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Effects of temperature and salinity on the growth of *Gracilaria verrucosa* and *G. chorda*, with the potential for mariculture in Korea

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Abstract

Effects of temperature and salinity on the growth of the two agarophytes, *Gracilaria verrucosa* (Hudson) Papenfuss and *Gracilaria chorda* Holmes were examined in Korea. Both species grew over a wide range of temperatures (10–30 °C) and salinities (5–35‰), and grew well at 17–30 °C and a salinity of 15–30‰. In culture, *G. verrucosa* grew faster than *G. chorda* and their maximum growth rates were 4.95% day^{-1} (30 °C, 25‰) and 4.47% day^{-1} (at 25 °C, 25‰), respectively. In the field population the maximum growth and fertility of *G. chorda* were observed in summer. The growth rate of *G. verrucosa* was slightly higher than that of *G. chorda* for 2 weeks on the cultivation rope and in culture but it was much lower after being contaminated with epiphytes. The biomass of the epiphytes was 0.82 g dry wt. per host plant in *G. verrucosa* and 0.001 g in *G. chorda*. *G. chorda* exhibited resistance to epiphytism and grew 7 times in length and the dry weight increased 15 times after 55 days. In conclusion, *G. chorda* appears to be a good agarophyte with a fast growth rate and resistance to epiphytism, and compared with *G. verrucosa*, has good potential for commercial cultivation.

Introduction

Seaweeds belonging to the genus *Gracilaria* are very important as a food for humans and marine animals, and as a source of industrial agars (Zemke-White & Ohno, 1999). *Gracilaria* is now the most important agarophyte, producing approximately 60% of the agar in the world (Tseng, 2001), and commercial cultivation is performed on a very large scale in several countries such as Chile, China and Taiwan (Dawes, 1995). There is increasing demand for industrial agars for use as materials in electrophoresis and as a culture medium for microbes.

Korea is a major country for algal production but the only species cultivated are *Laminaria japonica* Areschoug, *Undaria pinnatifida* (Harvey) Suringar, and *Porphyra* spp. Their price fluctuates annually with variations in production and weather. Therefore, it is essential to develop cultivation techniques for new species. In Korea, food grade agars are made from *Gelidium* spp., especially *G. amansii* (Lamouroux) Lamouroux. However, industrial agars extracted from *Gracilaria* spp. are imported from Chile and Brazil.

Gracilaria verrucosa, which is one of 8 species found on the Korean coast, occurs in the upper intertidal zone and is distributed widely from estuaries to open sea around the Korean Peninsula. *Gracilaria chorda* occurs in the lower intertidal zone of the southwestern coast of Korea and grows up to 7 m in length on the cultivation ropes of *U. pinnatifida*, which were established 2–3 m below the sea surface. A few studies have been performed on the commercial cultivation of *Gracilaria verrucosa* to develop cultivation techniques, particularly on the environmental conditions to induce release of spores for seedlings in the laboratory and on the growth and reproduction of *G. verrucosa*

field populations (Kim et al., 1998, 2001). However, there are no data on the growth and reproduction of *Gracilaria chorda*, even though the alga is of commercial interest as an agarophyte and foodstuff due to its higher production.

For cultivation, the growth responses of *Gracilaria chorda* to temperature and salinity should be studied in order to determine the choice of cultivation area (estuaries or open water) and cultivation season (summer or winter). In addition, data on the growth and reproduction of natural populations of *G. chorda* are needed. Accordingly, the aims of this study were to examine the effects of salinity and temperature on the growth of *Gracilaria chorda* and *G. verrucosa* in laboratory culture and to measure the growth of the two algae on cultivation ropes in order to determine which of the two species would be better for cultivation.

Materials and methods

Study site

Studies were conducted at Ihoijin Jangheung (34°27′N, 126°56′E), on the border between Gogeum Island, Wando, and Gangjin, on the southern coast of Korea. Rock beds lie along the shoreline and a large amount of gravel and vast mud flats are found in the intertidal zone in the study area. The seawater movement is relatively low and the transparency of seawater is approximately 0.8–2.0 m. The average sea surface temperature ranges from 7.11 to 23.73 °C throughout the year, and the salinity ranges from 30.22 ‰ in summer to 34.38 ‰ in winter. The dominant algae were *Enteromorpha prolifera* (Oeder) J. Agardh, *Monostroma nitidum* Wittrock, *Ulva pertusa* Kjellman and *Gloiopeltis furcata* (Postels *et* Ruprecht) J. Agardh, *Porphyra* spp., *Gracilaria verrucosa* and *Sargassum* spp.

Field population structure of Gracilaria chorda

Gracilaria chorda was collected seasonally on cultivation ropes of *Undaria pinnatifida* at Ihoijin, Jangheung, Korea from February 2003 to April 2004. The plants were transported to the marine laboratory of Wonkwang University and length was measured. The plants were dried in an oven at 80 °C for 5 days and then weighed to calculate the growth of the *Gracilaria chorda* field population. The population structures and size distribution were also examined in order to determine the recruitment season of the species.

Laboratory culture

For culture, vegetative plants of *Gracilaria verrucosa* and *G. chorda* were collected from the intertidal zone of Tangjasum and cultivation ropes of *U. pinnatifida* at Ihoijin, Jangheung, Korea in June 2003. The plants were transported to the laboratory and the apical parts of fronds were rinsed several times with filtered seawater to remove diatoms and detritus attached to the fronds. The healthy apical fronds, 10 mm in length, were excised from the vegetative fronds of the two species and kept for 2 days to reduce the negative effects of cutting.

Growth studies were carried out in five incubators at 10, 17, 25, 30 and 35 °C and salinities 5, 15, 25 and 35‰ for 2 weeks. The daylength (12: 12 h light: dark, LD) and irradiance (100 μmol photons m^{-2} s^{-1}) were also kept constant. Five apical fragments of each species were placed in a flask containing 100 mL of PES medium (Provasoli, 1968) and the experiments were replicated three times. The culture medium was changed every 4 days throughout the experimental period. After 2 weeks, the length of the plants was measured and the relative growth rate (RGR %day^{-1}) was calculated with the mean length for each replicate using the following equation (Rueness & Tananger, 1984):

$$\mathrm{RGR}\,(\%\mathrm{day}^{-1}) = 100\ \ln(\mathrm{Lt}/\mathrm{Lo})/\mathrm{t}$$

where Lo is the initial plant length, Lt is the final length after t days and t is the number of days.

Transplant experiment

Vegetative plants of *Gracilaria verrucosa* and *G. chorda* were collected at the two sites reported above. The fronds were cut into 15 cm lengths and inserted between the braids of polypropylene cultivation rope at 15 cm intervals (100 m for each species). The ropes were suspended at 1 m below the seawater surface at Ihoijin Jangheung from 25 March to 20 May 2004. For each species, 60 plants (20 replicate plants per period) were harvested 13, 27 and 55 days after transplantation. For both species, the plant length, weight and branch number were measured at each sampling date. The relative growth rate (RGR %day^{-1}) was calculated using the mean plant length for each replicate using the equation described above.

When transplanting the thalli of the two species, the mean length, dry weight and branch number of *G. verrucosa* was 15 cm, 0.09 ± 0.01 g (mean ± SE,