Effects of Temperature and pH on the Growth of *Sargassum linearifolium* and *S. podacanthum* in Potassium-Fortified Inland Saline Water

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Abstract: This study tested the effects of temperature and pH on water quality and the growth of *Sargassum linearifolium* and *S. podacanthum* in potassium-fortified Inland Saline Water (ISW) of Western Australia (WA), at two levels of pH (low pH range of 5.5-6.5 and ambient pH 7.0-8.2) and two levels of temperature (high temperature 26-27°C and ambient room temperature of 20-22°C) in triplicate for 42 days. The pH of ISW in WA varies from 3.9 to 9.1, whereas the temperature is from 6.1-28.1°C. The results showed that the high temperature initiated the mortalities of the both *Sargassum* species from the first 14 days of culture period. The high temperature also resulted in a reduction of dried weight and ash content of these two species of *Sargassum* by the end of the trial. *S. linearifolium* temperature tolerant threshold was larger than *S. podacanthum*. Since the day 14, the *S. linearifolium* biomass and specific growth rate were higher than *S. podacanthum* at both temperature levels under ambient pH. Higher crude protein in *S. linearifolium* than *S. podacanthum* was also recorded at high temperature. Ambient pH and ambient temperature resulted in higher biomass and higher specific growth rate than low pH and high temperature in both species, which is recommended for *Sargassum* spp. growth.

Keywords: pH, Temperature, *Sargassum linearifolium*, *Sargassum podacanthum*, Biomass

Introduction

Australia has a significant Inland Saline Water (ISW) resource (Nulsen, 1997; Allan et al., 2001; Timms, 2005). The wheat-belt area in Western Australia (WA), covering approximately 18 million hectares is the largest underground source of ISW in Australia (Doupé et al., 2003; Lymbery et al., 2006) that could provide a source of water for inland marine aquaculture (Partridge, 2008). Targeting to the farm sustainability and environmental protection, the land management of nearly 30,000 farms in Australia has changed to prevent the expansion of salinization, 470,000 hectares of land were fenced and 210,000 km of levees, banks, drains for salinity management has been built (ABS, 2002), providing an available water source for ISW aquaculture. Building onshore farm to culture seaweeds is cheaper than seaweed farms in the open sea (Borowitzka, 1997), as well as contributing to environmental protection by reducing the salinity contamination (Ogburn, 1997), considering the availability of inland water resources and farm infrastructure.

*Sargassum* has been cultivated in many countries, such as Korea, Japan and India, for human consumption (Bast, 2014) includes *S. naozhouense* and *S. fusiforme* (Wang et al., 2010a; Bast, 2014). The *Sargassum* have been used commonly in Asia as a source of alginate and medicine for human (Yende et al., 2014; Wiltshire et al., 2015). For instance, *S. naozhouense* has been used as a source of food and drugs for traditional orientation treatments (Hur et al., 2008; Wang et al., 2010b). *Sargassum* also provides a source of sargaquinic acid, sargachromenol for neurite growth and survival (Hur et al., 2008). The *Sargassum* can also be used for agriculture as biochemical compounds, cattle food, fertilizer (Ara et al., 1997; Huisman, 2000).

Both *S. linearifolium* and *S. podacanthum* can be found in Western Australia including around Perth beaches (Womersley, 1987). In South Australia, only rope-culture trial of *S. linearifolium* in the ocean has been practiced with low specific growth rate (Wiltshire et al., 2015), specially under summer conditions, when the temperature is from 28-32°C.
investigating what temperature and pH are conducive to grow these two fortified ISW (K⁺ ideal species for culture as plenty of available ISW during the winter months, meet the growing-seasonal requirements under 28°C of the S. linearifolium (Martin-Smith, 1993).

At the same salinity, the ISW ionic profile in Australia can be similar to the Ocean Water (OW) (Fielder et al., 2001; Prangnell and Fotedar, 2006a), but the potassium concentration ([K⁺]) is much lower (Ingram et al., 2002; Boyd et al., 2007) and varies (Nurmi et al., 1988; Nulsen, 1997). It is not feasible for marine shrimp, fish and molluscs to survive and grow without K⁺ fortification, similar to K⁺ levels to OW (Fielder and Allan, 2003; Doroudi et al., 2006; Prangnell and Fotedar, 2006b; Dinh, 2016). The S. linearifolium also needs K⁺-fortified at similar K⁺ concentration in OW to sustain its growth in ISW (Bui et al., 2017b). In southwest WA, while the pH of OW is stable from 7.8–8.2, salinity from 35.5–36.5 (Hoang et al., 2016) and temperature of 22.0–32.0°C (Martin-Smith, 1993), the pH, salinity and temperature of ISW in the wheat belt of WA are generally varied by the depth and location of the groundwater (Nurmi et al., 1988; Nulsen, 1997; Taukulis and John, 2009). The pH varies from 3.9 to 9.7 in the wheat belt of WA (Nulsen, 1997; Taukulis and John, 2006), or 7.4 at 35 ppt in Broome (Lee, 1997; Taukulis and John, 2006). The pH of ISW is lower and unstable than OW (Lee, 1997). The salinity of inland water in WA varies from 0 to 320 ppt and two-thirds of those areas has salinity 5–40 ppt (Mazor and George, 1992), which is suitable for the growth of seaweed, including Sargassum (Hwang et al., 2006; Jie et al., 2008). The temperature of ISW in WA is from 6.3–28.1°C with an average of 17.7°C (Taukulis and John, 2009). The pH and temperature are the two important environmental factors that strongly influence the growth and heavy metal biosorption of Sargassum spp. (Davis et al., 2000). In OW, the chlorophyll fluorescence of S. fusiforme and S. fulvum varies little over the pH of 4–10 (Hwang et al., 2015) and the suitable pH for S. honeri zygote germination is 5–10 (Ogawa, 1984). Similarly, the temperature is a vital factor affecting Sargassum growth (Uchida, 1993). The optimal growth temperature for S. muticum is at 25°C (Hales and Fletcher, 1989), while S. patents prefers 20–30°C (Endo et al., 2013).

ISW in WA is characterized by high changes in pH and temperature by location and seasons. In a contribution to the use of ISW for aquaculture to reduce the adverse impact of salinization (Kolkovski, 2010), an attempt to grow the Sargassum in K⁺-fortified ISW (K⁺ISW) has been investigated by investigating what temperature and pH are conducive to grow these two Sargassum species in ISW. Therefore, this study aims to evaluate the effects of temperature and pH on the growth of S. linearifolium and S. podacanthum and water quality in K⁺ISW.

Materials and Methods

Preparation of Sargassum Species

Sargassum linearifolium and S. podacanthum were hand-picked from Point Peron, WA (latitude 32° 16.3’S, longitude 115° 41.2’E) and then transported for two hours in containers filled with OW to Curtin Aquatic Research Laboratory (CARL). At CARL, the species were rinsed with OW to remove all surface fouling, sediments and epiphytic algae. Next, the Sargassum were acclimated for three days in aerated OW under indoor laboratory conditions (ambient room temperature, the light provided by plant white fluorescent lights of 90 µmol photon m⁻² s⁻¹ on a 14:10 h light:dark cycle, one third of OW was exchanged everyday) and then treated according to the procedures of Schaffelke and Klumpp (1998) to clean the thalli followed by (1) discarding all visible macro-epiphytes, (2) wiping with soft tissue, (3) washing in filtered OW and then quickly washed in fresh water, (4) and putting into filtered OW for one day to recover.

The whole Sargassum thallus including holdfasts was chosen at the pre-selected weight of about 145 g fond⁻¹, dried by paper towel, weighed (Model GX-4000, A&D Company Limited, Tokyo, Japan) and then placed into tanks to get stocking densities of and then placed into tanks to get stocking densities of 0.8 kg m⁻². The Sargassum thalli with similar height and weight were selected and their holdfasts were attached to gravel particles to keep them submerged in water.

Preparation of Inland Saline Water

The ISW at a salinity of 45 ppt was procured from a lake in Wannamal, WA (31°15S, 116°05E) and transported to CARL. The ISW was stored and aged in a reservoir of 10,000L for the duration of the experiment. The ISW was filtered through a 0.5 µm glass fibre membrane, then diluted with filtered fresh water to get the 35 ppt water used in this experiment. The [K⁺] in ISW was fortified to a level of 100% of the [K⁺] in OW by adding potash of sulphate K₂SO₄ receive cultured media K⁺ISW. As the [K⁺] in OW and ISW at 35 ppt is 351.1 and 84.4 mg L⁻¹ respectively; therefore, 642 mg L⁻¹ K₂SO₄ was added into ISW to achieve the desired [K⁺] of ISW. The HNO₃ was then added to water to reduce the pH to 5.5–6.5 and maintained at this pH level during the whole trial by adding HNO₃ daily at noon. During the experiment, the salinity of K⁺ISW was maintained within a range of 34–35 ppt in all the experimental tanks by adding fresh water to compensate for any increases in salinity due to evaporation.
**Table 1:** Eight treatments of the experiment testing the effect of two pH and two temperature levels on the growth of *Sargassum linearifolium* and *S. podacanthum* in K'-fortified inland saline water

| Treatment | Species           | pH (*) | Temperature (**) |
|-----------|-------------------|--------|-----------------|
| T1        | *S. linearifolium*| 7.94±0.01 | 21.67±0.08 |
| T2        | *S. linearifolium*| 6.12±0.06 | 21.54±0.08 |
| T3        | *S. linearifolium*| 7.93±0.00 | 26.67±0.09 |
| T4        | *S. linearifolium*| 6.30±0.03 | 26.73±0.06 |
| T1        | *S. podacanthum*   | 7.91±0.02 | 21.73±0.08 |
| T2        | *S. podacanthum*   | 6.04±0.08 | 21.68±0.12 |
| T3        | *S. podacanthum*   | 7.91±0.04 | 26.71±0.11 |
| T4        | *S. podacanthum*   | 6.02±0.20 | 26.73±0.04 |

(*)& – No significant difference of the pH at the same levels (Ambient pH: T1 and T3; Lower pH: T2 and T4) (t-test, p>0.05, N = 3);

(**) – No significant difference of the temperature at the same levels (Ambient temperature: T1 and T2; higher temperature: T3 and T4) (t-test, p>0.05, N = 3)

**Experimental Setup**

The experiment was conducted for 42 days using a total of 24 glass tanks of 54 L (60×30×30 cm), each holding 45 L of K’-fortified inland saline water. The treatments included two levels of pH (ambient of about 8 and lower at 5.5–6.5, of which the lower level is the natural acidity of ISW in many places) (Partridge et al., 2008), two water temperatures (ambient room temperature 21–22°C and higher at 26–27°C, which is the upper temperature level of ISW in WA (Taukulis and John, 2006) and two species of *Sargassum* (*S. linearifolium* and *S. podacanthum*) (Table 1). These eight treatments were randomly triplicated. The tanks were aerated by two air stones in two sides of each tank and exposed to a plant white fluorescent lights of 90 µmol photon m⁻² s⁻¹ on a 14:10 h light:dark cycle (Hanisak and Samuel, 1987). One submersible automatic heater (Sonpar. Model: HA-200, Zhongshan, Guangdong, China) was used for a tank to maintain a higher temperature of 26–27°C.

**Data Collection**

Nitrogen (NO₃⁻-N, NO₂⁻-N, NH₄-N) and phosphorus (PO₄³⁻-P) were measured every 14 days, using a Hach DR890 hand-held meter (Hach, Loveland, Colorado, USA). The Cadmium Reduction Method (Method 8171 and Method 8039) was used to measure NO₃⁻-N at low (0–5 mg L⁻¹) and higher concentrations. The Diazotization Method (Method 8507) was used to measure NO₂⁻-N at a lower range (0–0.350 mg L⁻¹) and the Ferrous Sulfate Method (method 8153) was used to measure NO₂⁻-N at a higher range (0–150 mg L⁻¹). The Salicylate Method (Method 8155; Method 10023) was used for NH₄-N at 0–0.05 mg L⁻¹ and higher concentrations and PO₄³⁻-P was measured by the Amino Acid Method (Method 8178). Method 937.48 from the Official Method of the AOAC (Helrich, 1990) to analyze N was applied to measure Total Kjeldahl Nitrogen (TKN) using a Kjeltac Auto 1030 analyzer (Foss Tecator, Hoganas, Sweden) every 14 days.

Salinity and Dissolved Oxygen (DO) were recorded daily from 9:00–11:00 using a portable refractometer (RHS-10ATC, Xiamen Ming Xin Instrument, Xiamen, Fujian, China) and a DO meter (YSI model 58, Yellow Springs Instrument Co., Ohio, USA) respectively. The temperature was recorded hourly by data loggers (HOBO Pendant temperature/light Data Logger UA-002-08, UA-002-64). The pH was recorded daily at 9:00–11:00 and 13:00–15:00 using a pH meter (CyberScan pH 300, Eutech Instrument, Singapore). Once a fortnight, the pH and DO variations in a day was collected hourly.

The ionic profile of cultured medium was analyzed using Inductively Coupled Plasma (ICP) spectroscopy at CSBP Soil and Plant Laboratory, Bibra Lake, WA.

The fresh biomass of *Sargassum* was measured every 14 days to calculate Specific Growth Rate (SGR) by collecting the whole thalli in each tank by a small net and then dried by paper towels. The thalli were weighed using a scale (AW220, d = 0.1 mg, Shimazu, Japan) and returned to their respective tanks.

The SGR of *Sargassum* was calculated as: \( \mu_w = \frac{\ln A_t - \ln A_0}{100/t} \). Where: \( \mu_w \) was the SGR (% d⁻¹); \( A_0 \) and \( A_t \) were the initial and final dried weights (mg) of the *Sargassum* in a fortnight; \( t = 14 \) (days).

Samples of approximately 10% of the fresh *Sargassum* were weighed and dried at 60°C for 72 h to get stable dried weights. They were then ground with a mortar and pestle to a fine powder and stored in a freezer at -18°C until the proximate composition was analyzed. The dried content of *Sargassum* was calculated by the ratio of the dried weight to fresh biomass. The ash content was determined by burning dried *Sargassum* at 550°C for 30 min.

Tissue N was determined every 14 days according to the Official Method of the AOAC (Helrich, 1990) (method 937.48) by analyzing N using a Kjeltac Auto 1030 analyzer (Foss Tecator, Hoganas, Sweden). The percentage of protein over the dried weight was calculated by multiplying the percent of N with a factor of 6.25.

At the commencement and day 28 of the experiment, the ionic composition of the *Sargassum* was analyzed using the prepared freeze fine powder by ICP spectroscopy at CSBP Soil and Plant Laboratory, Bibra.
Lake, WA. The total N and total C of Sargassum were also analyzed at the CSBP Soil and Plant Laboratory, Bibra Lake, WA.

Data Analysis

The SPSS for Windows version 24.0 was used to analyze data. Before applying parametric and non-parametric tests, the data were tested for normality and homoscedasticity. Multivariate Analysis of Variance (MANOVA), pair samples t-test and Least Significant Difference post hoc tests were used to determine the significant differences at p<0.05 among the means of tested variables. Regression correlations were used to find out the significant relationships among variables. The one-way Analysis of Covariance (ANCOVA) was used to determine the significance difference between the treatments of the water quality parameters on the SGR of the seaweeds.

Percentage data were arcsine-transformed and the homogeneity of variances confirmed with Cochran's test. Where the numeral data did not have a normal distribution and homogeneous variance, the Kruskal–Wallis (KW test) was used to verify the overall difference of all treatments and data were transformed by log (x+10) before conducting MANOVA test.

Results

Biomass of the Sargassum Species

At the commencement of the experiment, the fresh biomass (approximately 145 g tank⁻¹) of the Sargassum was similar among the eight treatments. The pH and temperature significantly (p<0.05) affected Sargassum biomass in the first 28 days and the pH and Sargassum species significantly (p<0.05) interacted at day 28 of the trial. At the ambient temperature, the lower pH resulted in significantly (p<0.05) higher standing biomass of both species than the ambient pH of 7–8. The fresh standing biomass of both species at ambient temperature was significantly greater than at higher temperature over the experiment period. The SGR of the two species were similar in other treatments as the experiment progressed (Table 2).

The SGR of the S. linearifolium was significantly (p<0.05) higher than the S. podacanthum in the first 14 days; however, due to the mortality at high temperature, the comparison between the two species could not be drawn. Only at the ambient temperature and ambient pH conditions, where the Sargassum spp. grew continuously, the S. linearifolium presented significantly (p<0.05) higher SGR than S. podacanthum over the experiment period. The SGRs of the two species were similar in other treatments as the experiment progressed (Table 2).

The effects of treatments on SGR of the Sargassum were only recorded at the first 14 days. By that time, the SGR of S. linearifolium was positive under the ambient temperature, which was significantly (p<0.05) higher than under higher temperature. At ambient temperature, SGR of S. podacanthum in lower pH was significantly higher than in ambient pH.

Compositions of the Sargassum

The dried weight of Sargassum was about 13% of the total fresh biomass at the commencement of the experiment and was similar in both species. The dried weight of S. linearifolium was significantly (p<0.05) reduced at both higher temperature and lower pH. The dried weight of S. podacanthum remained unchanged in all treatments (Table 2).

The ash content of the S. linearifolium (37.06±0.49%) was significantly (p<0.05) lower than S. podacanthum (44.14±0.67%) at the commencement of the trial, but became similar during the rest of the experiment, except at ambient temperature and low pH in the second fortnight (Table 2). A significant (p<0.05) reduction in ash content over time occurred in all treatments, but to the greatest extent in lower pH and higher temperature. The energy of the Sargassum was approximately 10,356±29.25 J g⁻¹ and remained unchanged over the experiment period.

The protein contents of S. podacanthum in lower pH (37.06±0.49%) was significantly (p<0.05) higher than S. podacanthum (44.14±0.67%) at the commencement of the trial, but became similar during the rest of the experiment, except at ambient temperature and low pH in the second fortnight (Table 2). A significant (p<0.05) reduction in ash content over time occurred in all treatments, but to the greatest extent in lower pH and higher temperature. The energy of the Sargassum was approximately 10,356±29.25 J g⁻¹ and remained unchanged over the experiment period.
The chemical composition of the Sargassum is presented in Table 3, of which, after one month of cultivation, the N content increased, the P reduced and C either remained unchanged or increased. Overall, the C:N:P ratios were higher than at the commencement of the trial. The Cu contents in both Sargassum spp. reduced significantly after a month in cultivation, however the Zn was accumulated from the water which resulted in higher Zn concentration in seaweed at day 28 compared to the commencement of the trial.

**Water Quality Parameters**

The water quality parameters, including NO$_3$-N, NO$_2$-N, NH$_4$-N, TKN and PO$_4$-P showed no correlation with SGR of the Sargassum. The [NO$_3$-N] at the lower pH was about 10–20 times higher than the ambient pH. The [NO$_3$-N] increased significantly (p<0.05; n=3) as the experiment progressed and the higher ambient pH. The NO$_2$-N, NH$_4$-N, TKN and PO$_4$-P showed no correlation with SGR of the Sargassum (Table 4).

The NH$_4$-N was negligible in the first month and close to 0.1 mg L$^{-1}$ at the completion of the trial. The SGR, dried weight, ash and protein content of the Sargassum spp. cultured in K$^+$-fortified inland saline water at two levels of pH and two levels of temperature by day 1 and day 28 of the experiment (Table 2).

### Table 2: SGR, dried weight, ash and protein content of the Sargassum spp. cultured in K$^+$-fortified inland saline water at two levels of pH and two levels of temperature

| Criteria | 21-22°C | 26-27°C | 21-22°C | 26-27°C |
|----------|---------|---------|---------|---------|
| S. linearifolium | pH 8 | pH 5.5–6.5 | pH 8 | pH 5.5–6.5 |
| Day 1-14 | 1.60±0.08 | 1.56±1.09 | 1.26±0.51 | 1.02±0.23 |
| Day 14-28 | 1.09±0.59 | 2.0±9.08 | 4.94±0.38 | 4.08±0.37 |
| Day 28-42 | 0.22±0.23 | 5.27±3.44 | - | - |
| Dried weight (%) | | | | |
| Day 1 | 13.31±0.80 | 13.31±0.80 | 13.31±0.80 | 13.31±0.80 |
| Day 28 | 13.31±0.49 | 13.31±0.49 | 13.31±0.49 | 13.31±0.49 |
| Day 1 | 13.31±0.80 | 13.31±0.80 | 13.31±0.80 | 13.31±0.80 |
| Day 28 | 13.31±0.49 | 13.31±0.49 | 13.31±0.49 | 13.31±0.49 |
| Day 28 | 13.31±0.49 | 13.31±0.49 | 13.31±0.49 | 13.31±0.49 |
| Protein (%) | | | | |
| Day 1 | 0.13±0.01 | 0.13±0.01 | 0.13±0.01 | 0.13±0.01 |
| Day 28 | 0.13±0.01 | 0.13±0.01 | 0.13±0.01 | 0.13±0.01 |
| Day 28 | 0.13±0.01 | 0.13±0.01 | 0.13±0.01 | 0.13±0.01 |
| Day 28 | 0.13±0.01 | 0.13±0.01 | 0.13±0.01 | 0.13±0.01 |

### Table 3: The chemical compositions of the Sargassum spp. cultured in K$^+$-fortified inland saline water at two levels of pH and two levels of temperature by day 1 and day 28 of the experiment

| Parameters | Unit | Day 1 | 21-22°C | pH 5.5–6.5 | pH 8 | 26-27°C | pH 5.5–6.5 | Day 28 | 21-22°C | pH 5.5–6.5 | 26-27°C | pH 5.5–6.5 |
|------------|------|-------|---------|------------|-----|---------|------------|-------|---------|------------|---------|------------|---------|------------|
| B          | mg/kg | 172.14 | 233.92  | 134.22     | 176.98 | 280.00  | 115.29     | 207.50 | 89.90  | 141.67     |         |           |          |
| Ca         | %     | 1.80  | 1.93    | 1.81   | 2.39 | 2.50 | 1.62 | 2.68 | 1.89 | 2.23 |         |          |
| C          | %     | 28.60 | 28.60 | 29.50 | 30.10 | 33.40 | 26.60 | 29.90 | 28.60 | 27.50 |         |          |
| Cu         | mg/kg | 135.00 | 13.96 | 19.32 | 13.72 | 38.31 | 50.55 | 20.86 | 21.88 | 17.59 |         |          |
| Fe         | mg/kg | 80.00 | 211.18 | 460.59 | 153.65 | 717.50 | 80.31 | 178.75 | 635.29 | 494.89 |         |          |
| Mg         | %     | 1.30 | 1.31 | 1.53 | 1.20 | 1.54 | 0.68 | 1.34 | 1.22 | 1.50 |         |          |
| Mn         | mg/kg | 11.54 | 20.68 | 9.09 | 28.03 | 6.29 | 7.95 | 15.24 | 10.55 | 6.26 |         |          |
| P          | %     | 0.18 | 0.14 | 0.11 | 0.13 | 0.15 | 0.14 | 0.15 | 0.11 | 0.08 |         |          |
| K          | %     | 9.05 | 7.38 | 3.93 | 5.08 | 1.07 | 12.17 | 6.47 | 8.05 | 2.31 |         |          |
| Na         | %     | 1.84 | 2.45 | 7.15 | 2.51 | 3.44 | 2.39 | 2.85 | 3.70 | 6.69 |         |          |
| S          | %     | 1.67 | 1.66 | 1.77 | 1.35 | 1.87 | 1.12 | 1.49 | 1.61 | 1.40 |         |          |
| Total N    | %     | 1.43 | 1.48 | 1.67 | 1.73 | 1.86 | 1.31 | 1.77 | 1.59 | 1.25 |         |          |
| Zn         | mg/kg | 65.00 | 468.90 | 392.21 | 444.83 | 510.00 | 29.08 | 755.13 | 497.72 | 370.88 |         |          |
| C:N:P      |      | 159.81 | 204.11 | 268.15 | 232.13 | 334.19 | 190.91 | 199.12 | 260.14 | 344.16 |         |          |

Note: The total mortality of S. podacanthum in cultured in K$^+$-fortified inland saline water at 26-27°C, water pH of 8 at day 28 providing no samples for analysis.
TKN significantly (p<0.05) decreased at the lower pH. The PO₄³⁻-P remained unchanged as the time progressed and presented no significant differences in various pH and temperatures; the exception being that in S. linearifolium where it was higher in low pH than ambient pH at the same temperature.

The lower pH significantly (p<0.05) resulted in higher NO₃⁻-N, NO₂⁻-N, TKN and -P concentrations in water than ambient pH due to the HNO₃ provided. However, no water quality parameter shown a significant effects on the SGR of the seaweeds (Table 5). The one-way ANCOVA results reprov the no significant (p>0.05) effect of NO₃⁻-N or NO₂⁻-N on the SGR of the seaweeds between two pH groups, neither nor among eight treatments (Table 6). The temperature presented no effect on these water quality parameters.

Table 4: Quality parameters (mg L⁻¹) of the K⁺-fortified inland saline water cultured Sargassum spp. at two levels of pH and two levels of temperature as the experiment progressed

| Parameters | S. linearifolium | S. podacanthum |
|------------|-------------------|----------------|
| pH 8       | pH 5.5–6.5        | pH 8           | pH 5.5–6.5        |
| NO₃⁻-N     |                   |                |
| Day 1      | 0.020±0.002       | 0.150±0.021a   | 0.150±0.021a      | 0.150±0.021a   |
| Day 14     | 0.005±0.002bc     | 0.018±0.005abc | 0.026±0.007abc   | 0.055±0.015abc |
| Day 28     | 0.002±0.000c      | 0.317±0.036a   | 0.102±0.033bc    | 0.166±0.073b   |
| Day 42     | 0.013±0.003b      | 5.333±0.667a   | 0.008±0.002b     | 0.333±0.667a   |

| NO₂⁻-N     |                   |                |
| Day 1      | 2.53±0.12a        | 27.67±0.44a    | 2.53±0.12a       | 27.67±0.44a    |
| Day 14     | 1.03±0.24a        | 27.87±0.37a    | 1.07±0.09b       | 33.13±0.95a    |
| Day 28     | 0.27±0.18b        | 28.53±2.47b    | 2.40±0.15b       | 25.71±1.13b    |
| Day 42     | 2.30±0.25b        | 25.40±0.42b    | 2.53±0.18b       | 22.71±1.22b    |

| NH₄⁺       |                   |                |
| Day 1      | 0.01±0.00         | 0.00±0.00      | 0.01±0.00        | 0.00±0.00      |
| Day 14     | 0.00±0.00         | 0.00±0.00      | 0.00±0.00        | 0.00±0.00      |
| Day 28     | 0.04±0.03         | 0.00±0.00      | 0.02±0.02        | 0.01±0.01      |
| Day 42     | 0.02±0.01         | 0.00±0.00b     | 0.02±0.00b       | 0.01±0.00      |

| TKN        |                   |                |
| Day 1      | 1.44±0.16b        | 10.48±0.06b    | 1.44±0.16b       | 10.48±0.06b    |
| Day 14     | 1.40±0.41b        | 9.85±0.12b     | 1.42±0.21b       | 8.68±1.28b     |
| Day 28     | 1.61±0.35b        | 22.17±1.11b    | 1.77±0.20b       | 3.67±1.22b     |
| Day 42     | 1.77±0.19         | 22.19±0.06b    | 1.91±0.05        | 1.77±0.25      |

| PO₄³⁻-P    |                   |                |
| Day 1      | 10.93±0.09        | 1.13±0.03      | 0.93±0.09        | 1.13±0.03      |
| Day 14     | 0.30±0.06b        | 0.67±0.12c     | 0.60±0.26bc      | 3.17±2.45b     |
| Day 28     | 1.00±0.06ab       | 2.50±0.52ab    | 0.93±0.02bc      | 1.60±0.29b     |
| Day 42     | 0.93±0.19         | 1.73±0.03      | 0.83±0.07        | 1.00±0.06      |

Values (mean ± SE) within a species sharing a common superscript are not significantly different (LSD test; p>0.05). Values (mean ± SE) within a column sharing a common subscript are not significantly different (LSD test or t-test; p>0.05; n = 3). (Data was transformed to log (x+1)) before conducting ANOVA test.

Table 5: Pearson correlation of SGR (% d⁻¹) of the Sargassum spp. cultured in K⁺-fortified inland saline water at two levels of pH and two levels of temperature and water quality parameters

| Criteria     | NO₃⁻-N | NO₂⁻-N | PO₄³⁻-P | NH₄⁺-N | TKN |
|--------------|--------|--------|---------|--------|-----|
| Pearson correlation | -0.120 | 0.145  | -0.027  | -0.032 | 0.235 |
| Significant (2-tailed) | 0.387  | 0.296  | 0.847   | 0.710  | 0.085 |
| N             | 54.000 | 54.000 | 54.000  | 53.000 | 55.000 |

Table 6: The effect of nitrogen on the SGR of the Sargassum spp. cultured in K⁺-fortified inland saline water between the two pH levels and among the eight treatments

| Group       | Source | Type III sum of squares | df | Mean square | F   | Significant | Partial eta squared |
|-------------|--------|-------------------------|----|-------------|-----|-------------|---------------------|
| Two pH levels | NO₃⁻-N | 0.00008                 | 1  | 0.00008     | 0.050| 0.825       | 0.001               |
|             | NO₂⁻-N | 0.00300                 | 1  | 0.00300     | 1.746| 0.192       | 0.033               |
| Eight treatments | NO₃⁻-N | 0.00100                 | 1  | 0.00100     | 0.293| 0.591       | 0.006               |
|             | NO₂⁻-N | 0.00500                 | 1  | 0.00500     | 3.676| 0.062       | 0.076               |

The ionic composition of water is provided in Table 7, of which, after a month of cultivating Sargassum, the sodium ions were different from the commencement, while the [K⁺] remained unchanged over the cultured period and the heavy metals remained less than 0.05 mg L⁻¹ except for Zn in water cultured S. linearifolium under low pH and low temperature and in water culture S. podacanthum under low pH and high temperature.

At high temperatures, the DO gradually increased from early afternoon to noon of the next day; whereas, at low temperature, the DO reduced by night and rose in the morning. During a day, the pH was normally increased in the morning, reached a peak at noon and decreased in the afternoon, lowest by 5.30 PM.
Table 7: Ionic profile (mg L\(^{-1}\)) of the K\(^{+}\)-fortified inland saline water cultured Sargassum spp. at two levels of pH and two levels of temperature by day 1 and day 28 of the experiment

| Parameters | S. linearifolium | S. podacanthum |
|------------|------------------|----------------|
|            | Day 28           |                |
|            | 21–22°C          | 26–27°C        |
| pH 8       | pH 5.5–6.5       | pH 8           |
| pH 8       | pH 5.5–6.5       | pH 8           |
| Mg         |                  |                |
| Ca         |                  |                |
| Cu         |                  |                |
| Fe         |                  |                |
| K          |                  |                |
| Na         |                  |                |
| S          |                  |                |
| Zn         |                  |                |

Discussion

Temperature and pH strongly influence the growth of Sargassum (Choi et al., 2007; Chen and Zou, 2014; Hwang et al., 2015). The Sargassum growth rate is strongly affected by the variation of temperature (Uchida, 1993; Endo et al., 2013) and the effect of temperature within the tested range was stronger than the pH, shown by the significant different SGR of Sargassum at different temperature levels. The temperature affects many aspects of the growth of seaweeds, such as the photosynthetic activity (Ding et al., 2013) and respiration rate (Davison et al., 1991), ammonium and nitrogen uptake rate (Duke et al., 1989; Hwang et al., 2004). The range of studied temperature was within a preferred range of 20–30°C for S. patens, resulting in higher SGR (Endo et al., 2013). In the open sea, the S. linearifolium maximum biomass increases in May, when temperature is about 22–24°C and reaches maximum wet weight and length in August to November when the temperature ranges from 24–28°C and ceases in summer when temperature reaches over 29°C (Martin-Smith, 1993). The temperature window in this experiment at 20–22°C, given the higher growth rate of Sargassum than the higher temperature of 26–27°C, is similar to the natural maximal growth rate condition. Both Sargassum species could not be sustained after a month at a high temperature of 26–27°C in KISW. Similarly, the growth of young seedlings S. henslowianum reduced when temperature increased to 30°C (Chen and Zou, 2014). The SGR of the Sargassum in this trial, were at adult stages, at 20–22°C is higher than the adult stage of S. muticum (Yamauchi, 1984) but is much lower than the juvenile S. horneri (Choi et al., 2007) and juvenile S. muticum (Hales and Fletcher, 1989) at 15°C, presented the lower SGR of adults thalli and juvenile, which is similar to S. horneri (Lee et al., 2009). This implies a limitation of this study to lower temperatures, where more than 60% of WA inland saline ground water has the temperature lower than 20°C ( Taukulis and John, 2009).

The lack of changes in the dried weight, ash and protein of the S. linearifolium as the trial progressed in the ambient temperature associating with the higher SGR than at higher temperature indicates the ambient room temperature 20–22°C was preferred for the growth of S. linearifolium than a higher temperature. The dried weight and crude protein of Sargassum in this trial is similar with Sargassum spp. from Casas-Valdez et al. (2006) (89 and 8%, respectively), but protein was lower than S. naozhouense (11.2%) (Peng et al., 2013). Although the pH and temperature did not affect the protein of the S. linearifolium, the effect on protein is similar to Porphyra (Kim et al., 2007), the S. podacanthum reduced protein shown a negatively affect by the high temperature and low pH. The protein level of the Sargassum increased significantly as the trial progressed. This indicates the protein of Sargassum under the laboratory conditions was better than in the wild, although no independent supplementary nutrients were provided.

Seaweed culture in ISW is expecting to be a potential means in the attempt to reduce the adverse effect of ISW in the agricultural farms (Borowitza, 1997). The K\(^{+}\) deficiency is in common in Australia and USA (Ingram et al., 2002; Boyd and Thunjai, 2003) although the ionic profile of ISW can be similar to OW at the same salinity (Fielder et al., 2001). Therefore, ISW should be fortified with K\(^{+}\) at similar or about 33–66% of the K\(^{+}\) concentration in OW at the same salinity for proper growth of S. linearifolium and Lomentaria sp., respectively (Bui et al., 2017a; 2017b). The K\(^{+}\) plays a major role in the growth of algae and cannot be substituted by any other ion (Yarish et al., 1980). The K\(^{+}\) is important in the photosynthesis of the marine diatom.
(Overnell, 1975) and higher plants through the mechanism of enzyme activation in protein synthesis (Checchetto et al., 2013). The low range of pH changes (within 0.5) do not affect the K⁺ movement within cells (Tromballa, 1978); however, the two different pH levels at 8.0 and 6.0 may cause the differential movement of K⁺, which in turn could affect the growth of Sargassum. As the K⁺ movement at pH 10.0 is slower than at pH 6.5 (Tromballa, 1978), it is expected that in this trial, at the pH 6.0, the K⁺ movement from the medium to the cell was faster than in the ambient pH of 8.0. This movement supports the photosynthesis of the Sargassum. In addition, the pH affects seaweed photosynthesis through the appearance of CO₂ or HCO₃⁻. At low pH where a higher concentration of CO₂ is available, the affinity for inorganic carbon is greater than at high pH (Aizawa and Miyachi, 1986; Drechsler and Beer, 1991), which is proved by Ulva rigida thalli photosynthesis rate (Björk et al., 1992). Thus, providing a higher biomass of Sargassum at low pH than the ambient pH in a short-term. Under the pH and temperature effect, the biomass of the Sagassum has varied significantly as time progressed.

The SGR of S. linearifolium in the ambient pH and ambient temperature of this study was much lower than S. linearifolium (Bui et al., 2017b), although the environmental conditions and growing season (during different years) were similar showing the different growth feasibility of whole thalli (this study) and small piece (Bui et al., 2017b).

This study reveals that the suitable pH for long-term growth of Sargassum in ISW was the ambient pH of 7.0–8.0. This pH range is similar to the red seaweed Gracilaria tikvahiae, G. secunda and G. manilaensis needs for high production and maximum growth rate (Skirrow, 1975; Lignell and Pedersen, 1989; Hidayat et al., 2015). Their maximal growth rate is 1.3% d⁻¹ (Hidayat et al., 2015), lower than S. linearifolium but higher than S. podacanthum at the ambient pH in this trial. The S. linearifolium biomass did not significantly respond to the pH variation in the first month, but S. podacanthum biomass reduction rate was significantly slower in low pH than in ambient pH. The S. linearifolium showed a higher SGR than S. podacanthum at both pH levels, suggesting S. linearifolium is a potential pH adaptation species in a culture where the pH variation is wide. The pH also affects the ionic absorption by seaweed (Basha and Murthy, 2007) which peaks at pH 4.5 (Figueira et al., 1997; Davis et al., 2000). The Sargassum accumulated Fe and Zn, particularly at low pH, but released the Cu to the environment when Cu in water is lower than 0.05 mg L⁻¹, which is a possible explanation for lower Cu concentration in the Sargassum tissues at the day 28 than the commencement. It is a role as a biosorbent of Sargassum in terms of environmental protection from the heavy metal pollution (Davis et al., 2003; Vijayaraghavan et al., 2009).

Hydrochloric acid (HCl) was used in the preliminary experiment, however, it proved to be strong and reduced the water pH quickly and could not stabilize the pH. On the other hand, acetic acid was too weak. Therefore, instead of HCl and acetic acid, HNO₃ was used to reduce pH which potentially could result in higher NO₃⁻N and NO₂⁻N concentrations than under the ambient pH treatments. However using statistical analysis, addition of HNO₃ had neither influenced SGR of Sargassum spp. nor it influenced the significant level pH and temperature on the SGR of Sargassum spp. Both the Pearson correlation and one-way ANCOVA presented no significant effect of NO₃⁻N or NO₂⁻N concentrations on the SGR of the Sargassum spp. Therefore using HNO₃ did not affect the outcomes of the experiment. The [NO₃⁻N] was sufficient for Sargassum under the both low and ambient pH treatments, as Sargassum consumes NO₃⁻N when NH₄⁻N is not available (Jie et al., 2008). As the N:P ratios under the low pH regime were much higher than the N:P ratios in the ambient pH, the nutrient consumption of the Sargassum was affected when the N:P ratio is high, resulting in higher biomass of the Sargassum in very short term.

The N:P ratio of the Sargassum in this study was much lower than the N:P of S. echinocarpum (Larned, 1998) and much lower than the C:N:P ratio for Australian Sargassum (Atkinson and Smith, 1983). The reason is the P content of Sargassum in this study was much higher whereas the C and N contents were similar. These can be explained by the N:P in this study was lower than 30:1, the Sargassum growth is N-limited (Harrison and Hurd, 2001) and the surplus P was stored in Sargassum tissue.

Conclusion

The Sargassum linearifolium and S. podacanthum grow faster in K’ISW 35 ppt at pH 7–8.2 and temperature 20–22°C than in lower pH and higher temperature, which are suitable for the growing season of Sargassum in the early summer and the availability of ISW after the rainy season. The low pH negatively affects the growth of Sargassum and significantly affects the water quality and the chemical composition of Sargassum. Only S. linearifolium can grow in either low pH (5.5–6.5) or at the temperature of 26–27°C in K’ISW up to 28 days. A further study about the higher than the ambient pH 8 and temperature of 15°C of K’ISW effects on the growth feasibility of Sargassum spp. is recommended.

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Author’s Contributions

Ha Thi Thu Bui: Correspondent author, as a part of the PhD thesis, who was responsible for setting up and running the experiment, collecting and analysing data, writing the manuscript.

Trong Quoc Luu: Helped with seaweeds collection, experimental setup and data collection.

Ravi Fotedar: Supervised the research, edit and approved the manuscript.

Ethics

This article is original material. The corresponding author confirms that all authors have read and approved the manuscript. No ethical issue that may arise after the publication of this manuscript.

References

ABS, 2002. 4615.0-Salinity on Australian farms. Canberra Time: Australia Bureau of Statistics.

Aizawa, K. and S. Miyachi, 1986. Carbonic anhydrase and CO₂ concentrating mechanisms in microalgae and cyanobacteria. FEMS Microb. Rev., 39: 19-19. DOI: 10.1016/0378-1097(86)90447-7

Allan, G.L., B. Banens and D.S. Fielder, 2001. Developing commercial inland saline aquaculture in Australia: Part 2. Resource inventory and assessment. FRDC Project No. 98/335, Canberra, Fisheries Research Development Corporation: Fisheries 389 Research Development Corporation.

Ara, J., S. Ehteshamul-Haque, V. Sultana, A. Ghaffar and R. Qasim, 1997. Use of Sargassum species for the control of Meloidogyne javanica in Okra. Nematologia Mediterranea, 25: 125-128.

Atkinson, M.J. and S.V. Smith, 1983. C:N:P ratios of benthic marine plants. Limnol. Oceanography, 28: 568-574. DOI: 10.2307/2835836

Basha, S. and Z.V.P. Murthy, 2007. Seaweeds for Engineering Metal Biosorption: A Review. In: Focus on Hazardous Materials Research, Mason, L. G. (Ed.), Nova Science Publishers, New York, ISBN-10: 1600214525.

Bast, F., 2014. An illustrated review on cultivation and life history of agronomically important seaplants. In: Seaweed: Mineral Composition, Nutritional and Antioxidant Benefits and Agricultural Uses, Pomin, V. H. (Ed.), Nova Publishers, New York, pp: 39-70.

Björk, M., K. Haglund, Z. Ramazanov, G. García-Reina and M. Pedersen, 1992. Inorganic-carbon assimilation in the green seaweed Ulva rigida C.Ag. (Chlorophyta). Planta, 406: 187-152. DOI: 10.1007/BF00201637

Borowitzka, M.A., 1997. Algae. In: Inland Saline Aquaculture, Smith, B. and C. Barlow (Eds.), The Australian Centre for International Agricultural Research, ACIAR proceedings No. 83, Western Australia, pp: 35-36.

Boyd, C. and T. Thunjai, 2003. Concentrations of major ions in waters of inland shrimp farms in China, Ecuador, Thailand and the United States. J. World Aquac. Society, 34: 524-533. DOI: 10.1111/j.1749-7345.2003.tb00992.x

Boyd, C.A., C.E. Boyd and D.B. Rouse, 2007. Potassium budget for inland, saline water shrimp ponds in Alabama. Aquacul. Eng., 36: 45-50. DOI: 10.1016/j.aquaeng.2006.06.002

Bui, H.T.T., T.Q. Luu and R. Fotedar, 2017a. The growth feasibility of Lomentaria sp. in laboratory conditions. Environ. Risk Assess. Remediat., 1: 47-55.

Bui, H.T.T., T.Q. Luu, R. Fotedar and U. Tantulo, 2017b. Productivity of Sargassum linearifolium in potassium fortified inland saline water under laboratory conditions. Aquac. Res., 48: 5631-5639. DOI: 10.1111/are.13385

Casas-Valdez, M., H. Hernández-Contreras, A. Marin-Alvarez, N.R. Aguilá-Ramírez and C.J. Hernández-Guerrero et al., 2006. The seaweed Sargassum (Sargassaceae) as tropical alternative for goats' feeding. Rev. Biol. Trop., 54: 83-92. PMID: 18457178

Checchetto, V., E. Teardo, L. Carraretto, E. Formentin and E. Bergantino et al., 2013. Regulation of photosynthesis by ion channels in cyanobacteria and higher plants. Biophys. Chem., 182: 51-57. DOI: 10.1016/j.bpc.2013.06.006

Chen, B. and D. Zou, 2014. Growth and photosynthetic activity of Sargassum henslowianum (Fucales, Phaeophyta) seedlings in responses to different light intensities, temperatures and CO₂ levels under laboratory conditions. Marine Biol. Res., 410: 1019-1026. DOI: 10.1080/17451000.2013.872798

Choi, H.G., K.H. Lee, H.I. Yoo, P.J. Kang and Y.S. Kim, 2009. Physiological differences in the growth of Sargassum horneri between the germling and adult stages. J. Applied Phycol., 20: 279-285. DOI: 10.1007/s10811-007-9281-5

Lee, K.H. H.I. Yoo, P.J. Kang and Y.S. Kim, 2007. Physiological differences in the growth of Sargassum horneri between the germling and adult stages. Proceedings of the 19th International Seaweed Symposium, Mar. 26-31, Springer, Dordrecht, Netherlands, Kobe, Japan.
Davison, I.R., B. Volesky and A. Mucci, 2003. A review of the biochemistry of heavy metal biosorption by brown algae. Water Res., 37: 4311-4330. DOI: 10.1016/S0043-1354(03)00293-8

Davis, T.A., B. Volesky and R.H.S.F. Vieira, 2000. Sargassum seaweed as biosorbent for heavy metals. Water Res., 34: 4270-4278. DOI: 10.1016/S0043-1354(00)00177-9

Davison, I.R., R.M. Greene and E.J. Podolak, 1991. Temperature acclimation of respiration and photosynthesis in the brown alga Laminaria saccharina. Marine Biol., 110: 449-454. DOI: 10.1007/BF01343636

Ding, L., Y. Ma, B. Huang and S. Chen, 2013. Effects of seawater salinity and temperature on growth and pigment contents in Hypnea cervicornis J. Agardh (Gigartinales, Rhodophyta). BioMed Res. Int., 2013: 1-10. DOI: 10.1155/2013/594308

Dinh, H.Q., 2016. Cultural biology of the blue mussel, Mytilus edulis (Linnaeus, 1758) in inland saline water in Western Australia. PhD thesis, Curtin University.

Doroudi, M.S., D.S. Fielder, G.L. Allan and G.K. Webster, 2006. Combined effects of salinity and potassium concentration on juvenile mulloway (Argyrosomus japonicus, Temminck and Schlegel) in inland saline groundwater. Aquac. Res., 37: 1034-1039. DOI: 10.1111/j.1365-2109.2006.01525.x

Doupé, R.G., A.J. Lymbery and M.R. Starcevich, 2003. Rethinking the land: The development of inland saline aquaculture in Western Australia. Int. J. Agric. Sustainability, 1: 30-37. DOI: 10.3763/ijas.2003.0104

Drechsler, Z. and S. Beer, 1991. Utilization of inorganic carbon by Ulva lactuca. Plant Physiol., 97: 1439-1444. PMID: 16668569

Duke, C.S., W. Litaker and J. Ramus, 1989. Effect of temperature, nitrogen supply and tissue nitrogen on ammonium uptake rates of the chlorophyte seaweeds Ulva curvata and Codium decorticatum J. Phycol., 25: 113-120.

Endo, H., K. Suehiro, J. Kinoshita, X. Gao and Y. Agatsuma, 2013. Combined effects of temperature and nutrient availability on growth and phlorotannin concentration of the brown alga Sargassum patens (Fucales; Phaeophyceae). Am. J. Plant Sci., 4: 14-20. DOI: 10.4236/ajpps.2013.42A2002

Fielder, D.S. and G.L. Allan, 2003. Improving fingerling production and evaluating inland saline water culture of snapper, Pagrus auratus. NSW Fisheries Final Report Series No. 43, CRC Project No. C4.2.

Fielder, D.S., W.J. Bardsley and G.L. Allan, 2001. Survival and growth of Australian snapper, Pagrus auratus, in saline groundwater from inland New South Wales, Australia. Aquaculture, 201: 73-90. DOI: 10.1016/s0044-8486(01)00555-5

Figueira, M.M., B. Volesky and V.S.T. Ciminelli, 1997. Assessment of interference in biosorption of a heavy metal. Biotechnol. Bioeng., 54: 344-350. DOI: 10.1002/(SICI)1097-0290(19970520)54:4<344::AID-BIT7>3.0.CO;2-K

Hales, J.M. and R.L. Fletcher, 1989. Studies on the recently introduced brown alga Sargassum muticum (Yendo) Fensholt. IV. The effect of temperature, irradiance and salinity on germling growth. Botarica Marina, 32: 167-176. DOI: 10.1515/botm.1989.32.2.167

Hanisak, M.D. and M. Samuel, 1987. Growth rates in culture of several species of Sargassum from Florida, USA. Proceedings of the 12th International Seaweed Symposium, (ISS’ 87), Springer Netherlands, pp: 399-404. DOI: 10.1007/978-94-009-4057-4_9

Harrison, P.J. and C.L. Hurd, 2001. Nutrient physiology of seaweeds: Application of concepts to aquaculture. Cah. Biol. Mar., 42: 71-78.

Helrich, K.C., 1990. Official methods of Analysis. 15th Edn., Association of Official Analytical Chemists Inc. Arlington, Virginia, USA, ISBN-10: 0095584420.

Hidayat, N.S.M., N. Mohammad-Noor, D. Susanti, S. Saad and Y. Mukai, 2015. The effects of different pH and salinities on growth rate and carrageenan yield of Gracilaria mangostana. J. Teknol., 77: 1-5.

Hoang, T.C., A.J. Cole, R. Fotedar, M.J. O’Leary and M.W. Lomas et al., 2016. Seasonal changes in water quality and Sargassum biomass in southwest Australia. Marine Ecol. Progress Series, 551: 63-79. DOI: 10.3354/meps11735

Huisman, J.M., 2000. Marine Plants of Australia. 1st Edn., University of Western Australia Press, Western Australia, ISBN-10: 1876268336, pp: 300.

Hurst, S., H. Lee, Y. Kim, B.H. Lee and J. Shin and T.Y. Kim, 2008. Sargaquinoic acid and sargachromenol, extracts of Sargassum sarganum, induce apoptosis in HaCaT cells and mice skin: Its potentiation of UVB-induced apoptosis. Eur. J. Pharmacol., 582: 1-11. DOI: 10.1016/j.ejphar.2007.12.025

Hwang, E.K., D.S. Ha, J.M. Baek, M.Y. Wee and C.S. Park, 2006. Effects of pH and salinity on the cultivated brown alga Sargassum fulvellum and associated animals. Algae, 21: 317-321. DOI: 10.4490/alga.2006.21.3.317

Hwang, E.K., H.C. Yoo, J.M. Baek and C.S. Park, 2015. Effect of pH and salinity on the removal of phytal animals during summer cultivation of Sargassum fusiforme and Sargassum fulvellum in Korea. J. Applied Phycol., 27: 1985-1989. DOI: 10.1007/s10811-014-0511-3

Hwang, R.L., C.C. Tsai and T.M. Lee, 2004. Assessment of temperature and nutrient limitation on seasonal dynamics among species of Sargassum from a coral reef in Southern Taiwan. J. Phyicol., 40: 463-473. DOI: 10.1111/j.1529-8817.2004.03086.x
Ingram, B.A., L.J. McKinnon and G.J. Gooley, 2002. Growth and survival of selected aquatic animals in two saline groundwater evaporation basins: An Australian case study. Aquaculture Res., 33: 425-436. DOI: 10.1046/j.1365-2109.2002.00691.x

Jie, B., T. Xiang-Li, D. Shuang-Lin and J. Hong-Bo, 2008. Effect of temperature, salinity and light intensity on nitrogen and phosphorus uptake by Sargassum thunbergii. J. Fishery Sci. China.

Kim, J.K., G.P. Kraemer, C.D. Neefus, I.K. Chung and L.K. Shin, 2008. Effect of temperature, salinity and light intensity on nitrogen and phosphorus uptake by four species of Porphyra (Bangiales, Rhodophyta) native to the New England coast. J. Applied Phycol., 19: 431-440. DOI: 10.1007/s10811-006-9150-7

Kolkovski, S., 2010. An overview on desert aquaculture in Australia. Proceedings of the Aquaculture in desert and arid lands: Development constraints and opportunities, Jul. 6-9, FAO, Heremossili, Maxico, pp: 39-60.

Larned, S.T., 1998. Nitrogen-versus phosphorus-limited growth and sources of nutrients for coral reef macroalgae. Marine Biol., 132: 409-421. DOI: 10.1007/s002270050407

Lee, C.L., 1997. Potential for Inland Aquaculture of Crustaceans. In: Inland Saline Aquaculture, Perth, Smith, B. and C. Barlow (Eds.), The Australian Centre for International Agricultural Research, ACIAR Proceedings No. 83, Perth, pp: 37-39.

Lignell, A. and M. Pedesén, 1989. Effects of pH and inorganic carbon concentration on growth of Gracilaria secundata. British Phycol. J., 24: 83-89. DOI: 10.1080/0007168900650071

Lymbery, A.J., R.G. Doupé, T. Bennett and M.R. Starcevich, 2006. Efficacy of a subsurface-flow wetland using the estuarine sedge Juncus kraussii to treat effluent from inland saline aquaculture. Aquaculture Eng., 34: 1-7. DOI: 10.1016/j.aquaeng.2005.03.004

Martin-Smith, K.M., 1993. The phenoiology of four species of Sargassum at magnetic Island, Australia. Botanica Marina, 36: 327-334. DOI: 10.1515/botm.1993.36.4.327

Mazor, E. and R. George, 1992. Marine airborne salts applied to trace evapotranspiration, local recharge and lateral groundwater flow in Western Australia. J. Hydrol., 139: 63-77. DOI: 10.1016/0022-1694(92)90195-2

Nulsen, B., 1997. Inland Saline Water in Australia. In: Inland Aquaculture Workshop, Smith, B. and C. Barlow (Eds.), The Australian Centre for International Agricultural Research, ACIAR Proceedings No. 83, Perth, pp: 6-11.

Nurmi, P.A., I.T. Kukkonen and P.W. Lahermo, 1988. Geochemistry and origin of saline groundwaters in the Fennoscandian Shield. Applied Geochemistry, 3: 185-203. DOI: 10.1016/0883-2927(88)90007-8

Ogawa, H., 1984. Effects of treated municipal wastewater on the early development of sargassaceous plants. Hydrobiologia, 116-117: 389-392. DOI: 10.1007/BF00027707

Ogburn, D.M., 1997. Environmental Considerations in the Use and Management of Inland Saline Water Bodies for Aquaculture. In: Inland Saline Aquaculture, Smith, B. and C. Barlow (Eds.), The Australian Centre for International Agricultural Research, ACIAR Proceedings No. 83, Perth, pp: 32-34.

Overnell, J., 1975. Potassium and Photosynthesis in the Marine Diatom Phaeodactylym tricornutum as Related to Washes with Sodium Chloride. Physiologia Plantarum, 35: 217-224. DOI: 10.1111/j.1399-3054.1975.tb03896.x

Partridge, G.J., 2008. Inland saline aquaculture: Overcoming biological and technical constraints towards the development of an industry. PhD thesis, Murdoch.

Partridge, G.J., A.J. Lymbery and R.J. George, 2008. Finfish mariculture in inland Australia: A review of potential water sources, species and production systems. J. World Aquac. Society, 39: 291-310. DOI: 10.1111/j.1749-7345.2008.00169.x

Peng, Y., E. Xie, K. Zheng, M. Fredmoses and X. Yang et al., 2013. Nutritional and chemical composition and antiviral activity of cultivated seaweed Sargassum naozhouense Tseng et Lu. Mar Drugs., 11: 20-32. DOI: 10.3390/md11010020

Prangnell, D.I. and R. Fotedar, 2006a. Effect of sudden salinity change on Penaeus latisulcatus Kishinouye osmoregulation, ionoregulation and condition in inland saline water and potassium-fortified inland saline water. Comparative Biochem. Physiol. Part A: Molecular Integrative Physiol., 145: 449-457. DOI: 10.1016/j.cbpa.2006.08.029

Prangnell, D.I. and R. Fotedar, 2006b. The growth and survival of western king prawns, Penaeus latisulcatus Kishinouye, in potassium-fortified inland saline water. Aquaculture, 259: 234-242. DOI: 10.1016/j.aquaculture.2006.05.023

Schaffelke, B. and D.W. Klumpp, 1998. Nutrient-limited growth of the coral reef macroalgae Sargassum baccularia and experimental growth enhancement by nutrient addition in continuous flow culture. Marine Ecol. Progress Series, 164: 199-211. DOI: 10.3354/meps164199
Skirrow, G., 1975. The dissolved gases – carbon dioxide. In: Chemical Oceanography. Riley, J.P. and G. Skirrow (Eds.), Academic Press, London, New York.

Taukulis, F.E. and J. John, 2006. Diatoms as ecological indicators in lakes and streams of varying salinity from the wheat belt region of Western Australia. J. Royal Society Western Australia, 89: 17-25.

Taukulis, F.E. and J. John, 2009. Development of a diatom-based transfer function for lakes and streams severely impacted by secondary salinity in the south-west region of Western Australia. Hydrobiologia, 626: 129-143. DOI: 10.1007/s10750-009-9741-9

Timms, B.V., 2005. Salt lakes in Australia: present problems and prognosis for the future. Hydrobiologia, 552: 1-15. DOI: 10.1007/s10750-005-1501-x

Tromballa, H.W., 1978. Influence of permeant acids and bases on net potassium uptake by Chlorella. Planta, 138: 243-248. DOI: 10.1007/BF00386818

Uchida, T., 1993. The life cycle of Sargassum horneri (Phaeophyta) in laboratory culture. J. Phycol., 29: 231-235. DOI: 10.1111/j.0022-3646.1993.00231.x

Vijayaraghavan, K., T.T. Teo, R. Balasubramanian and U.M. Joshi, 2009. Application of Sargassum biomass to remove heavy metal ions from synthentic multi-metal solutions and urban storm water runoff. J. Hazardous Mater., 164: 1019-1023. DOI: 10.1016/j.jhazmat.2008.08.105

Wang, B., H. Huang, H.P. Xiong, E.Y. Xie and Z.M. Li, 2010a. Analysis on nutrition constituents of Sargassum naezhouense sp. Food Res. Dev., 31: 195-197.

Wang, J., Q. Zhang, Z. Zhang, H. Zhang and X. Niu, 2010b. Structural studies on a novel fucogalactan sulfate extracted from the brown seaweed Laminaria japonica. Int. J. Biol. Macromolecules, 47: 126-131. DOI: 10.1016/j.ijbiomac.2010.05.010

Wiltshire, K.H., J.E. Tanner, C.F.D. Gurgel and M.R. Deveney, 2015. Feasibility study for integrated multitrophic aquaculture in Southern Australia: Report to the Fisheries Research and Development Corporation. 1st Edn., SARDI Aquatic Sciences, Adelaide, ISBN-10: 1921563869, pp: 115.

Womersley, H.B.S., 1987. The marine benthic flora of southern Australia. 1st Edn., South Australian Government Printing Devison, Adelaide.

Yamauchi, K., 1984. The formation of Sargassum beds on artificial substrata by transplanting seedlings of S. horneri (Turner) C. Agardh and S. muticum (Yendo) Fensholt. Nippon Suisan Gakkaishi, 50: 1115-1123. DOI: 10.2331/suisan.50.1115

Yarish, C., P. Edwards and S. Casey, 1980. The effects of salinity and calcium and potassium variations on the growth of two estuarine red algae. J. Experimental Marine Biol. Ecol., 47: 235-249. DOI: 10.1016/0022-0981(80)90041-6

Yende, S.R., U.N. Harle and B.B. Chaugule, 2014. Therapeutic potential and health benefits of Sargassum species. Pharmacognosy Rev., 8: 1-7. DOI: 10.4103/0973-7847.125514