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Research article

Seaweeds for the sustainable blue economy development: A study from the south east coast of Bangladesh

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ABSTRACT

Bangladesh is a maritime country with an area of 118000 km^2 which supports a large number of commercially important species. Currently seaweeds are considered as important component of blue economy development in Bangladesh and farming is practiced at small scale level (*Hypnea* spp, *Caulerpha reacemosa*, *Gelidium* sp. are cultured). For the expansion of the seaweed farming in Bangladesh, a complete understanding of social and economic status of current farmers is important. However, information on socio-economic status of seaweed industry in Bangladesh is very limited. Therefore, this study aimed to understand existing culture methods and their cost, marketing channel and problems with seaweed farming in south east coast of Bangladesh. We used questionnaire survey and focus group discussions to collect data from seaweed farmers, researchers, local community and entrepreneurs. The study found that farmers are currently practicing long-line and horizontal net methods for the seaweed farming in the south east coastal region. The study also found that these culture methods are economically profitable. Seaweeds are currently sold locally and a proper value chain for seaweed marketing is still missing. Existing seaweed farmers are facing the problems related to insufficient credits for starting seaweed farming, lack of proper guidelines for farming and processing of harvested seaweed. This study suggests that for industrial level expansion of seaweed production in Bangladesh a proper value chain, development of seaweed derived products, farm monitoring systems, smooth seed supply and information hubs are required.

1. Introduction

Seaweed farming is gaining worldwide popularity and currently is a well-established industry (Buschmann et al., 2017). Seaweed farming brings foreign currency and offers an opportunity of income earning for the coastal marginalized communities. Taking this into account globally seaweed farming is promoted to the coastal rural community by international development organizations to uplift their poverty (Campbell et al., 2019; Rimmer et al., 2021). Since seaweed farming has short culture cycle and simple low-cost farming technologies are available, seaweed farming has high economic returns (García-Poza et al., 2020).

Throughout the world, suitable are for seaweeds culture area covers 48 million km^2 of marine ecosystem in 132 countries, though only 37–44 countries are currently active in seaweed production (Froehlich et al., 2019). Seaweed farming contributes significantly to sustainable aquatic food production. In addition, farming of seaweed also offers ecosystem services, for example habitats for fisheries as well as sequestration of nutrients (Hasselström et al., 2018). Seaweed production does not need fertilizer or pesticide but extracts nutrients from the water, purifying surrounding water and maintains ecosystem health. For instance, uptake of phosphorus from large seaweed farming activities significantly contribute in mitigation of eutrophication in coastal area (Xiao et al., 2017).

Worldwide food and fertilizer are produced from seaweed. In addition, seaweeds are also used in industrial sectors (García-Poza et al., 2020). Seaweeds are rich with nutrients (i.e. proteins, carbohydrate, lipids and fibers) (Sánchez-Machado et al., 2004). Seaweeds are found as important source of bioactive compounds and have antioxidant activities (Wang et al., 2012). Seaweed industry is expanding rapidly throughout the globe for high economic returns. It is estimated that global seaweed production already exceeded 32.4 million tonnes which is three times more than the production of 2000 (FAO 2020). Most of the global

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seaweed productions (about 97.1%) comes from the offshore and onshore cultivation sites, and only 2.9% are harvested from wild sources (FAO 2020). It is interesting that, eastern and southeastern Asia is contributing in most of the seaweed production which is about 99.6% of global production. Only China is contributing about 58% of global seaweed production (FAO 2020). However, other countries (i.e. Indonesia, Philippines, South Korea, Japan and North Korea) are also producing seaweeds.

Seaweed farming in Bangladesh is an emerging sector (Sarker et al., 2019). Coastal zone of Bangladesh covers about 47201 km^2 area which is about 32% of the country (Sarker and Mahmudul Islam 2021). Total population in the coastal area is 35 million which is 29% of total population of the country (Sarker et al., 2018). The coastal zone of Bangladesh is relatively income-poor compared to the rest of the country. Marginalized coastal communities are mainly involved with fishing, agriculture, livestock rearing and day laboring (Sarker et al., 2021b). Thus, ongoing seaweed farming has great potentiality to uplift the poverty of poor coastal community in Bangladesh. However, the socio-economic status of seaweed industry in Bangladesh is not investigated yet. Therefore, current study aimed to understand the socio-economic impact of seaweed

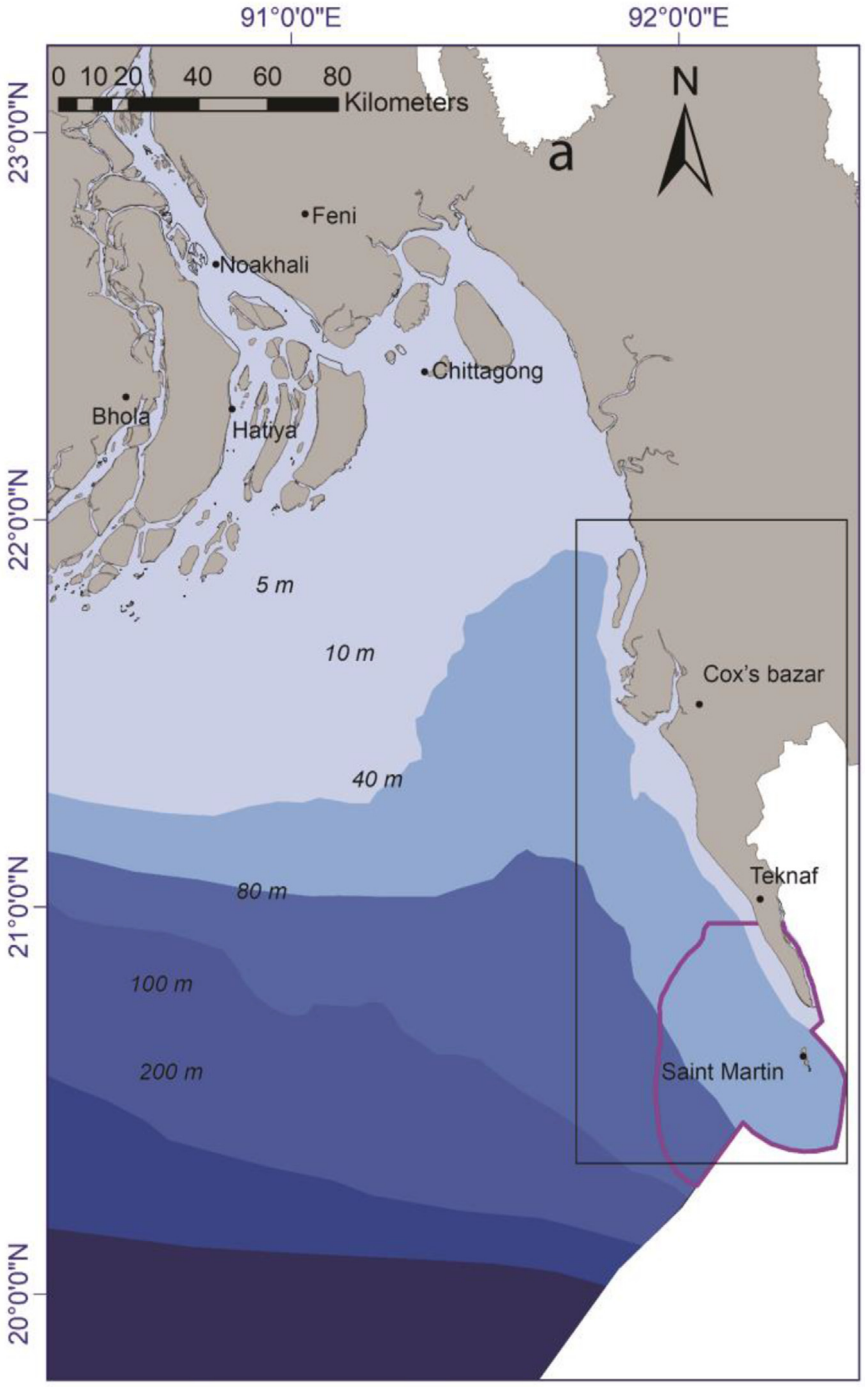

Figure 1. Locations of the study area showing the south east coast of Bangladesh in the black rectangle.

Figure 2. Information collections through Key informant interview with entrepreneurs and with farmers.

farming in Bangladesh. More specifically, this study explored existing culture methods and their cost, marketing channel and problems with seaweed farming in Bangladesh.

2. Materials and methods

2.1. Study area

Present study was conducted in the south east coastal zone of Bangladesh (Figure 1). The study area is surrounded by Chittagong Hill Tracts and Myanmar to the east, Chittagong to the north, Bay of Bengal and Myanmar coast to the south. The south east coastal zone is sheltered on mud and sand. Fishing is one of the most important livelihood options for the rural communities of this area. However, rural people are also involved with agriculture, aquaculture, tourism and day laboring activities (Sarker et al., 2021b). The study area has sub-tropical climate with monsoonal rainfall. This enables the aquatic ecosystem to support a diverse group of species diversity and habitats. The diverse habitats in the form of estuaries, mangroves, wetlands, mud flats and tidal flats provide essential habitats for a diverse group of biota.

2.2. Data collection

Present study used both secondary and primary data. Secondary data were collected from an extensive online search of research articles, government reports and research project reports related to socio-economic issues of seaweed industry in Bangladesh as well as at the global scale. Primary data on social and economic status of seaweed industry in Bangladesh were collected through questionnaire, focus group discussion (FGD) and informal meetings with relevant stakeholders from the south east coastal zone of Bangladesh from October 2020 to September 2021. These stakeholders include seaweed farmers, NGOs, academicians, commercial entrepreneurs, representatives from pharmaceutical companies and local leaders. We interviewed 100 farmers, 5 NGOs, 8 academicians, 3 researchers, 2 commercial entrepreneurs, 3 pharmaceuticals and 3 local leaders (Figure 2). During the survey a special focus was given to consider the women as interviewee and the ratio of men and women was 58:42. The questionnaire survey was conducted with the farmers to gather the information on current culture methods, source of seed, cost and benefits of existing farming techniques, women in seaweed farming, seasonal seaweed production, drivers of seaweed farming and requirements for sustainable seaweed industry in Bangladesh. The questionnaire used for this study is given in supplementary information 1 (S1). Focus group discussions were performed with few specific beneficiary groups. Each group had 5 to10 based on their gender and age. The FGD enables open discussion to collect semi-structured qualitative data. During the FGD, information on seaweed farming techniques and role of seaweed farming in their livelihood were collected. Informal meetings with NGOs, academicians, commercial entrepreneurs, representatives from pharmaceutical companies and local

Figure 3. Dried seaweeds in the Cox's Bazar coastal area Hypnea spp).

Figure 4. Seaweed farming in the coastal area of Bangladesh. Left-horizontal net method and right-long line method of seaweed farming.

Table 1. Cost analysis of horizontal net culture method of seaweed (1 USD = BDT 84.83).

Cost item	Quantity	Price (BDT)
Bamboo	2	170
Plastic floats	10	150
Rope	10 kg	520
Thread	2 bundle	80
Stone	4	00
Labor cost	1	500
Total		1420

leaders were conducted to collect the information on seaweed derived product development, existing problem in seaweed industry in Bangladesh. In addition, during the meetings suggestions for further expansion of seaweed farming focusing the way to develop a value chain in Bangladesh were also gathered. All collected data were feed into the statistical software R for analysis. It is important to note that we received all required ethical approval for conducting this study and confirmation from the participants of this study to use and publish their responses publicly.

2.3. Seaweed biomass estimation

Biomass of seaweeds was estimated based on the farms production data. Biomass data of seaweed was collected from existing seaweed farms. For this we interviewed 20 seaweed farms from the south eastern coastal zone of Bangladesh. We harvested seaweeds partially from the farms at two weeks interval (Figure 3). Farmers generally harvest the seaweed when seaweed attain an average length of 25 ± 3 cm. Partial harvest was done by clipping the seaweed hanging on the rope leaving the base on the rope to grow further. The daily growth rate of seaweed was calculated every 15 days of culture using the following formula of Hung et al. (2009) for *Hypnea* spp.

$$DGR = \left[\left(\frac{W_t}{W_0}\right)^{\frac{1}{t}} - 1\right] \times 100 \quad (1)$$

Where,W_0 = average cutting wet weight at start,W_t = average cutting wet weight at time *t*, and *t* = time intervals (days).

We expressed the seaweed biomass as fresh weight per unit culture area (kg/m^2). The biomass of seaweed was calculated by using following formula:

$$Y = \left(\frac{W_t}{W_0}\right) \Big/ A \quad (2)$$

Where, Y is biomass and A is area.

3. Results and discussion

3.1. Existing methods of seaweed culture

In the Saint Martin's Island culture period is December to February in other farms culture period is September to March. However, few farmers are found who usually culture during the whole year (Islam et al., 2019). We found that *Gracilaria sp* is cultured from September to March. On the

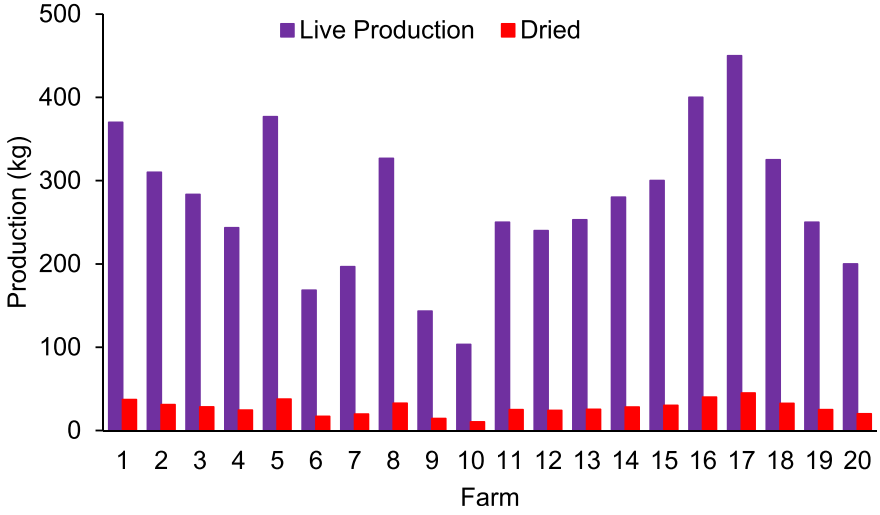

Figure 5. Average seaweed production by farmers in the coastal area of Bangladesh. The production presented for each month is based on the seaweed biomass/ 20 m^2.

other hand, *Gelidium* is usually cultured during October to March. January to March is suitable for farming of *Enteromorpha* while December to February is suitable for *Halimeda sp* farming. November to February offer suitable environmental conditions for *Padina* and *Dictyota* farming while December to February offer suitable condition for, *Caulerpa racemosa* culture. We found that November to March is suitable for *Sargassum* and November to March is suitable for *Kappaphycus alvarezii* farming. *Porphyra* is suitable for farming during December to March and *Hypnea* is cultured all the year round.

Commercial ventures collect seeds from wild (Sonadia during September, from Saint Martin's Island during December and from Paturatek during all the year round) sources from a depth up to 15 m. After collection of seeds, they wash the seaweed with clear seawater, cut in pieces (usually 6 inch each) and remove the different materials attached to the seaweed (i.e., mud, sand, barnacles etc.). Farmers usually plant the seaweed within 3 days of collection. The maximum culture depth for commercial ventures is 1 to 5m. They use about 15 m long rope and plant the seed at 6-to-8-inch interval. Farmers also use 8 m × 8 m or 4 m × 4 m mesh size net for seaweed culture. Currently most of the farms are in the intertidal area. They usually setup the farm in the area which has less wave energy, pollution free, have available stock of natural seaweed (Haque et al., 2021). Local farmers, who are not under a large commercial venture, collect the seed from the wild through hand pick method. In addition, a number of research organizations are also doing experimental culture of seaweeds (Hossain et al., 2021). Commercial ventures can setup farms up to 100 m distance from the coast though small-scale farmers restrict their farming area up to 20 m distance from the shore line. This is due to the expenses involved with the structure for farm development (Pradhan et al., 2021).

Farmers need to take the permission from the deputy commissioner of the district and local environment department to get an area for seaweed farm establishment. Recently, farmers also need to submit a report on environmental impact assessment which is generally conducted by local environment at free of cost. Seaweed farming practices in the coastal waters of Bangladesh are dominated by long line method in the intertidal zone (Figure 4). Islam et al. (2017) also mentioned about the similar culture methods in the southern eastern coastal zone of Bangladesh. About 70% respondents mentioned that bottom net and raft/hanging line methods are suitable to operate in lower intertidal and sub-tidal zones. On the other hand about 30% respondents mentioned that bamboo pole and planting/sowing of seaweeds in shallow intertidal zone are suitable for seaweed farming. Farmers (80%) found that horizontal net method is economically viable for them since production is higher in this method.

According to the farmers, south east coastal area (Saint Martin's Island, Teknaf and Cox's Bazar) is most suitable for seaweed farming. This is also consistent with the findings from Sarker et al. (2021a). Farmers from the south west coast informed us that their seaweed production is not as higher as of south east coast. During survey we also observed the occurrence of edible green, red and brown seaweeds in the pneumatophores of mangrove in the south west coastal area of Bangladesh. This suggests that south west is moderately suitable for seaweed farming. These findings are in line with the findings of Hoq et al. (2016). Interestingly no seaweed farms as well as wild seaweeds were found in the central coastal zone of Bangladesh. Our study and expert opinions suggest that this is due to high turbidity and less saline water which is mainly driven by huge freshwater discharge.

3.2. Economics of seaweed farming in the south eastern coastal zone of Bangladesh

Seaweed farmers in the coastal area of Bangladesh use locally available low cost materials for farm development. Cost involved with seaweed farming varies and largely varied based on culture techniques and farm size. The major cost items for seaweed farming are bamboo pole, rope, weight, float, seed and labour. We analyzed the cost involved with different seaweed culture method based on the survey with seaweed

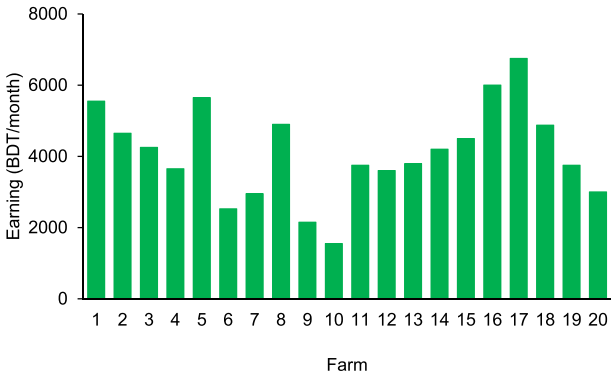

Figure 6. Average income earnings of farmers from the seaweed farm.

farmers. Minimum cost is involved with horizontal net method of seaweed farming (1420 BDT/16.50 USD; Table 1) while line and post method, and bottom net method of seaweed farming cost BDT 4200 (49.00 USD) and BDT 2000 (23.30 USD), respectively. It is possible for farmers to run 4–6 production cycles during favorable season.

3.3. Seaweed production

We analyzed the seaweed production data from 20 seaweed farmers (Figure 5). We found that live seaweed production ranges from 100 to 450 kg and dry seaweed production ranges from 30 to 50 kg. Monthly income of each farmer from each of the farms ranges from BDT 2000 to 6000 (Figure 6). Year-round production data of seaweed from a commercial venture indicate that their production and income from seaweed production is higher during October to April (Figure 7). Farmers usually harvest seaweed after two weeks of initial seedling and then harvest regularly at 11 to 15 days interval. During every harvesting cycle farmers usually leave 15.24 cm of seaweed to the rope for further growth.

Here, as an example production data of *Hypnea sp* is presented (Figure 8). Here data on *Hypnea* sp was presented because this species is widely found in the coastal area of Bangladesh. In addition, *Hypnea* is largely cultured by farmers in Bangladesh. In a 60 days cultured period both growth rate and yield showed an increasing trend. At day 15 average growth rate was 4.58 %/day and at day 60 the growth rate was found 8.95 %/day. At day 15, yield was estimated 0.8 kg/m^2 and at day 60 the yield was found 9.75 kg/m^2.

3.4. Existing marketing system of seaweed

Survey data with farmers and entrepreneurs suggest that after harvesting of seaweed, farmers (95%) wash the seaweed with saline water

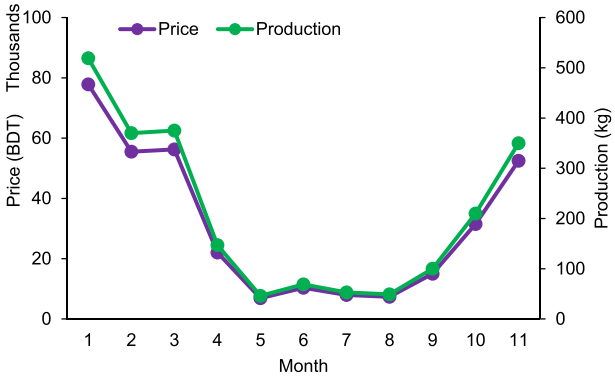

Figure 7. Seasonal dynamics of seaweed production in a commercial farm. The data is presented for Hypnea sp. Data were collected from 20 seaweed farms in the south eastern coastal zone of Bangladesh.

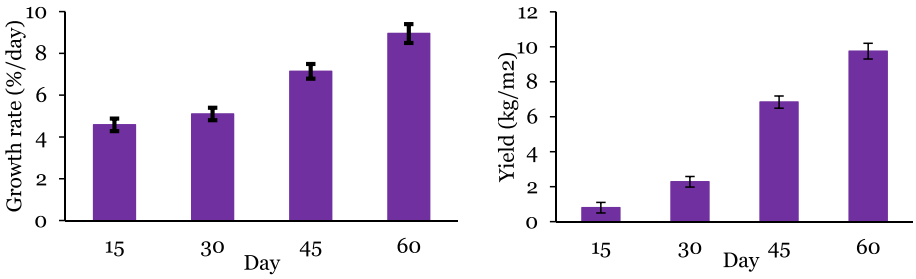

Figure 8. Growth rate (left panel) and yield (right panel) of Hypnea spp

and then with fresh water. Harvested seaweeds are then sundried. Air dry technique is not practiced here due to high expense involved with this technique. Local small scale farmers (60%) sale their seaweeds to the tribal communities. However, commercial ventures (100%) sell their seaweed to restaurants, do export and make seaweed products. About 60% farmers sell their seaweed to the local entrepreneurs who later export the seaweed outside of Bangladesh. About 20% of the produced seaweeds are consumed locally in Bangladesh and rests are exported to the Myanmar, India, Korea, China, Singapore and Chili (based on the statistics provided by seaweed entrepreneurs from the south east coastal zone of Bangladesh). Local pharmaceutical companies are interested in seaweed industries. However, they are interested only in seaweed products which they need in pharmaceutical industries. They are not interested to make these products from seaweed by themselves. Thus, special focus on seaweed-based products development for pharmaceutical industries is important. During survey, these companies informed that if they can buy these products locally rather than importing from outside, their medicine production cost will be reduced. A commercial venture, Falcon international is currently making some products from the seaweeds. For example, they are currently producing vegetable gelly from *Enteromorpha*, *Hypnea* and *Gracilaria*. They are also producing agar from *Hypnea* (12%) and *Gracilaria* (18%). This commercial venture is currently trying to produce alginic acid and Carrageenan from the seaweeds.

3.5. Existing problems in seaweed farming

Seaweed farmers in Bangladesh encounter a number of problems. For example, 50% respondents mentioned that structures of the farms are usually damaged by cyclones. Similar result was reported in earlier study (Sarker and Mahmudul Islam 2021). Pollution (64%) was also identified as an important problem in the seaweed farms. Interviewee also mentioned that turbid water (69%) led to a decreased production. Heavy wave (45%) washout the seaweed farms which lead to economic loss of farmers. During this study we found five farms which were washed out due to strong wave action. Respondents also mentioned that sometimes, the bamboo, nets and ropes are stolen (29%). In addition, farmers (38%) identified short production cycle, lack of technical knowledge (65%) are also hindering the seaweed production. For example, lack of knowledge on site suitability leads to choose an unsuitable site for cultivation. This ultimately leads to low production and even in some cases almost no production. Poor post-harvest technology is found as the technological challenge in Bangladesh. Few respondents (10%) mentioned that during culture period quality seeds are not available. This indicates the importance of seed bank for seaweed. Seaweed as food item has not gained so much interest in Bangladesh. Thus, demand of seaweed in the local market is low. Respondents also identified low farm gate price of seaweed (65%), absence of value-added products (68%), very weak supply chain (72%), limited financial support (71%) and limited research

Figure 9. Women involvement in sun drying of seaweed and seedling preparation.

support (21%) as the current problems of seaweed industry of Bangladesh.

3.6. Gender dimension in seaweed industry of Bangladesh

Both men and women are involved with seaweed farming. Women are mainly involved with preparation for seeding, seedling, seaweed harvest and sundry of seaweeds (Figure 9). Men are involved with seed collection, seeding, harvest, drying and marketing. Most of the women who are involved with the seaweed farming were previously employed in fish processing. On the other hand, most of male were involved with fishing. Majority of the respondents (85%) argued that women involvement in seaweed farming will bring positive changes in society regarding women empowerment.

3.7. Determinants of seaweed farming in Bangladesh

During the survey respondents were asked about the determinants of seaweed farming. Most the respondents argued that economic return is the major driver of seaweed farming. Very low investment also motivates coastal community to perform seaweed farming. In addition, farming technology is very simple and culture period is short. This enables them to get financial benefits within a short period of time. Farmers can take the training on seaweed farming from the local fisheries extension office and can achieve self-sufficiency by cultivating seaweed in the nearby intertidal areas. Materials used for seaweed farming are low cost and locally available which also motivate community for seaweed farming. Area for cultivation is easily available from the government.

Women can get easily involved with seaweed farming. This serves as the extra income source for their family. In addition, preparation from seedling and post-harvest processing can be done at home. This causes involvement of women in seaweed farming largely. In many cases intertidal areas are next to the settlement of marginalized coastal community. Easy access to the intertidal area plays a vital role for women involvement in seaweed farming. Women can easily participate in farm related activities (i.e., seedlings, regular monitoring, harvesting) along with their household works.

Most the men involved with seaweed farming were fishermen. Government of Bangladesh imposed fishing bans for several months throughout the year to conserve the brood fish and biodiversity. This leaded to leave the traditional fishing activities of few fishermen. These fishermen are currently involved with seaweed cultivation as alternative income generating option. It is important to note that few fishermen are involved with both fishing and seaweed farming since seaweed farming gives them some extra earnings.

4. Recommendations

During the survey we found that few farmers are trying the integrated farming of seaweed and green mussel. Farmers mentioned that they collect seed of green mussel locally and hand with a net bag in the pole of seaweed farms. Few farmers are also trying to cage culture of seaweed, sea bass, sea berm and oyster. However, all these are done experimentally and further study is required for integrated culture of seaweed with other organisms.

According to the suggestions of stakeholders, it is important to do research on seaweed in Bangladesh. However, currently research is limited. But seaweed industry has vast potentiality for income earning. Most of the farmers involved with seaweed farming were fishermen. Many of them are still do fishing along with seaweed farming. Since Bangladesh impose long fishing ban from November to January, thus local farmers want to do seaweed farming during this time as an alternative income option.

Policy makers and researchers also mentioned that government of Bangladesh increasing number of Marine Protected Area (MPA) to achieve the Aichi target. This may lead to a loose of fishing ground for many fishermen. Therefore, seaweed cultivation can be one of the good livelihood options. However, research is required to foster this industry. At this moment Bangladesh has no tissue culture laboratory for seaweed. Thus, a tissue culture laboratory is important to establish. Tax should be minimized for seaweed farming and this will reduce the chance of illegal fish catching by local fishermen. Seaweeds are currently sold locally (Hossain et al., 2021) and only few people use seaweed as food in Bangladesh (Sarker et al., 2021c). Seaweed business in Bangladesh is currently mostly discrete i.e. value chain for seaweed industry is not established (Sarker et al., 2021a). A proper value chain will ensure the proper economic returns from seaweed industry in Bangladesh. Thus, concentration needs to be given on the development of seaweed value chain.

5. Conclusion

Seaweed farming is widely practiced option for sustainable blue economy development in the coastal countries (Sarker et al., 2018). To foster the blue growth, Bangladesh is currently concentrating for the sustainable expansion of seaweed industry. However, seaweed farming in Bangladesh is considered as an emerging sector in blue economy. This study aimed to understand the socio-economic dimensions of seaweed farming in the coastal area of Bangladesh. The study found that seaweed farming is a potential sector for livelihood improvement of local coastal communities. Seaweed farming has potentiality to improve the livelihood conditions of women. Currently seaweed farming is practiced at the small scale level and farmers are mostly use long-line method of farming (Islam et al., 2017). This method is found comparatively less expensive than any other types of seaweed farming method (Islam et al., 2019). Though coastal area of Bangladesh offers a suitable condition for seaweed culture, however due to the absence of value chain the growth of seaweed industry is hampered (Sarker et al., 2021a). Therefore, development of a proper value chain for seaweed industry can ensure sustainable growth of seaweed industry in Bangladesh which will promote country's blue economy.

Declarations

Author contribution statement

Zahir Uddin Ahmed: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Omar Hasan, Muhammad Mizanur Rahman, Morgina Akter & Md Shajjadur Rahman: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Subrata Sarker: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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