Effects of Aeration Period on the Productivity and Agar Quality of *Gracilaria* sp.

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ABSTRACT

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Daily aeration periods of 4, 6, 12, and 24 h were examined for their effects on productivity of *Gracilaria* sp. Strain G-16 and on resultant agar quality. There were significant effects on biomass productivity, with decreases from 22 to 12 $g \cdot m^2 \cdot d^{-1}$ at decreases from 24 h to 4 h of daily aeration, respectively. However, there were no effects of daily aeration periods on agar content, gel strength, or gelling and melting temperatures, suggesting that daily aeration period can be adjusted to provide maximum economic return based on seaweed and agar productivity. An analysis of total revenue, marginal revenue and aeration costs indicated that the most cost-effective aeration period was 11 h/day.

INTRODUCTION

Land-based intensive seaweed cultivation for wastewater treatment and production of industrial hydrocolloids (carrageenan and agar) involves growing seaweed in tanks or raceways. In these systems, aeration provided through pipes on the bottom of the raceways is used to circulate both water and seaweed (DeBoer, 1979; Bidwell et al., 1985). The benefits of seaweed movement are not completely understood, but may relate to enhanced nutrient and dissolved carbon uptake, constant cycling of the seaweed in and out of the light, and prevention of detrital and diatom accumulations on the seaweed thalli.

The costs for air-suspended seaweed aquaculture systems can be divided into capital and operating components. Major operating costs are fertilizers, labor, water pumping, and aeration to keep the seaweed suspended. Pulse delivery of added nutrients reduces waste associated with continual nutrient additions and facilitates nutrient management (Ryther et al., 1981). Bidwell et al. (1985) describe how use of pH controllers and CO_2 addition can effectively provide dissolved carbon sources for *Chondrus* growth, leading to greatly reduced water-pumping costs. While most of the experimental *Gracilaria* cultivation research has been done with high water exchanges, short-term batch experiments have confirmed that pH control and carbon addition can lead to *Gracilaria* yields equal to those at 10 water exchanges/day (DeBusk and Ryther, 1984).

In an effort to reduce aeration costs, this research has focused on the effects of reducing the length of time of daily aeration on biomass productivity, agar productivity, and agar quality of *Gracilaria* sp. Strain G-16, a Harbor Branch strain with commercial quality agar. Previous studies have demonstrated that some reduction in amount of daily aeration does not significantly affect productivity of *Gracilaria* sp. grown at 1 and 0.1 water exchanges/day (Ryther et al., 1984), but the potential impact on agar production and quality has not been determined. In products (agar) oriented research, it is important to fully test experimental treatments on product quality. In this research, agar quality parameters of gel strength, gelling temperature, and melting temperature were examined as a function of aeration effects.

MATERIALS AND METHODS

Gracilaria Strain G-16 was grown in outdoor 1.7-m^2, 880-l concrete tanks receiving four water exchanges/day. Four daily aeration periods were used: 24, 12, 6, and 4 h/d. The mid-point of each aeration period was solar noon. Aeration periods were set by incorporating solanoid valves into the aeration lines, which in turn were connected to timers. Duplicate tanks were used for each treatment.

Tanks were stocked with 2 kg (wet)/m^2, and productivities were determined weekly for 10 weeks (5 May–15 July). After determination of productivity, the tanks were returned to the initial stocking density. Every week the harvested material was dried to a constant weight at 60°C for dry-weight determination, combined and agar analyses performed on biweekly samples.

Agar was extracted from dried, ground seaweed using an alkaline pretreatment process. Triplicate samples were pretreated in 1 N NaOH for 1 h at 80°C, then vacuum-filtered through cheesecloth and rinsed with water. The solid residues were adjusted to pH 7–8 in distilled water, and allowed to equilibrate overnight. Prior to agar extraction the next day, the pH was readjusted to a range of 7–8 and the samples then autoclaved for 3 h. The hot slurries were pressure-filtered through Celite and a 10-μm filter, followed by cooling of the filtrate. The agar filtrate was frozen and then thawed over a screen. The wet agar was then redissolved and the freeze–thaw process repeated. The final agar samples were dried at 40°C to a constant weight. In order to determine agar recovery efficiencies, spikes of known *Gracilaria* agar additions were added to

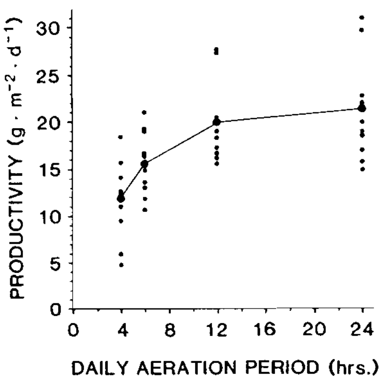

Fig. 1. Effects of daily aeration periods on productivity of *Gracilaria* sp. Strain G-16. Each point represents a 1-one week replicated measurement over a course of 10 weeks.

identical seaweed samples after the pretreatment and equilibration phase. The percentage recovery was determined by the agar content difference between the spiked and unspiked samples, and the amount of the original agar addition. The agar yield data were corrected for this recovery efficiency.

Gel strength (in triplicate) was determined by a Marine Colloids gelometer with a 1-cm^2 plunger using a 1.5% gel. It was necessary to allow the dried agar powders to equilibrate overnight in water before dissolving them in order to get the most complete agar dissolution. These same gels were redissolved after gel-strength determination, and used for melting and gelling temperature determinations. Melting temperature was determined as the temperature at which a small glass bead placed on top of the agar solid sank through the agar when gradually heated in a water bath (Craigie and Leigh, 1978). Gelling temperature was determined by slanting a rack of test tubes containing melted agar and periodically righting the tubes. The temperature of the agar at which the meniscus no longer returned to a level was noted as the gelling temperature. Comparative samples of a commercial grade *Gracilaria* agar obtained from TIC Gums Inc. (New York, NY) were also run.

RESULTS AND DISCUSSION

There was a clear effect of daily aeration period on productivity of *Gracilaria* Strain G-16. As daily aeration decreased from 24 to 4 h, seaweed productivity decreased from an average of 21 to 12 $g \cdot m^{-2} \cdot d^{-1}$ (Fig. 1). An analysis of variance showed that these means were significantly different at the $P<0.05$ level. There was no difference between a daily aeration period of 12 vs. 24 h. Similar results were found by Ryther et al. (1984) for a different strain (G-1) of *Gracilaria*. They also found these patterns were consistent at two water

TABLE 1

Effects of different periods (hours) of daily aeration on agar quality (content, gel strength, gelling and melting temperature) from *Gracilaria sp.* Strain G-16. Commercial *Gracilaria* agar gave a gel strength of 530 g/cm^2, gelling temperature of 40°C, and melting temperature of 91°C

	Agar quality															
	Agar yield (%)				Gel strength (g/cm^2)				Gelling temp. (°C)				Melting temp. (°C)			
Hours	24	12	6	4	24	12	6	4	24	12	6	4	24	12	6	4
Week																
2	17.6	17.0	15.8	17.6	651	735	910	790	38	39	40	39	98	102	102	102
4	13.4	12.4	15.0	14.8	880	922	742	720	38	38	39	39	100	99	99	99
6	14.2	11.8	14.6	14.6	1059	1064	903	815	42	43	42	42	102	103	102	101
8	11.6	12.2	10.8	11.6	1174	1047	1015	976	45	44	45	45	102	103	102	102
10	15.2	12.0	13.4	12.0	894	758	929	963	43	46	47	47	103	103	103	102

exchange rates, 1 and 0.1/d, although productivities were one-third lower at the lowest water exchange.

There were no effects of daily aeration period on percent dry weight of agar, gel strength, gelling or melting temperature as determined by analysis of variance. Agar yield ranged from 12 to 18%, but showed no significant differences (agar recovery efficiency was 51%). Gel strengths ranged from 630 to 1200 g/cm^2, and were representative or greater than a commercial agar from *Gracilaria* (Table 1). Melting and gelling temperatures ranged from 98 to 103°C and 38 to 47°C, respectively, values which are somewhat higher than the commercial agar samples.

As there was no effect of daily aeration on agar quality from the seaweed grown in the different aeration periods, it is clear that this cost can be managed for maximum productivity vs. cost. This has not always been the case for other seaweed cultivation practices. While N starvation can increase agar content (DeBoer, 1979), it also serves to decrease product quality (Bird et al., 1981). Water temperature can also affect agar quality (Craigie and Wen, 1984). There is less information on light intensity, pH, and salinity effects on agar quality. Identification of which environmental/culture factors do not affect agar quality can allow the mariculturist to manipulate those conditions for most cost-effective agar production without concern over loss of product quality.

In order to determine the most cost-effective daily aeration period, the total product revenue (based on dry seaweed production) was compared to the marginal revenue (Allen et al., 1984). The production system was sized at 4000 m^2, at the seaweed productivities determined in this study (Fig. 1) and sales price of $1300/dry ton. A blower was selected which delivered 1034 l/s, using a motor with a power requirement of 27.8 kW. At an energy cost of $0.09 kW-h,

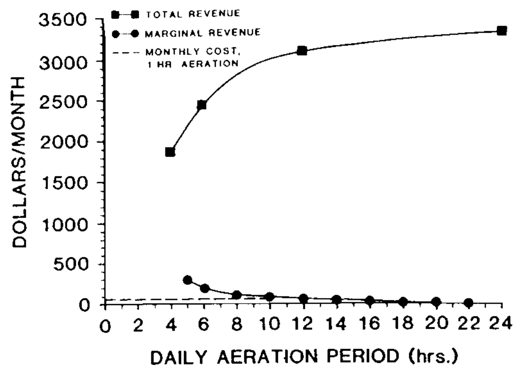

Fig. 2. The total and marginal monthly revenues of *Gracilaria* sp. Strain G-16 as a function of daily aeration period (based on the productivity data of Fig. 1). The dashed line represents the monthly cost of 1 h aeration.

the monthly cost for 1 h of daily aeration was $75.06. The intersection of this monthly cost with marginal revenues suggests the most cost-effective daily aeration period is 11 h (Fig. 2). During the winter period, the productivity of this strain can drop by one-half (Harbor Branch Oceanographic Institution, unpublished data, 1985). This would cause a concomitant reduction in marginal and total revenue, suggesting more cost-effective daily periods of 4–6 h. This study did not examine possible seasonal effects on the aeration period vs. productivity relationship. However, Ryther et al. (1984) found no seasonal effects on the relationship itself for *Gracilaria tikvahiae* Strain G-1, other than lower overall productivities at lower water temperatures.

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