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Postharvest handling and storage of the edible red seaweed *Gracilaria*

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Abstract

Red macro-algae (*Gracilaria* spp.) are used as a fresh food in Hawaii. Species commonly marketed include *G. coronopifolia*, *G. parvispora*, *G. salicornia* and *G. tikvahiae*, however, these seaweeds have a short postharvest life of about 4 d. This research was undertaken to determine the changes that occur postharvest and how the postharvest life of *G. salicornia* can be extended. The changes in color, phycobilins, respiration rate, ethylene production, protein content, leakage and ion thalli content were determined. Postharvest effects of storage temperature, light/dark storage, modified atmospheres, calcium and nitrogen nutrient treatments, chlorine and heat treatments were evaluated to extend storage life and minimize microbial growth. When stored overnight at 2 °C, thalli became limp and entirely pinkish-red indicating possible chilling injury. At 10 °C, the color change and decline in phycobilin content occurred in 2 d and by the 4th day more than 90% of the thalli were either pink or red, and the phycobilin content had declined by 50%. At 12.5 °C and higher storage temperatures, the rate of color change was similar and the optimal storage temperature was between 15 and 17 °C in the dark. This storage temperature maintained quality but did not extend overall postharvest life. A steady rise in respiration rate occurred when stored in the dark or in the light. Light seemed to stimulate respiration rate when stored at 16 °C, but not at 21 °C. No relationship was found between ethylene production and respiration rate either with or without light exposure during storage. Ethylene production did not appear to be related to any physiological changes. Light did increase the rate at which thalli turned pink. Seaweed submerged in seawater in the dark had an extended postharvest life of about 30 d. Treatment with chlorine (50 mg L^{-1}) to minimize microbial growth was phytotoxic. Neither a 2 nor a 60 min postharvest dip in artificial seawater supplemented with 1 or 10 mM calcium, potassium, sodium, ammonium as the nitrate salt extend postharvest life. Treating *G. parvispora* and *G. tikvahiae* with hot seawater at 42 °C for 5 min was beneficial in maintaining appearance and extended postharvest life 40–60%. Storage at 15 °C and submerged in seawater or treated at 42 °C for 5 min depending upon species, showed potential at increasing postharvest life of red seaweed.

Keywords: Seaweed; Gracilaria; Food; Storage; Postharvest changes; Microbial development

Numerous red macro-algae of the genus *Gracilaria* are utilized as fresh food in many parts of the world (Zemke-White and Ohno, 1999). In parts of the Caribbean, the Pacific and Asia, *Gracilaria* is a subsistence food utilized by islanders. In Hawaii, *G. coronopifolia*, *G. parvispora*, *G. salicornia* and *G. tikvahiae* are grown commercially or harvested from the ocean and used as a fresh food (Abbott, 1996). Prior to Western contact, seaweed or limu of a number species from the Chlorophyta, Phaeophyta and Rhodophyta were consumed and probably contributed significant amounts of nutrients to the diet (McDermid and Stuercke, 2003). Seaweed, especially *Gracilaria* spp. adds a succulent crunchy texture to food and is commonly mixed with raw fish to create the many varieties of poke and in other dishes (Abbott, 1978). It is estimated that the weekly demand in Hawaii exceeds 1000 kg, with higher demands during holidays and graduation, as well as during major sports events. Off-grade and female thalli with reproductive structures can be processed into salsa and Japanese styled pickles, such as namasu. *Gracilaria* spp. can also be used as fertilizer, and for fish, shrimp and mollusc food (Briggs and Funge-Smith, 1996).

The most commonly eaten seaweed is *G. parvispora*, known in Hawaii by its Japanese name ‘ogo’. To distinguish *G. parvispora* from other introduced ‘ogo’ species, it is called ‘long ogo’ and it is the most sought after, and formerly the most important edible seaweed on Hawaii’s reefs (Abbott, 1978). *G. tikvahiae*, also known as ‘ogo’, was introduced from Florida due to its greater cold tolerance compared to *G. parvispora*. *G. tikvahiae* has replaced *G. parvispora* in some markets, although it lacks the characteristic dark red color and crunchy texture found in *G. parvispora*. The introduced *G. salicornia* forms a mat and is

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hardier than the other species and is also found in local markets and called 'Robusta'.

However, the postharvest life of all species is about 4 d after arrival in Honolulu wholesalers which is normally the day after harvest. The first symptoms of quality loss are wilting and the thalli turning pink, the development of an off-odor and a slimy appearance. This short period severely limits marketing and the possibility of shipping to mainland U.S. market serving Asian, Hawaiian, and Pacific Islanders. *Gracilaria* research has focused on taxonomic studies, selection of species for agar yield and quality, cultural management, production systems, and plant nutrition (Alfsen, 1996; Dawes, 1995; Destomb et al., 1996; Friedlander et al., 1993; Glenn et al., 1998; Santelices and Doty, 1989). The objectives of this research were to determine: (i) the changes that occur postharvest that might affect postharvest life, (ii) the optimum storage temperature and maximum storage duration, (iii) whether various postharvest dips in nutrient solutions, postharvest heat treatments and modified atmosphere packaging can assist in quality maintenance and extend postharvest life, and, (iv) whether postharvest treatments can minimize epiphytic microbial growth.

1. Materials and methods

1.1. Plant material

Seaweed (*G. salicornia*), tentatively identified by Dr. Isabella Abbot, was purchased from a local tank-cultured aquaculture farm and picked up at a local wholesaler in the morning after the day of harvest. *G. salicornia* was used for all experiments except for the heat treatments when it was compared with *G. tikvahiae* and *G. parvispora*. *G. parvispora* were obtained from local wholesalers on the day after harvest and was from a pond-production farm on Molokai. The seaweed was separated, divided into 250 g batches, placed in polyethylene bags (0.0125 mm) and loosely closed before treatment on the same day.

1.2. Quality evaluation

Overall condition was estimated based on a scale from 5 to 1 with 5 fresh condition, 4 slight loss of appearance to 1 severe loss of appearance. The discoloration was ranked on a scale from 0 to 6 with: (0) no color change; (1) <10% color change; (2) 10–30%; (3) 30–60%; (4) 60–90%; (5) 90–99%; and, (6) 100% color change. Color was measured with a Minolta Chromameter CR-400 (Konica-Minolta Instruments, Ramsey, NJ) and expressed as CIE *b* value (yellow/blue), as the decline in the main accessory pigment in red algae, phycobilins, closely paralleled the rise in CIE *b* value. Ten grams were dried at 80 °C for 2 d then weighed and expressed as a percentage of the original weight. Individual thalli from each sample group were trimmed to 3 cm and subject to texture analysis (Texture Analyzer TA-XT2, Surrey, England). The instrument was fitted with a knife blade, a head speed of 3 mm s^{-1} was used and the maximum force recorded.

1.3. Respiration and ethylene production

For ethylene production and respiration rate, 500 g of seaweed was weighed and individual lots placed in a plastic chamber (*ca.* 2 L) and sealed with a plastic lid. After 1 h, triplicate samples of 1 mL of head-space gas were removed and injected into a nitrogen gas flow (0.5 mL s^{-1}) leading to a carbon dioxide analyzer (Model LI-6251, Infrared Gas Analyzer, LI-COR Inc., Lincoln, NE) to determine CO_2 production (Clegg et al., 1978). An additional triplicate samples (1 mL) of head-space gas were withdrawn and injected into a gas chromatograph (Shimadzu Model GC-8A, Shimadzu Corp., Kyoto, Japan) for the determination of ethylene production. Samples were separated using an alumina column (1.5 m × 3 mm, 60 mesh) and ethylene was determined with a photoionization detector. Injector port, column and detector port were 100, 70 and 120 °C, respectively, and the helium carrier flow rate was 30 mL min^{-1}. After the head-space gas samples were taken, the chambers were aerated, then kept at room temperature (22 ± 2 °C; 50–60% RH) until the next measurement.

1.4. Phycobilin

Seaweed (10 g) was ground with 50 mL of 100 mmol L^{-1} phosphate buffer (pH 7) in a blender for 1 min at medium speed. The homogenate was centrifuged at 14,450 × *g* for 15 min and pellet discarded. The absorption of aqueous extract was measured at 564 and 497 nm (Kursaar et al., 1983). An aliquot of supernatant was used to measure the protein concentration (Lowry et al., 1951).

1.5. Electrolyte leakage

Ten grams of seaweed were washed three times with distilled water and placed in 50 mL 0.6 mol L^{-1} mannitol solution with constant shaking. The conductivity was measured (Model CDM-83 meter, Radiometer, Copenhagen, Denmark) after 1 h. The tissue was then boiled for 1 h in a water bath to release all electrolytes and total conductivity measured. The electrolyte leakage was represented as the percentage of total conductivity.

1.6. Calcium/nitrogen application

Equal amounts of seaweed (250 g) were dipped for either 2 or 60 min in artificial seawater (Coralife Scientific Grade Marine Salt, Energy Savers Unlimited, Inc., Carson, CA) supplemented with calcium (10 and 100 mmol L^{-1}) or ammonium (1 and 10 mmol L^{-1}) as the nitrate salt. Treated seaweed was allowed to drain and then placed in a loosely closed polyethylene bag (0.0125 mm) before storage at 12.5–20 °C. Calcium was analyzed after digestion with HCl by inductively coupled plasma spectrophotometry, while nitrogen was determined by thermal analysis and nitrate by colorimetry.