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# Cultivation and utilisation of red seaweeds in the Western Indian Ocean (WIO) Region

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**Abstract** Seaweed farming in the Western Indian Ocean (WIO) Region is carried out in a number of countries, most of them farming *Eucheuma denticulatum*, *Kappaphycus alvarezii* and *Kappaphycus striatum*. These species are farmed mostly in Tanzania with limited production in Madagascar, Mozambique and Kenya; current production (2012) stands at 15,966 t (dry weight) year$^{-1}$ of *Eucheuma* and *Kappaphycus*, valued at US$ 4.2 million with 95 % of this tonnage coming from Tanzania. Other countries in the region have limited or no seaweed production owing to problems of epiphytes, ice ice and markets. The problem of epiphytes coupled with ice ice that WIO countries are facing causes die-off of *Kappaphycus* which is the preferred species in foreign markets for its thicker gel, kappa carrageenan (vs. the weaker iota carrageenan from *Eucheuma*). New efforts are put to curb these problems including moving seaweed farms to deeper waters and cultivation trials of other carrageenophytes as well as agar-producing species, agarophytes. Research work has been initiated to evaluate *Gracilaria* and *Hypnea* farming and processing in Tanzania, the Republic of Mauritius and Mayotte. *Gracilaria* farming is at experimental stages as a biofilter of fishpond effluents and as potential species for the production of agar with growth rates of 1.5–1.9 % day$^{-1}$. *Hypnea* farming is only being initiated in Mauritius and Mayotte at present. Other innovations including value addition by making various seaweed products and encouraging the consumption of seaweed as food at least in Tanzania and Mauritius are increasing further the importance of the seaweed farming and processing industry in the WIO Region.

**Keywords** Cultivation · Challenges · Value addition · *Eucheuma* · *Kappaphycus* · *Gracilaria*

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## Introduction

Red seaweeds in the Western Indian Ocean (WIO) Region are cultivated in mainly five countries, namely Tanzania, Madagascar, Mozambique, Mauritius and Kenya. Most of these countries cultivate three main seaweed species of *Eucheuma denticulatum* (J. Agardh), *Kappaphycus alvarezii* (Doty) Doty and *Kappaphycus striatum* (Schmitz) Doty ex P. Silva. *Gracilaria* (J. Agardh) cultivation trials have been carried out in Tanzania and Mauritius, and efforts to initiate cultivation at a commercial scale are underway. Cultivation of *Hypnea* (J. Agardh) is also being tried in Mayotte. Among the WIO countries, Tanzania is the major red seaweed producer, producing up to 15,088 t (dry weight (dw)) year$^{-1}$ (Department of Marine Resources and Zanzibar 2012). Seaweed produced in WIO is exported mainly to France, Denmark, USA, Spain, Chile and China. Seaweed produced in Mozambique was exported to the Philippines, but the market ceased owing to unreliable supply from Mozambique.

Coastal people in the WIO Region are known to use red seaweeds traditionally for many years for such purposes as export trade, fishing and food. Seaweed export trade based on collection from the wild is reported in Tanzania where 387 t dw year$^{-1}$ of *Eucheuma* and *Kappaphycus* was exported to Europe in 1951 (Mshigeni 1976; Msuya 2013a). The trade collapsed in the 1970s because of depletion of the wild stocks and higher production of clean cultivated seaweeds from South-east Asia and other countries. *Gracilaria salicornia* is known to be used in Mauritius as baits for fish cages and also boiled to form a gel (locally known as *goumon jelly*) used in foods such as juice (AREU 2011).

## Initial studies and establishment of red seaweed cultivation in WIO

Efforts to start the cultivation of red seaweeds in the WIO Region started in the 1970s when scientists studied the potential of cultivating seaweeds in the region. As early as 1973, documentation of potentials and possibilities of cultivating seaweeds was done in Tanzania, showing potential species and environmental conditions suitable for cultivating red seaweeds (Mshigeni 1973, 1976). Following these documentations, first experiments were conducted in the mid-1980s whose results showed that seaweeds can be farmed in the WIO (Mshigeni 1985). The success of the experiments paved way for private entrepreneurs to start commercial cultivation in 1989 in the Zanzibar Islands of Tanzania. Expansion of the cultivation to other areas occurred few years later, and by the year 1994, the farming had already expanded to mainland Tanzania, and by 1996, the farming was carried out all along the coast of Tanzania (Lirasan and Twide 1993; Msuya 1995, 1996). A similar situation was happening in Madagascar where first cultivation trials with wild local variety of *Eucheuma* sp. were carried out during 1989–1993. Commercial production started in 1997 with support of promoting programmes including “Amélioration des Revenus des Populations Littorales” (translated as “improving coastal communities incomes”) promoted by the European Development Fund and FMC Corporation, USA, although the production from collecting the wild stock was still higher than that from cultivation. In 1998, it was found important to import a variety of *K. alvarezii* from Zanzibar into Madagascar, a variety that had higher growth rate of above 5 % day$^{-1}$ compared with a maximum of 3.7 % day$^{-1}$ obtained earlier with the indigenous variety of *E. striatum* (Randriambola and Rafalimanana 2005).

Thirteen years after the commencement of commercial cultivation, the knowledge on seaweed cultivation expanded to other countries in the WIO. In 2002, the cultivation expanded to Mozambique where successful cultivation was observed in Pemba area, and in 2006, cultivation was conducted in the Nampula area. During approximately the same period, pilot experiments were carried out in Kenya in 2004, concentrated on the south of the country. Growth rates of between 3.5 and 5.6 % day$^{-1}$ were recorded (Wakibia et al. 2006). Commercial cultivation started in 2010 in the south coast of Kenya. Currently, there are seven villages practising commercial seaweed farming in Kenya. Among these villages, only three (Kibuyuni, Mkwiro and Nyumba sita) have substantial production to support seaweed commercialisation. A World Bank-funded project “Kenya Coast Development Project” is currently working on increasing seaweed production and spreading seaweed farming to the north coast of Kenya in order to boost Kenyan seaweed production.

In 2011, red seaweed cultivation expanded to Mauritius where *G. salicornia* previously identified for cultivation was experimented upon. The activity started with capacity building conducted in two phases: (1) training of research assistants in Zanzibar, Tanzania, and (2) training of scientists, fisher folks and other stake holders in Mauritius and Rodrigues. Experiments were conducted to assess growth rate where a growth rate (SGR) of 1.9 % day$^{-1}$ was obtained. Pilot (commercial) farming for this species is underway. Moreover, experiments on *Gracilaria* farming have been conducted to evaluate the seaweed as a biofilter of fishpond effluents and as an alternative species for cultivation in Tanzania (to produce agar and for other uses in value addition). *G. salicornia* (previously identified as *Gracilaria crassa*) was used as a biofilter of fishpond effluent waters in an integrated finfish–shellfish–seaweed land-based system. A growth rate of 1.5 % day$^{-1}$ was obtained with significant biofiltration properties, i.e. nitrogen removal and restoration of dissolved oxygen and pH of the fishpond water (Msuya and Neori 2002; Msuya 2011b). *Gracilariopsis mclachlanii* (previously referred as *Gracilaria verrucosa*) has been identified as potential for agar production. Studies on naturally growing *G. mclachlanii* as potential agar-producing seaweed were conducted in Tanzania. Results showed that the species contain 30–44 % agar yield and agar quality of 250–400 g cm$^{-2}$ depending on season and treatment (Buriyo 2006), results that are similar to those of Oyieke (1993) along the Kenyan coast. Indoor experiments are currently conducted at the University of Dar es Salaam, and efforts are underway to establish trial plots followed by commercial cultivation. Other red seaweeds of research interest identified as potential for cultivation in the WIO are the carrageenan-producing *Hypnea musciformis* and *Hypnea pannosa*.

### Seaweed production volumes in the WIO Region

Much of the seaweed production in the WIO Region comes from Tanzania which produces 15,088 t (dw) year$^{-1}$ involving 15,000–20,000 farmers. Other countries in the region report on productions of less than 3,000 t (dw) year$^{-1}$ in sporadic patterns of production. Production trend in the WIO countries is shown in Fig. 1a, b. From the figure, production from Tanzania increased from 808 t (dw) year$^{-1}$ in 1990 to around 4,000 t (dw) in 1995. The production stagnated at 4,000–5,000 t (dw) for 5 years until the year 2000. From 2001 to 2007, the production increased but then stagnated at around 7,000–8,000 t (dw) (with the exception of the year 2002 when production reached 10,000 t dw). The boost to production probably caused by increased world demand of carrageenan-producing seaweeds started in 2008 when production reached 11,000 t (dw) and currently increased to 15,088 t (dw) in 2012 (Fig. 1a). Most of the production is *E. denticulatum* and comes from Zanzibar Islands; mainland Tanzania produces less than 1,000 t (dw).

Madagascar had few commercial initiatives in three different regions, although only one initiative survived after 3 years. Production was significant in the north area during 2000–2010, and especially from 2006 onwards when new varieties of *K. alvarezii* and *E. denticulatum* were imported from Zanzibar, Tanzania. Production trends showed a maximum of 2,290 t (dw) involving more than 300 farmers in 2009, but production fell drastically to only 844 t (dw) in 2012 (Fig. 1b). Renewed efforts were started in 2010 with a 3-year programme to run up to 2013, involving several investments from private sector in different areas around the island. These investments include Norges Vel (Norwegian cooperation), Sustainable Management of the Coastal Zones of Indian Ocean Countries (ReCoMaP), African Development Bank (ADB) and NGO partners; several private initiatives around the island (N, E, NW and SW areas); and at least seven companies that made cultivation trials and requested licences. Some companies are already producing seaweed; for example, more than 200 t (dw) of *K. alvarezii* were produced in 2012 in the south-west area. The renewed efforts are mainly focused on *K. alvarezii*.

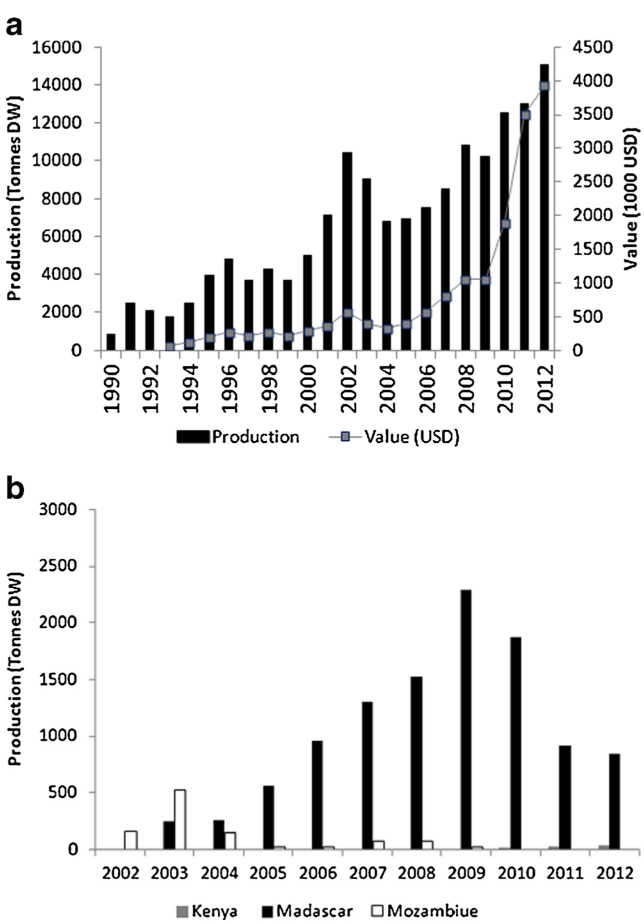


**Fig. 1** Seaweed production in the Western Indian Ocean Region. **a** Tanzania. **b** Other WIO countries

### Problems and challenges in the WIO Region

#### World market preference and failure of *Kappaphycus* in farms

The fact that *Kappaphycus* produces the stronger/thicker gel—kappa carrageenan—with a diverse product application than the weaker iota carrageenan from *Eucheuma* has raised the market for the former (i.e. preference of *Kappaphycus*), while the market for the latter is less lucrative. As a result, the price of *Kappaphycus*, for example, in Tanzania is double that of *Eucheuma*, i.e. US$ 0.51 kg$^{-1}$ of dry seaweed, twice that of *E. denticulatum* (US$ 0.25 kg$^{-1}$). Hence, the farming of *Kappaphycus* in the WIO Region is more lucrative than that of *Eucheuma*. Unfortunately, while this is the case, *Kappaphycus* has failed to grow in many of the WIO countries because of various problems including 'ice ice' and epiphytes. In Tanzania, the failure of *Kappaphycus* to grow caused a drop in the production of this species from 1,000 t (dw) in 2001 to only 13 t (dw) in 2010. New efforts to farm in deep waters show some signs of increasing the production; in 2011, the production was 62 t (dw), and in 2012, it was 90 t (dw) (Fig. 2). In Madagascar, the occurrence of persistent epiphytes since 2010 in the northern country production area caused a drastic decrease in the production of *K. alvarezii* from 1,860 t (dw) in 2009 to 110 t in 2012 (Fig. 3). The occurrence of epiphytes has been observed in *E. denticulatum* farms also in recent years (e.g. 2010 onward); this situation had not been observed in the past. We report here occurrence of epiphytes on *E. denticulatum* in four WIO countries where the seaweed is farmed, i.e. Kenya, Mozambique, Madagascar and Tanzania.

Apart from “ice ice” and epiphytes, farming of red seaweeds in WIO also faces the problem of unreliable international markets. For example, the international processors buy seaweed material near their factories from Asia before coming to the WIO Region including to the large producer, Tanzania. In Mozambique, the seaweed farming had to be abandoned in 2010 because of lack of markets. While in one area, Cabo Delgado, the seaweed buyer gave too low prices that the business was not profitable to the farmers; in Nampula, the buyer had legal problems and thus could not continue to purchase the seaweed. In Kenya, farmers had to wait for buyers from Tanzania to come and purchase the seaweed; the farmers had not managed to sell the seaweed for 5 months in 2012. However, the issue of marketing is currently being addressed by including a seaweed-buying company in the seaweed commercialisation since the onset of the 3-year EU-funded project. This provided a ready market for the farmers. Moreover, farmers have been organised into cooperatives and trained on how to look for potential buyers as a way to avoid exploitation from middle men and bargaining for competitive prices.

## Efforts to overcome challenges in the WIO Region

In efforts to combat or cope with the die-off of *Kappaphycus*, the stakeholders in WIO have been acting in their respective capacities. Whereas researchers have been conducting research in various aspects, exporters have been trying varieties of *Kappaphycus*, whereas farmers have been changing the farming areas.

### Documentation of causes of failure of *Kappaphycus*

Causes of failure of *Kappaphycus* including epiphytes and “ice ice” have been documented throughout the WIO (Mmochi et al. 2005; Wakibia et al. 2006; Vairappan et al. 2008; Msuya 2011d). Mmochi et al. (2005) conducted a study in northern Tanzania to look at the causes of the die-off. Working in five villages, the authors reported several causes of the die-off including high surface water temperatures, rapid changes in salinity, temperature etc. in shallow intertidal areas where *Kappaphycus* is farmed; fouling; and surface runoff. Similar efforts were made in Kenya where studies on ice ice disease in Kenya showed a significant correlation between plant loss and ice ice occurrence in sites with low water motion (Wakibia et al. 2006). Other workers in the region and elsewhere observed that high surface water temperatures cause die-off (Mollion and Braud 1993; CDI/VOCA 2005; Msuya and Salum 2007; Msuya et al. 2011). Surface water temperatures of 37–38 °C have been recorded in recent years in WIO (Msuya and Porter 2009; Msuya and Kyewalyanga 2010). Optimum water temperatures recommended worldwide for farming *Kappaphycus* are between 21 and 31 °C (Luxton et al. 1987; Glenn and Doty 1990; Ohno et al. 1994; Mairh et al. 1995).

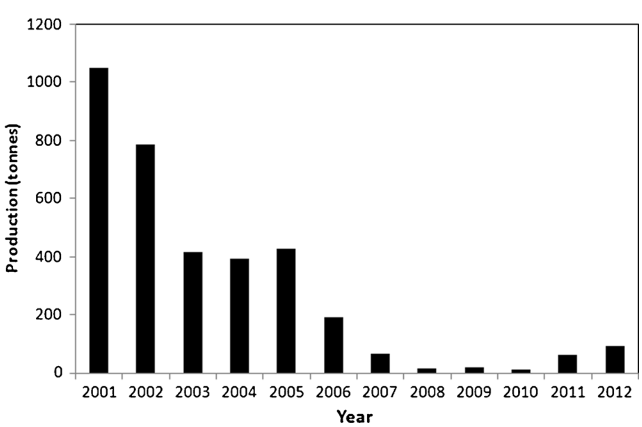


**Fig. 2** Variation in the production of *Kappaphycus* since the start of die-off in Tanzania

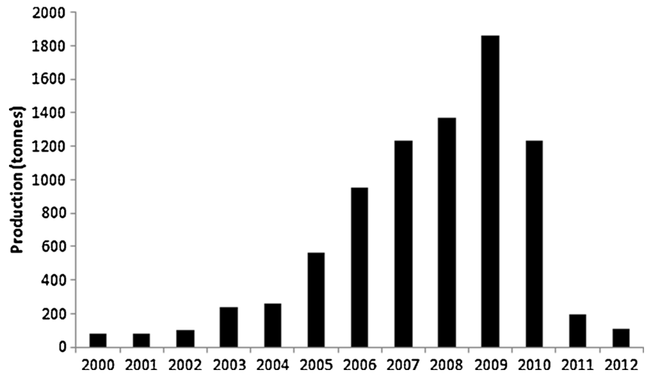


**Fig. 3** Variation in the production of *Kappaphycus* since the beginning of epiphytes in Madagascar

### Studies on new farming techniques

More efforts to combat the die-off of *K. alvarezii* including modification of the traditional off-bottom method have been done. Farms are being moved to deeper waters by using new techniques such as the deep-water floating line technique (Msuya 2006a, 2007; Msuya et al. 2007a) in which the seaweed is farmed in waters of 2–5 m, depending on the site. Other methods of farming in deep waters tried in the WIO Region are bamboo rafts (Zuberi 2000; Msuya and Salum 2006; Msuya 2011c). In Kenya, two small projects have been funded by the government of Kenya to address challenges posed by the widely used shallow water off-bottom method. Project 1 aims to come up with more farming methods that allow deep-water seaweed farming as an alternative to the widely used shallow water off-bottom method. Project 2 aims to come up with a controlled land-based seaweed farming system. This is an innovative grant that is currently running. However, these methods need more sheltered areas, while many areas for farming in WIO have rough seas. Thus, the methods are still being researched upon before being disseminated to farmers. Besides, farming in deeper waters is the only technique that is feasible for the production of *Kappaphycus* in WIO at present. Challenges associated with the technique, e.g. women's involvement in deep-water farming (most women cannot swim), availability of boats and conflicts with fishermen have been addressed (Msuya 2006b; Msuya et al. 2007b). These include farming as families with division of labour among female and male members and zoning of the intertidal areas.

In spite of this, *Kappaphycus* off-bottom farms in WIO are continually being moved to deeper waters. Farming in deeper waters also gives higher growth rates and production per unit area. Apart from higher growth rates recorded in deep-water farming (Zuberi 2000; Msuya 2007, 2011c), farming with the deep-water floating lines technique produces 0.35 kg per unit area more than the off-bottom method (Msuya et al. 2007a; Msuya 2013a). Other higher growth rate values in other countries in deep waters relative to those from shallow waters were recorded by Hurtado and Agbayani (2002). Standardisation of farms aimed at maximising the space for farming where empty spaces usually found in the un-standardised farms are practised is being applied in Tanzania (Msuya 2006a). This innovative standardisation module is already being applied in other countries including Indonesia.

### Introducing new species and varieties of *Kappaphycus*

Following the failure of *K. alvarezii* in its original cultivation sites, new species and varieties of *K. alvarezii* that are more resistant were introduced in the farms (while observing quarantine regulations). In Tanzania, for example, *K. striatum* (green and brown strains) was introduced in the Zanzibar Islands as an alternative species in around 2002. Likewise, a variety of *K. alvarezii* known as “bola bola” in the Philippines was introduced into northern Tanzania, in Tanga Region, in around 2008. The introduction of varieties of *E. denticulatum* and *K. alvarezii* from Zanzibar into Madagascar for commercial cultivation is another indicator of the efforts. Results from the introductions into Madagascar showed that the seaweeds grew at higher growth rates and were more resistant than the original varieties/species (Randriambola and Rafalimanana 2005).

## Recent developments and perspectives in the WIO Region

Most countries in the WIO Region are putting on a new push to the development of seaweed farming including formulation of policies, integrating partners such as the private sector, forming farmers associations, linking farmers with the academia and government in a triple helix model, developing strategic plans and engaging in value addition (Msuya 2011a). One example of such renewed efforts is in Madagascar where several initiatives to support seaweed farming started in 2010. Organisations such as the Norges Vel, ReCoMaP and ADB mentioned above have partnered with NGOs to promote seaweed farming as alternative livelihood for coastal population, whereas a 4-year cooperation programme with Belgium focuses on scientific studies. In addition, several private initiatives (run by at least seven companies) around the island have conducted cultivation trials and are working on legal licences to start large-scale production. The first legal framework to control the seaweed farming sector has been formulated. In Kenya, efforts to map out sites suitable for seaweed farming are currently being conducted by the Kenya Marine and Fisheries Research Institute. In Tanzania, there has been establishment of Aquaculture Departments (with mariculture divisions) and appointment of principal secretaries in the responsible ministries to cater for seaweed farming among other aquaculture organisms.

## Seaweed utilisation and value addition in the WIO Region

The utilisation of red seaweeds in the WIO Region is mainly focusing on making value-added products and direct consumption as food. Started in 2008, production of seaweed soaps, body creams and massage oils, and foods such as juice, jam and pickles as well as consumption as salads are reported (Msuya 2010, 2011a; CEVA 2011, 2012). Utilisation of seaweeds as fertilisers has been proposed (CEVA 2011, 2012), and some trials in the past are reported (Msuya 2011a). Other utilisations are in animal feed (CEVA 2011, 2012; Msuya 2013b) and market studies to initiate value addition (INAQUA 2011). One of the marked results of value addition is the marketing of seaweed powder at US$ 6.4 kg$^{-1}$ compared with the US$ 0.25 kg$^{-1}$ of dry seaweed exported as raw material (Msuya 2011a). All these efforts are geared towards the establishment of seaweed processing plants in the WIO with prospects of marketing crude or refined carrageenan and agar.

## Conclusions

The WIO Region has been farming seaweeds for two decades now. Most of the production comes from Tanzania (especially the Zanzibar Islands), and other countries have been making efforts to either increase production or start the farming. Effects of changes in the environment (a sign of climate change), specifically ice ice disease, and epiphytes are hampering the progress in the cultivation of red seaweeds in the WIO. Following the market trend with higher demand for *Kappaphycus* than *Eucheuma*, WIO countries are making efforts to farm the former species including moving the farms to deeper waters and trying more resistant varieties. The seaweed *Gracilaria* is emerging as a new species for cultivation in the WIO. Value addition is raising the economic benefits of the farmers and establishing seaweed as food while showing a great potential for the future of seaweed farming in the WIO.

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