simulations that vertical alignment of raft facilitates relatively better water movement enabling seedlings to have replenished supply of nutrients that are vital for their growth.

2. Material and methods

2.1. Field cultivation of gracilaria edulis

Cultivation of *G. eduils* was attempted at sub-tidal waters of Thonithurai along south-east coast of India. Although, peninsular India experiences intense summer during April–June, Mandapam coast due to its unique geographical location, experiences two elevated temperature periods coupled with feeble currents viz. October–December along Gulf of Mannar (GOM) and April–June along Palk Bay. Therefore, cultivation was attempted coinciding October–November 2013 along the Gulf of Mannar as well as during April–June 2014 along the Palk Bay to test feasibility. The raft method (2 × 2 m) was used and the details are as per Ganesan et al. (2011). The apical vegetative fragments weighing about 600 g fr wt per raft were used as initial seed material. Ten such rafts were placed horizontally with anchor stones (50 kg) in clusters of five (Fig. 1a). In another set of experiments similar procedure was followed for seeding 10 more rafts, however, the orientation of these rafts was made vertical during anchoring (Fig. 1b). The crop was harvested after 45 days in both the cases and weight of harvest recorded using digital balance. The biomass yield was expressed as kg fresh wt $raft^{-1}$, while the daily growth rate ($\%^{-1}$ day DGR) was determined as described by Ashok et al. (2016). To record average biomass of single plant, ten individual plants from each raft were randomly weighed. To note the frequency distribution of the range of biomass of a single plant from the harvest, hundred individual plants were randomly weighed (both orientation). Each plant was classified among four different categories based on its weight namely, 0–50; 51–100; 101–150 and 151–200 g fr wt. The percentage of plants was calculated to understand the range of frequency distribution.

2.2. Computational fluid dynamics (CFD) based unsteady numerical simulations

The numerical simulations were carried out by applying the computational dynamics principles to predict the velocity distributions around the ropes under usual wave conditions. The data reported in the literature for water current was used for computation (Ramesh, 2004; https://earth.nullschool.net/). The simulation was done independently for horizontal and vertical orientation of the raft. To get first order information, only two-dimensional simulations were carried out. A single scale turbulence model, which approximates the randomly varying multi-scale turbulence consisting of multiple eddies, with single frequency component (i.e. vortex shedding frequency) and corresponding single eddy size was adopted for the unsteady simulation. Sufficiently large computational domain sizes were used for both horizontal and vertical orientation cases by following Bosch and Rodi (1998). By taking the requirement on the minimum size of the computational domain into consideration, the velocity inlet, pressure outlet and side boundaries were modelled at 110D, 220D and 33D (Fig. 2a: horizontal orientation case) and 110D, 220D and 110D (Fig. 2b: vertical orientation case), respectively where D is diameter of the rope. In