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Research Article

Seasonal variation in growth rates and carrageenan properties of *Kappaphycus alvarezii* and *Eucheuma denticulatum* cultivated with and without additional nutrients, in Uroa, Zanzibar, Tanzania

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ABSTRACT
Kappaphycus alvarezii and *Eucheuma denticulatum* were cultivated under two treatments: with & without additional nutrients in Uroa, Zanzibar. The seaweeds were cultivated for 8 weeks (total of 15 weeks) in contrast to the 4-6 weeks normally used by farmers. Water column nutrients were 8-17µM total ammonia nitrogen & 2-38 µM soluble reactive phosphate. There were no significant differences in specific growth rates of fertilised & unfertilised seaweeds ($P>0.05$). However, during heavy rains & high surface seawater temperatures there were significant differences between the two treatments for both species ($P<0.05$). Whereas seaweed growth rates seemed to be affected by protracted periods of rain and a hot season of 31 0C maximum, fertilised *K. alvarezii* was more affected by the hot season than the unfertilised plant. For short rains and cooler months (27 0C maximum) both treatments showed similar rates. No significant differences ($P>0.05$) were found in carrageenan yield, dry matter, iota carrageenan percentage, and viscosity between fertilised and unfertilised treatments. Seasonal variations showed lower carrageenan yield & dry matter during heavy rains and higher values at the end of rainy season. Seaweed farmers in Tanzania could use a lower stocking density for higher seaweed biomass production & cultivate seaweeds for longer periods to satisfy customers in the carrageenan industry if so desired.

KEYWORDS: *Seaweed growth, carrageenan properties, nutrients, Eucheuma, Kappaphycus*

INTRODUCTION

Commercial seaweed farming in Tanzania started in 1989 using imported strains of *Eucheuma* (under the then commercial name but which included *Eucheuma denticulatum* and *Kappaphycus alvarezii*) from the Philippines (Pettersson-Löfquist 1995, Mshigeni 1992, Msuya 2006a). Seaweed cultivation was one of the major foreign currency earning industries in the country, contributing up to 27% of marine exports from the Zanzibar Islands in 1995 (Msuya 2006b). However, there has been a recent tendency by the world seaweed market to prefer and pay considerably higher prices for *K. alvarezii* over *E. denticulatum* since the former produces "kappa" carrageenan, a stronger gel, compared with "iota" carrageenan, a weaker gel, from the latter (Hayashi et al. 2010). For example, in Tanzania, the price of *K. alvarezii* has risen to almost double that of *E. denticulatum* (e.g. US$ 0.2 vs. 0.1 per kg. dry weight, Msuya 2006b). Consequently, the farmers try in vain to farm *K. alvarezii* in many cases in areas best suited for *E. denticulatum* thus wasting time and resources and causing potential down-grading of the seed stock. In addition, there has been a marked decrease in production of *E. denticulatum* which not only causes concern for the established

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seaweed buying companies but more seriously affects coastal populations involved in eucheumoids (or eucheumatoids - terms used to describe different commercial strains of both *Eucheuma* and *Kappaphycus*) production, who are mainly women who see seaweed farming as their economic and social liberator. It is unfortunate, but a reality, that women from the coastal populations of Tanzania have very few other economic options (Pettersson-Löfquist 1995, Mmochi et al. 2005, Msuya 2006a).

Studies on the means of increasing biomass and carrageenan yield and quality would boost the income and morale of the Tanzanian farmers. In addition, it is surprising as to how few studies have been conducted in Tanzania on various aspects of seaweed farming and production techniques to improve yield and quality of the raw materials for the commercial carrageenan industry. Some important factors such as the effects of nutrient concentration and seasonality, on the growth and quality/quantity of the carrageenan have scarcely been studied.

Nutrient concentrations are known to affect the growth and quantity of colloids in seaweeds as shown in the works on the effects of nutrients on growth and/or carrageenan properties on eucheumoids. These studies (mostly from countries other than Tanzania), include Qian et al. (1996), Mairh et al. (1999), Msuya and Neori (2002) and Hayashi et al. (2008) who variously showed both positive and negative effects of nutrients on cultivated seaweeds under a variety of conditions. Qian et al (1996) found higher growths with nutrient addition and Mairh et al. (1999) reported on higher growths with increased N accumulation. Hayashi et al. (2008) found higher growths but no change effect on carrageenan properties of *Kappaphycus* when cultivated in nutrient rich waters. Msuya and Neori on the other hand reported on lower growth rates for *K. alvarezii* and *E. denticulatum*, the reason being the sediment type in the land-based integrated system. In all these studies, the seaweeds were cultivated either on land-based systems or in cages in the sea. With the exception of Msuya and Neori (2002), which was conducted in a land-based system, no studies on the effects of nutrients had been done in Tanzania.

Studies on the effects of seasonality on growth rates and carrageenan properties of *Eucheuma denticulatum* and *Kappaphycus alvarezii* have been reported (e.g. Ohno et al. 1996, Wakibia et al. 2006, Hayashi et al. 2007a). Ohno et al (1996) obtained growth rates ranging from 4–11 % day^{-1} in *K. alvarezii* depending on season and cultivation area whereas Wakibia et al (2006) reported on growth rates varying from 4-6% d^{-1} in Kenya. Hayashi et al. (2007b) reported on co-variation between growth rates and seawater temperature with the rates ranging from 1.4 – 6.6% d^{-1} in four strains of *K. alvarezii*. No similar studies on Eucheumoids for Tanzania could be found in literature. The aim of this investigation was to evaluate the effects of seasonality and nutrient concentration, on the growth rate and physical properties of carrageenan in the commercially farmed seaweeds *Eucheuma denticulatum* and *Kappaphycus alvarezii. E. denticulatum* is the commercial source of iota carrageenan and the latter the commercial source of kappa carrageenan.

MATERIALS AND METHODS

Study site

This study was conducted in Uroa on the East Coast of Unguja Island, Zanzibar, Tanzania, where both species are farmed commercially. Unguja Island is located between latitudes 5° 40' and 6° 30' south; and longitude 39° east. Apart from having both seaweed species cultivated there, Uroa site was ideal for the study as it contained small pools of water that remained at low tides; this allowed for the addition of the fertiliser. Seaweeds were planted in these pools.

Experimental set up and frequency of ampling

Seaweeds were planted using 4 mm nylon ropes as used by farmers in Zanzibar (the traditional peg and line method where the lines are stretched between two wooden pegs which are pounded into the substratum). The lines on which seaweeds were tied were 2 m long. Seedlings of approximately 100 g were tied to the lines, at 20 cm intervals (as used by the farmers). The initial weight of each line was 1 kg (weighed by mechanical scale). The two species were cultivated under two treatments: with a commercial liquid fertiliser (12N:10P:8K+TE Mukpar Booster, Mukpar Tanzania Ltd), and without additional nutrients. Fertilisation involved the addition of 16 ml of the fertiliser at each sampling date, i.e. twice per month. This was done by mixing the 16 ml with seawater to make 1 litre for each treatment and sprinkling the fertiliser over the seedlings. Fertilisation was applied into the small water pools (~2.5x4 m and depth of about 1.5 feet at

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lowest tides) that remained during the ebbing of the tide (the pools were completely separated from the main water body during the low tides; they were also found in the same areas throughout the year). In these pools, the seaweeds were submerged at all times. Four such pools were used, two for each treatment. In each pool 25 lines of each species were planted. Two to three hours were available for the seaweed to take up the available nutrients, depending on the tide. The treatment without additional nutrients was placed 100m from the nutrient added treatment. The assessments were carried out for 15 months from March 2005 to June 2006. Sampling was undertaken bi-monthly at low tides. Each set of experiments lasted for a period of 2 consecutive months.

Sample collection and analysis

Growth rates

The seaweeds were harvested by untying the lines from their anchoring pegs. Three to five lines were harvested for each replicate (depending on the weights of the lines with five lines taken during the first two weeks and three lines during the last sampling). The same number of lines was taken for each treatment. The lines were taken randomly. After harvesting, the seaweed lines were shaken to remove excess water and weighed using a commercial weighing scale to obtain fresh weights. From the fresh weights, specific growth rate (SGR, %), was calculated according to Fujita (1985) as:

SGR = 100 X [ln (w_t/w_0)]/t, where w_0 is the initial biomass and w_t is the biomass at t culture days.

Carrageenan properties

Samples for carrageenan were collected from July when growth conditions had been perfected. Two samples of about 3.5 – 4 kg fresh weight (FW), to obtain 350 g dry weight (DW), were taken from each treatment at each sampling day, rinsed with fresh water to remove salt and debris, and weighed to obtain their fresh weight. Rinsed samples were dried in the sun by hanging on vertical poles to about 15 – 20% moisture content (as is done by farmers). The dried samples were packed in sealed plastic bags, silica gel powder was added, and the samples were shipped to the laboratories of Cargill Texturizing Solutions, Baupte, France, for carrageenan extraction and analyses.

Carrageenan extraction: Carrageenan yield, the quantity of carrageenan based on 100g dry material was measured as "native" carrageenan, i.e. without alkali treatment (used for transformation of precursors). Native carrageenan was extracted in distilled water at 60°C for 4h, under agitation. The digestion product was filtered and precipitated in 85% isopropanol with 0.2% KCl solution. The coagulum was recovered and dried in an oven at 60°C for 12h. The final carrageenan was ground to 500 µm. Native carrageenan yield was calculated on the basis of the seaweed samples dried in oven at 60 °C for 24 h and 105°C for 2 h to constant weight. Dry matter content was measured after drying in an oven at 60°C for 24 hours and at 105°C for 2 hours.

Carrageenan characterization: The iota content as the proportion of iota-carrageenan vs. total carrageenan was estimated by calculation from an IR spectrum and viscosity of a 1.5% solution measured at 75°C, with a Brookfield Viscometer at 30 RPM after Hayashi et al. (2007b). The iota fraction was estimated by Fourier transform-infrared spectrometry, in films of 0.4% native carrageenan in demineralised water. Viscosity was analysed in a 1.5% native carrageenan. Measures of viscosity were made with a Brookfield Viscosimeter at 75°C at 30 rpm.

Growth conditions

Nutrients: Three replicate samples of water were collected twice a month (on each sampling visit) in random locations of each treatment at each sampling date. After collection, the samples were stored in an icebox and transported to the laboratory where they were filtered using 0.45µm Whatman filter papers. Measurement of absorbency of the respective nutrients was made using a spectrophotometer (UV-1601-Visible Spectrophotometer, Shimadzu) following the methods of Parsons et al. (1984); concentrations of growth limiting nutrients, i.e. total nitrogen ammonia (TAN) and soluble reactive phosphorus (SRP) were calculated. Total nitrate (nitrite/nitrate) could not be determined.

Abiotic parameters

Two important abiotic parameters affecting growth were measured to establish the conditions where the seaweeds were growing. These were surface seawater temperature, which was measured with an OxyGuard meter (Handy Mk III, Denmark) and salinity measured using a Sper Scientific Ltd. USA refractometer Model no. 300011. Both parameters were measured *in situ* and were measured at each sampling day as was the case for other parameters.

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Three measurements of each parameter were taken at each replicate.

RESULTS

Growth conditions

The surface seawater temperature in which the seaweeds were growing varied from 27 – 33 ^{0}C and salinity from 31 – 35 ppt (fig.1). No statistically significant differences in water temperature (n=112) and salinity (n=97) were found between the fertilised and unfertilised treatments (Analysis of variance, ANOVA, p>0.05).

Water column nutrients were 0.0 – 2.0 µM TAN and 0.2 – 1.7 µM SRP before the addition of nutrients which increased to 8.0 – 17.4 µM for TAN and 2.3 – 38.2 µM for SRP after the addition of the nutrients (Fig. 2). The concentrations after the 3 h uptake were 0.7 – 6.8 µM for TAN and 0.6 – 2.4 µM for SRP (Fig. 2), values that were higher than those of the unfertilised treatment (0.0 – 1.6 µM TAN & 0.3 – 0.8 µM SRP) and the before nutrient addition mentioned above. Similar values for the unfertilised treatment have been reported in seaweed farms in the same area (Msuya and Salum 2006, 6-15µM TAN and 2 -3 µM SRP). TAN was taken up with an average efficiency of 70±15%, and SRP by 89±11%. These uptake rates are similar (for the TAN) and higher (for the case of SRP) to those reported by other works such as Qian et al. (1996, 82% TAN), Rodrigueza and Montano (2007, 41 – 66% TAN), Hayashi et al. (2008, max. 70.5% and phosphate=26.8%).

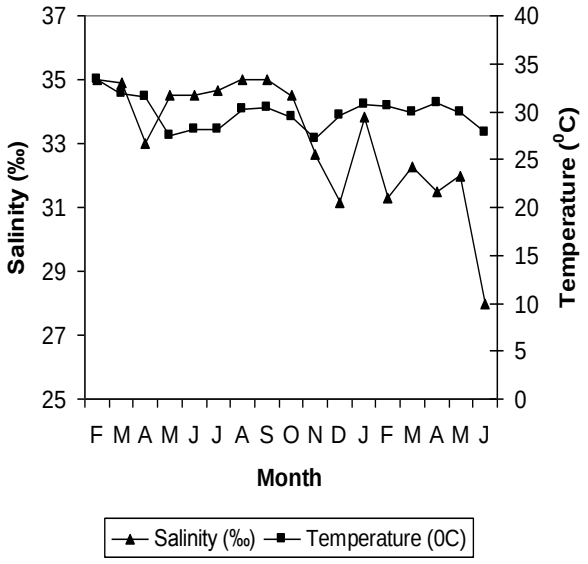
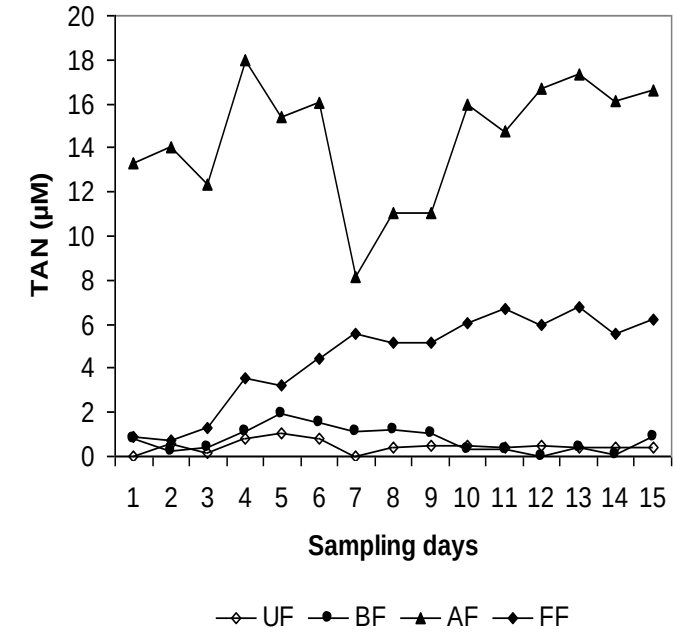
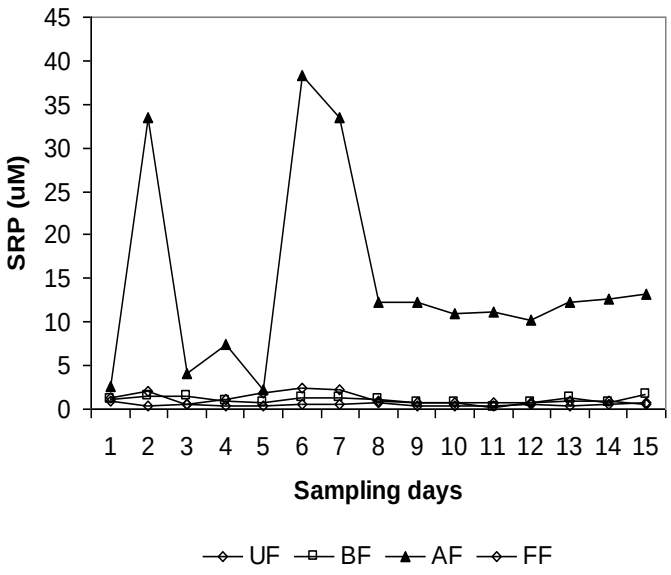


FIGURE 1: *Monthly variations (mean ± SD) in temperature and salinity , February 2005 – June 2006.*





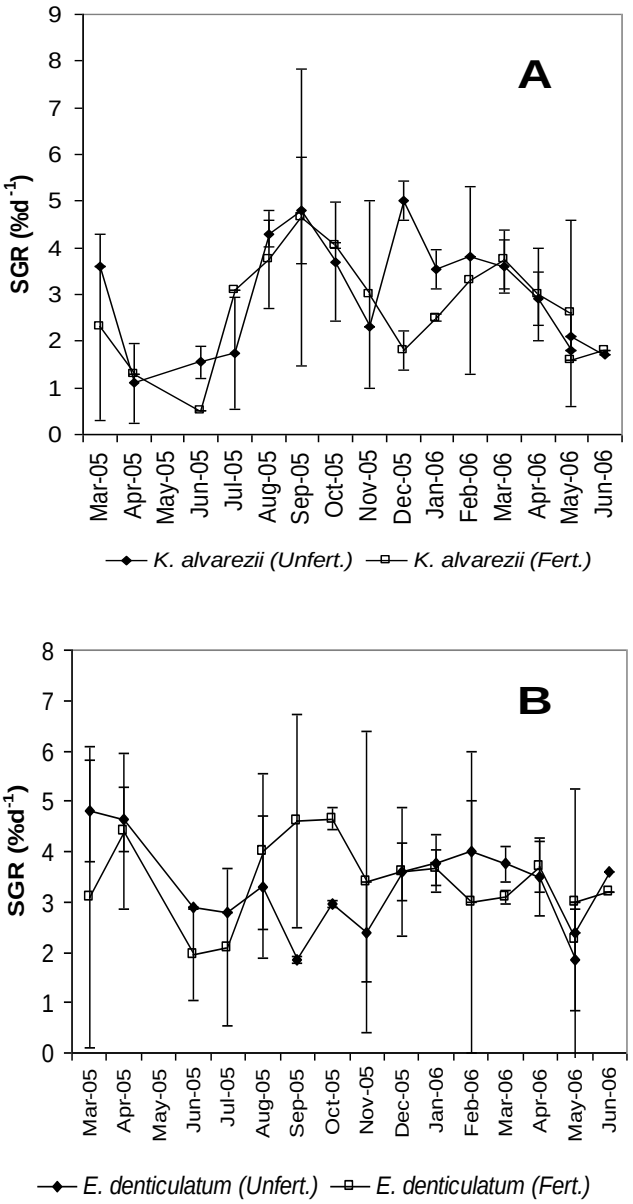
FIGURES 2*: Total ammonia nitrogen (TAN, µM) and soluble reactive phosphorus (SRP, µM) concentrations and uptake in the fertilised treatment. A: TAN uptake B: SRP uptake; UF=Unfertilised, BF=Before fertilisation, AF=After fertilisation, FF=Final readings after 2-3 hours.*

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Seaweed growth rate

Effect of nutrients

The final weights of the seaweeds were 5-9 kg per line for all the treatments and the species depending on the season. Generally, no statistically significant differences in specific growth rates (SGR) were found between fertilised (n=90) and unfertilised (n=89) seaweeds ($p>0.05$) except for fertilised *K. alvarezii* ($F=4.37$, $df=34$, $p=0.04$). However, an analysis of the growth rates during the "bad" (hot season-January – February, and heavy rains-March-April) and "good" (mild temperatures-June-August and rainfall-October-December—CHECK!!!) growing seasons showed significant differences between both species and their treatments, e.g. fertilised *K. alvarezii* ($F=32.7$, $df=30$, $p=3.1E-05$), unfertilised *K. alvarezii* ($F=37.1$, $df=26$, $p=1.97E-06$), fertilised *E. denticulatum* ($F=11.9$, $df=30$, $p=0.002$), and unfertilised *E. denticulatum* ($F=25.7$, $df=27$, $p=2.53E-05$). SGRs of fertilised *K. alvarezii* maximised at 7.6% d^{-1} whilst that of unfertilised was 5.6% d^{-1} (Fig. 3). Minimum rates were below 1% d^{-1} for both treatments. Fertilised *E. denticulatum* showed a maximum rate of 6.8% d^{-1} while the unfertilised reached a maximum of 5.1 % d^{-1}: the minimum value was below 1% d^{-1} for both treatments. Whereas growth rates seemed to be affected by protracted periods of rain and the hot season of 31 ^{0}C maximum surface seawater temperature, fertilised *K. alvarezii* was more affected by the hot season than the unfertilised seaweed. However, this was not the case for the rainy period. *E. denticulatum* had slightly higher growth rates in the fertilised than the unfertilised treatment during all seasons. For the rest of the seasons: short rains and cooler months (i.e. 27 ^{0}C maximum surface seawater temperature), growth rates of the unfertilised and fertilised seaweeds of both species were similar.



FIGURES 3: *Monthly variations (mean ± SD) in specific growth rates of unfertilised and fertilised K. alvarezii and E. denticulatum , March 2005 – June 2006*

Effect of cultivation duration and seasons

SGRs of both seaweeds in the fertilised and unfertilised treatments were highest two weeks after out-planting (data not shown); the rate decreased to a minimum during the 8th week. After six weeks, the seaweeds were breaking, most probably due to their heavy weights. During the months of heavy rainfall (March – May) when salinities were lower and the hot season when temperatures were highest

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(January – February), both seaweeds were growing at lower rates than the rest of the study period. Higher growth rates were generally recorded during the cold season (July-September) and warm months of October – mid December which are also associated with short rains and mild temperatures. Higher growth rates were recorded during the SE Monsoons (June-mid December) and lower rates during the NE Monsoons (late December – May). Strong winds that lead to strong ocean currents broke off the seaweeds from their anchorage lines, more seriously in January (NE Monsoons). It was also observed that *K. alvarezii* was highly grazed upon by sea urchins whereas no such effect was observed in *E. denticulatum*. This is not a result of the experiment but rather shows that *K. alvarezii* is more palatable to the sea urchins than *E. denticulatum*. This can cause considerable loss of the product and the farmers must replant the seaweed each time there are losses due to grazing.

Carrageenan properties

Effect of nutrients

There were no significant differences in all the carrageenan properties studied in Uroa i.e. dry matter (DM, n=83), yield (n=83), iota content (n=83), and viscosity (n=83) between the fertilised and unfertilised treatments (P>0.05). Figures 4-7 show the carrageenan properties of *K. alvarezii* and *E. denticulatum* cultivated in Uroa. As can be seen, the curves have overlapping error bars showing the absence of significant differences between fertilised and unfertilised treatments. No obvious trend was evident either.

Effect of cultivation duration and seasons

Dry matter (DM) of both fertilised and unfertilised *E. denticulatum* showed two relatively low peaks in February and June 2006 (Fig. 4). However, the low peak in June is a datum point from only half the month (collected on 13th June) and thus was not conclusive. The highest values were recorded during July – October 2005, one of the good growing seasons. The rest of the data showed similar values ranging from 58 – 82%. The results showed a tendency in decreasing DM throughout the study period. *K. alvarezii* showed lowest values in March – April 2006, again with a low June value (Fig. 4). For carrageenan yield, relatively lower values were recorded during good growth seasons (April – August) whereas higher values were recorded during the poor growth seasons in September to March.

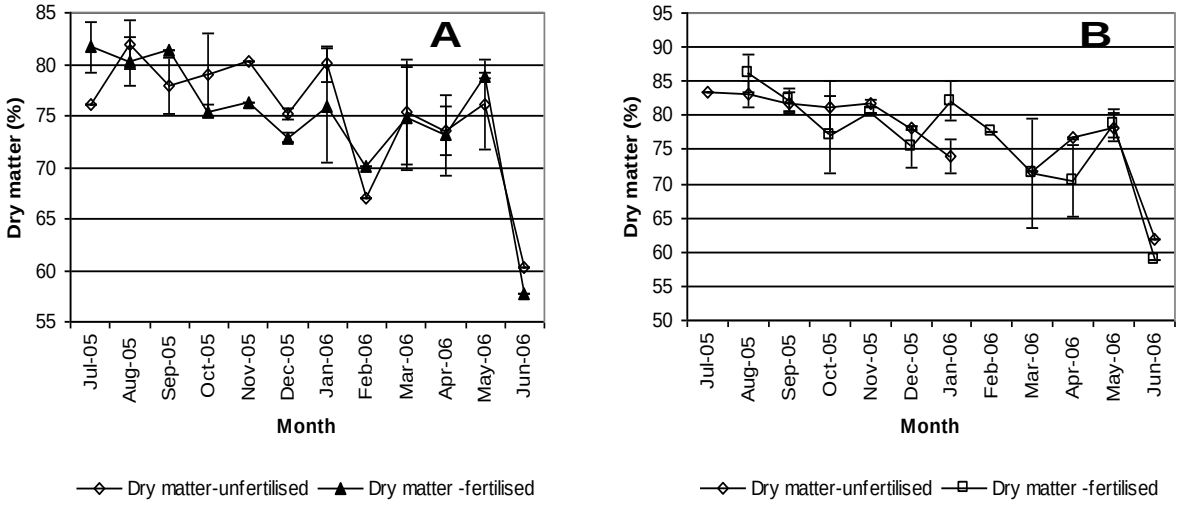


FIGURE 4: *Monthly variations (mean ± SD) in dry matter content of E. denticulatum (A) and K. alvarezii (B), July 2005 – June 2006.*

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The observation was more marked in *K. alvarezii* than *E. denticulatum* (Fig. 5). No definable effect on iota content could be observed in *K. alvarezii* and *E. denticulatum* (Fig. 6). However, there was a trend towards an increase in the relative iota content in *K. alvarezii* with the study period. Viscosity showed a clear trend of increasing values during the study period in *E. denticulatum* (Fig. 7). A similar trend, though not as significant, was observed for *K. alvarezii* (Fig. 7). A comparison of the two species showed significant differences only in values of viscosity (F= 5.27, df=39, P=0.027) of the unfertilised treatment *K. alvarezii* and *E. denticulatum* and of course iota content as expected (F= 4580.789, df=39, $P=4.69E^{-42}$ and F=5775.925, df=39, $P=7.05E^{-45}$ respectively).

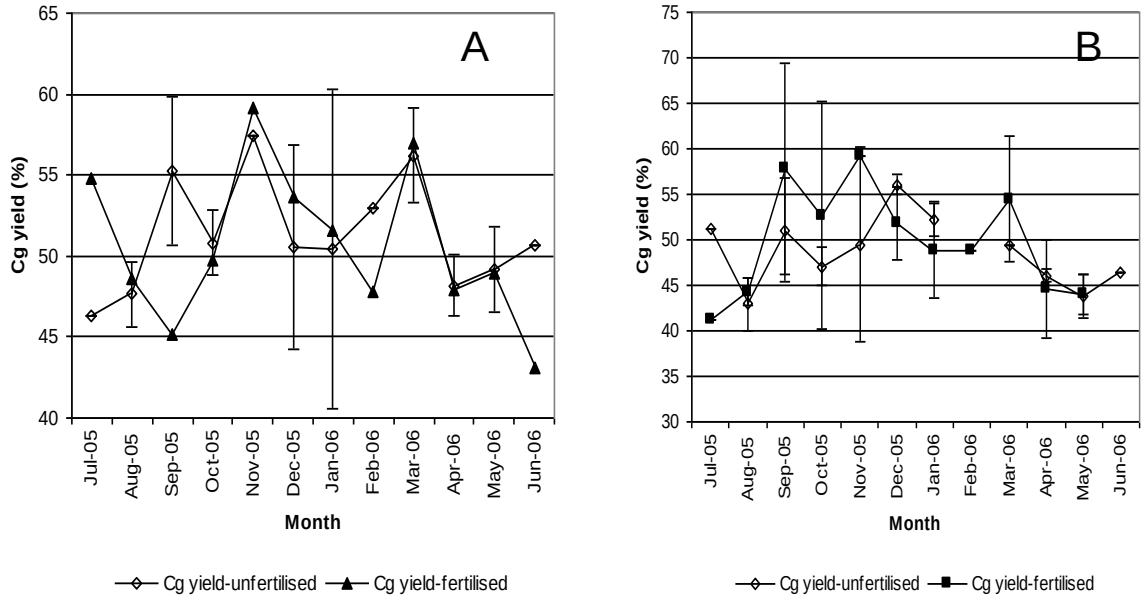


FIGURE 5: *Monthly variations (mean ± SD) in carrageenan content of E. denticulatum (A) and K. alvarezii (B), July 2005 – June 2006.*

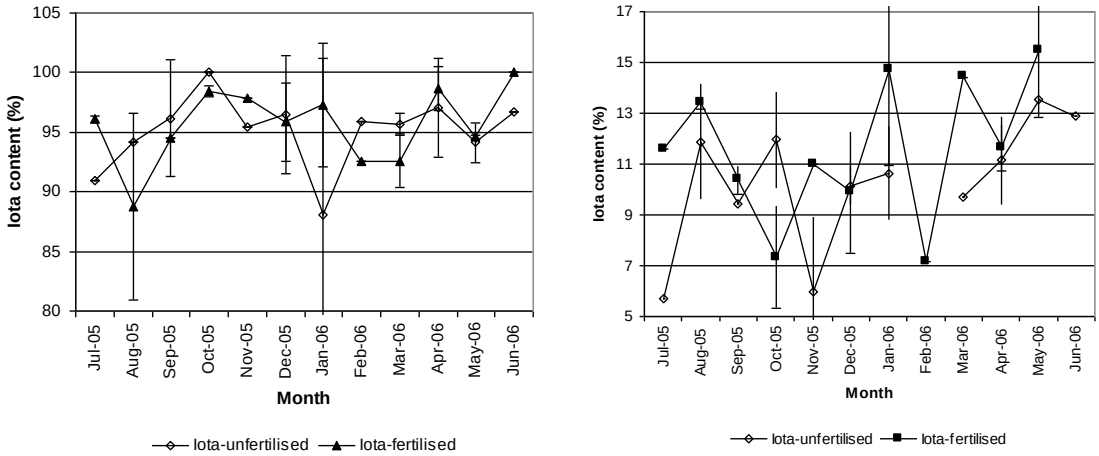


FIGURE 6*: Monthly variations (mean ± SD) in iota content of E. denticulatum (A) and*

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K. alvarezii (B), July 2005 – June 2006.

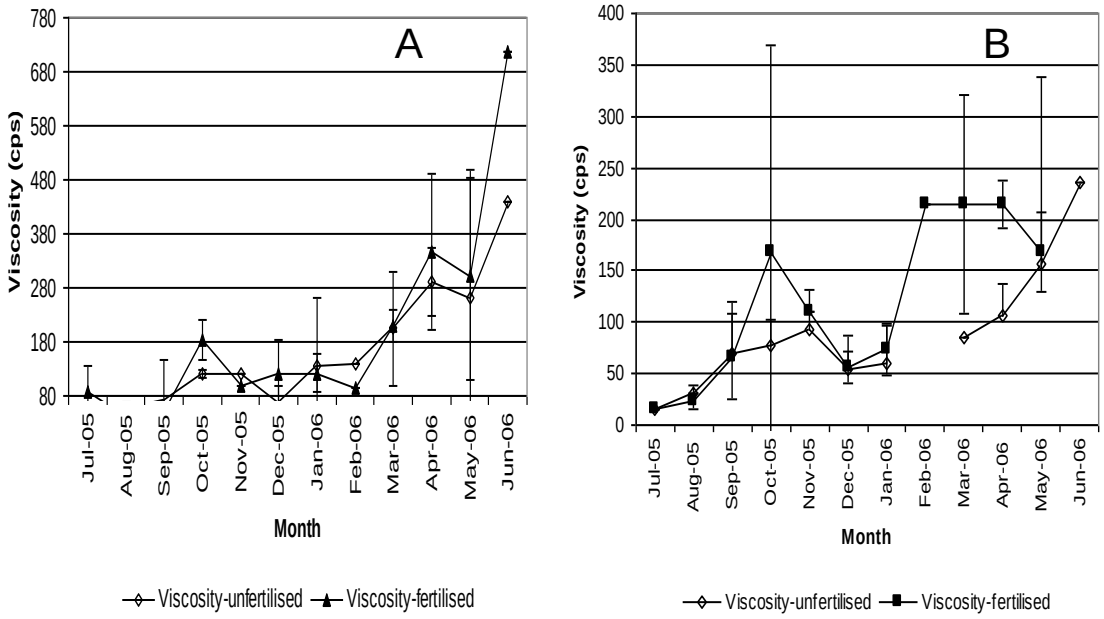


FIGURE 7*: Monthly variations (mean ± SD) in viscosity content of E. denticulatum (A) and K. alvarezii (B), July 2005 – June 2006.*

In native extracts, even *K. alvarezii* is found to contain varying small percentages of iota or non-kappa precursor fractions of carrageenan. During the first 15 days, there was a trend to decreasing relative iota content in *K. alvarezii* in both fertilised and unfertilised treatments (data not shown). The trend was, however, not observed after 15 days. The results could be an effect of "planting shock" when the seaweed is adjusting to the cultivation conditions (since vegetative propagation is as a result of cutting adult plants into the ~100g seedlings). Variations of dry matter content and carrageenan yield, as a function of time, showed much lower dry matter contents (68.4 and 69.9% respectively for unfertilised and fertilised *E. denticulatum*) during the heavy rains in March 2006 than at any time during the rest of the study. Similarly, there were higher contents of dry matter at the end of the rains in June (90.7 and 88.5% respectively). *K. alvarezii* showed similar results with lower carrageenan contents of 78.8 and 73.3% and higher values of 89.5 and 89.1% respectively. These are typical effects of heavy rains followed by the end of rains respectively which is common to many sub-tropical, monsoon affected areas where these seaweeds are cultivated.

With few exceptions, the viscosity values for *K. alvarezii* were lower than for *E. denticulatum*. Results of iota content showed a certain variability in the results with a trend towards decreasing although the value in mid-May was high. However, there is no trend for any dependence with the other parameters measured.

Correlation analysis

Correlation analysis showed a weak relationship between growth rate and carrageenan properties with all the environmental parameters measured (nutrients, temperature and salinity) in both *E. denticulation* ($r \leq 0.143$, $p>0.05$) and *K. alvarezii*. These results show that these parameters had no individual strong effect on seaweed growth but rather all the parameters contributed synergistically to the overall growth of the seaweeds. However, salinity showed a strong correlation with dry matter ($r=0.623$, $p<0.05$) but only in the unfertilised *K. alvarezii*, indicating a possible influence of salinity on growth.

DISCUSSION

Seaweed growth rate

The effect of nutrients was evident only when interacted with seasonal variations but not as stand-

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alone parameter. The results of seasonal variation enhancing the effect of nutrients on *K. alvarezii* which was negatively affected after 14 days (especially during heavy rains and hot seasons), was also reported by Doty (1986) in Hawaii and The Philippines. However, Rodrigueza and Montano (2007) found no significant differences in growth rates between nutrient rich and nutrient poor *Kappaphycus*, thus conforming to our majority of the results. Msuya and Neori (2002) obtained lower growth rates than those of the present study (i.e. 3% d^{-1}) in unfertilised *E. denticulatum* cultivated in a land-based integrated system in Zanzibar where the seaweed did not grow under fertilised treatments.

The effect of seasonality could have been enhanced by the difference in environmental parameters between the two years e.g. it was noted that the hot months of January and February did not show similar temperature values between the two years of the study; 2005 had higher values in February than 2006 (see fig.1). Similarly, the temperature value at the end of the rains in May 2006 was not as low as that of 2005. The ambiguity of the seasons was also depicted in the difference in salinities from March – June in 2005 and 2006 (see fig. 1). The latter also had heavy and prolonged rains that were more than the usual seasonal rains. This calls for further long-term studies to show the effects of the unusual seasonal changes on the environmental parameters and hence the growth of the cultivated seaweeds.

SGRs of the two seaweeds in the current study were highest two weeks after out-planting and then decreased afterwards. Other works have reported on similar results of relationship between growth and cultivation duration. One such work is that of Hayashi et al. (2007a,b) who obtained growth rates ranging from 5 – 7% d^{-1} and higher growth rates during the first month of cultivation, results that are similar to those of the current study. Similar results were obtained by Rodrigueza and Montano (2007) who found highest growth rates during the first week of cultivation. Glenn and Doty (1990) and Hurtado-Ponce (1992) obtained average growth rates for *Eucheuma denticulatum*, *Kappaphycus alvarezii*, and *K. striatum* of about 3.5% whereas Doty (1986) mentioned that growth rates of farmed *Eucheuma* spp. usually range from 2% - 10% per day depending on the goal of the farmer. Several other works have reported on variations in growth of seaweeds with seasonality. In most cases, these results, which are mainly from countries other than Tanzania, are similar to those of the current study and sometimes the results of the current study show higher growth rates. Studying the effects of seasons, Ohno et al. (1996) found lowest growth rates (<4% d^{-1}) during the hot season (temperatures above 30 ^{0}C) and the highest rates (7-11% d^{-1}) during cold seasons (temperatures below 30 ^{0}C) in *K. alvarezii* results that are similar to those of the current study. Similar results were obtained by Wakibia et al. (2006) who reported on the highest growth during the cold month of August and the lowest during hot month of January. A growth rate of 3.5% per day is considered significant in the commercial cultivation of *Eucheuma* spp. (Parker 1974, Adnan and Porse 1987, Luxton et al. 1987).

It was observed that *K. alvarezii* was highly grazed upon by sea urchins whereas *E. denticulatum* was not. This observation supports the fact that *K. alvarezii* is more palatable to the sea urchins and indicates that the species is also more prone to biotic damage as well as environmental changes (as explained above) than *E. denticulatum*. It is known, for example, that cultivation of *K. alvarezii* is not as successful as that of *E. denticulatum* e.g. in Tanzania (Msuya et al. 2007). As a result of grazing and plant breakage (increased weight of pant in heavy swells), some growth data were inevitably lost, which explains some of the missing data points in the figures (this is however not untypical of field dependent data). The breaking and grazing of the seaweeds however serves to illustrate some of the regular production problems the seaweed farmers face in the region.

Carrageenan properties

A possible reason for the lack of significant differences in carrageenan properties due to fertilisation treatment is because the residence time of the water with nutrients was relatively short. Since the nutrients were added in the sea, there was a maximum of 3 h before the flooding tide when the nutrient conditions went back to the unfertilised levels of the ambient seawater. There was perhaps insufficient time for the nutrient effects to be expressed. The situation might be improved if a future study were able to provide continuous fertilisation and longer nutrient residency times. However, setting up such an experiment in open water is rather difficult and not recommended due to possible negative environmental effects of local eutrophication in an otherwise oligotrophic system. The lack of effect of nutrients on carrageenan

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properties has also been reported by other recent eucheumoid studies; Hayashi et al. (2008) also found no significant differences in carrageenan yield in *K. alvarezii* cultivated with fish effluents and that with seawater in Brazil. However, tank culture experiments by Rodrigueza and Montano (2007) gave a significantly higher carrageenan yield in *K. alvarezii* grown in nutrient rich fish farm effluent with the highest value averaging (87.47± 4.21% dw). They also obtained significantly higher viscosity values in the nutrient rich seaweed material (i.e. 1,313 cps) than in the control (670 cps).

For carrageenan yield, in the present study, relatively lower values were recorded during good growth seasons whereas higher values were recorded during poor growth seasons. This supports the theory of the seaweeds using energetic resources for growth during good seasons and storing (in off-site nurseries) most of the resources during bad growth seasons. The results of a trend of increasing iota content (or non-kappa precursors) and viscosity in *K. alvarezii* with duration of the study period is similar to those of Mendoza et al. (2006) who found higher yields in the older tissues of *K. striatum*. The results of differences in carrageenan properties between the same two species were also obtained by Wakibia et al. (2006) in Kenya who found higher yields in *Kappaphycus* than in *Eucheuma*. Ohno et al. (1996) working with *K. alvarezii* in Vietnam showed a carrageenan yield of 18.8–24.6% and gel strength of 1566–1712 g cm^{-2}. These values are similar to the ones obtained from *K. alvarezii* cultivated in the Philippines and Indonesia.

In the cultivation of seaweeds, such as those used in this study, carrageenan properties usually vary with nutrients and season; the effect is dependent on growing conditions. In agreement with the results of the current study, Freile-Pelegrin and Robledo (2006) found the highest dry matter and carrageenan yield during their late rainy season in Mexico. The results of "native" carrageenan yield from *K. alvarezii* obtained in the present study were higher than those reported by Hayashi et al. (2007a, i.e. 21 – 35% DW); however, their study was conducted in a Brazilian winter. The results of the current study are also similar to commercial samples of cultivated raw materials from the western Pacific (i.e. 48-57% DW) used by the above mentioned authors. Ohno et al. (1996) obtained much lower yields of 18.8 – 24.6% (DW) in *K. alvarezii* in Vietnam and stated that the values were similar to those obtained from the same species cultivated in the Philippines and Indonesia. Results of variations in viscosity of the carrageenan, as a function of time and fertilisation, showed an increase in viscosity with time but also with large variations. The observations from the present study call for more work to be undertaken for a comprehensive understanding and management plan to be proposed. However, the results obtained are similar to those of Hayashi et al. (2007a,b) who found increased viscosity with increasing cultivation duration up to 44 days. The iota fraction obtained here (7-14% DW) is lower than that of Hayashi et al. (2007a,b, e.g. 9-20%) but higher than that of the commercial sample (3.3%) mentioned by these authors. Azanza-Corrales and Sa-a (1990) found viscosities ranging from 47-270 cps in *Eucheuma denticulatum*, that did not follow a definite pattern, while Laserna et al. (1981) reported viscosities for *E. striatum* and *E. denticulatum* of 85 and 230 cps respectively.

CONCLUSION

In conclusion, additional nutrients had effect on the growth of both cultivated seaweeds *K. alvarezii* and *E. denticulatum* in Tanzania but only during the poor growth seasons associated with high surface seawater temperatures and rainfall. Nutrient supplements have minimal effects on the yield and physical carrageenan properties of the seaweeds. On a DW mass basis, relatively more carrageenan is stored when the seaweeds are growing slowly; less is stored during the fast growing seasons. Eucheumoid seaweed growth has a strong correlation with seasonal variations where prevalent hot seasons and heavy rainfall have the most effect, whereas warm months and short rains may favour their growth. It is evident that *Kappaphycus alvarezii* is much more susceptible to abiotic and biotic pressures than *Eucheuma denticulatum* , as a result of possible local elevations in surface seawater temperature and also sea urchin grazing. These observations have a profound consequence on the site selection for cultivation of each type of carrageenophyte and it is obvious they cannot be grown in one and the same area and also that the potential sites for good *Kappaphycus* commercial cultivation are, therefore, more restricted than those for *Eucheuma*. This has to be taken into account when both the site and type of carrageenophyte for cultivation are selected.

Prolonging the cultivation period from the 3-6 weeks period to 8 weeks did not increase the growth of

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either of the two seaweeds tested here. The longer duration did, however, increase the colloid content. By harvesting the seaweeds after 3-6 weeks, farmers obtain a higher biomass; more dry weight and therefore more money per dry weight and perhaps unit effort. However, farmers may want to cultivate the seaweeds for longer periods than six weeks in order to obtain higher colloid yields and quality which helps satisfy the requirements of the commercial buyers when the yield and type of carrageenan obtained is taken into consideration. There may come a time when seaweed biomass is valued on colloid content and quality rather than total biomass. This will obviously require concerted efforts and education between farmers, suppliers and industrial carrageenan producers.

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REFERENCES

Adnan, H. & Porse, H. (1987) Culture of *Eucheuma cottonii* and *Eucheuma spinosum* in Indonesia. Hydrobiologia, 151/152: 355-358.

Azanza-Corrales, R. & Sa-a, P. (1990) The farmed *Eucheuma* species (Gigartinales, Rhodophyta) in Danajon Reef, Philippines: carrageenan properties. Hydrobiologia, 204/205: 521-525.

Doty, M.S. (1986) The production and use of *Eucheuma*. In M.S Doty, J.F. Caddy and B. Santelices 1986 (eds.). Case studies of seven commercial seaweed resources. FAO Fish. Tech. Pap., 281: pp 123-166.

Fujita, R.M. (1985) The role of nitrogen status in regulating transient ammonium uptake and nitrogen storage by macroalgae. J. Exp. Mar. Biol. Ecol., 92: 283-301.

Freile-Pelegrin, Y. & Robledo, D. (2006) Carrageenan of *Eucheuma isiforme* (Solieriaceae, Rhodophyta) from Yucatan, Mexico. II Seasonal variations in carrageenan and biochemical characteristics. Botanica Marina, 49: 72-78.

Glenn, E.P. & Doty, M.S. (1990) Growth of the seaweeds *Kappaphycus alvarezii, K. striatum* and *Eucheuma denticulatum* as affected by environment in Hawaii. Aquaculture, 84: 245-255.

Hayashi, L., de Paula, E.J. & Chow, F. (2007a) Growth rate and carrageenan analyses in four strains of *Kappaphycus alvarezii* (Rhodophyta, Gigartinales) farmed in the subtropical waters of Sao Paulo State, Brazil. J. Appl. Phycol., 19: 303-399.

Hayashi L., Hurtado A.Q., Msuya F.E., Bleicher-Lhonneur G. and Critchley A.T. 2010. A review of *Kappaphycus farming*: Prospects and constraints. In A. Israel, R. Einav J. Seckbach (eds.), *Seaweeds and their Role in Globally Changing Environments*, Cellular Origin, Life in Extreme Habitats and Astrobiology, 15, 251–283.

Hayashi, L., Oliveira, E.C., Bleicher-Lhonneur, G., Boulenguer, P., Pereira, R.T. L von Seckendorff, R., Shimoda, V.T., Leflamand, A., Vallée, P. & Critchley A.T. (2007b) The effects of selected cultivation conditions on the carrageenan characteristics of *Kappaphycus alvarezii* (Rhodophyta, Solieriaceae) in Ubatuba Bay, São Paulo, Brazil, J. Appl. Phycol., *19*:505–511.

Hayashi, L., Yokoya, N. S., Ostini, S., Pereira, R.T.L., Braga, E.S. & Oliveira E.C. (2008) Nutrients removed by *Kappaphycus alvarezii* (Rhodophyta, Solieriaceae) in integrated cultivation with fishes in re-circulating water. Aquaculture, 277: 185–191.

Hurtado-Ponce, A.Q. (1992) Cage culture of *Kappaphycus alvarezii* var. *tambalang*. J. Appl. Phycol., 4: 311-313.

Laserna, E.C., Veroy, R.L., Luistro, A.H., & Cajipe, G.J.B. (1981) Extracts from some red and brown seaweeds of the Philippines. Proc. Int. Seaweed Symp. 10: 443-448.

Luxton, D.M., Robertson M., & Kindley, M.J. (1987) Farming of *Eucheuma* in the South Pacific islands of Fiji. Hydrobiologia, 151/152: 359-362.

Mairh, O.P., Zodape, S.T., Tewari, A. & Mishra, J.P. (1999) Effect of nitrogen sources on the growth and bioaccumulation of nitrogen in marine red

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alga *Kappaphycus striatum* (Rhodophyta, Solieriaceae) in culture. Indian J. Mar. Sci., 28: 55-59.

Mendoza, W.G., Ganzon-Fortes, E.T., Villanueva, R.D., Romero, J.B. & Montan, M.N.E. (2006) Tissue age as a factor affecting carrageenan quantity and quality in farmed *Kappaphycus striatum* (Schmitz) Doty *ex* Silva. Botanica Marina, 49: 57–64.

Mmochi, A.J., Shaghude, Y.W., & Msuya, F.E. (2005) Comparative Study of Seaweed Farms in Tanga, Tanzania. Report submitted to USAID-ACDI/VOCA SEEGAAD Project, 37p.

Mshigeni, K.E. 1992. "Seaweed farming in Tanzania, a success story" In: Mshigeni, K.E., Bolton, J., Critchley, A. & Kiangi G. (eds.) Proceedings of the first international workshop on Sustainable seaweed resource development in Sub-Saharan Africa, Windhoek, Namibia, pp 221-245.

Msuya, F.E. 2006a. The impact of seaweed farming on the social and economic structure of seaweed farming communities in Zanzibar, Tanzania. In: Critchley, A.T., Ohno, M. & Largo, D.B (eds.) World seaweed resources: an authoritative reference system. Amsterdam, ETI BioInformatics.

Msuya, F.E. 2006b. Seaweed Farming as a Potential Cluster In: Mwamila, B.L.M. & Temu, A.K. (eds.). Proceedings of the Innovation Systems and Clusters Programme in Tanzania (ISCP-Tz): Cluster Initiative Launching Workshop, Dar es Salaam, Tanzania, pp 102-113.

Msuya, F.E. & Neori, A. (2002) *Ulva reticulata* and *Gracilaria crassa*: macroalgae that can biofilter effluent from tidal fishponds in Tanzania. Western Indian Ocean J. Mar. Sci., 1: 117–126.

Msuya, F.E. & Salum, D. (2006) The Effect of Cultivation Duration, Seasonality, and Nutrient Concentration on the Growth Rate and Biomass Yield of the Seaweeds *Kappaphycus alvarezii* and *Eucheuma denticulatum* in Zanzibar, Tanzania. Report submitted to the Western Indian Ocean Marine Science Association (WIOMSA) under the MARG I Contract no.5/2005, 24 pp.

Msuya, F.E., Shalli, M.S., Sullivan, K., Crawford, B., Tobey, J. & Mmochi, A.J. (2007) A Comparative Economic Analysis of Two Seaweed Farming Methods in Tanzania. The Sustainable Coastal Communities and Ecosystems Program. Coastal Resources Center, University of Rhode Island and the Western Indian Ocean Marine Science Association. 27p. (www.wiomsa.org, www.crc.uri.edu).

Ohno, M., Nang, H.Q. & Hirase, S. (1996) Cultivation and carrageenan yield and quality of *Kappaphycus alvarezii* in the waters of Vietnam. J. Appl. Phycol., 8: 431–437.

Parker, H.S. 1974. The culture of the red algal genus *Eucheuma* in The Philippines. Aquaculture, 3: 425-439.

Parsons, T., Maita, Y. & Lalli, C. (1984) A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press, New York., 170 pp.

Pettersson-Löfquist P. The Development of Open-water Algae Farming in Zanzibar: Reflections on the Socioeconomic Impact. Ambio, 1995; 24(7-8): 487-491.

Qian, P., Wu, C.Y., Wu, M. & Xie, Y.K. (1996) Integrated cultivation of the red alga *Kappaphycus alvarezii* and the pearl oyster *Pinctada martensi*. Aquaculture, 147: 21-35.

Rodrigueza, M.R.C. & Montano, M.N.E. (2007) Bioremediation potential of three carrageenophytes cultivated in tanks with seawater from fish farms. J. Appl. Phycol., 19:755–762.

Wakibia, J.G., Bolton, J.J., Keats, D.W. & Raitt, L.M. (2006) Seasonal changes in carrageenan yield and gel properties in three commercial eucheumatoids grown in southern Kenya. Botanica Marina, 49: 208-215.

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