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The viability of red alga (*Gracilaria salicornia)* seaweed farming for commercial extraction of agar at kibuyuni in kwale county South Coast Kenya

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Abstract
This experimental study investigated the growing and viability of the red seaweed *Gracilaria salicornia* for commercial extraction of agar; which has varied industrial uses. The study was carried out from January to December 2017 in Kibuyuni, South Coast Kenya, using the 'off-bottom' seaweed farming method. *G. salicornia* can withstand hash environmental factors unlike *Kappaphycus alvarezii* species, which was introduced in the area and failed to meet the livelihood needs of the communities. The seed yield, daily growth rate (DGR) and agar yield of *G. salicornia* were determined during the culture period and compared between three sampling sites and between the two monsoonal seasons. The statistical analyses show that the mean annual seed yield (wet yield rope^{-1}), DGR (%) and agar yield (% dry weight) were generally similar in all the sampling sites and seasons (p>0.05), suggesting that *G. salicornia* can be grown throughout the year at Kibuyuni.

Keywords: seaweed, gracilaria salicornia, seed yield, growth rate, agar, marine algae

1. Introduction
Seaweeds are species of macroscopic multicellular marine algae that are classified as red, brown and green seaweed types. Seaweeds products are used in food, pharmaceutical and cosmetic industries [1]. Seaweed farming has provided economic opportunities to many coastal communities in Indonesia, Philippines, Tanzania and Malaysia [1]. Red seaweed genera under cultivation include *Kappaphycus* and *Eucheuma*, which are primary raw materials for carrageenan while *Gracilaria* and *Nori* are used as raw materials for agar and for direct human consumption respectively. Agar and carrageenan are thickening and gelling hydrocolloids used as food additives and the demand has increased due to increased consumption of processed food [1].

The major challenges facing seaweed farming globally include the prevalence of epiphytes due to reliance on a highly limited genetic stock, vulnerability to natural disasters, marine environment user conflicts, non–indigenous pests and pathogens and occurrence of ice-ice disease [2]. Suitable seaweed farming methods include the off-bottom, long line, rock-based farming and floating rafts methods. The potential market for seaweed has been identified [3].

Two species of seaweed, *Kappaphycus alvarezii* and *Eucheuma denticulatum,* are grown in the South coast of Kenya and while *K. alvarezii* fetches high commercial returns in the global markets its poor growth performance has undermined the potential economic benefits and livelihood needs of the farmers [4].

Gracilaria seaweed genera are geographically widely cultivated in warm-water in tropical regions and have the potential for commercial production of agar. *Gracilaria salicornia* is a natural marine biomass with several applications including production of agar [5]. The tropical conditions of the Kenya coast is ideal for the cultivation of *G. salicornia,* which can be up scaled for commercial production of agar. The aim of this study was to investigate the growing and viability of the red seaweed *G. salicornia* for commercial extraction of agar, as well as diversify the varieties of seaweeds farmed at the coast of Kenya, owing partly to the collapse of *Kappaphycus alvarezii* farming.

2. Materials and Methods

2.1 Study Area

The study was carried out at Kibuyuni in Shimoni on the Msambweni-Vanga shoreline in the South Coast region of Kenya on latitude 4° 30' - 4° 35'S and longitude 39° 22'- 39° 27' E (Figure 1).

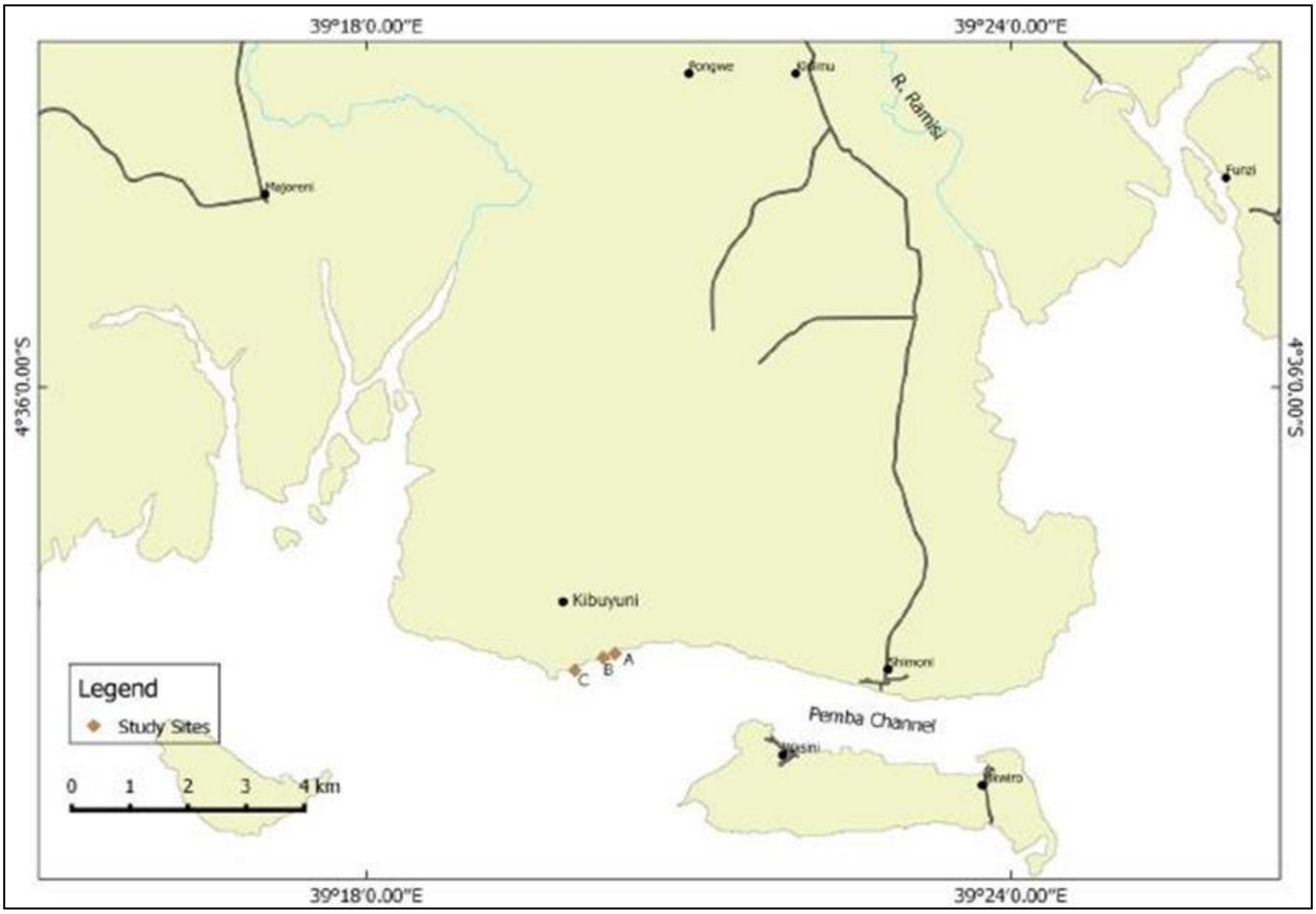

Fig 1: Map of the South Coast of Kenya showing seaweed farming areas

The experiment was conducted at three different experimental farm plots: A (4^{0} 38'.546S and 39^{0}20'.310E), B (4^{0}38'.589S and 39^{0}20'.310E) and C (4^{0}38'.708S and 39^{0}19'.941E). Cultivation of *G. salicornia* was done using the off-bottom method in shallow intertidal zone waters at an approximate depth of about 3.2 m at the highest tide, often exposed during spring low tide [6]. It is on these experimental sites that *G. salicornia* was grown and where growth rate and yield rate variables were obtained. The agar extraction process was carried out in the Kenya Marine and Fisheries Research Institute's laboratory.

A randomized experimental design was employed, where experimental farms were established and growth trials carried out. Three study plots were randomly identified at Kibuyuni experimental site taking care of the spatial environmental factors such as temperature and salinity. Each of the plots measured 10 m by 1.5 m in length and width respectively. Each plot had three ropes of *G. Salicornia* seedlings and one empty control rope, each measuring 10 m in length and 3 mm in diameter. The data was collected during seven experimental culture periods each lasting 42 days between January 2017 and December 2017 throughout both the North East Monsoon (NEM) and South East Monsoon (SEM) seasons.

2.2 Cultivation Methods and Growth Measurements

Wooden pegs, each measuring approximately 1.5 m and 10 cm in length and diameter respectively were driven into the sea bottom using a mallet and spaced 0.5 m apart in straight rows. Vegetative cuttings of *G. salicornia* seedlings with vigor from the wild, each weighing 50 g were tied 20 cm apart using cut pieces of monoline twines (tie-tie) fitted onto polypropylene ropes, each measuring 10 m and 3 mm in length and diameter respectively. Each rope was fitted with 50 tie-tie twines, thus each rope had 50 seedlings with a sum weight of 2.5 kg. The ropes were tied to the wooden stakes at opposite ends and suspended approximately 20 cm above the sea bottom.

Weights of individual seedlings and culture ropes were taken using a calibrated spring balance to the nearest 0.1 g during the study period.

Seed yield, expressed as (kg) rope-^{1} was determined using the following modified formulas that include the initial fresh weight of transplants:

$$Y = Wf - Wo/Lt,$$ [8] ....Eq. 1

Where *Wf* is the final fresh weight (kg), *Wo* is the initial fresh weight (kg); L is the total Length (m) of rope harvested.

The daily growth rate (DGR) was converted into % growth day^{-1} and calculated using the following formula taking into account exponential growth:

$$DGR\ \% = \ln(w_f/w_o)/t \times 100,$$ [9] ....Eq. 2

Where w_f is the final fresh weight (g) at t day, wo is the initial fresh weight (g); t is the number of culture days.

2.4 Extraction of Agar Content

Samples of *G. salicornia* were randomly collected from harvested plant from each of the 3 culture ropes per plot after 42 days of culture period and dried separately. Native agar extraction was then done according to the method described by Wakibia *et al.* [10].

The following formula was used to calculate the agar yield:

$$\%\text{Agar yield} = \frac{\text{Weight of agar gel}}{\text{Weight of algal powder}} \times 100 \ [10] \quad \text{Eq.3}$$

2.5 Data Analysis

The seed yield rate and growth rate data were calculated from 21observations in each site, the agar extract data was calculated from 7 observations in each site. A total of 12 observations were made during the NEM season and 9 observations during the SEM season. Similarly 4 and 3 agar extract observations were made in NEM and SEM respectively.

The data obtained were processed and analyzed using Microsoft ® Excel and Minitab ® software for a One way ANOVA statistical test to test the differences in the mean annual seed yield and daily growth rate between the three sampling sites, non-parametric Kruskal-walis test, to test the agar yield between the three sampling sites and the Mann-Whitney U Test, to test variation in the mean value of the variables between the two seasons at a significance level of 0.05 (p>0.05).

3. Results

3.1 Annual Growth of *G. salicornia*

The annual *G. salicornia* seed yield per rope at the experimental plots showed that the mean seed yields at the three experimental plots were generally similar [A= 3.500± 0.621, B=3.833 ± 0.571, C=3.822 ± 0.828 (Mean (± SD)]. The lowest seed yield was recorded at plot A, while the highest seed yield was recorded at plot B. However, the One Way ANOVA analysis shows that there is no significant difference in mean seed yields between the experimental plots (Table 1).

Table 1: Seed yield (kg) rope^{-1} of *G. salicornia*

Experimental Periods	Culture Ropes	Seed yield (kg) rope-1 of G. salicornia in experimental plots		
		Plot A	Plot B	Plot C
1st	1	3.100	3.839	3.558
	2	2.758	3.378	3.749
	3	3.171	3.703	3.711
2nd	1	3.700	4.032	4.494
	2	3.564	4.494	3.430
	3	3.564	4.387	4.600
3rd	1	3.648	3.767	3.378
	2	3.566	3.378	2.711
	3	3.304	3.502	2.771
4th	1	3.159	2.798	2.904
	2	3.105	3.337	3.346
	3	4.661	3.759	2.944
5th	1	5.088	4.500	5.314
	2	3.250	5.198	4.786
	3	4.000	4.625	5.397
6th	1	4.019	3.968	3.570
	2	3.839	3.818	3.136
	3	3.822	3.548	3.167
7th	1	2.563	3.833	4.064
	2	2.881	3.711	4.863
	3	2.748	2.929	4.373

Table 2: Daily growth rate (DGR %) rope^{-1} of *G. salicornia*

Experimental Periods	Culture Ropes	Daily growth rate (DGR%) of *G. salicornia* in experimental plots		
		Plot A	Plot B	Plot C
1st	1	0.512	1.021	0.840
	2	0.234	0.716	0.965
	3	0.566	0.935	0.941
2nd	1	0.933	1.138	1.396
	2	0.844	1.396	0.753
	3	0.844	1.339	1.452
Table 2 continued				
3rd	1	0.899	0.976	0.716
	2	0.845	0.716	0.193
	3	0.664	0.803	0.245
4th	1	0.557	0.268	0.357
	2	0.516	0.688	0.694
	3	1.483	0.971	0.390
5th	1	1.692	1.399	1.795
	2	0.625	1.743	1.546

	3	1.119	1.465	1.832
6th	1	1.130	1.100	0.848
	2	1.021	1.008	0.540
	3	1.011	0.833	0.563
7th	1	1.122	2.575	1.157
	2	0.753	2.003	2.116
	3	1.144	0.474	1.746

3.2 Seasonal Growth of *G. salicornia*

The mean seasonal seed yield rope^{-1} of *G. salicornia* are shown in Figure 2. The lowest mean seed yield rope^{-1} during NEM and SEM seasons were recorded at experimental plots A and C respectively. Conversely, the highest mean seed yield rope^{-1} was recorded at plots C and B respectively. Mann-Whitney U Test showed that there is no significant differences in the median seed yield rope^{-1} of *G. salicornia* between seasons at the three experimental plots.

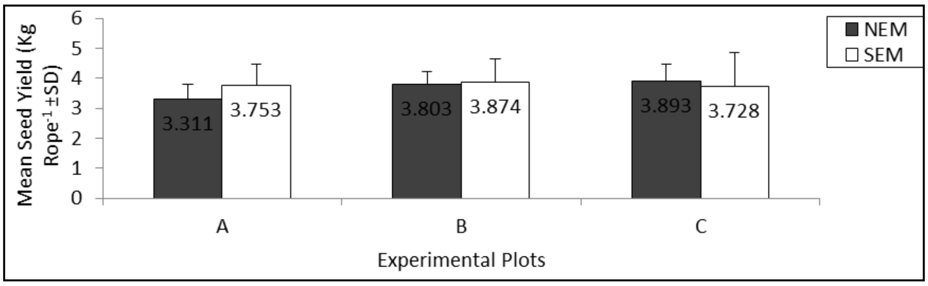

Fig 2: Mean seed yield of *G. salicornia* during NEM and SEM seasons

The mean daily growth rate (%) of *G. salicornia* was higher at plots B and C respectively during NEM season compared to SEM season. Conversely the mean daily growth rate of *G. salicornia* at plot A was higher during the SEM season compared to NEM season. However, the Mann-Whitney U Test revealed that there is no significant differences in the median daily growth rate (and, hence, the mean daily growth rate) of *G. salicornia* between seasons at the three experimental plots (Figure 3).

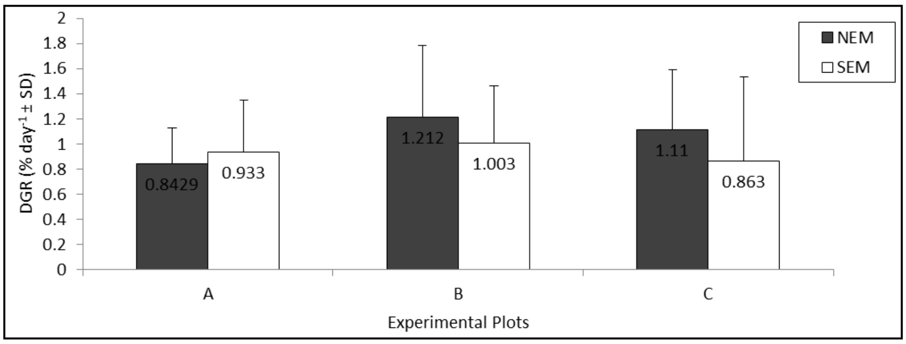

Fig 3: Mean daily growth rate (%) of *G. salicornia* at experimental plots during NEM and SEM seasons

3.3 Agar Yield

The annual agar yield had lowest dry weight value (40.4%) was obtained in plot A during the seventh experimental period, while the highest dry weight value was roughly 59% in plots A, B and C during the second, first and fifth experimental periods respectively. The mean annual agar yield in the three plots were similar (Mean (± SD): A=51.70 ± 6.74, B=51.94 ± 5.63, C=51.16 ± 5.46). The annual ranges of agar yield are; 40.42 - 59.43, 42.75 - 59.00, 44.89 - 58.82 (% dry weight) at plots A, B and C respectively and the Kruskal-Wallis statistical test revealed that there is no significant difference in the median percentage agar yield (Table 3)

Table 3: Annual agar yield (% dry weight) of *G. salicornia*

Experimental Plots	Percentage agar yield of *G. salicornia* in plots from the experimental replicates						
	1	2	3	4	5	6	7
A	46.8	59.4	57.8	55.3	48.8	53.3	40.4
B	59	42.8	48.6	57.9	49.3	53	53
C	52.5	56.2	47.6	44.9	58.8	53.1	45

3.3.2 Seasonal Agar Yield

The mean agar yield (% dry weight) of *G. salicornia* between seasons did not vary much except in plot A. The highest mean agar yields were 51.94 and 53.97 (% dry weight) in NEM and SEM respectively (Fig. 4). However, there were no significant differences in the median agar yield (% dry weight) of *G. salicornia* between seasons according to Mann-Whitney U Test.

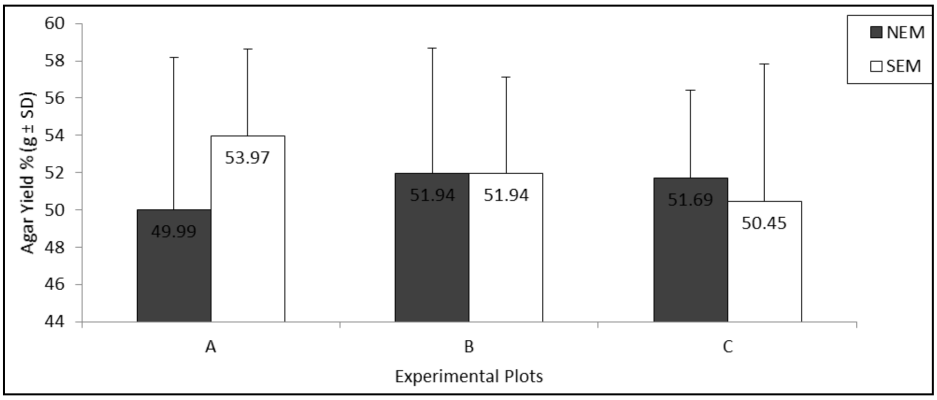

Fig 4: Mean agar yield (% dry weight) of *G. salicornia*

4. Discussion

The seed yield (wet weight rope^{-1}) of *G. salicornia* compares favorably with the results from another study in Chile where *Gracilaria sp*. attained an average density of 2.5kg (s.d ± 1.10) m^{-1} of rope [11]. The daily growth rates of *G. salicornia* obtained at the three experimental plots are in agreement with those from a similar study on *G. salicornia* [12]. The average growth rate of *G. salicornia* growing in dense beds was found to be ranging from 0.03 % - 1.28 % day^{-1}. Another study revealed that *G. salicornia* could attain daily growth rate of 6.04 % - 10.77% day^{-1} [13]. The variation in the growth of *G. salicornia* from these studies indicates that its growth is dependent on locality in relation to environmental conditions. The daily growth rate of *G. salicornia* at Kibuyuni compares fairly with the growth from elsewhere and therefore suggests suitability of the study area for commercial cultivation.

The seed yield of *G. salicornia* during the NEM and SEM seasons suggest that seasonality had no great influence on the growth of *G. salicornia* at Kibuyuni farming site. These results differ from a previous study where commercial farming of Gracilaria was done in Luderitz, Namibia where the suspended rope cultivation system was used. The Namibian alga showed a marked seasonal variation in growth reaching a maximum daily growth rate of 11.0 ± 1.56% (Mean SD) in spring decreasing towards autumn, reaching a minimum daily growth of 2.9±1.45% which gradually increased in winter [14].

Seasonality did not significantly influence the daily growth rate of *G. salicornia* within the experimental plots at Kibuyuni at (p>0.05). The results of growth rate analysis indicate that the growth of the test species was fairly similar during the two seasons within individual plots. The daily growth rates suggest that the seaweed species is resilient to seasonal environmental factors, perhaps because it is indigenous to the study area. Gracilaria *Sp*. can tolerate a wide range of temperatures, salinity and light intensities [15], which may partly explain the above observed phenomenon.

The annual ranges of agar yield is in concurrence with the both the seed yield and daily growth rate findings. The annual agar yield of *G. salicornia* in this study suggests that the agar yield of *G. salicornia* may be associated with both its seed yield and growth rate. The agar yields from gracilarioid isolates was found to range from 34.0% to 47.0% and 15.0% to 27.0% for native and alkali treated agars, respectively [10]. Another study reported native agar yields of 41.6 to 49.1% for *G.gracilis* [16], which also compared favorably with 43.3% obtained for *G. chilensis* in Chile [17]. The agar yield rates of *G. salicornia* obtained indicate that there is potential for commercial farming of the seaweed species at Kibuyuni.

The results of agar yield harvested during NEM or SEM seasons at Kibuyuni at were not different (p>0.05) and, suggests that the agar yield of *G. salicornia* was not influenced by the two seasons. These results again mimic the seasonal results regarding both the seed yield and daily growth rate of *G. salicornia* as described above. However, in a study conducted in Tanzania where seasonal agar yield of *G. salicornia* from Oyster Bay and Chwaka bay were determined the agar yield varied from 13.7 to 30.2% (dry weight) and was highest during the dry NEM period. Thus the study recommended NEM winds as the best period for harvesting *G. salicornia* for agar production in Tanzania [18]. The present study shows that the agar yield from *G. salicornia* grown in Kibuyuni is roughly twice that reported from Tanzania and thus further indicates possible viability of commercial farming of the native seaweed for commercial production of agar.

5. Conclusions

The similar mean annual values of seed yield, daily growth rate and agar yield of *G. salicornia* between experimental plots and seasons suggest that the environmental factors at Kibuyuni farming site are uniformly distributed and thus the area is potentially viable since its critical growth and agar yield values compared favorably with those of similar studies undertaken elsewhere and deemed to be feasible. There is also the potential for cultivation of *G. salicornia* for commercial extraction in Kibuyuni area.

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7. References

1. Valderrama D, Cai J, Hishamunda N, Ridler N. Social and economic dimensions of carrageenan seaweed farming. Fisheries and Aquaculture Technical Paper No. 580. Rome, FAO. (Eds.), 2013, 204pp.
2. Cottier-Cook EJ, Nagabhatla N, Badis Y, Campbell ML, Chopin T, Dai W *et al*. Safeguarding the future of the global seaweed aquaculture industry. United Nations

University (INWEH) and Scottish Association for Marine Science Policy Brief, 2016, 2. ISBN, 978-92-808-6080-1.
3. Becker KJ, Rotmann KWG. A marketing approach to agar. Journal of Applied Phycology. 1990; 2(2):105-110.
4. Macharia I, Kimani E, Syanda J, Kosiom T, Koome F. Post-Monitoring of seaweed, *Kappaphycus alvarezii* in Coast region of Kenya. http://www.kephis.org/phytosanitary2018/images/docs/presentations/6PosTMonitoringofimportedseaweedKappaphycusalvareziiinKwaleCountyV2.pptx.
5. Hurtado-Ponce AQ, Samonte GP, Luhan MR, Guanzon N. Gracilaria (Rhodophyta) farming in Panay, Western Visayas, Philippines. Aquaculture. 1992; 105(3-4):233-240.
6. Wakibia JG, Bolton JJ, Keats DW, Raitt LM. Factors influencing the growth rates of three commercial eucheumoids at coastal sites in southern Kenya. Journal of Applied Phycology. 2006; 18:565-573.
7. De San M. The farming of seaweeds. Smart Fish, 2012, 29.
8. Doty MS. Estimating returns from producing *Gracilaria* and *Eucheuma* on line farms. Monograph of Biology. 1986; 4:45-62.
9. Dawes CJ, Lluisma AO, Trono GC. Clonal propagation of *Eucheuma denticulatum* and *Kappahycus alvarezii* for Philippine farms. Hydrobiologia. 1993; 260-261:379-383.
10. Wakibia JG, Anderson RJ, Keats DW. Growth rates and agar properties of three gracilarioids in suspended open-water cultivation in St. Helena Bay, South Africa. Journal of Applied Phycology. 2001; 13(3):195-207.
11. Gonzalez MA, Montoya R, Candia A, Gomez P, Cisternas M. Organellar DNA restriction fragment length polymorphism RFLP and nuclear random amplified polymorphic DNA RAPD analyses of morphotypes of Gracilaria Gracilariales, Rhodophyta from Chile. Hydrobiologia. 1996; 326-327:229-234.
12. Nelson SG, Glenn EP, Moore D, Ambrose B. Growth and Distribution of the Macroalgae *Gracilaria salicornia* and *G.parvispora* (Rhodophyta) Established from Aquaculture Introductions at Moloka‘i, Hawai‘i. Pacific Science. 2009; 63(3):383-396.
13. Smith JE, Hunter CL, Conklin EJ, Most R, Sauvage T, Squair C *et al*. Ecology of the invasive red alga *Gracilaria salicornia* (Rhodophyta) on O‘ahu, Hawai‘i. Pacific Science. 2004; 58:325-343.
14. Critchley A. Growth Rates and Agar Quality of Gracilaria gracilis (Stackhouse) Steentoft from Namibia, Southern Africa, *in* Botanica Marina. 1996; 39(3):273-280.
15. Israel A, Martinez-Goss M, Friedlander M. Effect of salinity and pH on growth and agar yield of Gracilaria tenui stipifafa var. lial in laboratory and outdoor cultivation. Journal of Applied Phycology. 1999; 11:543-549.
16. Wilson AJ, Critchiey AT. Studies on Gracilaria gracilis (Stackhouse) Steentoft, Irvine and Farnham and Gracilaria aculeata (Hering) Papenfuss from southern Africa. II. Agar production. South African Journal of Botany. 1998; 64(2):110-115.
17. Matsuhiro B, Urzua C. Agars from *Gracilaria chilensis* (Gracilariales). Journal of Applied Phycology. 1990; 2:273-279.
18. Buriyo AS, Kivaisi AK. Standing stock, agar yield and properties of *Gracilaria salicornia* harvested along the Tanzanian coast. Western Indian Ocean Journal of Marine Science. 2003; 2:171-178.