A Review on Seaweed Farming in Western Indian Ocean: Benefits and Challenges

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Abstract

Seaweed farming in the Western Indian Ocean (WIO) is among the income-generating activities; apart from seaweeds being primary producers, they are foundation species important for marine ecosystem capable of modifying their surrounding abiotic and biotic environments. The WIO coast provides natural and necessary environments for seaweeds farming. In this review article seaweed farming in WIO was investigated; its contribution to provision of ecosystem services; medicinal and nutritional value; role of women; challenges and the wellbeing of farmers and the whole ecosystem. It was observed that among the challenges facing seaweed farmers include lack of modernized farming tools hence farmers use low depth areas leading to attack by diseases, death of seaweed, low yields, and income. Farmers has been reported to be affected by diseases which may be contributed by inadequate of use of protective gears, indicating the need for knowledge on personal protection. This may be contributed by lack of knowledge which leads to farmers participation without using protective equipment leading to contamination from toxic chemical compounds from seaweed, epiphytic bacteria or harmful algal bloom and absorbed heavy metals from seawater as a result of long-term exposure. Farming practices such as uprooting of seaweeds during farm preparation have been observed to cause degradation and decrease fish population. Therefore, there is the need for use of modern technologies; supervision of these activities by professionals in the field, and provision of knowledge to farmers for the sustainability of WIO marine ecosystem.

Introduction

Seaweeds denote thousands of species of macroscopic, multicellular, marine algae, such as Chlorophyta (green) ,Rhodophyta (red) and Phaeophyta (brown) (1, 2). Importance of seaweeds in provision of ecosystem services are known, for example species such as kelps provide essential nursery habitat for fisheries and other marine species and thus protect food sources (3); species of algae, play a vital role in capturing carbon, producing up to 50% of earth's oxygen (4). The practice of cultivating and harvesting seaweed is known as Seaweed farming (5). Management of naturally found batches of seaweeds mainly conducted in its simplest form and full controlling the life cycle of the algae in most advanced form of farming (6). Widely cultivated seaweed taxa are *Eucheuma spp., Saccharina japonica, Sargassum fusiforme, Gracilaria spp., Pyropia spp., Undaria pinnatifida* and*Kappaphycus alvarezii* (1). Seaweeds are farmed for different applications, for example *Gracilaria* is farmed for agar production; *Eucheuma* and *K. alvaraezii* are farmed for gelling agent (carrageenan); while the rest are for food (7, 8). China, the Philippines, and Indonesia are the largest seaweed producers, others include Zanzibar (Tanzania), Japan, North Korea, South Korea, and Malaysia (9). The improvement of economic conditions and the reduction of fishing pressure and overexploited fisheries are among the advantages of seaweed cultivation (10).

Overall global production of farmed aquatic plants have been observed to increase by more than 60% from 1995 to 2016 and is dominated by seaweeds while as of 2014, seaweed contributed only 27% of all marine aquaculture (11). Seaweed farming is a carbon negative crop, with a high potential for climate change mitigation (11). A great diversity of compounds exhibiting a broad spectrum of biological activities are currently produced from seaweeds hence attract attention of biotechnological interest (12). Bioactives from marine organisms has shown capabilities such as antiviral, anti-tumor, anti-inflammatory, and anti-lipedimic,which creates the burning need for management options for a sustainable approach to their use (13, 14). Seaweed farming in the WIO has great benefits to communities and should be encouraged as it provides nutrients, medicine and income to societies. Also, knowledge of the health and commercial benefit of seaweeds should be given to the community to increase their utilization and thus production.

Chemistry of seaweeds

Seaweeds are reported to contain innumerable minerals and bioactive molecules such as carbohydrates, proteins (15), and a lesser degree of lipid along with small molecules such as alkaloids, saponins, pigments, and peptides (16). Alginate is an example of polysaccharides composed of unbranched chain made of (1-53 4)-β-D-mannuronic acid residues and (1-4)-α-L-guluronic acid residues (17). These polyuronans exist in seaweeds as salts of more than 50 different metals frequently in the form of sodium and calcium (17). Structure of some bioactive compounds are known; **Figure 1** presents structure of bioactive compounds from seaweeds available in the WIO.

Figure 1 : Structure of bioactive compounds from seaweeds available in the WIO

Methodology

The research examines peer-reviewed research on seaweed farming that has been published in conference papers, book chapters, reports, academic journals, and books. The following databases were used as data sources: Google Scholar; Web of Science; Scopus, PubMed; Wiley Online Library, Science Direct; Taylor and Francis online; Sarge Publishing. The major search took place between April and June of 2021. The benefits of seaweeds in WIO were the topic and scope of this literature review. A review of the literature was conducted on papers containing information on nutritional values, medicinal, bioactives, and seaweeds farming. Search criteria involved multiple combination of search terms and among keywords linked to seaweed farming. Also, those linked to WIO and other parts of the world for references.

Exclusion and inclusion criteria

Any paper which reports on seaweeds farming, medicinal value, nutritional value were included otherwise excluded in the study

Seaweeds as source of bioactive compounds

The constituents of seaweeds are more innovative than those of many land plants and because of their varying biological capabilities, have long been recognized as a rich and significant natural resource of bioactive chemicals (18, 19). Compounds from marine organisms are pharmacologically bioactive and have shown significant effects against various types of medical conditions (20, 21). Natural compounds obtained from marine organisms are used in the treatment of various diseases and disorders since ancient times (22). Red seaweeds (*Kappaphycus alvarezii*) farmed at the Western Indian Ocean marine sites have been shown to have antioxidant and antibacterial activity against pathogenic bacteria (23). **Table 1** represents some of the bioactive compounds from seaweeds.

Table 1: Bioactive molecules reported in seaweed extract

S/N	Bioactive molecule	Type of seaweed	Properties	References
1.	Halimedatrial; Caulerpenin; Lanosol	Green Algae Halimeda macroloba	Antibacterial &antioxidant activities	(24, 25)
2.	Fucoxanthin	Brown Seaweed Himanthalia elongata	Antioxidant and antimicrobial activity	(26)

S/N	Bioactive molecule	Type of seaweed	Properties	References
3.	Bromoform	Red seaweed (Asparagopsis taxiformis)	Antimethanogenic activity	(27)
	Dibromochloromethane Dromochloroacetic acid Dibromoacetic acid			
4.	Vitamin E; flavonoids; phenols; hydroquinone and triterpenoids	Sargassum sp. and Eucheuma Cottonii Doty	Sunscreen agent	(28)
5.	Peptides (Gly-GLY-Ser-Lyr and Glu-Leu- Ser)	Red seaweed (porphyra spp)	α-Αμψλασε Ινηιβιτορψ Ποτεντιαλ	(29)
6.	Salicylic; ferulic acids; phenolic acids	Halimeda incrassata	Antioxidant activity	(30)
7.	n-nonadecane; 1,2,3- propane tricarboxylic acid; 2-(acetyloxy)-, tributyl ester; 2-methylhexadecan-1-ol; 1-docosene; 1-eicosanol and chloroacetic acid, octadecyl ester	C. sinuosa and C. officinalis	Antibacterial activity	(31)

Seaweeds farming in Western Indian Ocean

Western Indian Ocean covers the area from Somalia, Kenya, Tanzania, Mozambique, South Africa, Comoros, Madagascar, Seychelles, Mauritius, and Réunion (France) (32). Most seaweed farmers in WIO countries are farming *Kappaphycus alvarezii, Eucheuma denticulatum* and*Kappaphycus striatum* (33). These species are farmed mostly in Tanzania with limited production in Madagascar, Mozambique, and Kenya (34). Seaweed farming is named among activities that contribute toward attaining several targets of United Nations sustainable development goals (SDGs) and blue economic development in different parts of the world (35, 36) including the Western Indian Ocean.

Challenges of seaweed farming

Integration of seaweeds into marine aquaculture farms in the WIO is, nonetheless, not without its challenges (37). Despite of its benefits in economic, environment and health benefits, seaweeds aquaculture faces several obstacles that hinder its successful intergration in WIO. According to Msuya et al. (2014) (38) some potential species were unable to survive due to the problem of epiphytes coupled with ice-ice diseases in WIO region. Among the affected seaweed species was *Kappaphycus*which is preferred in the foreign markets for its thicker gel, kappa carrageenan as compared to weaker iota carrageenan from *Eucheuma*species (38). Moreover, Tobisson (2013) (39) reported low involvement of men in seaweed farming, this is caused by the little gain from seaweed farming process as compared to labour involved. Though there is high demand for seaweed products in the international market, the price paid to farmers is very low as compare to labour seaweed farming takes (39). Therefore, for the sustainability of seaweed farming, funders need to consider ways to improve the efficiency of seaweeds farming including value addition for more income generation and increase pay for farmers.

Apart from financial issues, reports of women involved in seaweed farming have health problems such as back pain and eye-related problem due to tedious work performed in the seaweed farming process; headache; allergies; injuries fatigue and respiratory problems are available (40). This may be contributed by lack of knowledge which leads to farmers participation without using protective equipment leading to contamination from toxic chemical compounds from seaweed, epiphytic bacteria or harmful algal bloom and absorbed heavy metals from seawater as a result of long-term exposure (41). It is important for responsible authorities and funders to incorporate seminars to all farmers and educate them about the need for protection for safety. Also, conflicts are arising among seaweed farmers and other users such as the tourism industry. In such a way that seaweed farming is prohibited in areas with more upmarket materials; accommodation on the north and south coast island and outside some hotels on the pretext that was visually unattractive (42). This may be caused by inadequate knowledge on coexistence between tourism and seaweed farming by putting clear boundaries and roads within the marine sites.

According to De la Torre-Castro and Lindström (2010) the process of uprooting the seagrass in preparation of seaweed farm contributes to the decreased fish population and coastal erosion (43). This is a challenge which needs vigilant supervision. On the other hand, apart from decades of its existence in WIO, seaweed farming suffers the use of inappropriate or outdated technology. Most commonly traditional off-bottom methods, using wooden stakes (pegs) planted in the sand and ropes to which seaweed bunches are attached (44). However, this technology is leading to low yield as it is labor-intensive and is utilized in a shallow area where environmental variables change rapidly and spoil productivity. Seaweed farming at low depth is more susceptible to changes in sea surface temperature and salinity, especially during the rainy season, resulting in disease outbreaks such as epiphyte infestation, which suppresses growth; discoloration of the seaweed thali that affects the quality and cause ice-ice (45). Indicating the need for seaweed farmers, funding, and responsible authorities to find the means to facilitate farmers to have modern farming equipment's to increase productivity and hence income. Moreover, the nature of technology renders it especially sensitive to currents and storms, resulting in tangled ropes, broken and lost products. In this case, maintenances of the seaweed plots becomes physically hard and dangerous; requiring daily attention and strain to farmers who are mainly women with low pay (45). In addition, climate variation impacts the high profitable species in WIO region, for example *Eucheuma cottonii* with higher price because of its higher carrageenan content cannot thrive in shallow waters, as a result, farmers opt to cultivate *E.spinosum* (45).

Apart from the challenges facing seaweed farmers in the WIO, there is the need to investigate possibility to grow other native seaweeds species, increase value addition to farmed species and use of modern technologies for sustainability of ecosystem. Also, there is a need for establishing product acceptability so as in the near future can be accepted as food; creation of sustainable market and balance demand in the local and international forum. Also, the need for utilization of both economic value of the seaweeds produced and ecosystem services offered by marine farming activities.

Contribution of seaweed farming in the Western Indian Ocean ecosystem

Currently, seaweeds are a significant component of marine aquaculture production and as the human population increases rapidly it is expected to play an increasing role in global food security (46). Seaweed farming is similar to plant-based agriculture, except that the crop is cultured in a marine environment (47).

Therefore, seaweed farming does not require arable land, fertilization, or freshwater, which are resources that may ultimately constrain the expansion of agriculture. Hence can be considered as restorative ocean farming, but also source of green vegetables and animal feeds (48, 49). Adoption and increased seaweeds farming in Western Indian Ocean ecosystem will help increase the quality and sustainability of WIO ecosystem.

Provision of ecosystem services

Wild and cultured seaweeds play a significant role in provision of ecosystem services, such as habitat for other marine organisms, mitigation of climate change, localized control of ocean acidification and bioremediation for coastal pollution (3, 22).Also, Seaweeds as an autotroph species, produce energy and food for itself due to the presence of the chlorophyll(50) and provides food for other marine animal especially for herbivore that only eat herb such as other marine plant, algae and seagrass (36, 50). Habitat such as mangrove, coral reef, and other marine habitat are given by seaweed (51, 52). Brown algae can make a forest in the ocean. Like as forest, seaweed provide all what other marine species need. Food, nutrient, energy, and others (53, 54). On the other hand, seaweed as sensitive organism that can be used as bioindicators of marine chemical pollution. As a practice disposal of untreated or partially treated wastewater from household, aquacultural, industrial and others enters the ocean (55, 56) carrying materials such as nutrient. Disturbance to nutrient balance in the ocean cause population leading to increased growth of seaweed, the phenomenon known as algae bloom which is the bioindicator of marine chemical damage (57, 58). Therefore, all species of seaweeds available in WIO can further be utilized to protects the ecosystem. Hence, it is important to increase scale of seaweed farming in the Western Indian Ocean to provide for ecosystem balance and protect marine biodiversity. **Figure 2**summarizes the benefits of seaweeds in marine ecosystem which can be adopted in Western Indian Ocean for greener ecosystem.

Figure 2: Seaweed farming for greener Western Indian Ocean marine ecosystem

Seaweeds can detect danger and alert other marine species via signals. For example, diseases in seaweed can affect the color or smell of the seaweed, signaling its presence in the marine ecosystem (59). On the other hand, seaweed has a bigger contribution on oxygen production as it produces 50-80% more than terestrial plants. This is contributed by the fact that photosynthetic processes can take place at all parts of the plants (60-63). Though feeding energy is generated for living, seaweed provides energy as a food for other marine species and also supplies organic nutrients for other marine life (8, 48, 64, 65). On the other hand, seaweed functions as nutrient absorbers in the marine ecosystem, this is important as not all nutrient entering the ocean have a good effect some may kill marine life and damage the marine ecosystem (66, 67). In this case seaweed will absorb and trap excess nutrients and make marine ecosystem safe (68). Although iron is essential for seaweed to undergo photosynthesis and other autotrophic organism, excessive iron ion in oceanic ecosystem may damage marine life (69-71). Therefore, the existence of seaweed in WIO marine ecosystem is important for continuation of life forms.

Application of seaweeds

Seaweeds are converted into a variety of goods, such as food and nutritional supplements for humans and livestock, fertilizer, unique biochemicals, and biofuels (72). Seaweeds have gained its diverse application in agriculture (73, 74) such as enhancement of health and growth of plants specifically root and shoot elongation (75), stimulation of seed germination (76) , improvement of nutrient and water uptake (77), biocontrol and resistance toward phytopathogenic organisms (78), frost and saline resistance, biocontrol and remediation of pollutants of contaminated soil and fertilization (79). Table 2 indicates selected applications of seaweeds in differing aspects of life.

Table 2: Some of reported applications of seaweed

Applications	Seaweed's species	Responsible components	Remarks	References
Animal feed (nutrition)	All edible species	Biomass	Sustainable source leading to greener ecosystem	(48, 80)
Bioindicator of marine pollution	***Dichotomaria marginate* (Rhodophyta)** All species	Live organism	Sustainable ecosystem	(81, 82)
Bioremediation and biomonitoring	All species	Live organism	Sustainable ecosystem	(83, 84)
Improve chlorophyl content	Ascophyllum nodosum	Extrct	Sustainable ecosystem	(85)
Enhance plant protection against disease		Extrct		(86)
Improve root growth and Development	Ascophyllum nodosum	Extract	Sustainable ecosystem	(75)
Trigger earlier flowering and fruit formation	Ecklonia maxima (Osbeck) Papenfuss, and others	Extrct concentrates	Sustainable ecosystem	(87)
Enhance postharvest shelflife& quality of perishable products	Kappaphycus alvarezii and Sargassum tenerrimum	Extract	Sustainable ecosystem	(88, 89)
Soil conditioner	All species	Biomass	Sustainable ecosystem	(77, 90, 91)
Dietary supplements	Edible seaweeds			(92)

Nutritional value

The seaweeds are cultivated both for commercial and domestic use in most countries of WIO region such as Tanzania, Kenya, Mozambique and Madagascar. The use of seaweed as food is well known and several nutrients have been identified in different species of seaweed. They contain valuable nutrients such as carbohydrate, minerals such as iron and calcium , fiber, protein which contain essential amino acids, vitamins and trace elements such as iodin\soute (93). Seaweeds are among natural food that provides a highly nutritious but low in calories diet. Seaweeds are therefore the best method that can be used to alleviate nutritional deficiencies of the current food, due to its abundant constituents of nutrients (94).

The use of seaweeds as a staple substance of diet date back to ancient times in several nations like Japan, Korea, and China (95, 96). The nutritional benefit of seaweeds was utilized since 8thcentury and there are about 21 species that are used in everyday meal (97). Some seaweeds were used since time immemorial for honored guests, even for the king (98-100). In Western cookery, there is little tradition of using seaweed though currently there is a renewed interest in the use of seaweed as sea vegetables (101). Seaweed is also used as a functional food due to its effect on one or more physiological functions, as increasing the welfare and decreases the risk of suffering from the onset or development of particular diseases mostly function as preventive rather than curative (102, 103). Moreover, seaweed has found its application as a nutraceutical, as supplements rather than whole food, and marketed as pills and tablets which can provide useful health benefits (104). The bioactive compound in seaweed such as*Kappaphycus alvarezii* and *Sargassum tenerrimum* contain valuable nutritional value which is important to human health (105).

Medicinal value

Seaweeds offer a wide range of therapeutic possibilities both internally and externally. The medicinal value of seaweed depends on the type and particular species. There are several types of seaweed both wild and cultivated (106) , this means seaweeds can be classified by its use such as medicine, fertilizer and industrial raw materials (105). Utilization of seaweeds as medicine date back to 13,000 years ago in Chile at late Pleistocene settlement (107). Also, there was more archaeological evidence as to the inclusion of seaweed in folk medicine for thousands of years ago in Japan, China, Egypt and India (108). Between 1977 and 1987, the newly discovered chemicals from seaweeds were 35%, followed by sponges 27% and cnidarians 22%.(108). Since then, there is an increasing trend of discovering pharmacologically active compounds from seaweed. This indicates that marine organisms can be utilized as a source of variety compounds with pharmacological activities including anticancer, antimicrobial, antifungal, antiviral and anti-inflammatory which are potential sources of new therapeutic agents (109).

Yi, et al. (2001) (110) investigated the extract from 23 species of marine algae belonging to the Chlorophyta, Phaeophyta, and Rhodophyta, using different solvents such as ethanol, acetone, and methanol-toluene. The results indicated that ethanol extract had the strongest antifungal activity, while the methanol-toluene extract had the weakest, indicating the possibility of using ethanol extract as antifungal agent. Similarly, Khanzada et al. (2007) (111) tested several fractions of an ethanolic extract of *Solieria robusta (Rhodophyta)* for antifungal activity against five fruit rotting fungi isolated from fruits in Pakistan and found that all fractions inhibited fungal growth ; ethanol had the highest inhibition ratios, followed by aqueous fraction. On the other hand, Saidani, et al. (2012) investigated antifungal action of four species of marine algae of Bejaia coast and reported that all experimented extracts displayed antifungal action, the maximum inhibiting effect was noted for *Rhodomela confervoides* (red algae) and *Padin apavonica* (brown algae), respectively against Candida albicans and Mucor ramaniannus (112). Furthermore, Indira, et al. (2013) presented the antifungal property of seaweed *Halimeda tuna* against nine fungal strains (Aspergillus niger, Aspergillus flavus, *Alternaria* , Candida albicans, Epidermophyton floccossum, Trichophyton mentagrophytes, Trichophyton rubrum, Pencillium sp. and Rhizopus sp.) (113). Therefore, there is a need to investigate further medical applicability of seaweeds present in the WIO in order to explore its benefits for sustainable ecosystem.

Anticancer properties

The global prevalence of cancer is currently significant, necessitating the development of a nature-based mitigation strategy such as the use of bioactives from natural products (114). Natural medicines have lately been acknowledged as a promising option for preventing or suppressing the progression of invasive malignancies (115). It was reported that breast cancer is the leading cause of death in women globally. Cancerous breast cells express survival factors that inhibit apoptotic cell death (116). Studies indicated the ability of seaweed extracts to prevent apoptotic cell death hence their application in treatment of breast cancer (117). In addition, some species of macroalgae had exhibited cytotoxicity against number of cancer cell lines (118, 119),indicating the potential of using seaweed extract for mitigation of cancer.

Antiviral properties

Seaweed has been reported important source of antiviral agents with high efficacy on resistant mutant viral strains and low toxicity to host (120, 121). Water soluble extracts from seaweeds demonstrated antiviral activity against a wide range of viruses (122). Among the bioactive molecule from seaweeds with antiviral activity are polysaccharides from marine organism which can either inhibit the replication of the virus by interfering with the viral life cycle or improve the host antiviral immune responses to accelerate the process of viral clearance (123). The life cycle of viruses differs greatly between species, but there are six basic stages in the life cycle of viruses; viral adsorption, viral penetration, uncoating of capsids, biosynthesis, viral assembly, and viral release (124). Therefore, Marine polysaccharides can inhibit viral life cycle at different stages or directly inactivate virions before virus infection.

Antifungal properties

The potential of seaweed as an antifungal agents was tested some decades back in several countries worldwide (125). Reports of adoption of seaweed extract as antifungal agent in agriculture are available (126). Hellio et al. (2000) (127), reported the significant reduction in the growth of the fungi after treatment with variety of seaweed extracts, indicating the possession of antimicrobial activity by tested extracts.

Antibacterial

Seaweeds cultivated in different parts of the world exhibit varying antibacterial properties which can be utilized for improving human health. For example, the extracts of *U. fasciata* isolated from the southeast coast of India demonstrated antibacterial properties and a broad spectrum of antibiotic activity against *Bacillus cereus, Escherichia coli,* Bacillus *subtilis, Aeromonas hydrophila, Vibrio fischeri, and Vibrio harveyi* (128). *Cladophora glomerata*exhibited substantial antibacterial activity against the MDR bacterium*Acinetobacter baumannii* and various human and fish pathogens, such as *E. coli, B. cereus, Vibrio anguillarum, V. fischeri, Vibrio parahaemolyticus, and Vibrio vulnificus (129).* An acetylenic sesquiterpene isolated from *Caulerpa prolifera, caulerpenyne*exhibited antifouling activity against bacteria and the microalga*Phaeodactylum tricornutum (130)* . Moreover, the ethanolic extracts of *C. decorticatum* displayed antibacterial activity (131). In this trend there is need for the researcher to explore more and educate the public and the community in general on the existence and application several medicinal potentials of seaweed species found in Western Indian Ocean.

Role of women

The participation of women in seaweed farming in WIO is reported to be more or same as that of men(132, 133). For example, since its introduction seaweed commercial farming in 1989 in Zanzibar Island women have been the main producer of this important product. It is supported by available data that in 1989 there were larger number of women farmers than men farmers on both Unguja and Pemba (134). In this case the gender data obtained from the Ministry of Agriculture, Natural Resources, Livestock and Fisheries (MANLF) in Zanzibar showed that the seaweed industry is dominated by women than men as 78% of farmers in Zanzibar were women and 90% of Tanzania mainland were women (93). The trend was not different according to MANLF statistics of 2012, the number of women farmers was 8094 on Unguja and 10,378 on Pemba, as compared with 605 and 4612 men respectively (93). This also led to the shift of some of household system from patriarch to matriarch. This means some women as they gain some stable income from seaweed farming become head of their household unit (135). The trend is not different in some other countries of WIO where seaweed farming takes place except for Mauritanius, where there is low involvement of women as compared to that of men (133). This is supported by the number of women who attended training sponsored by Mauritius Research Council (MRC) conducted in Mauritius and Rodrigues. In Mauritius 33% of the 40 participants were women and in Rodrigues, there were 26 women, 43% of the total of 61 people (133). However, this is not enough to justify those who participated in real farming as training attendance may be done by the nomination of members by respective organisation and cannot accommodate many people.

In Madagascar, commercial seaweed farming began in 1977 using the local strain of *kappaphycus striatus* as means of improving cash income for local communities. The project was supported by the European Development fund and Food Manufacturing Cooperation (FMC USA). Although there was no specific information available concerning the involvement of women in seaweed farming in Madagascar, however, most projects focused on women and their welfare. It was noted by a report from Blue Ventures (2015), that 50% of the 700 farm workers who were integrating seaweed and sea cucumber aquaculture operations in the WIO were women (136).

Therefore, living along the coastal area women participation in seaweed farming has benefit of increasing household income which allow increased accessed to food and education as well as alleviating pressure to marine biodiversity.

Conclusion and recommendations

Seaweed farming in Western Indian Ocean exist for decades but it was observed that apart from its existance there is insufficient adoption of technological developments. Indicating the need for the regulating authorities to find means to provide farmers with knowledge on modern farming equipment's for sustainable seaweed farming. There is the need to increase production of seaweeds in WIO to upsurge source of bioactive compounds to be used for different application such as food, medicine and cosmetics. Mostly seaweeds in WIO are sold as raw materials which has low returns, there is the need to add value by converting seaweeds to various products to increase its profitability and thus, stable income to farmers. This initiative may also help increase income to women, as it is among few activities where female participation is more or equal to that of male. Apart from other benefits protection of biodiversity against invasive species should be considered by farming native seaweeds species in WIO. Therefore, it is recommended that educating and motivating societies near the marine ecosystem to engage in seaweeds farming will not only provides income to them but also will be a road towards marine ecosystem management and conservation. Seaweed as producers is key to the sustainable provision of ecosystem services to the marine life. For sustainability of marine ecosystem and reduction of conflicts among stakeholders there is the need to provide knowledge for example on the benefits of coexisting activities such as seaweed farming and tourism. Emphasis should be given to the use of new technologies in farming and protection equipment's in order to promote health and wellbeing to farmers and workers for greener WIO.

Conflict of interest

Authors declare no conflict of interest

Data availability statement

This work used secondary data which are available online and referenced

Author's contribution

Authors contributed equally in reviewing and write up of this manuscript

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