Bangladesh J. Zool. **50**(3): 283-307, 2022 ISSN: 0304-9027
eISSN: 2408-8455

PRESENT STATUS OF SEAWEED RESOURCES IN BANGLADESH: A REVIEW ON THE DIVERSITY, CULTURE METHODS AND UTILIZATION

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Abstract: Seaweeds are one of the most potential aquaculture commodities in Bangladesh. It has a long back history of being used for its nutritional and pharmaceutical importance. This review summarizes seaweeds diversity and its culture, distribution and possible applications and uses in Bangladesh. Seaweed floras are distributed along the entire coastline, however, the higher abundance of these have found in the St. Martin Island, Cox's Bazar, and Sundarbans mangrove forest periphery. These included around 200 species and belong to 94 genera. About 12 of these genera, including *Hypnea, Gracilaria, Gelidium, Enteromorpha, Halimeda, Padina, Dictyota, Caulerpa, Hydroclathrus, Sargassum, Kappaphycus*, and *Porphyra* have substantial commercial importance. A total of 5,000 metric tons of seaweeds are likely available along the entire coastline between October and April. However, seaweeds commodity and its aquaculture production have a great potential in the coastal region of Bangladesh. Furthermore, the sustainable development of this industry could bring numerous benefits such as rural development, employment opportunity and income generation, women empowerment, disease prevention, and proper utilization of land. Therefore, this sector needs more attention for its expansion activities include culture, usages and bioactive compound developments. Additionally, seaweeds cultivation could have numerous environmental benefits include ecosystem services, removal of hazardous nutrients and pollutants, metal toxicants uptake, in turn estuaries and seas tackle pollution in natural process.

Key words: Algae, Blue-economy, Seaweed aquaculture, Bioactive compound

INTRODUCTION

Bangladesh, with its blessed fertile landmass, rivers, estuaries, open and deep seas; occupied of 147,570 km^2 land area, shared 118,813 km^2 newly defined maritime boundaries with Myanmar and India (Islam 2019). This country is blessed with numerous flora and faunal diversity, located in the Indo-Burma

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 DOI: https://doi.org/10.3329/bjz.v50i3.65537

hotspots, the region of Southeast Asia and the Indian subcontinent (Siddiqui *et al.* 2019). The southern part, coastal region of this country has covered an area of 47,201 km^2 which constituted at 32% of total landmass and bordered by a long coastline about 710 km of Bay of Bengal (Azad *et al.*, 2009, Ahmad 2019, Sajeeb 2021). This country has huge potential marine water recourses in Bay of Bengal about an area of 165,887 km^2 which is greater than the total landmass (Hoq *et al.* 2013). Additionally, the coastal belt of this country has continental shelf with an area of about 66,400 km^2 and up to 50 m depth, EEZ (Exclusive Economic Zone) spans 166,000 km^2 and its jurisdiction lies from the beach baseline to 200 nautical miles seawards (Hoq *et al.* 2013; Rashid, 2020). In Bangladesh, 81% of resources exist in the ocean while only 19% of resources are on land (Islam 2015). The coastline of country is regarded as one of the most unexplored regions in the world (Siddiqui *et al.* 2019).

Bangladesh marine and brackish water environment provide suitable conditions for a wide variety of seaweed species (Al *et al.* 2020, Kathiresan 2012, Ahmed and Taparhudee 2005, Sarkar *et al.* 2016). This country is home to more than 200 species of seaweeds that belong 94 genera constituting of three primary divisions *i.e.*, green algae (Chlorophyta), brown algae (Phaeophyta) and red algae (Rhodophyta) (Sarkar *et al.* 2016). The seaweeds floras are common in coastal climate zones in the tropical, subtropical and temperate areas globally (Wernberg *et al.* 2013). There are many nations including Chinese, Egyptians, Romans, Japanese etc. have a long history of using seaweeds commodities for many purposes in the daily life (Dillehay *et al.,* 2008). Currently, the scope and extent of seaweed utilization is increasing day by day (Rebours *et al.* 2014). Most of the industries use seaweeds, including the phycocolloid or hydrocolloid industry (Porse and Rudolph 2017), bioplastic industry (Rajendran *et al.* 2012), wastewater treatment industry (Arumugam *et al.* 2018), biofuel industry (Herrmann *et al.* 2015), and cosmetic industry (Pimentel *et al.* 2018). In addition, the pharmaceutical sector uses of seaweeds in the research and production of medications for Alzheimer's disease (Rafiquzzaman *et al.* 2015), gastric ulcer (Senthil and Murugan, 2013), and cancer (Gade *et al.* 2013). Seaweeds commodities contain lipids, proteins, polysaccharides and polyphenols as well as some auspicious bioactive components. These biochemical compounds have many benefits, including antibacterial, antifungal, and antioxidant properties (Holdt and Kraan 2011, Rafiquzzaman *et al.* 2016, Sobuj *et al.* 2021a, b).

In Bangladesh, seaweeds are mostly found in St. Martin Island, along the coastline of Cox's Bazar and Sundarbans mangrove forests (Al *et al.* 2020, Islam *et al.* 2020, Siddiqui *et al.* 2019). A total of 60 and 155 species of seaweeds have identified in the Sundarbans and Cox's Bazar, respectively (Sarkar *et al.* 2016).

Approximately 5000 metric tons of seaweed biomass are available annually from the month of October to April on the coast of Bangladesh (Sarkar *et al.* 2016). The occurrence of seaweeds in coastal water of Bangladesh has distinct seasonal variation, and this is likely due to the seasonal fluctuation of water quality parameters (Sarkar *et al.* 2016). However, seaweed vegetations are found between October and April while a highest abundance of seaweed was in January to March (Islam *et al.*, 2020; Sarkar *et al.*, 2016). Seaweeds commodity is not popular as food item in Bangladesh, there are few tribal communities likely Rakhyine or Mog, who are living in coastal region are eating seaweeds as foods items *i.e.*, salad, soup and, as a vegetable (Al *et al.* 2020, Majumder 2010, Sarkar *et al.* 2016).

In Bangladesh, the seaweed industry is in its beginning stages (Ahmed and Glaser 2016). The people of this country still have little knowledge about the potential of seaweed for various reasons (Ahmed and Taparhudee 2005). This country has a great prospect for seaweed cultivation; thus, the promotion of seaweed production and its usages may help to attain the dream of a blue economy (Hossain *et al.* 2021). Seaweed may readily be a new industry in Bangladesh's limited export portfolio, and it would significantly help to alleviate the country's enduring unemployment and poverty issues. Based on the above facts, the objective of this review was to describe the present diversity, distribution, seasonal variation, abundance, and cultivation of naturally occurring seaweeds with its utilization and prospects in Bangladesh. Additionally, this review will help the researcher, academician, policy maker and entrepreneur to understand the possibility of seaweeds production and their sustainable use in order to industrial development for its local uses and international market demand.

An overview of Seaweeds: The term "seaweed" sometimes known as "macroalgae" refers to the thousands of different types of large, multicellular marine algae (Lewis *et al.* 2011). The word "seaweed" is a colloquial name for a group of primarily microscopic, multicellular marine algae that lack roots, flowers, leaves, stalks, fruits, and seeds. These algae often grow and reside stuck to hard surfaces below the high tide line or drift in the oceans (Chapman 1973, Okazaki 1971). These are resembled to non-arboreal terrestrial plants that contain a thallus (the algal body), sorus (a spore cluster), lamina or blade (a leaf-like and flattened structure), air bladder (an organ on the blade of kelp that aids in flotation), float (a flotation-assisting organ between the lamina and stipe), holdfast (a specialized basal-like structure that provides attachment to a surface, typically a rock or another alga), stipe (a stem-like structure that may be present or absent), frond (the blade and stipe are collectively referred to as the frond), and haptera (a component of the holdfast that looks like a finger and is anchored to a benthic substrate); these are the identifying characteristics of seaweeds (Fig.1) (Bhuyar *et al.* 2016, Stiger-Pouvreau *et al.* 2016).

There are more than 15,000 species of seaweeds are found globally (Hossain *et al.* 2020), of which about 10,500 seaweeds are known (Chopin and Tacon 2021). Furthermore, Chopin and Tacon (2021) mention in a review, about 220 species of seaweeds has farmed worldwide, but FAO FISHSTAT database for 2018 was listed only 20 seaweed species. Currently, seaweed mariculture is steadily increasing and recognized as one of the first growing mariculture sector, globally around 132 countries are likely having suitable environments includes nutrient levels and physicochemical properties; however, 37-44 countries are active in seaweed mariculture production (Froehlich *et al.* 2019; Hossain *et al.* 2021).

The majour seaweeds producing countries are China, Indonesia, South Korea, North Korea, Philippines, Japan, Malaysia, Taiwan, Viet Nam, Tanzania and Chile (Chopin and Tacon 2021). Historically, seaweeds have been used as human and other animal foods as well as and medicinal purposes from 2000 years back to in this modern era (Chopin and Tacon 2021, Wang *et al.* 2020). Although, the direct consumption of seaweeds or its commodity as human food sources are not much popular globally (Fleurence *et al.* 2012). But some Asian countries (e.g., China, Indonesia, Japan, Malaysia, North Korea, south Korea) are traditionally eating seaweeds as sea vegetables (Fleurence *et al.* 2012, Mahadevan 2015). While, limited consumption of seaweeds has shown in many western parts of the world (e.g., Canada, France, Iceland, Ireland, Scotland, USA, Wales) (Mahadevan 2015, Van Den Burg *et al.* 2021).

Seaweed flora provide essential nursery habitat for many invertebrate and vertebrates in estuaries and seas, especially juvenile fishes (Tano *et al.* 2017). Additionally, the seaweeds vegetation can be considered as an ideal homestead or shelter for many species of biota, in which these animals are foraging on seaweeds and its assemblage organisms (Al-Hafedh *et al.* 2012, Duffy and Hay 1990). The seaweed floras have played paramount role to marine and brackish water ecosystems by absorbing carbon dioxide and providing more than fifty percent of oxygen that are utmost requirement for ocean life including plant, animal and other organisms (Chapman 2013). Seaweeds do participate in bioremediation process in estuaries and seas are removing hazardous compound (nitrogen and phosphorus) and toxic metals (cadmium, copper, lead, Mercury, Zinc) (Foday *et al.* 2021, Roleda and Hurd, 2019, Saldarriaga-Hernandez *et al.* 2020). Their bioremediation process in estuaries and seas are tackled the pollution naturally that are added from anthropogenetic activities, industrial wastes, agrochemicals and so on.

Phaeophyta-brown seaweed/algae: Brown algae or seaweeds, belong to the group Heterokontophyta (Coyer *et al.* 2006), which arose as a result of a symbiotic interaction between a basic eukaryote and another species and have chloroplasts encircled by four membranes (Schwartzbach *et al.* 1998; Sheath and Wehr, 2015). Most of the brown algae contain pigment fucoxanthin, which is responsible for their greenish-brown hue and designation as brown algae (Song *et al.* 2015). Brown seaweeds are majour seaweed producer that has accounted about 80.7% of total global production. *Saccharina* is key brown algae contributed of 50.8% and total brown algae production, while *Undaria Sargassum,* and other Phaeophyceae have been produced at 2.9%, 0.1% and 26.9%, respectively (FAO 2020). In Bangladesh, *Padina australis, Sargassum caryophyllum, S. flavicans, S. vulgare, Ectocarpus breviarticulatus*, etc. are commonly available brown algae.

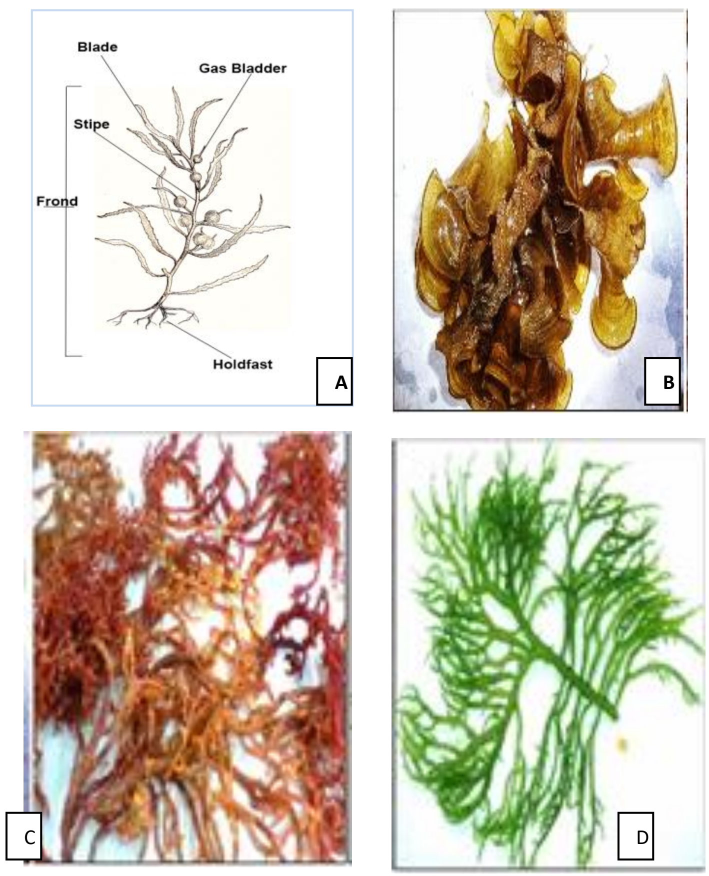

Fig. 1. Different type of seaweeds; (a) typical seaweed structures, (b) brown seaweed, (c) red seaweed and (d) green seaweed

Rhodophyta-red seaweed/algae: Red algae or seaweeds are a unique category distinguished by centrioles, eukaryotic cells lacking flagella, unstacked thylakoids, and chloroplasts lacking an external endoplasmic reticulum (Cole and Sheath 2011). It used phyco-bili-proteins as auxiliary colors, which provided them with their red pigment (Bleakley and Hayes 2017). Currently, this group of algae has contributed 18.5% of global algae production (FAO 2020). The key genera of this group are *Porphyra/Pyropia*, *Kappaphycus, Eucheuma*, *Gracilaria*; these have contributed at 9.0%, 6.1%, 2.9% and 0.5% of production, respectively (FAO 2020). The commonly available red algae in Bangladesh are of *Hypnea musciformis, H. pannosa, Gracilaria textorii, Halymenia floresia, H. discoidea, H. floridana* etc.

Chlorophyta-green seaweed/algae: Chlorophyta algae or green algae has chloroplasts that contain chlorophyll a and b (Turner *et al.* 1989), which gives them a bright green color (Aramrueang *et al.* 2019). It also contains the accessory pigments xanthophyll (Masojidek *et al.* 2004) and beta-carotene (Pilát *et al.* 2012). The cell ramparts of green seaweed store carbohydrates in the form of starch, and they usually consist of cellulose. Moreover, green seaweeds have paired flagella (Polotzek and Friedrich 2013) that are being used to move the cell and mitochondria with flat cristae (Solari *et al.* 2006). They are secured by a cross-shaped structure of fibrous strands and microtubules (Roberts 1992, Marshall 2012). Green seaweeds are least dominant contributing seaweed, *Ulva* and *Caulerpa* are important globally. *Enteromorpha clathrata, Caulerpa racemosa, Ulva lactuca, Codium fragile*, etc. are available in Bangladesh.

Factors considered for seaweed cultivation: Successful development of the seaweed sector demands not only the availability of effective technical methods and suitable natural environmental conditions but also responsive and encouraging social and economic conditions (Tisdell 1999). Significant social repercussions include property security, the types of social elements utilized for asset allocation and asset assurance, the legal system, the political system, tastes, and social worth (Ahmed and Taparhudee 2005). In order to advance seaweed farming, the comprehensive strategies are required that have mention previously and showing in the Fig. 2. The strategies have potential challenges, and equally significant for sustainable development of seaweed cultivation in Bangladesh (Ahmed and Taparhudee 2005).

Global seaweed aquaculture production was at 10.6 million tonnes in 2000, within a decade it increased about two-fold (20.2 million tonnes) in 2010; and currently it reached at 35.8 million tonnes in 2019, this production is contributed by 49 countries (Cai 2021, Chopin and Tacon 2021). Asian countries have been producing about 97% of seaweeds; Asian, African and Oceanian production are dominated by cultivation, while American and

European seaweed production are shared by wild collection (Cai 2021). Globally, 145 species of seaweeds are used as human consumption and 110 for phycocolloid production (Joseph and Jayaprakash 2003, Khan and Satam 2003). Currently, 34 species of seaweeds are cultured globally (Hossain *et al.* 2020). There are 77 genera, including about 200 species of seaweeds are available in Bangladesh (Aziz *et al.* 2015, Islam *et al.* 2021). Among them, 18 species belong to 12 genera are commercially important (Siddiqui *et al.* 2019) (Table 1). Some limited culture activities have shown in Bangladesh to examined the feasibility, these studies were used four species i.e., *Gracilaria tenuistipitata*, *Ulva intestinalis*, *Ulva lactuca* and *Hypnea musciformis* (Hossain *et al.* 2020).

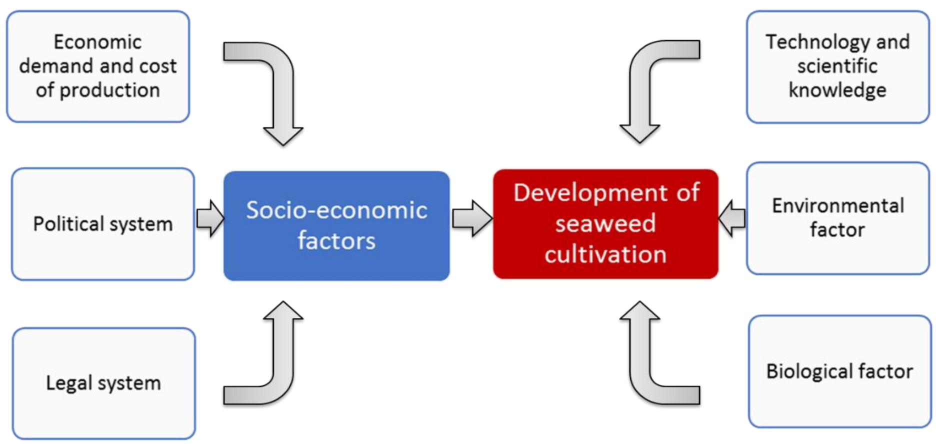

Fig. 2. Schematic diagram of factors that affect the expansion of seaweed aquaculture (Source: Ahmed & Taparhudee, 2005) Current status of commercially important seaweed resources of Bangladesh

Present status of seaweed cultivation in Bangladesh: Seaweed cultivation is at its initial stage, and currently no commercial cultivation system is being practiced in Bangladesh. Most of the seaweed is naturally produced in Cox's Bazar, the Sundarbans mangrove forest and St. Martin Island, and among them, St. Martin is considered a hotspot for seaweed cultivation (Islam et al. 2017, Sarkar et al. 2016). This is because of the physical and chemical characteristics of this area (Table 2) offer favorable conditions for the growth and survival of seaweed.

From November to January, some local seaweed harvesting may take place for two to three months (Aftab Uddin *et al.* 2021). In defiance of the government restriction, poor inhabitants of St. Martin Island collected seaweed on a small scale during the months of April and May for their livelihood, which was transported to China (Siddique *et al.,* 2013a), Singapore (Siddique *et al.* 2013b) and Myanmar (Ahmed and Taparhudee 2005, Siddiqui *et al.* 2019). Seaweed culture in Bangladesh could be considered low environmental risk or climate-friendly as it uses coir rope for the culture. However, indigenous materials like rope (Islam *et al.* 2021) and bamboos (Khan 1990) are used to cultivate seaweed, and a few individuals work in seaweed farming on Bangladesh's south-eastern and south-western beaches (Siddiqi et al. 2019).

Table 1. Commercially important seaweed species in Bangladesh (Siddiqui *et al.*, 2019)

Genus	Species	Type
Caulerpa	*Caulerpa racemose* *Caulerpa sertularioides*	Green Seaweed
Enteromorpha	*Enteromorpha intestinalis* *Enteromorpha moniligera*	Green Seaweed
Codium	*Codium fragile*	Green Seaweed
Gelidiella	*Gelidiella tenuissima*	Red Seaweed
Halymenia	*Halymenia discoidea*	Red Seaweed
Hypnea	*Hypnea pannosa Hypnea valentiae* *Hypnea musciformis*	Red Seaweed
Gelidium	*Gelidium pusillum Gelidium amansii*	Red Seaweed
Catenella	*Catenella* spp.	Red Seaweed
Porphyra	*Porphyra* spp.	Red Seaweed
Hydroclathrus	*Hydroclathrus clathratus*	Brown Seaweed
Sargassum	*Sargassum oligocystum Sargassum coriifolium*	Brown Seaweed
Padina	*Padina tetrastromatica*	Brown Seaweed

Table 2. Physical and chemical conditions are favorable for seaweed growth at Sundarbans, Cox's Bazar and St. Martin (Satpati *et al.* 2012, Islam *et al.* 2021)

Parameters	Optimum range for Seaweed culture	In St. Martin, Cox's Bazar & Sundarbans
Salinity (ppt)	28-34	32-34
Temperature (℃)	24-28	20-28
pH	7.5-8.5	7.5-8.5
Dissolved Oxygen (mg/L)	4-6	5-6

Table 3. Culture method followed by farmers at present for seaweed culture in Bangladesh (Islam *et al.* 2017, Siddiqi *et al.* 2019, Abdul 2020)

Species	Location of cultivation	Culture method
Hypnea sp	Cox's Bazar, Innani, Bakkhali, Saint Martin Island	Rope & net culture
Caulerpa sp	Saint Martin & Cox's Bazar	Long Line Floating
Enteromorpha sp	Cox's Bazar	Rope culture
Gracilaria , *Ulva*	Nuniarchora , Cox's Bazar	Rope culture

Among 18 commercially important seaweed species, only a few are found cultivated in the suitable coastal regions of the country (Table 3) and the rest of the naturally produced seaweed are just harvested from the coastal region. It is estimated that each year almost 5,000 metric tons of seaweed is accessible (Hussain *et al.* 2019). Both the growth rate and the yield of seaweed that has been farmed were determined to be quite high. From 2015 to 2018, Islam et al. (2017 and 2021) carried out studies on the cultivation of various species of seaweed (*Hypnea* sp., *E. intestinalis, H. musciformis*, and *P. tetrastromatica*) in a variety of coastal locations in Bangladesh, including Saint Martin's Island, the Bakkhali river estuary, and Inani of the Cox's Bazar district (Fig. 3). They found comparatively better yield in St. Martin's Island, which indicates favorable water quality variables in St. Martin's culture site (Table 4).

Table 4. Maximum biomass yield (Mean ± SE) of seaweed cultured in different locations Bangladesh (Islam *et al.* 2017 Islam *et al.* 2021)

Cultured species	Duration of culture period	Maximum yield (kg m^{-2}) of seaweed in different locations			
		St. Martin	Bakkhali	Inani	Total
Hypnea sp.	60-days	8.03±0.14	6.83±0.18	4.80±0.05	19.66±0.37
E. intestinalis	90-days	24.50±0.08	23.74±0.87	13.84±1.06	62.08±2.01
H. musciformis	90-days	30.23±0.40	21.40±0.09	14.82±0.16	66.45±0.65
P. tetrastromatica	60-days	10.18±0.45	8.34±0.25	5.14±0.54	23.66±1.24

Additionally, Bakkhali and Inani are located upstream, where the magnitude of water quality parameters does not remain consistent like in St. Martin and does not have a large enough substratum to support a massive colony of seaweed. Farmers on the Cox's Bazar coast frequently culture seaweeds using the off-bottom net and long line techniques (February and Report 2022). Seaweed farming is becoming more and more popular among Bangladesh's coastal residents as a new source of income because of the growing demand for it on both the domestic and global markets (Mamun 2022). Fishermen in the southern Cox's Bazar coastal zone are interested to seaweed culture because of affordable way of using local resources needs short period of time and easy culture methods. The seaweed industry has recently emerged as one tiny glimmer of hope for the fishing neighborhood of this region of Bangladesh (Islam 2022)

Land utilization possibility of seaweed culture in Bangladesh: Cox's Bazar beach and St. Martin's Island in the Bay of Bengal are simply two examples of Bangladesh's 710 kilometers of coastline (Ahmad 2019). The continental self extends over an area of about 24,800 sq. miles. In addition, 19 districts are in the coastal region (Haque *et al.* 2020). Seaweed can be cultured in these areas and we could use our land properly as aquaculture in the coastal areas is not well practiced in our country. Seaweed can be cultured in both land based and integrated aquaculture system (Hortsmann 1983; Chopin *et al.* 2001; Bolton *et al.* 2009). A variety of benefits are provided by land-based seaweed cultivation in the production of raw materials for the creation of functional products (Friedlander 2008).

Fig. 3: Seaweed cultivation in Cox's Bazar coast (Billah & Naher, 2021)

Present status of naturally occurring seaweeds in Bangladesh: Seaweed can grow naturally without any artificial fertilizer or sustenance, unlike other terrestrial plants (Pati *et al.* 2016). It does not take up much space on land as it grows offshore (Chowdhury *et al.* 2022). In Bangladesh, naturally growing seaweeds are shown in the sub-littoral and littoral zones of St. Martin's Island (Billah *et al.* 2018, Aziz *et al.* 2015), and this region is the southernmost land of Bangladesh. Additionally, seaweeds can be found in the region surrounding Cox's Bazar and Sundarbans (Quader 2010, Mitra, 2017, Hossain *et al.* 2021). About 400 tons of seaweed are grown each year in Cox's Bazar, Chattogram, Noakhali, Patuakhali, Satkhira, and Bagerhat (Islam 2022). Therefore, these areas could be considered a promising seaweed cultivation zone for Bangladesh.

Moreover, government and private sectors should go forward to identify the suitable cultivable seaweed species and seaweed based industries for sustainable development of blue economy in Bangladesh.

Abundance of seaweed in St. Martin's Island: Many seaweed species are found in St. Martin's Island (Billah *et al.* 2018). There are four different coastlines on St. Martin's Island: the northern, southern, eastern and western. The higher abundance of seaweed vegetation has found in northern and southern shores of St. Martin's Island (Sarkar *et al.* 2016). The higher abundance of seaweeds was in the January, February and March, and it was probably due to favorable water quality conditions in this period. Billah *et al.* (2018) recorded 37 seaweed species, of which 11 species belong to Chlorophyceae, 14 to Phaeophyceae and 12 to Rhodophyceae. Interestingly, the higher species of seaweed at 14 species was under Phaeophyceae group in March (Billah *et al.* 2018). These authors also stated that temperature has substantial impact on seaweed density, distribution and species diversity. The increasing of temperature has greatly declined the seaweed vegetation, and lower number of seaweed species at 18 was recorded at the end of June (Table 5).

The northern coastline of St. Martin's Island is home to Phaeophyceae, which is the most abundant. Similarly, the higher number of species diversity was shown in this coastline than that of southern coastline of St. Martin's Island. However, the occurrence of Phaeophyceae and Rhodophyceae seaweed species were not different in the southern coastline of St. Martin's Island. The variation of temperature over the months of April, May and June have decreased the seaweed species diversity, abundances and distribution when compared to the month of February and March (Siddiqui et al. 2019).

Table 5. Number of species found in St. Martin's Island (Month wise) (Billah *et al.* 2018).

Name of Class	January	February	March	April	May	June	Total
Chlorophyceae	11	10	11	8	7	5	52
Phaeophyceae	13	12	14	11	9	7	66
Rhodophyceae	11	10	12	9	7	6	55
Total	35	32	37	28	23	18	173

Abundance of seaweed in Sundarbans: The natural availability of seaweeds in the Sundarbans is made possible by ideal climatological and environmental conditions (Harley *et al.* 2012). Varieties of seaweeds are found throughout the Sundarbans mangrove forest in inter-tidal zones on mangrove tree pneumatophores, other wooden logs, and in tree bark (Mitra *et al.* 2014, Mitra *et al.* 2018). About 60 different types of seaweeds have recorded in the Sundarbans

(Siddiqui *et al.* 2019). Some of these are *Boodliopsissun darbanensis, Ulva lactuca, U. intestinalis, Catenella repen, C. nipae, Gelidium amansii, Polysiphonia mollis*, and *Ceramium gracillimum.* Due to their functional properties, these species have potential commercial applications in the pharmaceutical, biotechnology, cosmetic, and food industries (Yu-Qing *et al.* 2016; El-beltagi *et al.* 2022).

Abundance of seaweed in Cox's Bazar coast: Around 155 species of seaweeds have found in Cox's Bazar (Sarkar *et al.* 2016; Siddiqui *et al.* 2019). The seaweed flora also available in Teknaf, Bakkhali-Moheshkhali river estuary, Jaillapara, Shilkhali coast, Moheshkhali Island (Abu Hena *et al.* 2013.; Aziz and Alfasane 2020, Islam *et al.* 2020). Seaweeds vegetation are naturally occurred Nuniarchara to Nazirartek parts of the Bakkhali River (Hoq *et al.*2016, Islam *et al.* 2017) and the Moheshkhali Channel estuary (Aziz and Alfasane 2020, Aziz *et al.* 2021) and on Moheshkhali Island. *E. intestinalis* and *H. musciformis* are the main seaweed species in Cox's Bazar (Sarkar *et al.* 2016, Siddiqui *et al.* 2019).

Seasonal variation in seaweeds availability: The availability of seaweed varies seasonally owing to changes in water quality (Abhilash *et al.* 2019). The distribution of seaweed and its growth are both affected by a wide range of environmental factors, including water temperature, salinity, pH, dissolved oxygen, water clarity, and nutrients, among many others (Luning 1990). In Bangladesh, seaweed is found in the summer, winter, and spring seasons and is unavailable in the autumn and rainy seasons (Sarkar *et al.* 2016, Siddiqui *et al.* 2019). Accordingly, seaweed is often accessible in Bangladesh from October to April, while the peak abundance occurred from January to March (Sarkar *et al.* 2016).

Utilization of seaweed: The ethnic people of Bangladesh have likely relied on seaweed for their nutritional needs (Siddiqui *et al.* 2019). As, there is paucity of regular seaweed industry in Bangladesh, people of coastal region still depend on the naturally occurring seaweeds flora (Sarkar *et al.* 2016; Siddiqui *et al.* 2019). Seaweeds can be used as cosmetics, fertilizers, human foods, and chemicals, as well as for the extraction of industrial gums (Table 6). They offer a significant amount of untapped potential as a source of both long- and short-chain chemicals that have applications in industry and medicine.

Possibility of seaweed in diseases prevention: Bangladesh exposes millions of people to goiter and related disorders (Laz and Arifuzzaman, 2017). People suffer from serious mental and thyroid issues as a result of the iodine shortage alone (Mansourian 2011). The majority of seaweed contains more iodine than saltwater and is a vastly superior option to iodized salt or medications for regulating thyroid hormone synthesis (Laurberg *et al.* 2010, Andersen *et al.* 2019). Seaweed should be consumed on a regular basis by malnourished children, pregnant women, and nursing mothers. This will guarantee that they get a suitable amount of the element that is found in the highest concentration in humans (Leyman 2002). Anhalt (2003) stated that the compounds found in green seaweed have been linked to several benefits including lower blood pressure, lower cholesterol, and the prevention of stroke.

Table 6. General uses of Seaweed (Veluchamy *et al.* 2020)

Application	Product	Function
Food Additives	Dairy Products	Gelation, foaming, suspension.
	Baked food	Improving quality, controlling moisture
	Sweets	Gelation, increase viscosity, Viscosity,
	Juices and Sauces Breweries	emulsifier
	Processed meat	Stabiliser
	Frozen Fish	Adhesion
		Adhesion and moisture retention
Medicinal-pharmaceutical	Tablets	Encapsulation
	Laxatives	Indigestibility & lubrication
	Dental mould	Form retention
	Metal poisoning	Binds metal
	Herpes Simplex virus	Inhibit virus
Cosmetics	Shampoos	Interface vitalisation
	Toothpaste	Increases viscosity
	Lotions	Emulsification, elasticity & firmness to skin
	Lipstick	Emulsification, viscosity
Other Industrials uses	Paints	Viscosity and suspension, Glazing
	Thread making	Viscosity
	Textiles	Sizing and glazing
	Paper making	Viscosity and thickening
	Adhesives and starch	Suspension
	Casting and welding rods	Chemical reactivity
Chemicals	Analytical separation and purification of base.	Gelling
	Bacteriological media	Gelling
	Electrophoresis gel	Gelling

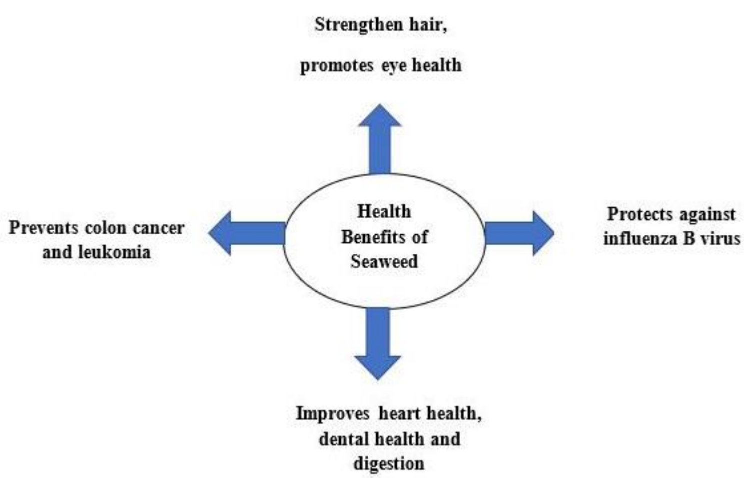

Fig. 4: Some health benefits of seaweed (Source: Lomartire *et al.*, 2021)

Possibility of seaweed to blue economy of Bangladesh: Seaweeds are primary producers and are among the chief ecological engineers that are crucial to brackish water and marine ecosystems. These are influencing biotic and abiotic factors of estuaries, salt marshes, mangrove swamps, coral reefs, open ocean and deep ocean (Generally, seaweeds mostly grow above 100 m depths, but a few could grow about 295 m depths in the Bahamas) (Fredericq 2010, Cotas *et al.* 2023). The southern coastline of Bangladesh has enormous prospects on commercially important seaweeds cultivation, because the brackish water and marine environments of these area are likely favorable (Islam and Mostaque 2016).

The cultivation of seaweeds could bring more benefits to the local and international levels. For example, it could be a great food commodity for local and international sea foods markets, thus these commodities can be an aid of foreign currency earning source, in turn this could boost up the national economy. Furthermore, culture of seaweed can be attracted brackish water and marine fishes, and these Eco-traps are likely used to have in increasing the marine catches which may enhance and ensure sustainable blue economy of Bangladesh. Additionally, the development and expansion of sea-weed based technologies, industries as well as entrepreneurs among the privates and government sectors could open a new window in increasing the blue economy and its sustainability (Hossain *et al.* 2021; Hussain *et al.* 2017). Therefore, seaweed farming and its industrial developments are likely escalated and ensured employment opportunities, livelihoods, food security and economic growth among the various seaweed value chain actors along with small holders, improvised farmers, entrepreneurs and seaweeds goods sellers and wholesalers (Seraj 2018).

Future directions: Currently, blue economy action plan, policies, strategies are paramount issues in Bangladesh that have received much attention, in which seaweed management, harvest, cultivation and conservation as well as its commodities utilization and industry setup is one of the key components. However, this sector needs concrete information, sophisticated technologies, more experts and proper understanding in ensuring the sustainable use of seaweed resources to enhance the blue economy. Hitherto, the seaweed sector does not address its importance as well as in relation to resource management in local level, and does not recognize its potential global commodities despite having great prospects. Therefore, we recommend a couple of future directions for this emerging issue in Bangladesh.

Firstly, the suitable wild harvest seaweed hotspots and their possible yield should be identified in estuaries and seas without its overexploitations, while other marine resources should be conserved. Secondly, seaweed cultivation technology should be initiated in estuaries, oceans and landmass using reproducible culture methods that has been demonstrated in other parts of Asia. In this case, local culture material could be used. Currently, integrated fish-seaweed, shrimp-seaweed are shrimp-tilapia-seaweed are considered a viable multitrophic aquaculture system (Kang *et al.* 2021, Ly *et al.* 2021, Tran *et al.* 2020). However, these systems should be developed using promising brackish or marine water fish, giant river prawn, *Macrobrachium rosenbergii* (Hosain *et al.* 2021a,b) and recently introduced whiteleg shrimp *Litopenaeus vannamei* in indoor system or outdoor confined pond culture system (Naser *et al. 2022*). Thirdly, more research should be needed to develop the human food commodities for local peoples as well as others seaweed products (e.g., carrageenan, alginate, agar, soil additives, fertilizer, seaweed meal, pharmaceuticals, cosmeceuticals, nutraceuticals, bioactives etc.). Fourthly, seaweed using wastewater plant should be developed, this could help to support industry setup in rural coastal regions as well as industrial biosecurity (Arumugam *et al.*, 2018; Hamd *et al.*, 2022; Znad *et al.*, 2022). Finally, the seaweed sector needs a center of excellence/policy making branch that should be established wild seed bank to conserve genetic diversity in order to ensure the sustainable use and development of seaweed industry in Bangladesh.

CONCLUSIONS

In conclusion, seaweed has immense potential in Bangladesh for various applications, including food, medicine, aquaculture, biofuel production, and environmental remediation. Seaweed cultivation and utilization can provide a sustainable solution to many of the challenges faced by coastal communities in Bangladesh, such as poverty, malnutrition, and environmental degradation. The country's favorable climatic and geographical conditions, combined with its long coastal line, make it an ideal location for seaweed cultivation. However, to fully exploit the potential of seaweed, more research and development efforts, as well as investment in infrastructure and training, are required. The establishment of seaweed-based industries can create employment opportunities and contribute to the country's economic growth while promoting sustainable development. Overall, the prospects of seaweed in Bangladesh are promising, and its cultivation and utilization can be a game-changer for the country's coastal communities and the environment.

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(Manuscript received on 10 October 2022 revised on 26 December, 2022)