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Protocols for successful commercial farming of *Kappaphycus alvarezii,* a potential carrageenophyte in Indian waters

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ABSTRACT

Seaweed commercial farming has a long history. At present approximately 221 species of seaweeds are used worldwide for food and phytochemicals (agar, algin and carrageenan), of which about 10 species or genera are being intensively cultivated viz., brown algae *Laminaria japonica* and *Undaria pinnatifida*; red algae *Porphyra, Eucheuma, Kappaphycus* and *Gracilaria*; green algae *Monostroma* and *Enteromorpha* and the other two being micro algae. Recently released FAO statistics showed that the world seaweed aquaculture production in 2012 was 23.78 million tons wet. Around 30 countries have introduced carrageenan yielding seaweeds viz., *Eucheuma, Kappaphycus, Chondrus, Sarcothalia* and *Griffithsia* to evaluate their potential biomass production under cultivation. However, warm water seaweeds such as *Kappaphycus alvarezii* and *Eucheuma denticulatum* have been cultivated substantially and commercially. *Kappaphycus* alone has been introduced in 26 countries and its production in the world through cultivation alone has been reported to be 1, 83,000 tons dry in 2010. Its production in Indian waters has been very meagre ie., 1490 tons wet. In India *Kappaphycus alvarezii* cultivation is of recent origin ie., it has been introduced by Dr. P. V. Subba Rao, CSMCRI – MARS (CSIR) during his tenure as Scientist-in-Charge in the last quarter of 1995 at Thonithurai (Mandapam), near Pamban bridge, in Gulf of Mannar waters of Bay of Bengal on the Southeast coast of India. Its cultivation has got a boost with the sanction of a project by the Department of Biotechnology (DBT), New Delhi (2006 to 2009) to Aquaculture Foundation of India (AFI), Chennai which has introduced a five member self help groups (SHGs) to rehabilitate the Tsunami affected fisherfolk in Tamil Nadu and this project has been accomplished along with PepsiCo India Holdings Private Llimited, Gurgoan, Haryana. Subsequently some companies such as Aquagri Processing Private Limited, New Delhi, Linn Plantae Private Limited, Madurai and SNAP Natural and Alginate Products Private Limited, Ranipet are involved in cultivation as a tie up with SHG's on a buyback agreement. Its cultivation has been expanded commercially in the coastal waters of Ramanathapuram, Pudukkottai, Tanjore and Tuticorin Districts in Tamil Nadu. However, its cultivation has been taken up very recently at a few places along Gujarat coast and at two places along Andhra Pradesh coast. In several places, commercial cultivation has failed due to unforeseen and unacquainted problems. Companies are standardizing the products derived from fresh seaweed as biostimulent and from dry seaweed as semi refined carrageenan (SRC). Lack of awareness and proper knowledge among the farmers and lack of support from Government has become the impediments for developing commercial farming in new localities. The protocols for site selection, standardization of cultivation methods and crop logging for successful commercial farming of *Kappaphycus alvarezii* at new locations are reviewed and discussed in this paper.

Introduction

Kappaphycus alvarezii is a red seaweed yielding *kappa* carrageenan. Around 30 countries have introduced carrageenan yielding seaweeds viz., *Eucheuma, Kappaphycus, Chondrus, Sarcothalia* and *Griffithsia* to evaluate their potential biomass production under cultivation (Neish, 2008). However warm water seaweeds such as *Kappaphycus alvarezii* trade name "cottonii" and *Eucheuma denticulatum* trade name "*spinosum*" have been cultivated substantially and commercially (FAO, 2013). *K. alvarezii* alone has been introduced in 26 countries (Chandrasekaran *et al*., 2008; Mandal *et al*., 2010; Sureshkumar *et al*., 2016) and its

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production in the world through cultivation alone has been reported to be 1, 83,000 tons dry (Bixler and Porse, 2011). As per FAO (2013) report rapid expansion of *Kappaphycus* and *Eucheuma* cultivation from 2000 has resulted the production increase from 944, 000 wet tons (in 2000 - 48% of the total red seaweed production) to 5, 600, 000 wet tons in 2010 (63% of total red seaweed production) with the increase in farm gate value from US$ 72 million to US$ 1.4 billion. Their production level has also surpassed that of Japanese kelp (*Laminaria japonica*) production in 2010 (FAO, 2014). As per FAO (2013) report major carrageenan seaweed producing countries included Indonesia (60.5%), Philippines (31.9%), Malaysia (3.7%), United Republic of Tanzania (2.3%), China (1.1%) and other countries (0.4%). Its production in Indian waters has been very meagre ie. 1490 tons wet in 2010 (Krishnan and Narayanakumar, 2013).

In India, *Kappaphycus alvarezii* was introduced in September 1995 at Thonithurai (Mandapam near Pamban Bridge), in Gulf of Mannar waters of Bay of Bengal, Southeast coast of India by Dr. P. V. Subba Rao, the then Scientist in Charge, Marine Algal Research Station (MARS), Mandapam Camp, Tamil Nadu, a unit of Central Salt & Marine Chemicals Research Institute (CSMCRI) Bhavnagar, Gujarat – a National Laboratory of Council of Scientific and Industrial Research (CSIR), Ministry of Science and Technology, Government of India), New Delhi. Indian *Kappaphycus* owed its origin from Philippines although it was brought from Japan during 1984 for research and cultivation, after following the necessary quarantine and introduction procedures (Mairh *et al*., 1995; Mandal *et al*., 2010). Its introduction and domestication in Indian waters have been published by Subba Rao *et al*. (2008) and Periyasamy *et al*. (2014). After repeated domestication and experimentation at Mandapam, PepsiCo India Holdings Private Limited, Gurgaon took up this cultivation after getting it transferred in 2001 from CSMCRI, Bhavnagar, Gujarat and in July 2008 PepsiCo India Holdings Private Limited transferred the project to M/s Aquagri Processing Private Limited, New Delhi. Its cultivation has got a boost with the sanction of a project by the Department of Biotechnology (DBT), New Delhi (2006 to 2009) to Aquaculture Foundation of India (AFI), Chennai which introduced a five member self help groups (SHGs) to rehabilitate the Tsunami affected fisherfolk in Tamil Nadu. This project has been accomplished with PepsiCo India Holdings Private Limited, Gurgoan, Haryana. Subsequently some companies such as Aquagri Processing Private Limited, New Delhi, Linn Plantae Private Limited, Madurai and SNAP natural and alginate products private limited, Ranipet are involved in cultivation as a tie up with SHG's on a buyback agreement. Its cultivation has been expanded to other localities of Ramanathapuram, Pudukkottai, Tanjore, Tuticorin and Kanniyakumari Districts in Tamil Nadu, a few places in Gujarat and at two places in Andhra Pradesh. However, commercial farming has been going on only in Tamil Nadu ie., along the coastal waters of Ramanathapuram, Pudukkottai, Tanjore and Tuticorin districts in Tamil Nadu. In several places, commercial cultivation has failed due to apathy and lack of awareness among the farmers and lack of support from Government. Companies involved in seaweed industry are standardizing the products derived from fresh seaweed as bio-stimulant and from dry seaweed as semi refined carrageenan - (SRC). There is an urgent to need develop commercial farming of this seaweed in new locations to effectively meet the demand of the products (bio-stimulant and SRC). The protocols needed for site selection, crop handling and standardization of cultivation methods and crop logging for the successful commercial farming of *Kappaphycus alvarezii* at new locations are reviewed and discussed in this paper.

Advantages for cultivating *Kappaphycus alvarezii*

Kappaphycus cultivation has socioeconomic advantages in the creation of self employment opportunity for the livelihood of coastal rural people in India and improves their living standards (Periyasamy *et al*., 2014a; 2014b; 2015). Further, this cultivation does not involve sophisticated and expensive infrastructure or highly needed expertise which could be the reason for its big popularity in the countries where its cultivation has been introduced and adopted by the people as source of livelihood (Bast, 2014). Besides possessing the tendency of fast growth, easy handling has proved to be of tremendous advantage (Sureshkumar *et al*., 2016). Moreover this cultivation provides climate protection and help in carbon sequestration to mitigate global warming (Hayashi *et al*., 2010). Besides these the seaweed itself has following advantages (1) It is an autotrophic plant; (2) Propagates vegetatively through cuttings without a sexual phase; (3) Cultivation does not involve application of fertilizer, growth hormones, pesticides, insecticides, herbicides etc and is totally organic; (4) Cultivation technology is simple and eco-friendly; (5) Seeding the raft/ net bag, harvesting the same by pulling on to the shore and sun drying and these are shore-based activities; (6) Two to three persons of a family may handle this activity with an average income of Rs.15, 200/- to Rs.17, 200/- per month/ person; (7) It enhances biodiversity; (8) Farming, harvesting and processing generate opportunity for employing thousands of men and women of the coastal poor people. (9) Nationalised banks provide loans to SHGs even without collateral security up to Rs. 5.0 lakh/SHG; (10) An excellent rehabilitation programme for fisherfolk away from fishing activity and it will pave the way to reduce fishing pressure and reduce over-exploitation of fishery resources; (11) It is the major source for *kappa* carrageenan, besides its use in food formulations and pharmaceutical industries; (12) The raw material may be used as manure/ fertilizer. Liquid Seaweed Fertilizer (LSF) may be extracted for its use as foliar spray for commercial crops; (13) It may be eaten raw or used in salad and (14) It will pave the way for establishment of carrageenan industry and stops the import of carrageenan (Periyasamy *et al*., 2016a).

Seaweeds have played an important role in creating an organic agricultural revolution elsewhere because of their role as a source of growth promoters and micro nutrients (Boney, 1965; Khan *et al*., 2009). Experiments using liquid seaweed fertilizer (LSF) from *Kappaphycus alvarezii* have proved to increase growth from 10% to 40% in several crop plants like rice, sugarcane, ground nuts, corn, wheat etc (US 6893479 b2). Successful farming is defined as socially, economically and environmentally sustainable production. *Kappaphycus* farming has been proved sustainably both socially and economically in different countries (Philippines, Indonesia, Malaysia, Tanzania, China etc.). Successful *Kappaphycus* farming requires the following steps (a) Selection of sites (b) Selection and standardization of farming methods and (c) Crop logging procedures.

A. Selection of sites

Protocols must be developed with a clear understanding of what seaweeds need in order to grow. Seaweeds differ from animals in aquaculture in the following way. They get all the nutrients from the seawater that moves fast and do photosynthesis on their own (no need of feeding), utilize carbon dioxide and releases oxygen (opposite to animals), nitrogen compounds released by the animals are crucial nutrients to seaweeds and they won't move like animals and are suspended in the water column. For selecting a farming location, one has to understand the basic elements required for *Kappaphycus* farming and farming site characters.

Basic elements for farming

Seawater temperature

It affects the plants directly by disturbing the physiological processes or indirectly impacts the surrounding environment. For example temperature affects the water motion, generating wind, waves and currents and farm productivity. *Kappaphycus* could grow well in the temperature ranging from 22.8 to 29.2 ^{0}C (Ohno and Orosco, 1987). Njoman *et al*. (1987) found that temperatures from 27 to 32^{0}C were most effective for the growth of *Kappaphycus* on the Southwestern shore of Sumatra. Farmers reported rapid growth and high biomass production of *Kappaphycus* during the months characterized by seawater temperatures ranging from 25 to 30^{0}C (Neish, 2003). In India, *Kappaphycus* growth rate was high during north east monsoon due to less seawater temperature. *Kappaphycus* could yield good growth and biomass at temperature of 30^{0}C ± 3^{0}C (Subba Rao *et al*., 2008; Periyasamy *et al*., 2014a; 2015; Sureshkumar *et al*., 2016). In general, at high temperature above 35^{0}C the seaweed won't survive much. Ohno and Orosco (1987) and Mairh *et al*. (1986) reported that *Kappaphycus* transferred in November 1983 to Tosa Bay, Japan from the central Philippines was dead, when the temperature fell below 20^{0}C. Thus seawater temperature is one of the most important factors influencing the growth of *Kappaphycus*.

Water motion

Water motion has generally been noted when *Kappaphycus* grows best. Water motion helps to clean plants, bring fresh nutrients, remove metabolites and apply hydraulic forces that stimulate plant growth. In San Bernardino Strait, Philippines, where rapidly flowing water produced *Kappaphycus* plants as much as two metres long and with major branches more than 2cm across (Neish, 2003). Effects of water motion are confused with those of temperature, light and nutrients. Azanza *et al*. (1996) reported the importance of water motion in the seeding or natural sporulation experiments done in *Eucheuma* and *Kappaphycus* farms in Philippines. Water motion is an important factor to be taken into account during the selection of farm sites and crop logging (Periyasamy *et al*., 2015; 2016a).

Salinity and water quality

The salinity and nutrition are critically important for seaweed growth. At most successful farm sites salinity seemed to be in the order of 30 to 35 ‰ (Neish 2003; Periyasamy *et al*., 2016a). Salinity and terrestrial influence are significant for seaweeds in both negative and positive ways. In terrestrially contaminated waters, *Kappaphycus* grew at about half its normal growth. Nutrients such as phosphate, nitrate, nitrite and silicates also play an important role for *Kappaphycus* growth. Among the macronutrients, nitrogen is crucial for productive farming and this nutrient might be a limiting factor in sea cultures (Mairh *et al*., 1999; Neish, 2008). According to the site fertility concept, seaweed growth rate would be regulated by a complex interaction of irradiation, temperature, nutrients and water movement (Santelices, 1999). Some of these factors might interact regulating the growth target species and the major decline of one factor (for example, nutrients) could be compensated by some other factor (water movement). Thus, in environments with low or erratic nutrient supply, surge ammonium uptake was described for *K. alvarezii* as a strategy to avoid nitrogen limitation of growth (Dy and Yap, 2001).

(iv) Light

Exposure to optimal amounts and wavelengths of photosynthetically active radiation is undoubtedly essential for *Kappaphycus* seaplants as it is for other plants. Mairh *et al*. (1986) found that maximum growth rates in *Kappaphycus striatum* were obtained with a 12:12 L: D cycle at 6000 lμx and the growth rates started to drop above about 10000 lμx. Photosynthesis in *Kappaphycus* above a diurnal pattern showed a peak in late morning and it also appeared that excessive light could have deleterious effects on the growth of *Kappaphycus* seaweed. Dawes (1992) found that different responses on exposure to light and as a general rule it appeared that the darker the plant, the more stored nitrogen it contained.

Site characteristics

The basic elements of seaweed growth dictate that successful farm systems must have the following features as advocated by Neish (2003). (1) Large surface area exposed to sunlight having optimum characteristics, (2) Effective even water flow to and from all plants in the system, (3) Even dispersion of plants throughout the farm sites, (4) Amenable to frequent cropping, cleaning and adhering so weeds, pests, disease and fouling organisms cannot overrun seaplant cultures, (5) Rugged enough to withstand the substantial hydraulic forces of moving water and wind, (6) Located in places with environmental conditions as close to ideal as possible for the crops being grown, (7) Minimal fixed and variable production costs, (8) Protected from weather and sea conditions beyond farm habitats structural limits, (9) Secure from human interferences and (10) Ultimately the only way to find out whether a given site supports vigorous plant growth is to plant test plots and expand where plants grow best.

Only growing plants over several seasons confirm which locales are the best. Site selection is critical to farm success. Site choice can lead to project failure or to success and competitive advantage. Critical factors at a good site are as follows: (1) Communities of people willing and able to become effective seaweed farmers; (2) Clean nutrient rich water at the right temperature, 3. Low probability of force critical episodes due to natural or human causes; (4) Access to essential inputs, infrastructure and resources at attractive cost and (5) A stable friendly climate for business, political and socioeconomic activity. Among the different water bodies such as semi enclosed or enclosed land pounded systems (Backwaters), Ponds (Prawn, milk fish, etc.), protected salt water bodies (Bay, cannels and other inlets) and open water ocean systems, salt water bodies are preferred for *Kappaphycus* farming. The enclosed or enclosed land pounded systems (Backwaters) and ponds were not suitable because of expensive operational cost and variations in essential parameters. In open water ocean systems, large available area and sites tend to be less effected by seasonality, grazing and some other problems of near shore operation. Commercial *Kappaphycus* farming were proved in different coastal waters in India ie., shallow water (Periyasamy *et al*., 2014a; 2015), lagoon open seawater (Subba Rao *et al*., 2008; Sureshkumar *et al*., 2016) and open sea (Periyasamy *et al*., 2016c).

Selection and standardization of farming methods

The fundamental basis of seaweed agronomy is that the farmer works with other people to create habitats suitable for the desired crops with in natural environments. The farmer uses different farming methods to monitor the status and behavior of the fundamental elements as follows and then, to the best of his/ her ability, the farmer manages and controls the farm system to profitably produce salable crop. Elements of this process are crop, habitat, environment and people. These elements have to be controlled and monitored. The commercial success of *Kappaphycus* farming is based on the fact that these plants produce vegetative thalli large enough to be economically planted as cuttings and harvested individually. Commercial farming of *Kappaphycus* was adopted using different method during the earlier days. Worldwide different cultural techniques were in practice for *Kappaphycus* farming. But in most of the places either raft or monoline cultures were widely used. In India, raft method and monoline open methods are widely used in the places where the wave motion is relatively calm. Monoline netbag and monoline tubular methods were used in the heavy wave action areas. The below mentioned cultural techniques were widely used in India.

Raft method

The raft method adopted by Trono and Ohno *et al.* (1989) and Subba Rao (2008) was followed. In Indian waters, raft method was standardized after conducting 120 field experiments viz., raft size, rope size, knots, tie tie, seed weight, space between seed, space between ropes, etc. Finally 3m x 3m size bamboo rafts with 15 cm line spacing, 15 cm knots spacing (20 knots line^{-1} I Made loop) and 150 g seed knot^{-1} (400 seeds raft^{-1}) were finalized and placed parallel to the shore and widely used by the growers. Total initial weight per raft was 60 kg. 45 such rafts were floated in 5 clusters of 9 rafts each using anchor. Periodical weeding and maintenance were attended to ensure good growth. The harvesting was done after 45 days of growth and reseeding was done on the day of harvest. Every day one raft used to be harvested and replanted. The harvested seaweeds were dried in open sunlight for 2 to 3 days. The dried seaweeds were cleaned and packed as per the buyer's advice (Periyasamy *et al*., 2014a; 2015; 2016a).

Monoline method

Monoline method has been widely used worldwide for *Kappaphycus* seaweed farming. The monoline method is of different types. This method involved single lengthy rope cultivation either in longline (more than 100m) or in less length (less than 100m). In India, after conducting several trials the following three methods were widely practiced and recommended for commercial farming.

Monoline open method (MOM)

The monoline open method adopted by Hayashi *et al*. (2010) was followed. Monoline rope length was 60m having 400 knots (HDEP braider – I Made Loop) at an interval of 15cm. At each knot 150g seed material was inserted and thus one monoline contained 60 kg of seed material (150gm x 400 knots). Forty five such seeded monolines were prepared and placed horizontal to the shore in the sea in such a way that they were not exposed even at low tides and were aligned parallel to each other at an interval of 1.0m in a plot area of 60m x 45m. The whole plot (60m x 45m) was fenced with HDEP fishing net (20mm mesh size and 1.5mm thickness). Periodical weeding and maintenance were attended to ensure good growth. The harvesting was done after 45 days of growth and reseeding was done on the day of harvest. Every day one monoline (60m) was harvested and replanted. The harvested seaweeds were dried in open sunlight for 2 to 3 days. The dried seaweeds were cleaned and packed as per the buyer's requirement. This method is widely used in the coastal waters of South Tamil Nadu particularly in Ramanathapuram, Pudukkottai and Tanjore Districts.

Monoline netbag method (MNM)

The monoline netbag method adopted by Subba Rao (2004) and Suresh Kumar *et al*. (2016) was followed. In general, monoline rope length was 60m having 120 knots (HDEP braider – I Made Loop) at an interval of 50cm. At each knot 500g seed material was inserted and was covered with net bag (0.5m x 0.5m size – HDEP, 20 x 20mm opening and 1.5mm thickness). The seed material used was 60kg per rope (120 knots of 500 gm each). Net bags were tied properly with the monoline rope using 2 mm PP rope. Forty five such lines (seeded and net bag tied around each seedling) were floated and placed horizontal to the shore in the sea in such a way that they were not exposed even at low tides and were aligned parallel to each other at an interval of 0.5m in a plot area of 60m x45m. Periodical weeding and maintenance were attended to ensure good growth. The harvesting was done after 45 days of growth and reseeding was done on the day of harvest. Every day one monoline (60m) was harvested and replanted. The harvested seaweeds were dried on open sunlight for 2 to 3 days. The dried seaweeds were cleaned and packed as per the buyer's need. This method is widely used in the coastal waters of South Tamil Nadu and parts of Gujarat.

Monoline tubular method (MTM)

The monoline tubular method adopted by Hayashi *et al*. (2010) was followed. In general, the monoline rope length was 60m having 120 knots (HDEP braider – I Made Loop) at an interval of 50cm (Fig. 2). At each knot 500g seed material was inserted and thus one monoline contained 60 kg seed material (500gm x 120 knots).The entire seeded monoline was covered with tubular net (0.5m x 0.5m size – HDEP, 20 x 20mm opening and 1.5mm thickness) of 60m x 0.75m size. Net was tied properly at both ends with 2 mm PP (Polypropylene) rope. Forty five such seeded and covered tubular monolines were prepared and placed horizontal to the shore in the sea in such a way that they were not exposed even at low tides and were aligned parallel to each other at an interval of 0.5m in a plot area of 60m x 45m. Periodical weeding and maintenance were attended to ensure good growth. The harvesting was done after 45 days of growth and reseeding was done on the day of harvest. Every day one monoline (60m) was harvested and replanted. The harvested seaweeds were dried in open sunlight for 2 to 3 days. The dried seaweeds were cleaned and packed as per the buyer's order. This method is widely used in the coastal waters of Andhra Pradesh, North Tamil Nadu and Gujarat.

Per raft or monoline expected output would be minimum 260 kg FW raft^{-1} or monoline^{-1}. A farmer was supposed to harvest one line (60m) or one raft (3m x 3m) per day and reseed it on the same day. The seed required for reseeding one monoline or raft was 60 kg. Net seaweed after deducting seed (60 kg) was arrived at 200 kg FW and after drying 20kg DW was arrived (fresh weight to dry weight ratio = 10:1). Daily income could be Rs. 700 person^{-1} at the rate of Rs. 35 per kg dry weight. The income might increase if the farmers maintain the farm well coupled with per kg cost increase by the buyer.

Crop logging

Recording crop logging data is very important for reviewing the *Kappaphycus* farming in an area. The record has to be maintained regularly upto the farm existence in that area. *Kappaphycus* cultivation has been going well in the coastal waters of Ramanathapuram and Pudukkottai districts (Tamil Nadu, India) on a commercial way since 2006. But from 2012 onwards, the production has decreased drastically in these two coastal districts (Vaibhav *et al*., 2016). There was no detailed scientific record of crop logging data in these areas. Resulting, there is a problem for identifying the scientific reasons for the decreased production. So recording of crop logging data is very important in any farming. Crop logging includes the following. It is a process of recording environmental variables, crop production and condition in a structured and methodical manner. Recorded data must be saved in databases and must be circulated to technical and management personnel. Seaweed farming is among the arts and sciences that confirm to natural condition. It is not a set of methods for bending nature to our will. Observe and learn from what crop and associated organisms are doing in the location.

Plant appearance

In general the following crop conditions were commonly seen and should be recorded in crop logging as per suggestion of Neish (2013). (i) Plants may appear to be healthy but have very pale colour, growth slowing or negative, essential nutrient depleted and ice ice symptoms appears (Bleaching), (ii) Plants show early symptom of bleaching and show signs of noticeable grazing (Bleaching and Grazing), (iii) Plants show early symptom of beaching and show signs of weeds, epiphytes, epizoa or diseases (Weed and Bleaching), (iv)

Plants show early symptoms of bleaching and show signs of noticeable grazing (Grazing, bleaching and weed), (v) Plants are healthy, with good colour and nil grazing (Good), (vi) Plants are healthy, with good colour but show signs of noticeable grazing. Significant grazing means significant yield losses. Severe grazing means total crop loss (Grazing). (vii) Plants have good colour but if weed become significant farm economics will be less and if it is severe total crop loss (Weeds, epiphytes, epizoa or disease). (viii) Plants are healthy with good colour but grazers and weed are both taking over the farm (Grazing and Weed).

Grazing

The following types of grazing were recorded worldwide in the *Kappaphycus* farming (1) Gouging is a sort of damage caused by small chunks (snail and sea urchins) which removed the pigmented tissues; (2) Planing is a sort of damage caused by lager sea urchins which removed the tissues as if a plane; (3) Stripping is a sort of damage when gouging and planing were severe causing complete removal of the plants pigmented cortical layer; (4) Tip nipping is a sort of damage when growing tips are bitten away. Tip nipping is commonly seen and is often attributed by rabbit fish juvenile surgeon fish or parrot fish; (5) Total damage includes all the types of grazer damage except total loss and (6) Chopped is done by green turtles (*Chelonia midas*) and these places have to be avoided for farming. Among these above six types of grazing, first four were common in Indian waters, the fifth one was recorded in May 2003 at T. Nagar, Mandapam, Ramanathapuram District, Tamil Nadu and in September 2013 at Munaikadu, Mandapam, Ramanathapuram District, Tamil Nadu. The sixth one was recorded in April to June 2014 at Mukkam, YM Palem and Neelageddapeta in Andhra Pradesh (Periyasamy *et al*., 2016c). To avoid crop loss, grazers free sites or grazers less area has to be selected for commercial farming.

Diseases and Malnutrition

"Ice Ice" was reported as a problem early in development of farm techniques (Doty and Alverz, 1975; Uyenco *et al*., 1981; Vairappan *et al*., 2008). The term was coined by Fillipno farmers to break off devoid of pigment that causes branches to break off. Doty (1978) identified stress as the major factor promoting ice ice and drew a correlation between its occurrence and that of epiphytes. The symptoms of ice ice would be healthy dark coloured clean, vigorously growing plants loose pigmentation in a matter of days, the loss of pigmentation may become severe and growth rate becomes very low or negative. At this stage if the plants are moved to "better water" they may exhibit full recovery. Ice ice disease was reported in most of the *Kappaphycus* farming countries (Vairappan *et al*., 2008), whereas in Indian waters, there is no scientific report on ice ice diseases as on 2016. Largo *et al*. (1995a, b) reported that biotic factors could generate symptoms and light intensity of less than 50 micro mole photon M^2S; Salinity of less than 20‰; higher temperature above 35^0C induced ice ice in *Kappaphycus alvarezii* planted in sub tropical waters in Southern Japan. The same temperature issue was also recorded as a probable reason for crop reduction in Mandapam and Rameswaram coastal waters during 2013 to 2016.

Weeds, epiphytes and epizoa

The drifted macro algae such as *Ulva, Enteromorpha, Cladophora* and *Sargassum* used to settle and entangle or attach to farm habitat structures (raft, monoline, tubes or bags) or to the crop seasonally for duration of a few weeks or months. Drifted seagrasses also used to settle on the habitat and crop during monsoon periods. True epiphytes often chronic, usually filamentous algae, used to attach to cortical layer and damage *Kappaphycus* seaweed (Ask, 1999). In Tamil Nadu coastal waters, drifted seagrasses settlement was reported in Pudukkottai District during February to April (Periyasamy *et al*., 2014b). Micro algae *Lyngbya* (blue green) and macro algae *Cladophora* (green) used to cause severe problem forming mats during summer months (May and June) (Periyasamy *et al*., 2015). Micro algae and diatoms were formed a scum on the crop, often due to poor water quality (low flow; high silicon; eutropication).

Maintenance of crop logging records

Implementing crop logging system will be a mandatory for successful *Kappaphycus* farming. It will facilitate timely tracking of seasonal changes. A good crop log database comprises valuable income for any seaweed farming business. Proper development and use of this information preserves experience and knowledge through successive generations of management. Successful crop logging involves vigilance and methodical recording of data using the following regularly.

Keeping accurate record of planting, harvesting and growth rates

The agronomy officials have to record the date of planting of their test plots. They also make sure that the farmers are maintaining their farms properly. A superficial examination of *Kappaphycus* farms can mislead the observer into thinking that it is a low effort occupation such that farmers simply tie cuttings to strings, go away and return to harvest the crop after 45 days. Seaweed farming is an occupation in which the most successful are those with skill, diligence and a green thumb (Neish, 2003). This could be attributed to as tender loving care (TLC). This means that the farmer must ensure daily attention to functions as (1) replacing loose or week propagules; (2) shaking silt or other loose scum off the plants; (3) removing drift material such as plastic bags, debris and weeds that get tangled in the crop; (4) reattaching or tightening detached or loose lines and (5) replacing or repairing loose netting, stakes, floats, etc.

Care for farm structures and crop is essential for success but it is equally important to take care of the surrounding environment. Farmers must take care to avoid trampling or damaging local habitats; littering the environment with trash; polluting farm areas with human and other waste; or undertaking collateral activities such as the use of fish bombing and other destructive activities. So farm maintenance also important during trials. After 45 days, harvesting will be done and the harvested weight has to be recorded in fresh form. Then the seaweed was dried under the sunlight for proper drying as per the buyer's requirement. The daily growth rate was calculated from the recorded data using the formula of Dawes *et al*. (1994).

Recording of oceanographic and meteorological parameters

Recording of oceanographic and meteorological parameters also guides the farmers for proper maintenance of their farms. In India, several institutions maintain the environmental data bases that are made available for seaweed farmers for farm setting, planning and management during the site selection. After plantation every day/ periodically, the agronomy officials have to record the following parameters (a) Seawater temperature (b) Salinity (c) Water motion and its quality and (d) Light.

Monitoring of crop condition

Monitoring of crop condition includes plant appearance, grazing, diseases/ malnutrition and weeds, epiphytes and epizoa. These have to be recorded every day/ periodically during the growth period (Periyasamy *et al*., 2016b).

Protocols for the expansion of *Kappaphycus alvarezii* at new locations

Commercial farming of *Kappaphycus alvarezii* at new locations includes the following steps. a) Selecting a farming location after assessing farming site characters; (b) Selecting farmers adjacent to the location selection; (c) Selection and standardizing the farming methods; (d) Maintaining test plots for minimum one year; (e) Keeping accurate record of planting, harvesting and growth rates (test plots/ lines); (f) Measurement of oceanographic and meteorological parameters; (g) Monitoring of crop condition includes plant appearance, grazing, diseases/ malnutrition and weeds, epiphytes and epizoa; (h) Periodical maintenance of the farm and farming area; (i) Managing non epiphytic weeds can be done by removing them manually as soon as possible they appear inorder to prevent their reproduction and spreading; (j) Calculating the income of a farmer per month that should be attractive; (k) Analyzing phycocolloid (carrageenan) yield and its quality to attract the buyers; (l) Once the trial results are attractive, new farmers have to be identified; (m) Identified farmers will be trained for five days; (n) Trained farmers will be formed into five member self help groups (SHG)/ joint liability groups (JLG); (o) Applying for subsidy and loan for farming; (p) Tripod agreement to be made between self help groups, bankers and buyers; (q) Expansion of the seaweed farming for better output/ income; (r) Maintaining and monitoring the expanded farm properly; (s) Providing regular scientific updates and advices to the farmers (t) Harvesting the crop, drying, selling and repaying the loan; (u) Disclose the income earned by the SHGs to the other coastal people to attract more people to take farming; (v) Finally expand the farm in all directions involving more people.

Future Prospects

In India, total rural employment has been growing at the slow rate of 0.58% per year with the rural population growing at 1.7% per year (Singh, 2005). The large scale cultivation of this seaweed in this context could provide a face lift to rural employment by providing urban facilities in rural areas. It could play a catalytic role in rejuvenating the coastal rural economy. The length of coastline of Indian peninsula (08°04'- 37°06'N and 68°07'- 97°25'E) is 7516 km excluding its island territories (1256 islands) with 2 million square kilometer Exclusive Economic Zone (EEZ) (Subba Rao, 2000). Indian coastline is a part of the Arabian Sea in the west, Bay of Bengal in the east, and Indian Ocean in the south and with nine maritime states viz., Gujarat, Maharastra, Goa, Karnataka, Kerala on the west, Tamilnadu, Andhra Pradesh, Odisha and West Bengal on the east (Subba Rao and Mantri, 2006) and two third of its coastal waters are conducive for *Kappaphycus* cultivation and as such the cultivation could be done in 200 000 ha or 0.01% of the 2 million Exclusive Economic Zone (EEZ) (Krishnamurthy, 2005). Tamilnadu itself has a coastal length of 1076 km with 13 coastal districts namely Thiruvallur, Chennai, Kancheepuram, Villupuram, Cuddalore, Nagapattinam, Thiruvarur, Tanjore, Pudukkottai, Ramanathapuram, Tuticorin, Thirunelvelli and Kanniyakumari. Among these 13 coastal districts seaweed farming is being accomplished and the fisherfolk are earning lucrative income only in four districts viz., Tanjore, Pudukkottai, Ramanathapuram and Tuticorin. Now efforts are being taken to popularise and implement the same in the other coastal districts of Tamil Nadu for the benefit the poverty stricken coastal rural people to improve their living standards (Periyasamy *et al*., 2015; 2016b).

Kappaphycus cultivation may be proposed as an important alternative livelihood option to the coastal fisherfolk especially women. This seaweed farming could also reduce the fishing pressure and helps in carbon sequestration to combat global warming. Before implementing commercial farming, the growers (farmers) have to be well educated on cultivation protocol involving farm maintenance, harvesting, drying, quality maintenance, packing and selling. If this protocol is followed scrupulously, the SHGs/growers will get good income through seaweed farming. The earnings of one village people could motivate the other adjoining village people and thus resulting commercial expansion which would fullfil the problem of unemployment in rural India and also paves the way for starting *Kappaphycus* based industries. The successful model of cultivation in Tamilnadu could be promoted to all the other coastal states of India (Periyasamy *et al*., 2015; 2016b). It has been estimated that India has the potential to produce 1 million tons of dried seaweed, *Kappaphycus alvarezii* per annum (Krishnan and Narayanakumar, 2013). Indian government should take seaweed cultivation on a mission mode programme to eradicate poverty in the coastal villages and initiate indigenous production of carrageenan (refined /semi-refined) for internal use thereby saving the foreign exchange hitherto being incurred for importing the same and also for export of this chemical to earn foreign exchange.

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