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Growth rates of *Eucheuma denticulatum* (Burman) Collins et Harvey and *Kappaphycus striatum* (Schmitz) Doty under diferent conditions in warm waters of Southern Japan

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Abstract

Green and brown strains of *Eucheuma denticulatum* and new cultivated strain *Kappaphycus striatum* were collected from commercial cultivation ground in Philippines. Daily growth rates (DGR) of the materials were measured under different temperatures and photon fluence in laboratory controlled conditions and at different depths in the sea using the floating raft culture method in Uranochi Inlet, Tosa Bay, Southern Japan.

The highest DGR of *E. denticulatum* (brown strain) (2.76% ± 0.64) and *K. striatum* (green strain) (4.5% ± 1.51) were recorded at 25 °C. *K. striatum* (both strains) had the highest DGR and grew over a wide range of temperatures. Observation on the effect of photon fluence showed that *K. striatum* (brown strain) grew well (DGR = 5.16% ± 1.3) at 145 μmol photon m^{-2} s^{-1}. In the floating raft cultivation, *K. striatum* (green strain) had a DGR of 3.1% ± 0.93 higher than *E. denticulatum* (brown strain) (2.73% ± 0.43).

Introduction

Eucheuma and *Kappaphycus* have both become economically important seaweeds as sources of raw material for the extraction of carrageenan. These two genera of red algae are important carragenophytes which are abundant in the Philippines, tropical Asia and the Western Pacific region and have been farmed in the shallow reefs of the Philippines since early 1979 (Lim & Porse, 1981; Trono, 1993).

The thallus of *E. denticulatum* consists of many cylindrical branches, tapering to acute tips. Branches are usually densely covered with 1-8 spinose, determinate branchlets, arranged in whorls forming distinct 'nodes' and 'internodes' especially at distal portions in the branches positions. The thallus of *K. striatum* may be erect or decumbent. The main branches are not percurrent and there are branches roughened by the precence spinose processes. Branched and covered with coarse spinose branchlets (Trono, 1993). These species has been cultivated in large scale *Eucheuma* farm in nothern Bohol, Philippines recently, but there is a few reports on the growing of cultivated *K. striatum*.

Recently the demand for carrageenan has increased worldwide and this has encouraged commercial production of both genera, and stimulated the cultivation of these species outside of their region of origin. Annual production and daily growth rate (DGR) of carrageenophytes differs depending on the species, location of cultivation and environrnental conditions e.g. Tanzania (Lirasan & Twide, 1993) Indonesia (Luxton, 1993) and Madagascar (Mollion & Braud, 1993).

Japan is a major importer of carrageenan, as there are no local suitable sources of the colloid. The plants utilized in the present investigation, were obtained from the Philippines and cultured both under controlled laboratory conditions and also in Uranochi Inlet, Tosa Bay, Shikoku Island, Japan. This study presents work on the effects of environmental factors on the DGR of *Eucheuma denticulatum* (brown and green strains) and *Kappaphycus striatum* (brown and green strains), to assess the optimal conditions for their cultivation in southern Japan.

Table 1. Daily growth rate (mean %, ± s.d.) of *Eucheuma denticulatum* (brown and green strains) and *kappaphycus striatum* (brown and green strains) under different experimental conditions.

Experimental conditions	*Eucheuma denticulatum* brown	*Eucheuma denticulatum* green	*Kappaphycus striatum* brown	*Kappaphycus striatum* green
Temperature (°)				
21	1.86 ± 0.19	1.65 ± 0.24	1.09 ± 0.22	1.64 ± 0.39
23	2.06 ± 1.94	2.23 ± 0.96	2.18 ± 0.49	2.94 ± 1.94
25	2.76 ± 0.64	2.62 ± 2.31	2.96 ± 0.56	4.50 ± 1.51
27	0.99 ± 0.33	2.41 ± 0.65	2.22 ± 1.10	2.10 ± 0.63
Irradiance (μmol photon m^{-2} s^{-1})				
125	2.21 ± 1.90	1.75 ± 1.60	2.81 ± 1.70	2.5 ± 1.40
145	2.21 ± 1.80	2.10 ± 1.40	5.16 ± 1.30	2.91 ± 1.30
165	1.22 ± 1.50	1.33 ± 1.20	4.69 ± 1.50	2.49 ± 1.50
Depth (m)				
0	2.34 ± 0.82	1.47 ± 0.37	2.63 ± 1.26	1.81 ± 1.03
1	2.73 ± 0.43	1.48 ± 0.59	2.34 ± 0.83	3.10 ± 0.93
2	1.97 ± 0.69	1.4 ± 0.60	1.97 ± 0.93	1.60 ± 0.47
3	1.21 ± 0.60	1.02 ± 0.39	1.77 ± 0.56	1.66 ± 1.11

Materials and methods

Samples of *E. denticulatum* and *K. striatum* were brought from the *Eucheuma* farm, Nothern Bohol in the Philippines. One to two gram cuttings of thalli were selected for the experiment. Five replicates of the brown and green colour strains of the two species were hung horizontally in a temperature-controlled closed-circulating system 'aquatron' (Ohno, 1977).

The growth medium used for the growth experiments was plankton net filtered seawater (450 L) from Uranochi Inlet, Tosa Bay, with salinity of 33–34‰. Light was provided by cool white fluorescent tubes with a 12:12 h light: dark cycle. The tank was covered with black cloth to eliminate any influence from extraneous light. The system was run for 24 h daily for 60 days under each of the different experimental conditions.

The effect of temperature on DGR was measured at 21, 23, 25 and 27 °C at 150 μmol photon m^{-2} s^{-1} irradiance. The effect of irradiance on DGR was measured at 125, 145 and 165 μE m^{-2} s^{-1}, at 25 °C. Irradiance was measured using a digital Li-Cor photometer LI-189.

In order to assess the DGR of *Eucheuma* and *Kappaphycus* under open water field conditions, five thalli (26–30.7 g) of both strains of the two genera were hung horizontally at various depths (0, 1, 2 and 3 m) from a floating raft in Uranochi Inlet Tosa Bay in order to study the effect of depth on their growth rate.

This experiment was carried out for a period of 60 days (June 20 to August 19, 1996). The increase in weight of plants was measured every 10 days. DGR (mean%, ± s.d) was calculated using the formula $G = [(W_t/W_o)^{1/t} - 1]$, where the G = % increase in fresh weight per day, W0 = initial weight, Wt = weight after *t* days.

Results and discussion

Seawater conditions during the period of outdoor investigation ranged in from 27–34‰ salinity 23–31 °C temperature, 165 to 476 μmol m^{-2} s^{-1} irradiance. Daily growth rates are shown in Table 1. The maximum growth was observed in the green strain of *K. striatum* was 3.1% ± 0.93 and in the brown strain *E. denticulatum* was 2.73 ± 0.43), both at 1 m depth.

Kappaphycus alvarezii grows well at a depth of 1 m (3.69%), 2 m (3.84%), and 3 m (4.17%) (Ohno et al, 1994). Hurtado-Ponce (1992) reported that the daily growth rate of *K. alvarezii* in cage culture ranged from 3.72–7.17%. These authors suggested that the following environmental parameters were suitable for *Kappaphycus* growth: water temperature at 28–30 °C, salinity at 33–35‰, and pH at 8.5–8.35.

The values of % DGR of thalli grown in the aquatron at various temperatures and photon fluence are shown in Table 1. In the present study *Eucheuma* and *Kappaphycus* showed a marked seasonal variation

under different environmental conditions. Althought *K. striatum* (green strain) showed the highest % DGR at 25 °C (4.5 ± 1.5), results showed that the imported material could grow over the temperature range of 23-27 °C except for *E. denticulatum* (brown strain) which showed a decline in growth at 27 °C (0.99 ± 0.33). In addition they did not grow well at temperatures under 21 °C. This indicates that *E. denticulatum* has a narrow range of temperature tolerance and that temperature is an important factor affecting the growth and probable distribution of this species.

The mean daily growth rate, in response to different irradiances under controlled environmental conditions showed that *K. striatum* (brown strain) had a wide tolerance range beyond the irradiance values tested. The growth rates of *E. denticulatum* and *K. striatum* showed positive relationships with photon fluence. The brown strain of *K. striatum* showed DGR of (5.6% ± 13) while *E. denticulatum* brown strain showed a DGR of 2.21% ± 1.18 at 145 μmol m^{-2} s^{-1}. Irradiance is one of the most important factors controlling the growth of seaweeds. Most algae have a well defined photon fluence tolerance range, bleaching under high light intensity and ceasing growth under low light intensity (Dawes, 1981).

The data in this present investigation indicate that the optimum conditions for the growth of *E. denticulatum* and *K. striatum* in the aquatron was 25 °C with irradiance of 145–165 μmol photon m^{-2} s^{-1}, under laboratory conditions. These algae grow well at depths of 1 m in open water growth trials.

From the results presented here and in conjuction with information from Mairah et al. (1986) and Ohno et al. (1994), it can be seen that there is potential for the commercial cultivation of *E. denticulatum* and *K. striatum* in Uranochi Inlet, Tosa Bay, southern Japan, particularly during the period when the area is influence by the warm water of the Kuroshio current. Clearly further work is required to optimise the site specific techniques for field cultivation of this species at this site.

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