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Experimental tank cultivation of *Porphyra* in Israel

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Abstract

Outdoor tank cultivation of several *Porphyra* (nori) species was carried out from late November 2002 through early May 2003 using 40 L (with a surface of 0.25 m^2), 600 L (1 m^2), and 24,000 L (30 m^2) fiberglass or PVC tanks provided with continuous aeration and seawater flow. Sexual and asexual spores produced from cultured conchocelis and frozen thalli in the laboratory, respectively, were subsequently grown to produce young fronds (ca. 5–10 cm) in an average time of 8 weeks. Growth in outdoor tanks and ponds was possible for a period of up to 20 weeks (i.e. growth season), with yields above 100 g FW m^{-2} d^{-1} occurring during 12–14 weeks from late December through late March, when seawater temperatures were below 20 °C. These yields correlated with the species and depended on the type of tanks in which the algae were cultivated, with the highest yields observed for *Porphyra* sp. and *Porphyra yezoensis* when fertilized twice a week with NH_4Cl and NaH_2PO_4 in 40 L tanks. Calculations of productivity for an entire growth season based on ≥100 g FW m^{-2} d^{-1} yields exceed the average productivities using seeded nets in open sea, for all *Porphyra* species tested (0.96–4.06 kg DW m^{-2} $season^{-1}$ vs. 0.7–1.0 kg DW m^{-2} of net $season^{-1}$). Therefore, tank cultivation of *Porphyra* can offer an additional source of nori biomass to international markets. Land-based tank cultivation also offers an environmentally friendly practice that allows for the manipulation of growth conditions to enrich seaweeds with specific, valuable chemicals such as protein and minerals.

Introduction

Out of the approximately 130 identified species of *Porphyra* only a few have served as commercial, sea-vegetable foods (nori, purple laver). Several variants of these naturally occurring species have been produced to enhance yields and culinary parameters of nori production in Japan, Korea and China. Until the late 1980's, production of nori was almost equally balanced with consumption (Miura & Aruga, 1987). Rapidly expanding seaweed markets and degradation of marine environments have both led to steadily increasing demands for nori worldwide (McHugh, 2003; Merrill, 1993).

On-land seaweed tank cultivation has several advantages over traditional, open-sea aquaculture. In tanks, algal growth can to some extent be manipulated and seaweeds can be enriched with desired bio-chemicals. Abrupt pollution events may become detrimental for cultivation in the open sea. This and other environmental factors during the growth season make biomass yields unpredictable. Nevertheless, few studies have reported successful, sustainable cultivation of seaweeds in land based tanks or ponds, and even fewer have described tank cultivation for *Porphyra*. In fact it is likely that tank cultivation is more common than reported in the scientific literature, as seaweeds have gained crucial roles in, for example, developing integrated aquaculture (Chopin et al., 2001; Fei, 2004). Mencher et al. (1983) described the use of ocean thermal energy conversion effluents to cultivate *Porphyra* in 1 m^3 tank compartments. Yamamoto et al. (1991) tested outdoor raceways as an alternative cultivation approach to grow *P. yezoensis* in Japan. Hafting (1999a,b) demonstrated

monospore production, after cutting and maceration of foliose thalli as seeds, to establish a tank cultivation technology for *Porphyra*, while Notoya (1999) also proposed seed production from tissue culture of both monoecious and dioecious species. In Israel, tank cultivation has been a common practice for at least a decade, both experimentally and commercially (Friedlander & Levy, 1995; Neori et al., 2000).

The current study describes a tank cultivation technology implemented for various *Porphyra* species, and presents their fresh weight and dry weight yields during a full growing season, while discussing the advantages of land-based cultivation over conventional, open-sea seaweed culture.

Materials and methods

Algal material

The species tested for tank cultivation were *Porphyra linearis* Greville, a winter annual species of uncertain taxonomic determination collected from a nearby shore, *Porphyra tenera* Kjellman and *Porphyra yezoensis* Ueda brought to our laboratory from commercial cultivars in Japan, and *Porphyra* sp. collected from East Taiwan in 1997, also of uncertain taxonomical status. These species are part of a seaweed culture collection maintained at Israel Oceanographic & Limnological Research, Ltd (IOLR), Haifa, Israel. They were maintained in a growth chamber at 15°C, 70 μmol photon m^{-2} s^{-1} and 10 h photoperiod as seedlings or cultured conchocelis.

Indoor seedling production

Seedlings were obtained from sexual spores (conchospores, obtained from all species except *Porphyra* sp.) by manipulation of conchocelis filaments to obtain mature conchosporangia (Sidirelli-Wolff, 1992), or from vegetative spores (archeospores, obtained from all species) after foliose thalli were frozen at –20°C for 24 h and thawed in seawater. In the latter case spore release was considered terminated after 24–48 h. The spores obtained using either of the two sources were grown in 250 ml glass beakers ($n = 20-30$) filled with enriched (PEM-II; Provasoli, 1968) seawater medium at 15 °C, 70 μmol photon m^{-2} s^{-1} and 10 h photoperiod in a growth chamber. The beakers were placed on a shaker set at low speed and the seawater media changed every 5–7 days. Seedlings were allowed to reach about 0.5 cm length before being transferred to outdoor cultivation settings.

Outdoor growth

Outdoor culture extended from 22 November 2002 to 28 April 2003, totaling 5 months. Few experiments were continued until mid May 2003. An average seedling biomass of 10–15 g FW was transferred to 5–8, 40 L (0.25 m^2), fiberglass tanks equipped with running seawater and aeration, similar to the system described by Israel et al. (1999). The tanks were covered with plastic nets to reduce irradiance to approximately one third of incident sunlight. Transfer from seedling incubators to outdoor tanks was carried out when ambient seawater temperature was 20 °C or below. Biomass yields were determined by weighing the algae every one or two weeks after carefully allowing excess seawater to drip off the algal material.

Porphyra thalli averaging 2–3 cm long were then moved to 2–3, 600 L (1 m^2) plastic tanks, also receiving continuous seawater flow, aeration and reduced sunlight. Next, when the young thalli reached ca. 5–12 cm long, 10–15 kg FW were used to inoculate 2, 24,000 L (30 m^2) PVC or concrete ponds supplied with running seawater and aeration. During all steps of outdoor cultivation the algae were pulse fed twice a week for 24 h with NH_4Cl and NaH_2PO_4 added to the medium to reach 1.0 and 0.1 mM final concentrations, respectively (Friedlander & Levy, 1995). The data were statistically analyzed with two-way ANOVA and Duncan's tests.

Results

Seawater temperatures and growth

Seawater temperatures below 20 °C were regarded as a prerequisite for outdoor culture in all four species. Temperatures in *Porphyra* culture tanks varied similarly for all three types of tanks, and they fell below 20 °C from late November 2002 to late April 2003, approximately 20 weeks (Figure 1). Average daily yields determined in 40 L tanks of *Porphyra* sp., *P. yezoensis* and *P. tenera* ranged from 126 to 305 g FW m^{-2} d^{-1} and these yields decreased in a similar fashion for all species when seawater temperatures approached 18 °C (Figure 2). *Porphyra* sp. exhibited the highest yields at lower temperatures while *P. tenera* was the most sensitive to higher temperatures (Figure 2).