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Tilapia: Fish of the Future for Aquaculture Blooming in Bangladesh

Dr. Yahia Mahmud[1] and Dr. A H M Kohinoor[2]

Abstract

Tilapias are now considered as 'wonder fish' by some and as 'aquatic chicken' by others. The introduction of improved variety of tilapia and expansion of cultural practice of this fish contributed significantly in aquaculture production. Tilapia production of Bangladesh is about 0.38 million tons in 2017. During the last 12 years (2005 – 2017) there has been a tremendous progress in tilapia farming in this country. Bangladesh Fisheries Research Institute (BFRI) introduced GIFT strain in 1994 from the Philippines and conducted research for further stock improvement using family selection protocol and disseminated the improved strains and low-cost appropriate aquaculture technologies to the end users. Meanwhile, BFRI developed improved generation (F-10 generation) of tilapia showed 56% higher yield compared to foundation stock. BFRI has a programme to distribute improved germplasm of tilapia in commercial tilapia hatcheries all over the country for sustainability of quality tilapia fry production. Tilapias have great potential in Bangladesh and they are going to be the prime culture species in near future. It is expected that by 2030, the tilapia production would reach to 1.0 million tons.

Introduction

Tilapia is the most widely cultured fish in the world and is second only to carps as the most widely farmed freshwater fish in world aquaculture. Tilapia is grown in more than 85 countries. The global tilapia production is about 5.60 million tons in 2015 (FAO Aquaculture Newsletter, 2017). Asian countries are the leading producers of tilapia with a production of more than 4.0 million tons. Although a freshwater fish, tilapia can tolerate some salinity, it is harder than many other fish breeds, which can grow in adverse situations, and is quite disease resistant as well. Farming practices of the fish ranges from extensive to super intensive both in fresh and brackish waters have significantly expanded in many countries of the world. Bangladesh is one of the top ten countries in tilapia production and ranked fourth in the world after China, Indonesia and Egypt (Table 1).

Table 1: Production of tilapia in top ten tilapia producing countries of the world (FAO, 2017)

Sl No.	Country	Production (Million MT)
1	China	1.80
2	Indonesia	1.10
3	Egypt	0.875
4	Bangladesh	0.378
5	Viet Nam	0.258
6	Philippines	0.261
7	Brazil	0.219
8	Thailand	0.177
9	Colombia	0.061
10	Uganda	0.057

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[2] Principal Scientific Officer, BFRI

Tilapia (*Oreochromis mossambicus*) was first introduced in Bangladesh in 1954 and then *O. niloticus* in 1974, with a hope to contribute in protein supplement to the people. These attempts were unsuccessful due to lack of knowledge of their biology and culture technologies. Subsequently, Bangladesh Fisheries Research Institute (BFRI) again introduced *Oreochromis* species in 1986, Genetically Improved Farmed Tilapia (GIFT) strain in 1994 and 2005, and Chitralada strain in 2007 by Chitralada Aqua Park Ltd. All these species and strains came from Thailand except GIFT, which was brought from the Philippines. Breeding and culture technologies of these species have already been developed by BFRI. In the meantime, monosex (all male) tilapia hatcheries have been established in different places of the country with the technical assistance of BFRI. Over the last 15 years, its demand has gradually increased to the consumers as food fish. It has already emerged as an important species of aquaculture in Bangladesh. Already there has been a tremendous progress in tilapia production in the country (Fig. 1) in the last 12 years (2005–2016). According to the Department of Fisheries (DOF), Bangladesh is now producing about 0.38 million tons of tilapia (FRSS, 2017).

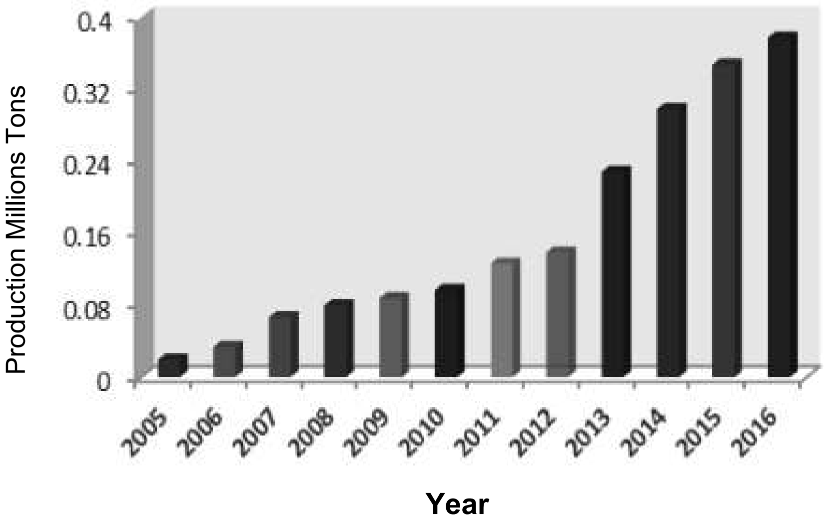

Fig. 1. Trends in Tilapia production in Bangladesh

Aquaculture Potentials of Tilapia in Bangladesh

Tilapia has become the shining star in international aquaculture with farms starting and expanding across the globe. Production of tilapia for local consumption and export rose tremendously during the last decades. The commodity is considered as the most important aquaculture species of the 21st century. Some favourable characteristics of tilapia have made it extremely suitable for aquaculture such as:

- The fish can grow in low oxygen and adverse water conditions,
- Potential for high yield and faster growth,
- Able to grow both in fresh or brackish water,

- Important source of protein, especially for poor people, and
- Tolerant to high-density aquaculture, and relatively disease resistant.

The development of Genetically Improved Farmed Tilapia (GIFT) that is based on traditional selective breeding technique as a means to improve commercially important traits of tropical farmed fish is a major milestone in the history of tilapia aquaculture. In on-station and on-farm trials of BFRI, the GIFT strain was reported to show 35 - 57% superior growth than that of the existing strain of the country.

Tilapia farming is gaining popularity day by day in Bangladesh. In the meantime, a large number of entrepreneurs have established tilapia hatchery in different parts of the country for commercial production of mono-sex tilapia seed for farming. More than 500 private mono-sex tilapia seed production hatcheries have so far been established under the technical assistance of BFRI and producing 5-6 billion tilapia fry every year. Due to excellent growth performance and other better traits (survival, fecundity and disease resistance, etc.), the improved strain developed by BFRI has been named as BFRI-GIFT strain. Presently BFRI, as a center of excellence for genetic up-gradation of tilapia strains, is distributing on an average 0.5 – 0.7 million improved tilapia germplasm every year to hatchery operators and entrepreneurs all over the country.

Stock Improvement of Tilapia

In Bangladesh, cultivation of tilapia in different types of culture systems has proven its value to both current and future fish producers. Both rural and urban consumers are likely to be benefitted from more widespread stocking of tilapia within conventional polyculture and intensive monoculture systems. However, ensuring availability of improved strains at the farm gate as well as maintaining consistent quality of seed stock is critical to this development. Production of monosex tilapia is already established in the private sector, but it requires high investment and critical inputs (hatchery and pond complex, chemicals, etc) which are affordable only by resource rich intensive producers. Over the last five years, more than 500 tilapia hatcheries have been established that are supplying over 5.0 billion tilapia fry to support commercial farming in >15,000 tilapia farms all over the country. Rapid expansion of tilapia hatcheries contributed to this dramatic increase of seed production. However, genetic quality of those seeds could not be maintained due to poor brood stock management. On the other hand, most of these hatcheries function in genetic and reproductive isolation (i.e. no introductions or replaced by new stocks) and repeated use of the same stock every year to maximize the quantity of seed production.

In view of overcoming this situation and meeting the growing demand for genetically improved tilapia brood stock for quality seed production in the country, BFRI has been implementing a family selection program since 1995 for continued improvement of the genetic quality of the GIFT strain. After ten generations of genetic selection, general linear model analysis indicated that the selected fish had 7.17, 13.60, 23.21, 30.30, 35.38, 39.25, 43.19, 49.09, 52.82 and 56.25% higher harvest weight than that of the founder population in G1, G2, G3, G4, G5, G6, G7, G8, G9 and G10 generations, respectively (Fig. 2). The continued stock improvement of GIFT strain by family selection in every generation at BFRI, enabled the institute to supply improved germplasm to over 200 tilapia hatcheries every year for the production of high-quality seed in the country. This achievement of BFRI greatly contributed to sustainable increase of tilapia production in Bangladesh.

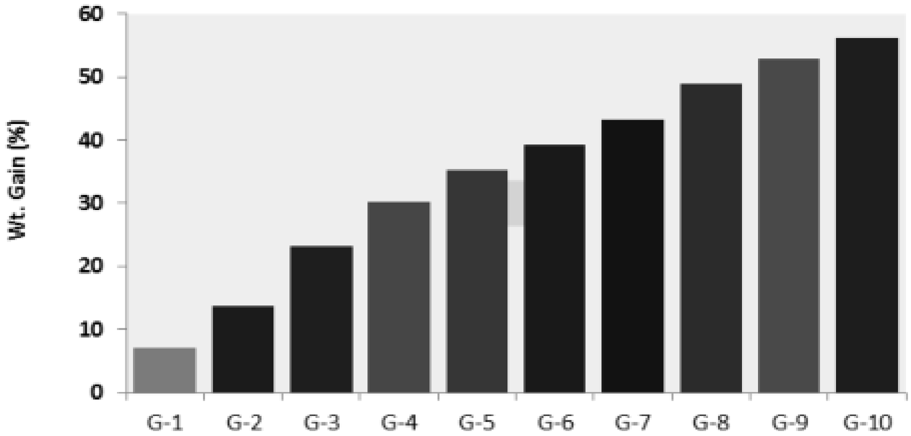

Fig. 2. Generation-wise percent weight gain of BFRI GIFT

Environmental Impacts of Tilapia Species and Culture System

Farming of tilapia does not generally pose adverse environmental impacts. However, poor fish husbandry practices (as in all forms of fish farming) can contribute to water pollution. Discharges of nutrient-rich water from commercial tilapia farms into natural water courses can cause water pollution. Daily application of large quantities of supplemental feeds to fish cages in water bodies can place large nitrogen and phosphorus loadings on the water. Good husbandry and environmentally friendly farming practices are key requisites for minimizing these adverse environmental effects from tilapia farming.

Health Aspects of Farmed Tilapia

Tilapia is the third largest consumed fish in USA. It is also a popular food in many countries of Europe and Asia. Globally tilapia ranks 6thin terms of production among the cultured fish providing food, employment and export earnings. The global tilapia production is 5.6 million tons in 2015. Bangladesh is the 4th largest producer (0.38 million tons). The volume of tilapia trade is about 1.2 million tones with a value of USD 3.7 billion. Tilapia is a good source of animal protein, vitamins and minerals. It contains about 20% protein, 2% fat, vitamin B6, B12, niacin, vitamin D, vitamin E, pantothenic acid and minerals like phosphorus, Selenium, Potassium, Magnesium, and Iron. The fat in tilapia contains polyunsaturated fatty acid- omega 3 and omega 6, which contributes to heart health, vision and joint health. It means that eating tilapia is way better than red meat in terms of heart healthy food. However, in recent years, social media made some false propaganda against consumption of tilapia claiming that it is not safe to eat tilapia as it is a voracious eater and grows in unsafe water. Though there was no scientific evidence of such claim, the consumers were scared of such propaganda resulting in some reduction in market price. Bangladesh Fisheries Research Institute, Bangladesh Council of Scientific and Industrial Research (BCSIR) and the Department of Fisheries had been monitoring cultural practices and doing laboratory tests of the quality of tilapia produced in Bangladesh since couple of years and so far, no harmful elements was found in the production of tilapia in Bangladesh. On the other hand, International Livestock Research Institute and World Fish Center have also conducted laboratory tests for the quality of tilapia. They also did not find presence of any elements harmful for human health such as antibiotic, pesticides, dioxin or any carcinogenic elements in tilapia. It may be mentioned that the US Food and Drug Administration (FDA) listed tilapia as one of the best choices for pregnant or breast-feeding women and children over two-year age. So, the propaganda against farmed tilapia as a health risk food is not correct. However, we must remember that farming of any fish including tilapia, good quality feed, clean environment and good farming practices usually produce safe fish.

Role of BFRI

Aquaculture has been one of the fastest-growing economic subsectors of Bangladesh, providing high-protein food, income, and employment and earning foreign exchange. Tilapia has great potential in Bangladesh and it is going to be the prime culture species in the near future for fresh and brackish water ecosystems. It is expected that about 50% of total aquaculture output can be contributed by tilapia farming. It can provide livelihoods for millions of people by employing them in small and large-scale tilapia aquaculture industries in the country.

BFRI has a programme for national seed distribution of tilapia particularly of GIFT strain. Under this programme, BFRI has been imparting training on "Quality seed production techniques and improved Culture Management of Tilapia" for field level extension officers and technicians of major GO and NGOs involved in aquaculture in the country. Plans are being made to involve DoF for further spreading of tilapia farming in the country utilizing its Fish Seed Multiplication Farms for dissemination of BFRI evolved technology to farmers all over the country through their extension systems.

Export Market of Tilapia

There is a great demand for tilapia in the international market. During the first half of 2017, approximately 170, 000 tons of tilapia (whole, fillets and beheaded) have entered the international market. Asia and Latin American markets continue to be strong as their production increasingly stays within their own domestic markets in addition to imports from China. Asia being the largest producer, exported approximately 145,000 tons of tilapias in Europe and USA. Approximately 55 percent of Asia's total exports were comprised of frozen fillets and 45 percent whole frozen. The top five producers in the region other than Bangladesh are China, Indonesia, Taiwan, Thailand and Malaysia. No doubt, Bangladesh being the fourth largest producer of tilapia with a production of 0.38 m tones could be in the same line to export tilapia like shrimp to the world market.

Frozen beheaded and gutted whole or fillet from large or medium sized red or white tilapia have good potential for export in the international market. Price of red tilapia is 1.5 times higher than white tilapia. Tilapia farms of Bangladesh are now in a position to make a steady supply of required size tilapia for international market. Both Frozen Food Exporters Association (BFFEA) and the tilapia farmers should begin the process in this regard under the aegis of BFFEA.

Economics of Tilapia Farming

Tilapia farming has the lowest energy requirement for protein production. This indicates the suitability of tilapias as a subsistence system of protein production in those parts of the world, where there is a high level of malnutrition, but a low level of technology and where the economy is too poor to develop a sophisticated intensive or super intensive fishery development process. In terms of land and labour requirements, the tilapia farming unit has much less requirement than from any other fish farming system. In terms of protein production per unit area, tilapia is more productive than carps and catfish. In terms of market price, the price of tilapia is good enough to have reasonable profit margin by the farmers. Presently, in the markets of Dhaka, 1 kg tilapia is sold at US$ 1.25-1.50, whereas, carp is sold at US$ 1.5-2.0. The time is not too far, when tilapia will command a higher market price in Bangladesh like “Red tilapia” in Japan and Taiwan.

Future of Tilapia

Tilapia has a great potential in Bangladesh as an alternate and additional species for aquaculture. In view of taking tilapia as one of the important and potential aquaculture fish species, the following areas have been identified for necessary action. Among the South East Asian Countries, Bangladesh is particularly abounds in numerous seasonal water bodies like ditches, shallow ponds, road side canals, barrow pits etc. which retain water for 4-6 months and are not suitable for carp culture. In such cases, tilapia can be a promising candidate for aquaculture in the suitable seasonal water bodies. Recently, shortage of feed and low market price of exotic riverine catfish (*Pangasiadon hypophthalmus*) has severely affected farming of this fish in the country. Therefore, a large number of commercial catfish producers have found tilapia as an alternate species to culture in their farms to maximize profit. In brackish water zones and coastal farms (0.20 m ha) of the country, where shrimp culture is suffering from occasional disease outbreak, tilapia farming is likely to be an important alternative. Bangladesh has an extensive network of rivers and tributaries, haors and baors. These waters are suitable for commercial intensive cage culture of monosex tilapia. Frozen Food Exporters should initiate export of frozen fillets and whole tilapia, and should encourage entrepreneurs and farmers to culture tilapia following Good Aquaculture Practice (GAP) to ensure steady supply of tilapia for regular export.

Conclusions

Tilapia aquaculture is gaining popularity in Bangladesh. By 2030, tilapia production can be reached to 1.0 million tones. Tilapia aquaculture industries can also provide livelihoods for millions of people of the country. Bangladesh Fisheries Research Institute (BFRI) is pioneer in tilapia breeding and genetic research and development activities and is maintaining the gene pool of true breeding strains of “BFRI-GIFT” of the Nile and Red tilapia. The genetically improved strains have great potential to obtain higher production and can easily be fitted in the existing suitable water bodies. Semi-intensive or well managed aquaculture of these superior strains of tilapia can fulfill the demand of domestic consumption of fish protein. It can also help the country in earning foreign exchange through exporting in the form of whole frozen or fillet products. Therefore, production of tilapia should be scaled up through developing appropriate strategies.

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Journal of Bangladesh Agriculture, 9 (1) December, 2019: 7-21

Potentials for the Development of Blue Economy: Prospects and Challenges of Mariculture in Bangladesh

M. Gulam Hussain[a], Sheikh Aftab Uddin[b] and Pierre Failler[c]

Abstract

This paper sets out to address the prospects and potentials for the development of blue economy in Bangladesh through the sustainable use of its vast marine resources. It lays out the current state of comprehensive knowledge regarding opportunities and challenges for developing the sector as well as the emerging potentials in developing the blue economy for improving social and economic conditions of the country. The paper also highlights a total of 26 productive blue economy development and economic sectors, which have been identified for full utilization of ocean-based resources within the present maritime boundary of Bangladesh, among which 12 sectors have been prioritized as major sectors including Marine Fisheries and Aquaculture. Emphasis has been given to this sector as the most potential one for overall economic benefit and livelihood development of hundreds and thousands of coastal rural peoples of the country. Specifically, prospects for developing mariculture opportunities of both brackish and marine fish species as well as mariculture of non-traditional marine species in the coast, near shore and offshore areas have been addressed. In fine, the paper describes the current framework of marine resource management in the Bay of Bengal, delves into the challenges of mariculture development under the concept of blue economy in the seventh 5 Year Plan of the Govt. of Bangladesh and also recommends ways to advance blue economy governance in order to address pressures and ensure sustainable development of mariculture in the country. However, further researches/investigations are required to make a detailed account about the prospects, contributions, challenges and managements of maricuture-based blue economy in the development of Bangladesh's economy in commensurate with the national and international perspectives.

Keywords

Potentials; Blue Economy Development; Bangladesh; Mariculture; Prospects; Challenges
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1. Introduction

In Bangladesh, discussions on blue economy started after the settlement of maritime boundary delimitation dispute with Myanmar in 2012 and India in 2014, respectively. The productive economic sectors of blue economy are emphasised and considered in harnessing the full utilization of ocean-based resources within the present maritime boundary of Bangladesh. If these ocean-based resources are managed by proper planning and inter-sectoral coordination of public-private partnership and investment, it will certainly generate strong foundation for earnings and economic benefits under the

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approach of blue economy. On the other hand, the blue economy can create some opportunities to resolve the issues of climate changes at the coastal areas provided these marine based economic resources with potential sectors be managed and governed by principles of biodiversity protection, conservation and efforts for care with a vision of scientific understanding. It might also generate jobs and bring about tangible changes in the lives and livelihood of the millions of people inhabiting along the coastline and islands in Bangladesh. A coordinated approach with concerned stakeholder groups is required to determine the extent to which the constraints can be turned into opportunities, and to ensure that development of the blue economy does not result in unsustainable and damaging practices towards the benefit of short-term economic gains over long-term sustainable economic and social benefits. In particular, for Bangladesh, this involves developing a maritime/marine spatial planning directive to detail coordination between blue economy sectors and stakeholders to ensure sustainable development.

A total of 26 productive blue economy development and economic sectors have been identified for full utilization of ocean-based resources within the present maritime boundary in Bangladesh, among which 12 sectors have been prioritized as major sectors including Marine Fisheries and Aquaculture. This sector is most potential for overall economic benefit and livelihood development of hundreds and thousands of coastal rural peoples of Bangladesh. Aquaculture and Fisheries in Bangladesh has three main subsectors: aquaculture (contributing 56.44 % of total production), inland capture fisheries (28.14 %), and marine and coastal capture fisheries (15.42 %), with the estimated total production of 4,134,434 MT in 2016-17 (DoF, 2017). As in much of Asia, capture fisheries production of Bangladesh has been declining with a dramatic increase in aquaculture production. About 94 percent of aquaculture production in Bangladesh is destined for domestic consumption, especially farmed carp and tilapia, which helps in domestic food security and related livelihoods. Both homestead farms and intensive farming techniques have contributed to the aquaculture industry. So, presently aquaculture (mostly inland freshwater and partly coastal aquaculture) is making a major impact on production, protein supply, economic development and livelihood aspects for the millions of people of the country. On the other hand, the country owns vast coastal and marine water resources, and therefore, the recent blue economy concept of the government has extensively widen up the potentials for developing mariculture opportunities in the coast, near shore and offshore areas of the Bay of Bengal.

This paper addresses the emerging blue economy in Bangladesh, and the potentials and opportunities regarding its development. The paper is laid out as follows: the next section considers the blue economy concept and its relevance to Bangladesh along with other sections where mariculture of both brackish and marine fish species as well as mariculture of non-traditional marine species have been briefly described. The overall future perspectives and challenges of mariculture development were empahsized under the concept of blue economy development and seventh 5 Year Plan of the Govt. of Bangladesh.

2. The Concept of Blue Economy

Oceans cover over 70% of the surface of the planet. Life originated in the oceans and they continue to support all lives today by generating oxygen, absorbing carbon dioxide, recycling nutrients and regulating global climate and temperature. Further, they are the means for providing a significant amount of the world's demand for food and livelihood generation, accounting for a mean of transport for over 80% of international trade (UNCTAD, 2012). However, development of the oceans, as a source of food and economic activity, has affected the resilience of oceans, reducing biodiversity and ecological function as well as causing the decline of environmental services. For example, the FAO (2014) estimated that over 75% of commercial fish stocks are fully or over-exploited. Both developed and developing countries have recognized the potential of the blue economy to deliver on development purposes. For example, the UK is one of the world's leaders in offshore renewable energy platforms and many developing countries have developed coastal aquaculture and tourism.

The development of the blue economy in a country like Bangladesh, leading to a sustainable marine economy that can generate jobs and bring significant tangible benefits to change the lives and livelihoods of millions of people inhabiting coastal areas, can develop a strong economy to benefit the country's population. This is, of course will be possible, if resource management is governed by the principles of the protection of the oceans, including biodiversity conservation, ecological function and sustainable environmental services. A country like Bangladesh, who currently have an underdeveloped blue economy, is well positioned to develop sectors related to the blue economy. For example, coastal aquaculture offers huge potential for the provision of food and livelihoods by creating sustainable employment and producing high value species for international export markets. However, a strategic approach, supported with a governance structure, is imperative to develop the blue economy – otherwise the example of coastal aquaculture development given here could easily lead to resource exploitation (e.g., biodiversity loss and ultimately the destruction of ecological function).

3. Maritime Boundary Settlement and Current Situation of Marine Economic Sectors in Bangladesh

Bangladesh has received entitlement to 118,813 km^2 in the Bay of Bengal (BoB) after the end of the final settlement of maritime boundary disputes with neighboring countries Myanmar and India in 2012 and 2014 respectively. This award allowed Bangladesh to establish sovereign rights over the living and non-living resources of BoB territorial waters up to 12 nm, Exclusive Economic Zone (EEZ) within 200 nm and Continental Shelf extending up to 354 nm from the Chittagong coast (MoFA, 2014). Side by side, all major river inlets and estuaries comprising together as a part of the marine ecosystems, and finally the total marine waters of the country stand at 121,110 km^2 of which coastal waters and the shallow shelf sea constitute about 20% and 35%, respectively, and the remaining 45% is lying in deeper waters (Hossain *et al.* 2017a). So, the Government has recently started dialogues with the stakeholders to adopt the concept of blue economy across relevant policies and plans (Hussain *et al.* 2017a; Hussain *et al.* 2017b). Figure 1 shows the present maritime boundary/area of Bangladesh (Chowdhury, 2014).

In fact, Bangladesh having the widest shallow shelf area within the BoB, extending more than 100 nm (185 km), is 3-4 times wider than those of Myanmar, even wider than eastern coast of India and global average (65 km), ultimately having a greater shallow bottom fishing area per unit length of coastline than its close neighbours (Hossain *et al.*, 2014). The coast of Bangladesh is in a continuous process of reshaping itself, which will continue towards millennia in the future due to being located in the largest delta of the world. For the national economy and overall social benefits, marine resources are extremely important because one fifth of the population (i.e., about 30 million peoples) are dependent on these resources for activities like fisheries, aquaculture, tourism, shipping, shipbuilding and ship decommissioning, salt production, and offshore oil and gas production (Hossain *et al.*, 2014). Table 1 presents the monetary valuation of production of major economic sectors for the last five years (2010 – 2015) related to blue economy in Bangladesh.

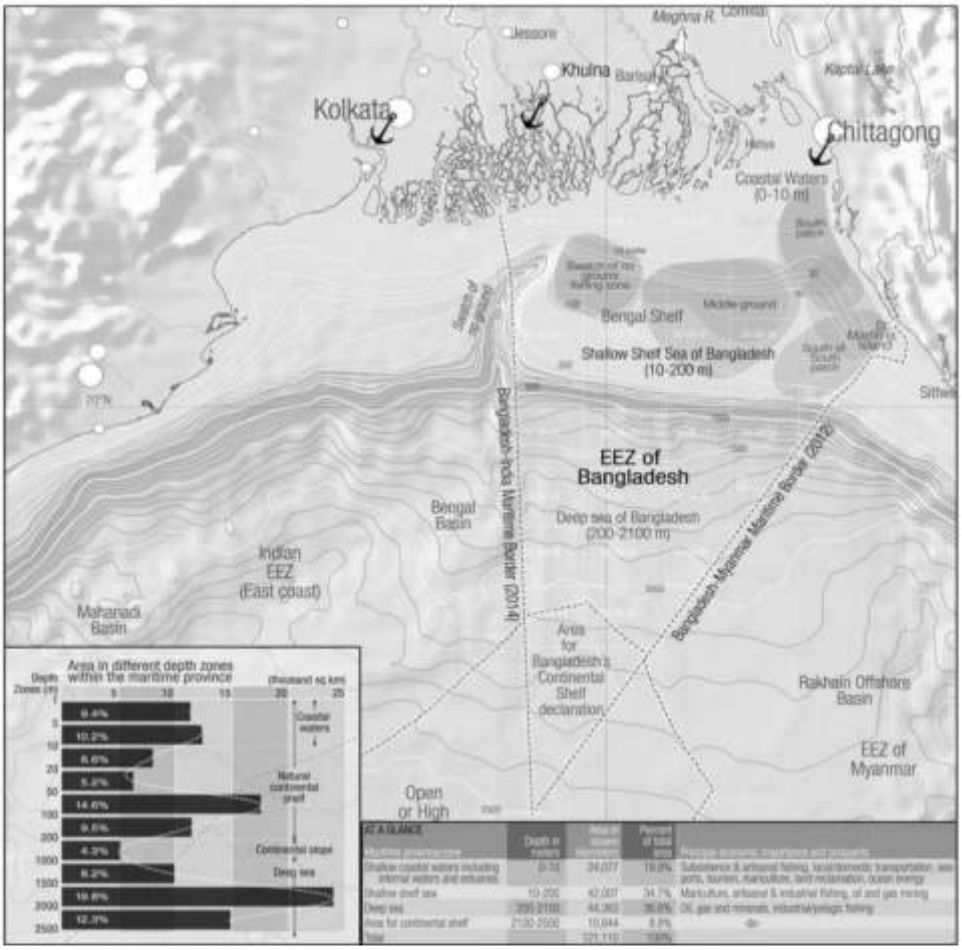

Fig. 1. Maritime area of Bangladesh (Chowdhury, 2014).

Patil *et al.* (2018; 2019) showed in their recently published report of World Bank Group regarding the annual gross value-added Ocean Economy from different activities of Bangladesh. In that report, they mostly used disaggregated data provided by Bangladesh Bureau of Statistics (BBS) and supplemented by reports from industry and other agencies where available. Figure 2 summarizes an initial estimate of the gross value added (GVA) to the Bangladesh economy from ocean activities in recent years. These estimates are coarse and should be seen as indicative of only the order of magnitude of the annual output from Bangladesh's ocean economy. However, such estimates reveal a baseline measure of the ocean economy, which can be a useful as the starting point towards setting targets for Bangladesh's blue economy aspirations (Patil *et al.* 2018).

Table 1. Monetary valuation of production (2010 – 2015) of major economic sectors related to blue economy in Bangladesh (Million US$)

Economic sector	2010	2011	2012	2013	2014	2015
*Inland Fisheries	3,632.34	4,113.20	4,844.21	5,596.15	6,308.16	7,089.66
*Marine Fisheries	843.75	949.48	1,107.42	1,231.06	1,384.77	1,475.66
*Oil	21.90	23.84	26.82	28.77	29.35	34.05
*Gas	948.35	956.30	1,041.35	1,127.73	1,158.13	1,305.42
*Sea salt	119.25	123.48	160.90	206.00	212.35	214.84
*Coals, sands and minerals	735.18	944.39	1,183.79	1,452.46	1,644.08	1893.14
*Water transport	1,215.14	1,330.36	1,450.21	1,606.10	1,682.31	1,816.67
*Trade & other transport	31,390.15	36,178.04	41,728.94	47,156.44	52,078.80	58,466.90
**Shipping (Freight in/out bound shipping	-	15.77	16.28	19.07	22.48	25.83

Source: *Data from Bangladesh Bureau of Statistics (BBS) ** Data from Ministry of Shipping, Bangladesh Shipping Corporation

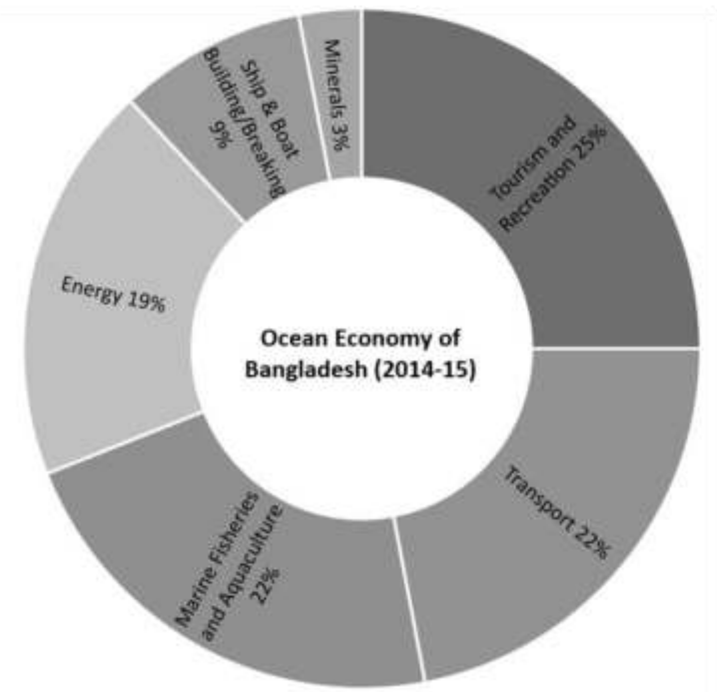

Fig. 2. Composition of the percent contribution of Gross Value Added Ocean Economy from different activities (2014-15) in Bangladesh (Patil *et al.*, 2018)

4. Blue Economy Opportunities: Potentials of Marine Fisheries and Aquaculture

Meanwhile, in Bangladesh within its present maritime boundary, a total of 26 productive blue economy development and economic sectors have been identified for full utilization of ocean-based resources. Among these, the major economic sectors are: i) Marine Fisheries and Aquaculture; ii) Marine Non-Traditional Species Culture; iii) Marine Biotechnology; iv) Carbon Sequestration; v) Oil, Gas and Minerals Mining; vi) Ocean Renewable Energy; vii) Sea Salt Production; viii) Marine Trade, Shipping and Transport; ix) Marine Tourism; x) Marine Education and Research; xi) Maritime Surveillance; xii) Marine Spatial Planning etc (Fig. 2). Under the blue economy approach within a comprehensive framework of ecosystem based management, if ocean spaces are properly planned and managed to carryout inter-sectoral coordination with public-private partnership and investment, it will certainly generate strong foundation of huge earnings and economic benefits for the country.

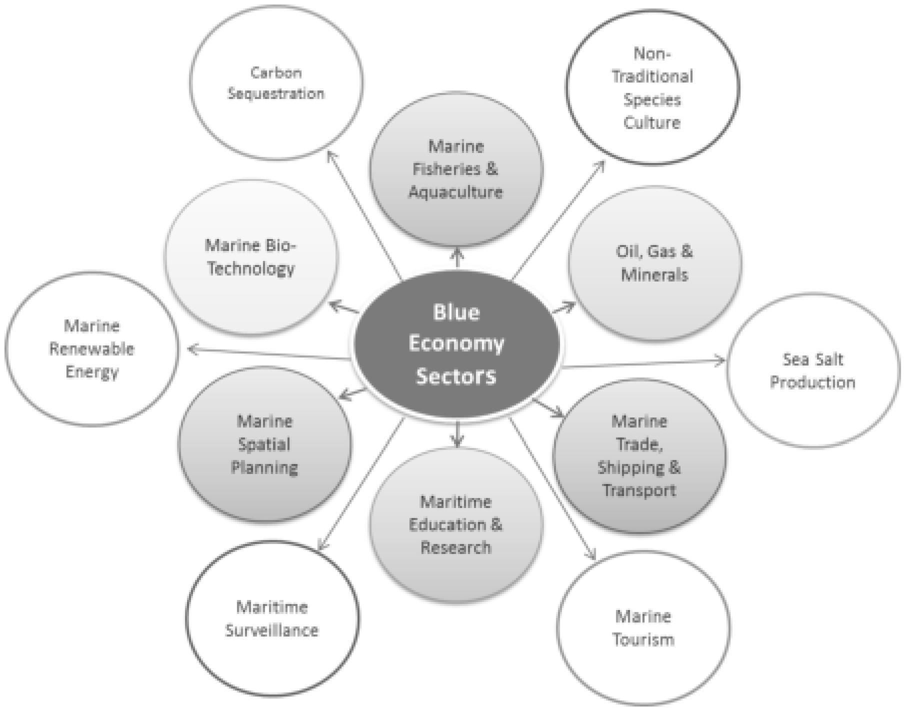

Fig. 3. Major economic sectors related to blue economy in Bangladesh (Hussain *et al.* 2017a; Hussain *et al.* 2017b)

Among these sectors, Marine Fisheries and Aquaculture sector is most potential for overall economic benefit and livelihood development of hundreds and thousands of coastal rural peoples of Bangladesh. Compared to inland capture and culture fisheries, production of marine capture fisheries is meagre because almost all of Bangladesh's marine fishing is carried out in shallow and shelf waters, beyond which no fishing is being currently practiced due to lack of vessel capacity and appropriate fishing technologies. But under the concept of the blue economy, marine fisheries and aquaculture are extremely promising. In view of expanding capture fisheries production, the country should adopt appropriate deep sea fishing technologies such as long line and hook fishing and the utilization of supporting gears and vessels for harvesting large pelagic fish (i.e., tuna and other pelagic species). Being a new member state of IOTC (Indian Ocean Tuna Commission), Bangladesh is yet to achieve the access for tuna fishing in the BoB of Indian Ocean. It is expected that the country would be able to earn huge foreign exchange by exporting tuna fillets and other value-added items to the international markets. Rehabilitation of hilsa fishery is another important task that requires intervention at the trans-boundary level. At present 50-60% of global hilsa catch takes place in the coastal and marine waters of Bangladesh, followed by 20-25% in Myanmar, 15-20% in India and the remaining 5-10% in other countries (Hossain, *et al.*, 2014). Bangladesh is one of the leaders and stands 5th in the ranking among the top 10 countries of the world for freshwater aquaculture. There are opportunities to initiate and introduce both brackish and marine aquaculture as well.

4.1 Prospects and Challenges of Mariculture Development

Marine aquaculture is demarcated as the establishment of land-based ponds, enclosures/cages in the onshore and offshore areas to raise marine aquatic species/groups such as finfish, shellfish & seaweeds for commercial farming to get economic benefit as well for the human consumption purposes. There have been limited attempts to promote mariculture in Bangladesh over the last 40 years except the tiger shrimp (*Penaeus monodon*) farming, using traditional and improved extensive practices in the coastal areas. In the Asia Pacific region, the countries such as China, Indonesia, Malaysia, Taiwan Province of China, Thailand, Singapore and Vietnam are making headway in finfish mariculture using hatchery produced seeds and formulated feeds. Lessons can be learned from these countries and the concept of blue economy development of the government. Bangladesh might initiate marine aquaculture farming urgently with the available and identified finfish, shellfish and non-traditional species. As it is mentioned in earlier section that after the end of the final settlement of maritime boundary disputes recently with neighboring countries viz., Myanmar and India, Bangladesh is allowed to establish sovereign rights over the living and non-living resources of the huge maritime areas. The shallow coastal waters (including internal waters and estuaries) and shallow sea shelf constitute about 20% and 35% of total marine waters, respectively (Hossain *et al.* 2017a). These facilities have extensively widen up the potentials and opportunities for developing mariculture in the coast, near shore and offshore areas. So, there are enormous scopes for flourishing mariculture of both brackish and marine fish species as well as opportunities exists also for mariculture of non-traditional marine species like seaweed, macro algae, shellfish (i.e., mussel, oyster etc.), sea urchin, sea cucumber etc. (Hussain *et al.* 2017a, Hussain et. al. 2017b). If these opportunites could successfully be implemented under the concept of blue economy development and seventh 5 Year Plan of the Govt. of Bangladesh in the coast, near shore and offshore areas, the country would be able to achieve expected solutions for the requirements of mass protein in the diet of the people as well as get sustainable benefits in economic sectors. The vision in this respect is to develop a viable and sustainable mariculture industry for producing suitable and selected marine fin fish, shellfish and marine plants for the long term benefits of Bangladesh's economy, environment and coastal communities.

4.1.1 Potential species for mariculture

A wide range of biodiversity such as bony and cartilaginous fishes, shrimps, crabs, seaweeds, mollusks and mammals exists in the coastal and marine ecosystems of the Bay of Bengal (Hossain, 2001; Islam, 2003; Ahmed *et al.*, 2008). Murshed-E-Jahan *et al.*

(2014) listed around 511 marine species together with shrimps, that exist within Bangladesh marine waters. Among these marine species, categorically species/groups are: i) Marine fish such as Sea bass (*Lates calcarifer*), Grey mullet (*Mugil cephalus*), Green back mullet (*Chelon subviridis*), Pomfret (*Pampus argenteus*), Hilsa (*Tenualosa ilisha*), saline tolerant tilapia and other species; ii) Marine shrimps such as *Penaeus monodon, P. indicus, P. Merguiensis*; iii) Marine crab such as Mud crab, *Scylla serrate* etc. are potentially important for mariculture. Among marine non-traditional species, seaweeds (both macro and micro algae); mussels such as green mussel (*Perna viridis*), Clam (*Meretrix meretrix*) and oyster (*Crassostrea madrasensis*); corals, sea cucumber, sea urchin etc. are also important for marine aquaculture in Bangladesh.

The marine aquaculture potentials and opportunities were thoroughly discussed in recent regional workshop on "Blue Economy in South East of Bangladesh: Major Opportunities and Constraints", held in Chittagong, Bangladesh and jointly organized by Chittagong University, European Union Delegation (EUD), Dhaka and Maritime Affairs Unit, Ministry of Foreign Affairs, Govt. of Bangladesh (Hussain et. al. 2017b). Several potential areas of marine aquaculture have been identified for implementation under the concept of blue economy in Bangladesh (Table 2).

4.1.2 Prospective future and challenges of marine aquaculture

There is no marine aquaculture currently being practiced in Bangladesh and no marine/coastal fin finfishes are farmed (Hossain, 2014). Mariculture is completely a new arena of farming marine animals (i.e., marine fish and shellfish and other non-traditional species) and aquatic plants (i.e., sea weeds and other macro algae). So lessons can be learned from our inland aquaculture as well as recent development in other countries to develop the mariculture industry to its full potential. The essential requirement of the elements for successful implementation of mariculture is described in the following paragraphs:

4.1.2.1 Suitable site selection for mariculture farming infrastructures

In view to the establishment of all necessary mariculture facilities, suitable site selection in the coast, inshore and offshore areas is extremely important. The geographical position and climatic condition of Bangladesh have made her coastal and related areas suitable for varied species and forms of marine aquaculture. So, site selection should be species specific. Before selecting the sites for specific mariculture, a thorough feasibility studies considering a required environmental and ecosystem related parameters should be given extreme priority. All ideal sites either seed producing hatcheries, nurseries or commercial farms should have well road connections, essential value chain infrastructures, ice factories and market access.

4.1.2.2 Establishment of hatcheries for seed production of marine species

Hatcheries are the most vital and integral part of infrastructures for the production of abundant seeds to support successful mariculture development. It is obvious that the mariculture industry will not thrive without adequate quality, quantity and consistency of seeds or juveniles of marine species (Anon, 2018). Unfortunately, there is no seed producing hatcheries/centers available for marine fin fish, crabs, mussels and sea weeds in the country. However, there are quite a good number of shrimp hatcheries in the Cox's Bazar region, from where tiger shrimp seeds are air lifted to Khulna and Shatkhira regions to support existing shrimp farming. But the indoor facilities of most of these shrimp hatcheries are primitive except very few of those infrastructures. There is only a Specific

Pathogen Free (SPF) seed production hatchery of tiger shrimp named M.K.A. Shrimp Hatchery, which is located at Sonapara, Ukhia, Cox's Bazar. Inadequate SPF seeds are produced using base population of tiger shrimp taken from Hawaii, USA. More SPF hatcheries are needed to be established at South East and South West coasts of Bangladesh. A number of marine fin fish and crab hatcheries need to be urgently designed and established in the suitable sites of Khulna, Shyamnagar, Shatkhira, Moheshkahi, Kutubdia and Cox's Bazar regions. These hatcheries should have all modern indoor and outdoor seed growing facilities like egg incubators and jars, larvae rearing troughs and tanks, fry nursing tanks and ponds etc. including adequate saline water supply systems. Side by side, special hatchery technologies could be taken from South Korea, Japan and Australia to design and establish mussel and seaweed seed production hatcheries and seed growing facilities/centers at the coast of Saint Martin's Island and other similar places.

Table 2. Species/ group wise opportunities of aquaculture in coastal and marine waters of Bangladesh

Species/Group	**Main locations/areas for mariculture**
Marine fin fish breeding and farming	
Sea bass (*Lates calcarifer*), Grey mullet (*Mugil cephalus*), Green back mullet (*Chelon subviridis*), Pomfret (*Pampus argenteus*), Hilsa (*Tenualosa ilisha*), saline tolerant tilapia and other species	Land-based brackishwater pond culture, cage culture and pen culture in inshore and offshore areas i.e., Moheshkhali-kutubdia channel, Sonadia island and Dubla island
Marine shrimp broodstock domestication, and SPF seed production and farming	
Broodstock domestication, and breeding and farming of *Penaeus monodon, P. indicus, P. merguiensis*	Cox's Bazar, Satkhira, Khulna
Crab breeding and farming	
Mud crab, *Scylla serrata*	Shamnagar, Shatkhira; Moheshkahi; Cox's Bazar
Mussel breeding and culture	
Clams (Anadara)	Chittagong, Moheshkhali, Kutubdia coast
Mussel (green mussel, *Perna viridis*)	St. Martin's Island, Moheshkhali, Kutubdia
Clam (*Meretrix meretrix*) and oyster (*Crassostrea madrasensis*)	Cox's Bazar, Sundarban mangrove
Pearly oyster (blacklip, nei)	Cox's Bazar, Patuakhali
Culture of marine aquatic Plants	
a. Seaweeds *Sargassum* sp., *Hypnea* sp., *Caulerpa* sp. *Ulva* sp. and others.	St. Martin's, Cox's Bazar and Khulna
b. Marine micro algae Marine micro algae viz. *Skeletonema costatum*, *Thalassiosira* sp., *Chaetoceros gracilis*, *Tetraselmis* sp., *Nanochloropsis oculata, Chlorella* sp. etc.	Chittagong, Cox's Bazar, Dhaka, Khulna (can be used as live feed and biodiesel production by marine biotechnology)
Culture of marine coral and other non-traditional species	
Corals, sea cucumber, sea urchin etc.	St. Martin's Island

4.1.2.3 Designing and implementation of marine aquaculture farming infrastructures and other related facilities

While adequate seeds/juvenile production and availability will be ensured, then next task is to build commercial marine aquaculture farming infrastructures for growing marine fish/shellfish and other suitable species. In view of that following systems need to be constructed as priority basis:

a. Development of coastal earthen ponds

For traditional shrimp farming in Bangladesh, generally vast areas of law lying coastal lands are used mostly in South West region, Khulna and Shatkhira areas, where yield of shrimp per unit area become extremely low, which is around 250-300 kg/ha. Better farming infrastructures can be constructed in those areas, particularly in greater Khulna region as well as in Chakuria, Kutubdia and Moheshkhali of Cox's Bazar region to initiate semi-intensive shrimp and crab farming, and fin fish species like Sea bass (*L. calcarifer*), Grey mullet (*M. cephalus*), Green back mullet (*C. subviridis*), Pomfret (*P. argenteus*) etc. In this system artificial feeding with high quality floating or sinking pelleted feeds will be a prerequisite for better yield and production. A well-designed earthen farms should be >5– 25 hectares with adequate saline water supply and recommended water depths.

b. Development of inshore raceways

There are many suitable coastal areas to construct inshore raceways, where net enclosures can be building up at different lengths and desired depths in the coastal lagoons and canals. Polyethylene/nylon net materials having mesh sizes >2–5 cm can be fixed with bamboo, PVC or steel made poles. Marine finfish juveniles like hilsa, seabass, grey mullet etc. can be stocked intensively and cultured to grow them marketable size with supplementary feeding.

c. Floating net cages at offshore areas

Offshore net cage farming of marine finfish species will be a new initiative in Bangladesh. It is a common practice in Indonesia, China, Norway, Japan, Brazil, Mexico and some countries of Indo-Pacific Region. Net cage farming can be introduced in the country at artisanal level with simple design and small size of 3 x 3 m to 5 x 5 m and depth of 4-5 m (Hussain *et al.* 2017a). They suggested that local fishers/farmers themselves can make cages using locally available materials including bamboo, wooden boards, steel/PVC pipes and nylon nets. In future, much better construction of net cages can be initiated at offshore areas of Moheshkhali-Kutubdia channel, Sonadia island, Andermanik rivers and other suitable places. To grow in net cages, marine finfish juveniles like hilsa, seabass, grey mullet, sea bream etc. can be stocked intensively and cultured with regular high quality artificial feeding.

d. Mussel culture hanging racks and floating rafts

The non-traditional marine species like mussels are very much common in the littoral zone of our marine waters. These animals being the filter feeder of phytoplankton and various detritus materials available in the sea water, are attached in clusters on various substrates. Mussels are the most efficient converter of organic matters produced by marine organisms into palatable and nutritious animal protein (Aypa, 1980). Both hanging racks in the shallow region and floating rafts are generally used to grow the collected mussel spats into marketable size. This will certainly be a new practice in this country. There are good opportunities for green mussel (*P. viridis*), clam (*M. meretrix*) and oyster (*C. madrasensis*) production, especially in Moheshkhali, Kutubdia and Sonadia islands of Cox's Bazar and Teknaf regions (Shahabuddin *et al.*, 2010). Lessons regarding the most useful techniques for breeding and culture of various types of mussels can be learned from the countries like Australia, Japan, South Korea, Philippines, Spain etc.

e. Seaweed culture at reef flats, mangrove stakes/nets and long lines

Seaweeds are being used as delicious food items, particularly in China, Japan, Korea and Thailand. As these marine aquatic plants have a tremendous advantage and being utilized in those countries in producing phycocolloid or hydrocolloid, cosmetics, biofuel, pharmaceuticals, waste water treatment and bioplastic industries. Therefore, seaweed culture could be widely initiated in this country for using as food items as well as for foreign exchange earnings. In Bangladesh, naturally growing seaweeds are seen in the littoral and sub-littoral zones of St. Martin's Island to Sundarbans Mangrove forest, and are available from October to April throughout the whole Southern coast (Islam and Aziz 1987; Islam, 1998). Suitable water quality parameters and rocky substratum make the St. Martin's Island an excellent place for naturally occurring seaweeds (Khan, 1990; Tomascik, 1997; Zafar, 2005). In total, 193 seaweed species including 19 commercially important species are found in Bangladesh and about 5,000 metric tonnes of seaweed biomass are available (Sarkar *et al.*, 2016). For the commercial culture of seaweeds, both reef flats and long line methods (as the most common practice) could be introduced in this country. Seedlings are usually tied to monofilament lines and strung between mangrove stakes pounded into the substrate. This off-bottom method is still considered as one of the major methods used to set up in one meter depth. There are new long-line cultivation methods that can be used in deeper water approximately 7 metres in depth. It is widely said that seaweed farming can also be an actor in biological carbon sequestration.

4.1.2.4 Domestication of potential mariculture species

Domestication of wild fish species for using them in artificial seed production is a common practice both for inland aquaculture and mariculture systems all over the world. Similar mariculture practices both for marine fish breeding and farming will be more or less similar for selected marine fin fish and shellfish species in Bangladesh. So prior to initiate seed production in the marine hatcheries, wild collected juveniles or brood stocks need to be accustomed and domesticated in the captive conditions at the breeding tanks or ponds under optimum salinity for few months by adequate care and feeding to enhance their sexual maturity. Next step is to select best-sized and well-ripped fish/shellfish for breeding in the hatcheries. Similar situation might need to be followed for growing mollusks and other non-traditional species. To avoid genetic deterioration conventional selective breeding or marker assisted selective breeding technique(s) could be followed for some selected breeding stocks for marine aquaculture.

4.1.2.5 Production of high quality feeds

Intensive feeding with high quality feeds is required for some species, such as tiger shrimp and carnivorous finfish such as seabass and may be desirable in the case of other marine species to increase yield, reduce grow out times, pay off investment in ponds or cages more rapidly. The trend in Bangladesh has been towards the application of dry pelleted formulated feeds, as the country have some reputed feed mills (e.g., Saudi Bangla fish feed, Quality feed, Paragon feed mills etc,). Modern fish feeds are scientifically and economically optimal in producing high and consistent performances. They are easy to store and handle and thus greatly reduce labour costs. Unfortunately, feed conversion ratios and feed management practices for marine fish/shrimps are not well-established in Bangladesh, and therefore need to be initiated at the same time of expanding marine aquaculture. Side by side, import of high quality fish meal or other essential ingredients from abroad for ensuring optimum standard of such feeds need to be considered to maximize the feed costs vs quality perfectly.

4.1.2.6 Necessary investment in mariculture

As mariculture is presently a new venture and risky task, securing adequate capital to support mariculture operations remains a challenge for many interested parties in Bangladesh. Development of new infrastructures for marine hatcheries, commercial land based farms, inshore raceways, offshore cages etc. need huge investment. No party will be interested unless or until any foreign donor or internal state owned bank will come forward to support such initial costs for infrastructural development and mariculture operations. Obviously, it will be wiser to develop Public-Private Partnership for running long term mariculture industry. In this respect, concerned Govt. Department(s) and Ministries should take proper initiative for the benefit of industry.

4.1.2.7 Mariculture related public understanding and support

Unlike other fisheries and agricultural sectors/sub-sectors, one of crucial elements of developing mariculture in Bangladesh is building public understanding and support for one of the newly emerging sectors of blue economy like mariculture. Without the strong support to the affected peoples related to mariculture as well as the subsequent political approval, no amount of public and private investment can result in implementation and success (Anon, 2018). It is obvious that sustainable impact of mariculture will affect positively on coastal-resource poor community and will ultimately enhance the environmental and economic benefit of the country.

4.1.2.8 Mariculture markets and products development

It is a reality that some of the mariculture items and processed products like shrimps, carbs, mussels and seaweeds might not have enough consumers in the country at this moment. So it will be an anxiety of the producers as well relevant Government Departments/Ministries on how to export those mariculture products to domestic and international markets. In this respect, mutual collaboration among domestic and international marketing agencies will be required to find out an effective solution.

4.1.2.9 Establishment of mariculture research and technical education institutions

In regards to apply mariculture research and education, no sole technical institutions are available in Bangladesh except the Marine and Technology Station of Bangladesh Fisheries Research Institute (BFRI). Research facilities at BFRI's Marine Research Station in Cox's Bazar are not adequate yet to carryout need-based marine fisheries/aquaculture and oceanographic research (Hussain *et al.* 2017b). In this context, there is scope and opportunity for an equitable and mutually beneficial collaboration between Bangladesh's research institutions/universities and some European and other international universities to develop high tech mariculture related education systems. On the other hand, a new initiative can be undertaken soon to establish a full-fledged new mariculture research institution having all labs and facilities including breeding/propagation, biotechnology, culture and product development of marine fish/shellfish and non-traditional species in the coastal belt of Cox's Bazar.

5. Conclusions

The Blue economy conceptualizes oceans and seas as "Development Spaces" where spatial planning integrates conservation, sustainable use of living resources, oil and mineral extraction, bio-prospecting, energy production and marine transportation (Alam 2014). The Blue Economy approach is founded upon the assessment and incorporation of the real value of the natural (blue) capital into all aspects of economic activities (viz., conceptualization, planning, infrastructure development, trade, travel, renewable resource exploitation and energy production/consumption). Thus Blue Economy requires a balanced approach between conservation, development and utilization of marine and coastal ecosystems, all oceanic resources and services with a view to enhancing their value and generates decent employment, secure productive marine economy and healthy marine ecosystems (Patil *et al.*, 2018). In respect of sectoral issues, Fisheries and Aquaculture is one of the priority sectors. Presently, Bangladesh is one of the leading countries for aquaculture production in Asia Pacific region as well in the world. Over the last 15 years, major advancement has been occurred in freshwater aquaculture sub-sector rather than in marine aquaculture. Although marine fish farming is a promising area of aquaculture here but it was not properly flourished except partly in shrimp, due to less availability of hatchery produced seeds, low levels of farming technology development and transfer to the farmers, lack of affordable formulated feeds, and lack of serious initiatives by the public and private sector organizations and entrepreneurs. In Asia Pacific region, the countries like China, Indonesia, Malaysia, Taiwan Province of China, Thailand, Singapore and Vietnam are making headway in finfish mariculture using hatchery produced seeds and formulated feeds. Lessons can be learned from these countries and under the context of blue economy development of the government, Bangladesh might urgently initiate marine aquaculture farming with the available and identified finfish, shellfish and non-traditional species (mentioned above). Respective Ministries, Departments and Research Institutions along with interested Private Entrepreneurs might sit together for proper formulation of strategies, planning and coordination for effective development and implementation of marine aquaculture farming in the coast, near shore and offshore areas of the country.

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জিনোম এডিটিং প্রযুক্তি ক্রিসপার-ক্যাস (CRISPR-CAS): কৃষি উন্নয়নে নতুন সম্ভাবনা

নীলুফার ইয়াসমিন শেখ[১]

জীব দেহের একক হচ্ছে কোষ (Cell), যার ভেতরে আছে নিউক্লিয়াস (Nucleus)। এটা জীব কোষের মূল চালিকা শক্তি। আর এই নিউক্লয়াসের ভেতরে থাকে ক্রোমোজোম (Chromosome), যা জীবের সকল বৈশিষ্ট্যের ধারক ও বাহক। আবার এই ক্রোমোজোম এর মধ্যে বাস করে জিন (Gene)।

আমরা প্রায়ই শুনে থাকি, ডিএনএ (DNA) পরীক্ষার মাধ্যমে কোনো শিশুর পিতামাতাকে সনাক্ত করা, এমনকি সামান্য চুল থেকে কোনো অসামান্য অপরাধীকেও সনাক্ত করা সম্ভব। এই ডিএনএ (De-oxzribo Nucleic Acid) আসলে জিন এরই অংশ বিশেষ। সুতোর মতো জড়িয়ে থাকা ডিএনএ এর ডাবল হেলিক্স কাঠামোটি তৈরী হয় De-oxzribose, Phosphate এবং চার ধরনের নাইট্রোজেন বেস (Nitrogenous base) দিয়ে। সহজ করে এভাবে বলা যায় যে, ডিএনএ যদি বর্ণমালার বিভিন্ন অক্ষর হয়, তাহলে জিন হচ্ছে সেই অক্ষরগুলো সাজিয়ে দিয়ে তৈরী অর্থবোধক শব্দ। জন্মের পর কোনো জীব লম্বা হবে না খাটো হবে, কালো হবে না ফর্সা হবে, চুল ঘন হবে না পাতলা হবে ইত্যাদি সকল বৈশিষ্ট্য ঠিক করে দেয় এই জিন। জেনেটিক কোডের বর্ণমালায় রয়েছে ডিএনএ এর A, T, G, C এ চারটি নাইট্রোজেন বেস। এই অক্ষরগুলোর বিভিন্ন বিন্যাস তথা ডিএনএ কোডই জীবের শারীরবৃত্তীয় এসকল বৈশিষ্ট্য নির্ধারন করে। কোড সমৃদ্ধ সকল জিন ও কোড বিহীন ডিএনএ সমূহ সম্পূর্ণটা নিয়ে তৈরী হয় প্রতিটি জীবের জিনোম (Genome)। অর্থাৎ জিনোমে ডিএনএ এর পুরোটাই কিন্তু জিন নয়। সেই অংশই জিন যা নির্দিষ্ট কোনো প্রোটিন তৈরীর কোডকে ধারণ করে।

একটি সুষ্থ্য ও স্বাভাবিক জীবের জিনের গঠনে যখন কোনো কারনে পরিবর্তন হয়, তখনই শুরচ হয় নানাবিধ জটিলতা, উদ্ভব হয় জটিল সব রোগের। ক্রিসপার-ক্যাস জেনেটিক ইঞ্জিনিয়ারিং এর এমন একটি প্রযুক্তি যার মাধ্যমে ক্ষতিকারক জিন অপসারন করা, এমনকি ক্ষতিগ্রস্ত কোনো জিন মেরামত করাও সম্ভব। জিনোম থেকে কিছু অংশ কেটে বাদ দিয়ে নতুন অংশ যুক্ত করে জিন সম্পাদনা (Gene Editing) এর নতুন প্রযুক্তির নামই ক্রিসপার-ক্যাস (CRISPR-CAS) টেকনোলজি। কাঙ্খিত বৈশিষ্ট্য অর্জনের জন্য জিন অপসারন (Genomic deletion), জিনের কার্যকারিতা রোধ (Gene Knockout), এবং ভাইরাস রোগ প্রতিরোধ এর মাধ্যমে সুনির্দিষ্টভাবে জিন এডিটিং করে জিনোমের ভেতর পরিবর্তন আনতে পারার এই নতুন প্রযুক্তি জীবপ্রযুক্তিকে আরও একধাপ এগিয়ে দিয়েছে (Haque et al. 2018, Ma et al. 2016)।

ক্রিসপার (CRISPR) হলো ব্যাক্টেরিয়া জিনোমের একটি নির্দিষ্ট অংশ, যেখানে বেশ কিছু ডিএনএ সিকোয়েন্স এর পুনরাবৃত্তি থাকে। এই সিকোয়েন্সগুলো প্যালিনড্রমিক অবস্থায় থাকে অর্থাৎ একটি সিকোয়েন্স যদি ATCGAG হয় তবে অপরটি হয়, TAGCTC, তার মানে একে অপরের ঠিক উল্টো। এ কারনে জিনোমের এই অংশের নাম Clustered Regularlz Interspaced Short Pallindromic Repeats (CRISPR) এবং এতে গুচ্ছাকারে অবস্থিত পুনরাবৃত্তি সিকোয়ন্সগুলোর নাম রিপিটার (Repeater) সিকোয়েন্স। জিনোমের ক্রিসপার অংশে কিছুদূর পরপর এই রিপিটার সিকোয়েন্স থাকে। আবার দুই রিপিটারের মাঝে থাকে ভিন্ন কোনো ধরনের সিকোয়েন্স।

[১] এস. এস. ও., বায়োটেকনোলজি বিভাগ, বাংলাদেশ ধান গবেষণা ইনস্টিটিউট, গাজীপুর।

যেমন, দুটো ATCGAG এর মাঝে একটি ভিন্ন সিকোয়েন্স GGCTT থাকতে পারে। এগুলোকে বলা হয় স্পেসার সিকোয়েন্স।

কোনো ব্যাক্টেরিয়া যখন ভাইরাস দ্বারা আক্রান্ত হয়, সাথে সাথে ব্যাক্টেরিয়া ভাইরাসের জিনোমকে কেটে দেয়। ফলে সংক্রমিত হওয়ার ভয় আর থাকে না। এমনকি কেটে ফেলা ডিএনএ এর একটা অংশ সে সংরক্ষিত রাখে নিজের জিনোমের ক্রিসপার অংশে, দুটো রিপিটার সিকোয়েন্সের মাঝে স্পেসারে। এভাবে ডিএনএ কাটা ও সংরক্ষনের কাজটি করে CAS প্রোটিনসমূহ। CAS শব্দটি এসেছে CRISPR Associated Protein থেকে। এই প্রোটিনগুলো তৈরীর পেছনে কাজ করে ক্যাস্ জিন (CAS Gene), সেগুলো থাকে ডিএনএ এর ক্রিসপার অংশের পাশেই। ক্রিসপার ডিএনএ, কেটে ফেলা ভাইরাসের ডিএনএ এর অনুরূপ একটি আরএনএ তৈরী করে, যার নাম CRISPR RNA (crRNA). এতে সংরক্ষিত থাকে ভাইরাসের সকল তথ্য। এরপর crRNA I CAS এবহব থেকে উদ্ভূত Cas9 প্রোটিন (CAS Associated 9 Protein) সম্মিলিত ভাবে ব্যাক্টেরিয়ার কোষকে পাহারা দিতে থাকে। পরবর্তীতে সেই ভাইরাস পূণরায় কোষে প্রবেশ করা মাত্রই CAS Gene, crRNA তে থাকা তথ্যের সাথে ভাইরাস ডিএনএ এর মিল পেলেই সাথে সাথে সেটিকে কেটে ফেলে।

বিজ্ঞানীরা ব্যাক্টেরিয়ার এই আশ্চর্য ক্ষমতাটি জানার পর একে জিনোম এডিটিং এর কাজে লাগানোর চেষ্টা করছেন। তারা ইচ্ছে মতো ডিএনএ এর অংশ কাটা যায় কিনা তার পরীক্ষা করেন। কেননা তাহলে এই প্রযুক্তির মাধ্যমে কেবল ভাইরাস হতে প্রতিরক্ষাই নয়, উদ্ভিদ ও প্রাণীর জিনগত বিভিন্ন রোগেরও প্রতিকার পাওয়া যেতে পারে। সেই সাথে কৃষি উন্নয়নের জন্য ফসলী উদ্ভিদের গুণগত মান বৃদ্ধি, ঘাত ও পীড়া সহনশীল কাঙ্খিত বৈশিষ্ট্যও অর্জন করা সম্ভব হবে। এই ক্রিসপার-ক্যাস প্রযুক্তি আবিষ্কারের ফলে বিজ্ঞানীদের স্বপ্ন সত্যি হতে চলেছে কেননা মৌলিক গবেষণা, উদ্ভিদ প্রজনন, জেনেটিক ইঞ্জিনিয়ারিং ও জিনোম এডিটিং এর নতুন এক সম্ভবনার দুয়ার খুলে গেছে (Gaozuan et al. ২০১৬)।

CRISPR Cas9 প্রোটিনের কাজ মূলত: ভাইরাসকে আক্রমন করে এর ডিএনএকে কেঁচির মতো কেটে দেওয়া। তবে crRNA এর তথ্য ছাড়া সে এ কাজটি করতে পারেনা। তাই বিজ্ঞানীরা কৃত্রিম উপায়ে crRNA Ges transactivating crRNA (tracrRNA) যুক্ত করে সিঙ্গেল গাইড আরএনএ (sgRNA) তৈরী করে ফেলেন (P. Horvath et al. 2010; M. Jinek *et al.* 2012)। তাঁরা Cas9 প্রোটিনের সাথে জুড়ে দেন এই সিঙ্গেল গাইড আরএনএ (sgRNA) অণু। এতে মাত্র ২০টির মতো বেসপেয়ার থাকে। এটি টার্গেট জিনকে সনাক্ত করতে সক্ষম। তবে এ ক্ষেত্রে সিঙ্গেল গাইড আরএনএ এর সিকোয়েন্স অবশ্যই টার্গেট ডিএনএ এর সিকোয়েন্স এর অনুরূপ হতে হবে যাতে Cas9 প্রোটিন জিনোমের সঠিক জায়গায় কাটতে পারে (E. Deltcheva et al. 2011)। Cas9 nuclease নামক এনজাইম এসময় Protospacer Adjacent Motif (PAM সাধারণত ৫’ NGG) এর পরের ৩-৪ টি বেসকে বিভক্ত করে দেয় (Jinek et al. 2012) । Cas9 nuclease এনজাইমটি RuvC like Domain এবং HNH Domain নামক দুটি ডোমেইন এর সমন্বয়ে গঠিত (Xuan et al. 2017)। প্রতিটি ডোমেইন একটি ডিএনএ সুত্রকে (DNA strand) কাটতে পারে। এভাবে এই Single strand Nuclease (SSN) টার্গেট ডিএনএ তে দুটি সূত্রের ভাঙন (Double Strand Breaks) ঘটায়। এই ভাঙা অংশগুলো Non Homologous End Joining (NHEJ) অথবা Homologz Directed Recombination Pathwaz এর মাধ্যমে মেরামত হয় যার ফলে টার্গেট স্থানে সংযোজন/ অপসারন (insertion/ deletion; INDELS) এবং মিউটেশন ঘটে (Jinek et al. 2012) ।

কাঙ্খিত ফসলের জাত উদ্ভাবনের জন্য ক্রিসপার-ক্যাস প্রযুক্তি ব্যবহার করে জিনোম এডিটিং করার ধারাবাহিক ধাপসমূহ হলো: (ক) এডিট করার জন্য জিন বাছাই (খ) টার্গেট জিনের ভেতরের PAM সিকোয়েন্স সনাক্তকরণ

(গ) sgRNA ডিজাইন এবং সিন্থেসিস করা (ঘ) সুবিধাজনক বাইনারী ভেক্টরের ভেতর sgRNA ক্লোনিং করা (ঙ) তা জেনেটিক ট্রান্সফরমেশনের মাধ্যমে উদ্ভিদের সারিতে ঢুকানো (চ) এডিট করা ট্রান্সজেনিক উদ্ভিদ পরীক্ষণ ও নিশ্চিতকরণ। (ছ) কাঙ্খিত বৈশিষ্ট্য সম্পন্ন উদ্ভিদ মূল্যায়ন ও বাছাইকরণ (Deepa J. et al. 2018)।

ক্রিসপার-ক্যাস প্রযুক্তি জেনেটিক ইঞ্জিনিয়ারিংয়ে এক নতুন দিগন্তের সূচনা করেছে। আবার কাঙ্খিত বৈশিষ্ট্য অর্জনের জন্য যে কোনো জীবের জিনোম সিকোয়েন্সকে সুনির্দিষ্টভাবে সম্পাদনার জন্য এ প্রযুক্তি ব্যবহার দ্রুত বৃদ্ধি পাচ্ছে (Haque et al. 2017)। বর্তমানে চীন, আমেরিকা, জাপান, কোরিয়া, ইন্ডিয়া সহ ইউরোপের বিভিন্ন দেশে জীবপ্রযুক্তি গবেষণাগারে এই প্রযুক্তি কাজে লাগিয়ে বিভিন্ন উদ্ভিদ ও প্রাণীর জিনোম এডিটিং করা হচ্ছে। এমনকি মানুষের বিভিন্ন রোগ নিরাময়ের ক্ষেত্রেও এ প্রযুক্তি ব্যবহৃত হচ্ছে। বিগত কয়েক বছর ধরে ক্রিসপার-ক্যাস প্রযুক্তিটি এর সহজ ব্যবহার, উচ্চমানের ফলপ্রসূতা এবং বিবিধ ক্ষেত্রে ব্যবহার করা যায় বলে জীবপ্রযুক্তি বিজ্ঞানীদের যথেষ্ট মনোযোগ পেয়েছে (Xuan et al. 2017)। তবে এই প্রযুক্তির প্রধান সীমাবদ্ধতা হলো CRISPR Cas9 off target cleavage যার ফলে জিনের আকাঙ্খিত কার্যকারিতা পরিবর্তন হতে পারে। জিনোমের ভেতর sgRNA এবং Complementarz target DNA এর বেসপেয়ার নিয়ম অনুসারে না হলে অথবা PAM এর কোনো অসামঞ্জস্যতাজনিত জটিলতার কারণে off target cleavage site তৈরী হয়। তবে আরও বেশী সুক্ষ ও সতর্কতার সাথে sgRNA ডিজাইন করলে এই off target সীমাবদ্ধতা এড়ানো সম্ভব।

ক্রিসপার-ক্যাস এর মাধ্যমে জিনোম এডিটিং প্রযুক্তি ব্যবহার করে রোগ প্রতিরোধী জিন যুক্ত করে অথবা রোগ সংবেদনশীল জিন অপসারন করে দ্রুত রোগ প্রতিরোধী ফসলের জাত উদ্ভাবনের ক্ষেত্রে নতুন সম্ভাবনার দুয়ার খুলেছে (Haque et al. 2018)। আলুর শর্করার গুণগত মান বাড়াতে (Andersson et al. 2016), Brown streak ভাইরাস রোগ প্রতিরোধী কাসাভা উৎপাদনে (Gomez et al. 2017), এবং পেঁপের Papaza Ring Spot Virus রোগ প্রতিরোধী পেঁপে উৎপাদনে (Green and Hu 2017) ক্রিসপার-ক্যাস প্রযুক্তি ব্যবহৃত হয়েছে। আবার পাউডারি মিল্ডিউ (Powderz Mildew) রোগ প্রতিরোধী টমেটো (Nekrasov et al. 2017) এবং পার্থেনোকার্পিক (Parthenocarpic) টমেটো উৎপাদনে (Rodriguez-Leal et al. 2017; Ueta et al. 2017) ক্রিসপার-ক্যাস প্রযুক্তি ব্যবহৃত হয়েছে।

ধান, গম, ভূট্টা, যব, আলু, টমাটো ইত্যাদি ফসলী উদ্ভিদের ফলন বৃদ্ধি সহ বিভিন্ন বৈশিষ্ট্যের উন্নয়নে এই প্রযুক্তির সফল ব্যবহার খুবই আশা ব্যাঞ্জক (Agnes et al. 2017)। ক্ষরাপ্রবন এলাকায় ভুট্টার ফলন বাড়াতে (Shi et al. 2017), সরিষার প্রতি সিলিকে বীজের সংখ্যা বৃদ্ধি করতে (Haque et al. 2018) এবং বীজের ঝরে যাওয়া (Pod shattering) নিয়ন্ত্রনে (Lawrenson et al. 2015), এবং গমের বীজের আকৃতি বৃদ্ধি তথা ফলন বৃদ্ধি করতে (Wang W. et al. 2018), পাউডারি মিল্ডিউ (Powderz Mildew) রোগ প্রতিরোধে (Wang W. et al. 2014) এই ক্রিসপার-ক্যাস প্রযুক্তি ব্যবহৃত হয়েছে।

এছাড়াও ধানের বীজের আকৃতি বৃদ্ধি করতে (Xu et al. 2016), হার্বিসাইড রেজিস্ট্যান্ট ক্ষমতা বাড়াতে (Shimatani et al. 2017), ব্যাক্টেরিয়াল ব্রাইট সংবেদনশীল জিনের কার্য্যকারিতা রোধ করতে (Jiang et al. 2013; Jhou et al. 2015), ব্রাস্ট প্রতিরোধী ধানের সারি উদ্ভাবনে (Xie et al. 2014; Wang et al. 2016; Ma et al. 2017), ধানের জাতকে লবনাক্ততা সহনশীল করতে (Duan et al. 2016), চালে অ্যামাইলোজ এর পরিমান বাড়াতে (Sun et al. 2017) এবং আলোক সংবেদনশীল মেল স্টেরাইল (Photo sensitive male sterile) ধানের লাইন তৈরীতে (Li et al. 2016) ক্রিসপার-ক্যাস প্রযুক্তি কাজে লাগানো হয়েছে।

এভাবে বিভিন্ন উদ্ভিদের রোগ প্রতিরোধ ক্ষমতা বাড়াতে এবং ভাইরাস ও জিনগত রোগের বিরুদ্ধে এক বিধ্বংসী অস্ত্র হিসেবে ক্রিসপার-ক্যাস প্রযুক্তির ব্যবহার কৃষির উন্নয়নে ব্যাপক ভূমিকা রাখবে এই প্রত্যাশা সকলের। সেই সাথে ফসলী উদ্ভিদের ফলন ও গুণগত উন্নয়নের জন্য এই ক্রিসপার-ক্যাস প্রযুক্তি ব্যবহারের মাধ্যমে জীব প্রযুক্তি বিজ্ঞানীগণ অদূঢ় ভবিষ্যতে খাদ্য নিরাপত্তা নিশ্চিত করতেও সচেষ্ট হবেন।

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Bangladesh Agriculture at a Crossroads: What Needs to Change?

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Agriculture sector used to be the backbone of Bangladesh's economy in early years of its emergence as an independent country. In 1974, value added in the sector accounted for 56.6% of the nation's gross domestic product (GDP). Forty-four years later in 2017, this share dwindled to 13.4% as the country's economy expanded and diversified fuelled by manufacturing, services and industrialization. However, it doesn't mean agriculture sector is now producing less output than in the past; in fact it is now producing many times more enabling the country to reach almost 100% self-sufficiency in rice. The sector retains its importance because it still provides employment to 40.6% of the labour force and generates livelihood for large numbers of rural people through various off-farm agriculture-related income-generating activities. The dynamism of Bangladesh's agriculture sector is evident in its continuing strong growth. Annual growth of the sector varied from 2.46% to 6.69 % during 1996–2016 except the year 2002 when growth plummeted to minus 0.12 percent.

A 20-year period of sustained positive growth averaged at 4.28 percent per year is a clear vindication of rising productivity and growing resilience of Bangladesh's agriculture sector. The past three years (2016/17–2018/19) saw food production in Bangladesh cross all historical limits. As evident from DAE data, on the heels of a record harvest of rice in 2018 at 36.28 million tons of milled rice, the country again set a new record of rice production in 2019 estimated at 37.33 million tons. Production of total cereals (milled rice, wheat and coarse grains) increased from 41.27 million tons in 2018 to 43.51 million tons. Rice production during the period 2016/17–2018/19 increased at an annual compound growth rate of 5.08%. Most of this growth came from intensification of rice cropping reflected in annual 3.03% growth in rice cropped area and the remainder is contributed by an annual 2.05% growth in yield. Having travelled such heights Bangladesh agriculture has arrived at a turning point, where it needs a new direction if it is to retain its dynamism and simultaneously address multiple other challenges of equitable and sustainable growth. The search of a new direction should begin with understanding how the sector has changed over the years and identifying the areas where transformational changes can be brought about. Bangladesh Government has identified mechanization, commercialization, and making smallholder farming profitable and economically attractive as among those areas. Obviously, it makes ample sense to drive desired changes in the sector.

It goes without saying that smallholder farming systems dominate Bangladesh's agriculture. But, how many of them are there in the country and how small they are? The information that we have is little more than a decade old. According to 2008 agriculture census, there were 14.87 million farm holdings in the country (58.7% of total holdings) who cultivated 18,815,381 acres (7.614 million ha) of land with an average farm size of 1.26 acre, a parcel of land about 100 meters long and 50 meters wide. Of the total farm

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households, small farms ranging in size from 0.02 ha to 1.008 ha constituted 84.27%, medium farms with size from 1.01 ha to 3.031 ha 14.71%, and large farms ranging in size from 3.032 ha and bigger 1.51%. Landless farm households constituted 9.58% of the total farm households. Field work for a new agricultural census has begun since June 2019. But it is possible to predict the trend based on data reported in previous three agricultural censuses (1983-84, 1996 and 2008). The total number of farm households expected in 2019 stand at 16.86 million; as a share of total farm holdings small farms are expected to constitute 91.47 percent and medium farms 8.75%. Large farms are most likely to disappear as a farm category in 2019. This brings us to the reality that smallholder farms constituting about 90 percent of the total farms produce most of the food in the country from land holdings as small as 20 m by 20 m and as high as 100 m by 100 m. Technologies and innovations designed to continue boosting productivity of smallholder farming should be within reach of these smallholders and suitable for adoption by them. However, agriculture sector still employs close to half of the workforce. It means over half of the economically active population draws their livelihood from a sector whose contribution to GDP continues declining as the overall economy keeps growing and now constitutes just one-seventh of the total. What does it tell us? It tells that individually very few producers in the agriculture sector make net addition to the economy; most consume what they produce. In short, subsistence orientation of Bangladesh agriculture has deepened over time. On the other hand, fragmentation of land holdings into tiny plots of microscopic sizes also reduces their efficiency, constrains adoption of improved farm practices and limit bargaining power of small-scale producers in selling their produces. Therefore, halting fragmentation of farm holdings and their consolidation in sizes that permits farm operations to be conducted at reasonable economies of scale should be seen as a key approach to lift smallholder farming from subsistence trap and set it on course to commercialization.

But there are many other challenges deeply rooted in the farm economy that need to be addressed in order for commercialization to gather steam and make farming profitable. Profits originate from remunerative prices, also called fair prices, which are most coveted by small-scale producers but remain elusive for them because of limited bargaining power and constraints of the marketplace. A wall of intermediary traders ranging from small to large separates them from the markets; these traders buy produces from farmers in rural weekly markets and sell to the next higher level of traders making a profit; they in turn sell to the next bigger trader extracting a profit. After several change-over; when the product reaches urban market, buyers pay a hefty price several times higher than the production cost. But all the profits are pocketed by intermediary traders sitting on the way as the food product travels from the field to market shelves, although they produce nothing. It is the farmers who lose more often and gain seldom. There had been little change in this story; it remains equally valid today.

Paradoxically, a bumper harvest of paddy may be good news for the macro economy because of its contribution to economic growth and also for most consumers because prices remain affordable. But for the producers it is most often a bad news because of depressed selling prices and many producers incur losses when these prices fall below the production costs. The saga of farmers losing was amply demonstrated in 2018-2019 Boro rice crop when production hit an all-time high exceeding past year’s record harvest by 4.1%. The losses that the rice growers had suffered varied widely across different regions of the country. However, the general consensus is Tk. 300 per maund (37.32 kg) of paddy produced. If this loss is extrapolated to the entire Boro cropped area of 4.9 million ha, the total becomes Tk. 233 billion (2,330 crore) which is equivalent to about USD 2.8 billion at current exchange rate. As a share of agricultural GDP in 2017 estimated by the World Bank at USD 34 billion, it stands at 8.2% which is quite significant. The losses incurred by the farmers were gain for the middlemen taking advantage of the shortcomings of the market mechanism. It is an example of just one season; it is going on and this scenario will be repeated with the next record harvest. Public policy making should focus on closing existing loopholes of the marketing chain that allows intermediaries appropriate so easily lion's share of the value generated in the farm economy.

The conventional method of assisting farmers by subsidizing production inputs (chemical fertilizers, seeds, irrigation pumps, electricity and diesel fuel) also needs closer scrutiny because times have changed. It would have made sense during the era of green revolution when the goal was rapidly increasing food production, no matter what it takes. Specifically farm subsidies then were aimed at encouraging farmers use more of chemical fertilizers and pesticides to grow high-yielding varieties.

That rationale no longer exists. On the contrary, the focus now is on cutting excessive use of chemical inputs to promote sustainability of intensive farming and contribute to climate goals. Blanket provision of subsidies should be replaced by their improved targeting so that they reach deserving smallholders, who are resource-poor, have genuine need of assistance and who otherwise wouldn't use purchased inputs if they are not affordable. Improved targeting would help save significant amount of resources that can be spent to help smallholders in a much better way avoiding wasteful expenditure of resources.

The other approach of assisting farmers, which is hotly debated for its efficiency, is buying by the government of grain during the harvest time through offering prices higher than the prevailing harvest time market prices (so called "fair price"). As the experience of the past Boro season showed, paddy prices nosedived under the weight of the glut in market supply of paddy during the harvest time which resulted from record domestic production, carry-over stocks from the previous year, and import by traders ironically coinciding with the harvest time. Government's buying of harvested grain with fair prices apparently looks a sensible policy because it helps farmers avoid losses in farm production. But the reality is different and whether farmers really benefit from this policy support is questionable. The conventional practice of government's buying is buying from rice millers, who are now more organized and powerful to manipulate market price of rice. So, the incentive price is appropriated by millers and doesn't go to farmers.

This year driven by public pressure, the government made an exception by buying some quantities of paddy directly from farmers. But the results are mixed; the difficulties in buying directly from numerous farmers have been exposed. In reality, it is not possible for the government to buy from all farmers because of both technical and logistical challenges. The next big question is what to do with the government-procured grain; capacity of grain storage warehouses is limited, a few new can be built but endless expansion of storage warehouses isn't a feasible option. And then there is the challenge of handling procured grain in storage, particularly with regard to enormous losses incurred in storage and transportation. In short, there are so many loopholes in public grain procurement and handling in storage, of which some will remain in place for ever, that supporting farmers with fair price hardly qualifies as an efficient, smart policy. Apparently looking farmer-friendly, it in effect leads to enormous wastes and the benefits again are grabbed by intermediaries instead of reaching the intended beneficiaries. However, the bottom line is that if smallholders are to remain in the business of food production, farm economy must be profitable. It is a key prerequisite for graduating from subsistence to commercial levels. For this purpose, other innovative tools and approaches to ensure farmers get remunerative prices should be designed and implemented.

Bold decisions are needed when turning points are reached. Transforming potential which is in waiting into reality depends on how wisely choices are made at this point. The National Agriculture Policy 2018 sets its main goal as "Achieving a safe (meaning food safety), profitable farming and sustainable food and nutrition security". It is notable "food self-sufficiency", which was the key policy goal of the agriculture sector for a long time since the green revolution, has been replaced by "food and nutrition security". The stated goal of the sector policy reflects the current potential of the country's economy by not emphasizing food self-sufficiency which is essentially own production. The emphasis is now on food supply which results from own production and, if needed, food imports to close the gap between demand and domestic production.

With an economy that has grown 22 times since 1974 when "food self-sufficiency" was the main goal, Bangladesh can now afford importing large quantities of foodgrain which is, in fact, happening over the past few years. The question now if "food self-sufficiency" is no longer the policy goal, the rationale for continuing build-up and maintenance of large stocks of foodgrain in storage, presumably as a hedge against unforeseen hazards and which entails colossal losses, doesn't also look valid. On the contrary, availability of large carry-over stocks of stored grain is contributing to oversupply and depressing prices at the harvest time. Before Bangladesh, Vietnam also confronted similar situation. Then its leaders took a momentous decision to begin exporting rice and within a decade transformed the country into the world's top exporter of rice. A similar opportunity is now unfolding for Bangladesh too and it should not be wasted.

Theoretically, the country already sits on an exportable surplus. If we make a simple calculation that in a country of 160 million, everyone eats on daily basis 450 grams of rice (which is higher than official estimate), the annual demand comes at 26.28 million tonnes. In 2018/2019, total production of rice amounted to 37.33 million tonnes generating a surplus of 11.05 million tonnes. Of this amount, some is lost in post-harvest handling and storage; some is used in running various public food entitlement programmes and some may be destined for other social welfare purposes. Even after all these, a significant amount is left that can be considered for export. On the contrary, bulk of the production surplus is held in storage by rice millers and traders for manipulating domestic market prices of rice. On top of this rice millers and traders also import large quantities of rice and hold in storage, the aggregate capacity of private sector storage in Bangladesh closely parallels that in the public sector. With such huge excesses in storage, why should one expect that paddy prices during the harvest time will remain high enough to ensure farmers make profits and do not lose? In the short term, there is little that can interfere with the current upward trend of rice production in Bangladesh; with a fair level of confidence, it can be predicted that rice production in 2019/2020 would surpass the record of 2018/2019 and the same story of farmers facing losses would surface again.

Under these circumstances, exporting rice looks as an appropriate approach to reduce domestic storage of rice and keep it at a level that doesn't distort market pricing of rice to the extent where farmers are forced to count losses. Of course, there is great temptation for governments to keep food prices low because that benefits all consumers and can be sold as people-friendly pro-poor policy, but eventually farmers, primary food producers, lose. However, there is natural limit to enduring losses and if farming is not made profitable, farmers may consider abandoning rice production and focus on other profitable farming activities.

Years of sustained high growth of the economy has transformed Bangladesh's rural economy promoting upward mobility of the labour force. As a result, supply of farm labour during the time of crucial farm operations is not as abundant as it was in the past. Many farm households have to rely on family labour. In response, farm machines are increasingly used, particularly for land preparation. However, harvesting still relies on manual labour and its acute shortage was demonstrated in the past Boro season. Accelerating mechanization of harvesting, drying, and processing should be seen as vital to commercialization of farming.

Globally the agenda for sustainable development across sectors of national economies will be driven by UN's 17 Sustainable Development Goals (SDGs) (2015-2030). Therefore, policy making for the agriculture sector should be brought in sync with the challenges of implementing SDGs. Out of 230 SDG indicators, 21 have relevance for agriculture. But in UN's concept of agriculture with respect to SDGs, it comes along with food, in other words, agriculture means food and agriculture. In Bangladesh, for the purpose of governance, food and agriculture are considered as distinct areas and there are two separate government ministries for dealing with them: Ministry of Agriculture and Ministry of Food. This would have made sense for an era, when food was typically primary food, and was considered mainly as an issue of supply; build-up, management, and disposal of publicly held food stocks. But conceptually within the framework of SDG, food is a complex issue inseparably linked with agriculture because of concerns for food safety and quality management along the supply chain, management of food losses and wastes; healthy diets and nutrition. To address these issues more effectively by avoiding wasteful duplication of efforts and building on synergies, consideration can be given to merging agriculture and food under a single ministry named Ministry of food and agriculture. Incidentally, the National Agriculture Policy (2018) starts with emphasis on food safety in its principal goal.

1. Ideally, where it is possible to provide direct oversight and streamline administrative control, it is better to avoid lateral structures such as various coordination committees to do things across various government departments and ministries. In a broad sense, structural reform of the agriculture sector is long overdue to steer the development of the sector in a new direction. The institutions and structures that were built in the 1970s and 1980s to support agricultural development in Bangladesh seem to have exhausted their potential. Trying to adapt them to cope with the new challenges can produce at best incremental results. But if revolutionary change, much in the same vein as green revolution, is the goal, then the need for structural reform and institutional rebuilding in the agriculture sector cannot be ignored.

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Agricultural Price Policy for Bangladesh

Dr. Jahangir Alam Khan[1]

Agricultural price polices are in place in different countries to influence price of agricultural products. It is an important instrument for providing incentives to farmers and protecting interest of consumers. In a developing country like Bangladesh where majority of the population is engaged in agricultural sector and where most of the people devote 2/3 of their expenditure on food alone, prices affect both income and consumption of the cultivators.

The objectives of Agricultural Price Policy

Prices have three functions viz.,

(1) to allocate resources,

(2) to distribute income, and

(3) to induce capital formation.

The objectives set for the farm price policies in different countries naturally have their origin in these three functions. Other functions include

(4) to moderate price fluctuations

(5) to raise or stabilize farm incomes, and

(6) to increase production and export and reduce import.

Policy Instruments

A--Minimum Support Price: **MSP** is an Agriculture product price set by the government to purchase directly from the farmer. This rate is to safeguard farmer to minimum profit for the harvest, if the open market has lesser price than the cost incurred. MSPs are annually fixed and are meant to be the floor levels below which the market prices would not be allowed to fall.

In Bangladesh, we do not announce support price. In India, Government sets the price for 23 commodities from time to time. The Indian Union Budget for 2018-19 has promised to support MSP for at least 50 per cent returns on production costs.

B-- Procurement Price: Procurement price is the price at which the government procures grain from producers. Normally, the procurement price is lower than the minimum price. The procurement prices should be decided close to the time of harvest. In Bangladesh, Government announces procurement prices for rice and wheat at the time of harvest which is about 6 to 10 percent above the cost of production.

Criteria for Determination of Procurement Prices

- Price fixed in the previous year
- Cost of Production
- Need for securing a balanced growth in the output of related crops

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- Trends in open market prices
- Import Parity Price
- Export Parity Price
- Buffer Stocks
- Likely effect on cost of living
- The general price level and the need to curtailing inflation

In Bangladesh, only the cost of production is considered for determination of procurement Price.

C - Incentive Price : It is a price that is well above the cost of production and at this price the farmer is expected not to spare any effort at increasing his production within the constraints of his own and national resources. Thus, an incentive price is one that induces the farmer to make capital investment for the improvement of farm organization, and expand the use of inputs so as to move up to a higher point on his production possibility frontier and optimize his farm income.

D—Issue Price : A price fixed by the Government for releasing grain stocks from the central pools and are usually concessional and subsidized. In Bangladesh, Government announces issue price for open market sales of food grains which is much below the market price.

Shortcomings of Agricultural Price Policy

1. Inadequate Coverage

Inadequate coverage of procurement facility has rendered the price ineffective. The facility of official procurement reaches hardly to real farmers—of the total food gains production, procurement covers only 3 to 4 per cent.

2. Remunerative Price

The remunerative price and/or subsidized inputs have failed to keep pace with the rate of increase in costs. It has had two consequences. The farmer is discouraged from producing the maximum level of output; he tries to balance his output against the level of costs, and settles for a lower level of output.

3. Ineffective Public Distribution System

The public distribution has not been very effective. A large section of the poor people is outside the purview of the system. Even those who are covered under the system do not necessarily get the benefit of issue prices. The system has largely failed to serve the objective.

4. Difference in Prices

There is an important issue of wide difference between prices received by the producers and prices paid by the consumers. The spread is very high. In this context, issues relating to the network of regulations, incidence of middleman, increase in transportation costs, over fragmentation of the distribution network etc. require careful study.

5. Unaccompanied by Effective Policy

The efficacy of the price policy depends on a number of other factors inherent in the system of agricultural operations like land holding patterns, income distribution, general disparities and cropping pattern. But, it is pity to say that the price policy has not been accompanied by any effective policy for a total development of agriculture.

Suggestions to reorientation of the agricultural price policy

(i) Setting An Agricultural Price Commission

An agricultural price Commission has to set up to announce the minimum support prices and procurement prices for the agricultural products.

Agricultural Price Commission of India

The Agricultural Prices Commission was set up in India in January, 1965 to advise the Government on price policy of major agricultural commodities. Since March 1985, the Commission has been renamed as Commission for Agricultural Costs and Prices (CAPC), with a mandate to recommend minimum support prices (MSPs) and raise productivity and grain production to serve the emerging demands of the country.

The Commission for Agricultural Costs & Prices (CACP) is an attached office of the Ministry of Agriculture and Farmers Welfare, Government of India. Currently, the Commission comprises a Chairman, Member Secretary, one Member (Official) and two Members (Non-Official). The non-official members are representatives of the farming community.

As of now, CACP recommends MSPs of 23 commodities, which comprise 7 cereals (paddy, wheat, maize, sorghum, pearl millet, barley and ragi), 5 pulses (gram, tur, moong, urad, lentil), 7 oilseeds (groundnut, rapeseed-mustard, soyabean, seasmum, sunflower, safflower, nigerseed), and 4 commercial crops (copra, sugarcane, cotton and raw jute).

We can follow India to establish an Agricultural Price Commission in Bangladesh

(ii) Minimum Support Price

The government has to announce minimum support prices of agricultural products like rice, wheat, maize, jute, sugarcane, oilseeds, pulses etc. regularly to safeguard the interest of farmers. The price has to set at least 20 percent above the cost of production.

(iii) Extension of coverage

The extent of coverage of procurement should be increased significantly from the current 3 to 4 percent. At least 10 to 15 percent of the produce has to be procured directly from the farmers to save them from very low market prices at harvest. The magnitude of Government procurement will however depend on the magnitude of marketable surpluses.

(iv) Protecting the Consumers

To safeguard the interest of the consumers, the agricultural price policy has to make provision for buffer stock of food grains for its distribution among the consumers through public distribution system. The quantity of food grains in buffer stock should be more than 4 million if we want to make a positive effect on the market price.

The primary responsibility of the government in relation to price level is:

(a) to keep in check the inflationary forces bringing about increases in the overall price level, and

(b) elimination of collusive and manipulative practices leading to artificial scarcity and high prices for particular commodities.

(vi) Fixation of Maximum Price

In order to have a control over the prices of essential commodities the government has to determine the maximum price of agricultural products so as to protect the general people from exorbitant rise in prices.

(vii) Ensure an Efficient Market Structure

The price that the farmer gets for his agricultural produce depends upon the organizational and operational efficiency of the market structure. It is therefore, not enough to have a Price support/procurement policy for agricultural commodities. In fact, it is even more important to develop a market structure which enables the farmer to realize at least the minimum support price.

'Marketing efficiency' defines as the movement of goods from producers to consumers at the lowest cost consistent with the provision of services consumers desire. It is well known that the establishment and effective functioning of regulated markets not only keep in regulating and standardizing the marketing margins but also assist the farmer in realizing a better price for his produce.

(viii) Integration

The agricultural price policy has to be made an intraoral part of the general agricultural development policy of Bangladesh. The policy should cover overall agricultural sector including crops, livestock and fisheries.

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Response of Wheat and Lentil to Herbicides Applied in Proceeding Non-Puddled Transplanted Rainy Season Rice

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Abstract

A two-year field study was conducted in Mymensingh, Bangladesh to evaluate the carryover effect of herbicides applied in rainy season rice on growth and yield of two probable succeeding crops, *viz.* wheat and lentil by following micro-plot bio-assay technique. Five herbicides named pyrazosulfuron-ethyl, butachlor, orthosulfamuron, butachlor + propanil and 2,4-D amine were applied in strip-tilled non-puddled transplanted rice according to eight treatment combinations maintaining their recommended rate and time of application and were compared with one untreated control. The study demonstrated that germination of wheat and lentil was not significantly varied with the residue of herbicides applied in the preceding rainy season rice. Shoot length of wheat and lentil seedlings of herbicide treated plots were also non-significantly differed with untreated control plots. SPAD value of wheat leaves in herbicide treated plots were higher than control plots by 1.8-14.0% whereas SPAD values of lentil leaves were negligibly lower in the herbicide treated plots. Grain yields of wheat and lentil in herbicide treated plots were higher over control plots by 2.8-6.6% and 0.2-10.9%, respectively. Therefore, two-year bioassay study claimed that tested herbicides applied in rainy season rice under strip-tilled non-puddled field condition did not show any adverse residual effect on growth and yield of the succeeding wheat and lentil.

Keywords: Crop sensitivity, herbicide persistency, minimum-tilled rice, phytotoxicity

Introduction

Herbicide application is now a common practice of weed control in Bangladesh (BBS, 2017). There is evidence that farmers of Bangladesh usually consume more herbicide in pre-rainy season rice than the rainy season rice and even more than the dry season crops (BBS, 2017). The area of rainy season rice cultivation is greater in Bangladesh than the area of cultivation of any other seasonal crop. Because of labour crisis and high wage of labour, farmers mostly depends on herbicides to control weeds in rainy season rice. Generally it is expected to have efficient controlling effect of herbicides on weeds but it is not desirable to have effect of herbicide residue on the succeeding crops grown after rice in a crop rotation. But several researches reported that some herbicides belong to some specific chemical families have high persistency in soil (Tworkoski *et al.*, 2000) and accumulation of those herbicide residues in excess amount can hamper vigor or growth of the non-target species or the subsequent

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growing season crops (Wyk and Reinhardt, 2001; Houge and Neilsen, 1988). Even some researches reveal severe damage in the rotational crops due to the presence of few sulfonylurea herbicides at low concentration (Janki *et al.*, 2015; Hernandez-Sevillano *et al.*, 2001).

Persistency of herbicide in soil is largely depends on several soil factors like soil composition, soil chemistry and microbial activity in soil, but the amount of tillage has a vital role that directly affect the persistence of herbicide in soil (Curran, 2001). Zero or minimum tillage helps to leave a greater concentration of herbicide near the surface layer of soil and therefore presence of herbicide residue in this confined zone of soil may affect the shallowly planted succeeding crops. In most part of northern Bangladesh, farmers usually grow wheat or lentil after harvest of rainy season rice by following minimum tillage system. Therefore, it is necessary to examine the residual effect of herbicides applied in rainy season rice on the succeeding minimum tilled wheat or lentil.

Bioassay technique is a cheap and convenient way to examine the presence of herbicide residue in soil (Hager and Nordby, 2007) and through micro-plot bioassay technique the presence of a very small amount of herbicide residue can be detected under field condition (Sandin-España *et al.*, 2011). But this technique is unable to quantify the amount of herbicide residue in soil. On the other hand, chemical analysis is costly and sometimes fails to trace small amount of herbicide residue in soil. Therefore, micro-plot bioassay technique is more representative and accurate to express the residual effect of herbicide under field condition.

Cultivation of wheat or lentil after harvest of rainy season rice is common in many parts of the country especially in the northern and north-western parts. Therefore, residue of herbicide applied in rainy season rice is a great matter of concern for the subsequent wheat or lentil crop. Considering this issue, a bioassay study was done for two years to evaluate the residual effect of the herbicides applied in strip-tilled non-puddled rainy season rice on the succeeding crops.

Materials and Methods

Experimental site

The study was conducted at Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh ($24^0 75'$ N latitude and $90^0 50'$ E longitude in the south-west part of old Brahmaputra) of Bangladesh. The experimental site was medium high land having sandy clay loam soil texture with soil pH 6.8 and soil organic matter 1.74%. The study was started from July 2013 and ended in March 2015. During that period, the studied area received total rainfall of 1051.6 mm in 2013, 1916.6 mm in 2014 and 35.5 mm in 2015. At that area, monthly averaged maximum air temperature rose at the peak in the month of June during 2013, in April of 2014 and in October of 2015 and it ranged between 32.5 to 33.5°C. After then temperature decreased and the lowest temperature was prevailed in January during each year of the study. Weather information of the experimental site during 2013, 2014 and 2015 has given in Fig. 1.

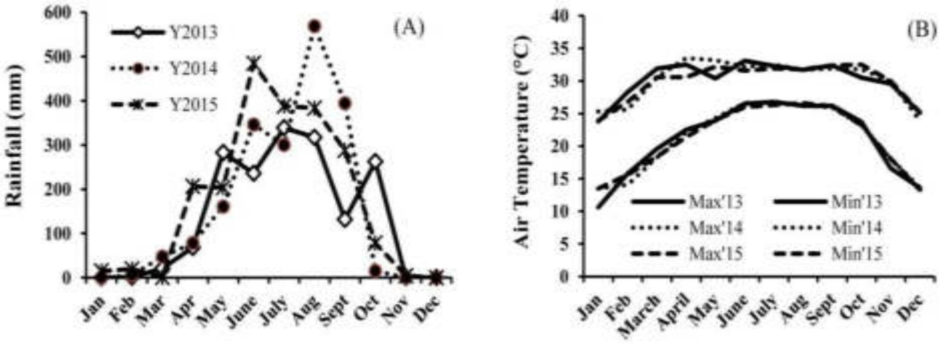

Fig. 1. Monthly (A) total rainfall and (B) averaged maximum and minimum temperature of the experimental area during January 2013 to December 2015 (Source: Weather Yard, Department of Irrigation and Water Management, BAU, Mymensingh)

Bioassay study

A micro-plot bioassay study was done to evaluated the residual effect of five herbicides (two pre-emergence: pyrazosulfuron-ethyl and butachlor, one early post-emergence: orthosulfamuron and two late post-emergence: butachlor + propanil and 2,4-D amine) applied in the preceding rice on the probable next crop of a rotation like wheat and lentil. This study was initiated by transplanting rice seedlings on 22 July 2013 and 20 July 2014 in strip tilled non-puddled field and herbicides were applied in rainy season rice as treatments of nine combinations *viz.*, T_1 = Untreated control, T_2 = Pyrazosulfuron-ethyl, T_3 = Butachlor, T_4 = Pyrazosulfuron-ethyl + orthosulfamuron, T_5 = Butachlor + orthosulfamuron, T_6 = Pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil, T_7 = Butachlor fb orthosulfamuron fb butachlor + propanil, T_8 = Pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine and T_9 = Butachlor fb orthosulfamuron fb 2,4-D amine. During both the year, experiment was laid out in a randomized complete block design with three replications having unit plot size of 5m × 6m. Application time of herbicides has mentioned in Table 1 along with their mode of action, amount of active ingredient and rate of application.

Rice was harvested on 02 November 2013 and 25 October 2014 and after harvest, micro-plot bioassay was established in each of the unit plots under the main experiment of rice. Two micro-plots of 2 m × 2.5 m were marked out within each of the unit plot and these micro-plots were made by removing of all standing stubbles and weeds and were prepared by required number of spading and hoeing. The two test crops were assigned randomly into two micro-plots of a unit plot. Thus, the residual effect analysis trial for each test crop received 27 plots and followed the same design (RCBD) of the main experiment.

Crop husbandry

The land of each micro-plot was fertilized by potassium and sulphur @ 25 and 17 kg/ha, respectively in the form of muriate of potash and Gypsum before sowing of wheat and lentil. Nitrogen and phosphorus fertilizer were applied @ 32 and 46 kg/ha in the form of Di-ammonium Phosphate (DAP) at 10 days after sowing. Within each of the micro-plots, five shallow furrows were made with the help of a wooden stick and 100 seeds of each crop were placed in those lines on 16 November 2013 and 12 November 2014. The test varieties of wheat and lentil were BARI Gom-26 and BARI Masur-6, respectively. After sowing seeds of the tested crops, a light irrigation was provided to ensure proper germination. No herbicide was applied during the period of bioassay study for managing weeds and even no manual weeding was done to obtain the residual effect of herbicides applied in the previous crop on growth and yield of the succeeding wheat and lentil.

Table 1. Mode of action, active ingredient, time and rate of application of herbicides used in strip-tilled non-puddled transplanted rice

Herbicides	Mode of action	Active ingredient	Time of application	Application rate
Pyrazosulfuron-ethyl	Inhibitor of acetolactate synthase (ALS)	100g kg^{-1}	25 July 2013 & 23 July 2014 (3 DAT)	150 g ha^{-1}
Butachlor	Inhibitor of microtubule assembly	50 g kg^{-1}	25 July 2013 & 23 July 2014 (3 DAT)	25 kg ha^{-1}
Orthosulfamuron	Inhibitor of ALS	500 g kg^{-1}	06 August 2013 & 04 August 2014 (15 DAT)	150 g ha^{-1}
Butachlor + propanil (proprietary mixture)	Inhibitor of very long-chain fatty acid synthesis and photosynthesis at photosystem II site A	700 mL L^{-1}	16 August 2013 & 14 August 2014 (25 DAT)	1.0 L ha^{-1}
2,4-D amine	Synthetic auxin	720g L^{-1}	16 August 2013 & 14 August 2014 (25 DAT)	2.25 L ha^{-1}

DAT= days after transplanting

Data collection

Before sowing the seeds of wheat and lentil in field, germination percentage was confirmed by testing seeds of each crop in the laboratory by following top of the paper method in the petridish.

Daily counting of the germinating seedlings was done up to 8th day of seed germination test. The number of normal seedling was counted at 8 days and the germination percentage of seed was measured with the following formula:

$$\text{Germination (\%)} = \frac{\text{Number of normal seedlings}}{\text{Number of seeds sown}} \times 100 \qquad (1)$$

SPAD values of wheat and lentil leaves were recorded from the average of the randomly selected 10 fresh non-destructive sample leaves and shoot lengths of wheat and lentil were also measured but from the average of the randomly selected 10 destructive plant samples at 25 days after sowing from each micro-plot. Leaf greenness (SPAD value) was measured by using SPAD-502 plus meter and shoot length was measured in centimeter. Wheat and lentil were harvested at maturity on 03 and 08 March 2014 and 28 February and 04 March 2015, respectively from the central 1.0 m^2 (1 m × 1 m) area of each micro-plot and the grain yield was converted into ton per hectare (t ha^{-1}).

Statistical analysis

Analysis of variance was carried out by using the statistical computing package program of R software (version 3.3.3) and means were compared by following Duncan's Multiple Range Test (DMRT) at 5% level of probability.

Results and Discussion

Seedling emergence

Percentages of wheat and lentil seedling emergence were non-significantly affected by herbicides applied in the preceding rainy season rice during 2013 and 2014 (Table 2 and Table 3). In case of wheat, the highest percentage of emergence was recorded from butachlor treated plots in 2013-14 and from pyrazosulfuron-ethyl followed by orthosulfamuron followed by butachlor+ propanil treated plots in 2014-15. In case of lentil, the highest percentage of emergence was counted from pyrazosulfuron-ethyl treated plots in 2013-14 and from pyrazosulfuron-ethyl followed by orthosulfamuron treated plots in 2014-15.

Table 2. Effect of applied herbicides in non-puddled transplanted rainy season rice on percentage of seedling emergence of the succeeding wheat during 2013-14 and 2014-15

Treatment	2013-14		2014-15	
	% emergence	% change	% emergence	% change
T_1	87.0±1.53	-	85.3±0.88	-
T_2	89.7±2.33	+3.1	88.7±1.67	+4.0
T_3	93.0±2.52	+6.9	88.3±1.20	+3.5
T_4	89.0±2.31	+2.3	89.0±2.08	+4.3
T_5	91.7±2.40	+5.4	87.7±1.86	+2.8
T_6	90.7±1.76	+4.3	90.7±1.86	+6.3
T_7	88.7±2.96	+2.0	84.0±2.65	-1.5
T_8	91.0±1.53	+4.6	84.3±2.96	-1.2
T_9	92.7±1.33	+6.6	87.3±0.88	+2.3
Level of sig.	ns		ns	
CV (%)	4.35		4.50	

Here, data expressed as mean ± SE (standard error). CV means co-efficient of variance.

T_1 = Control, T_2 = Pyrazosulfuron-ethyl, T_3 = Butachlor, T_4 = Pyrazosulfuron-ethyl + orthosulfamuron, T_5 = Butachlor + orthosulfamuron, T_6 = Pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil, T_7 = Butachlor fb orthosulfamuron fb butachlor + propanil, T_8 = Pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine and T_9 = Butachlor fb orthosulfamuron fb 2,4-D amine

The two-year results demonstrated that seedling emergence of wheat and lentil was not affected by the residue of herbicides applied in the preceding rainy season rice. This result indicates that applied herbicides in non-puddled transplanted rice had no or very small residue in soil that not affected the seedling emergence of the succeeding crops. This might be related to have low organic matter content of sandy clay loam type of experimental soil and also might be due to the less half-life of the tested herbicides. According to Curran (2001) clay soil with high organic matter content have high potentiality for herbicide persistence or carryover. Particles of herbicide are adsorbed to the surface of organic matter and clay results less microbial degradation, therefore carryover risk is also high. Moreover, half-lives of the tested herbicides might be much less than the crop duration of rainy season rice, thus the chance of persistence of herbicide action up to the next crop growing season may not be possible; however, half-lives of herbicides varies with soil types. In addition, half-life of herbicide determined in laboratory research sometimes may not reflect at all field conditions (Colquhoun, 2006). But several previous literatures are in agreement with the finding of the present study and in one of the earlier studies, Vaghasia and Nadiyadhara (2013) reported that germinations of *rabi* season wheat and gram were not affected by post-emergence herbicides like imazethapyr, imazamox, quizolofop-p-ethyl and fenoxaprop-p-ethyl applied to the preceding kharif season groundnut.

Table 3 Effect of herbicides applied in non-puddled transplanted rainy season rice on germination percentage of the succeeding lentil during 2013-14 and 2014-15

Treatment	**2013-14**		**2014-15**	
	% germination	**% change over control**	**% germination**	**% change over control**
T_1	71.3±1.86	-	86.0±2.08	-
T_2	76.0±1.15	+6.6	82.0±2.52	+4.7
T_3	70.0±2.52	-1.8	89.0±2.31	+3.5
T_4	76.7±0.67	+7.6	92.0±3.51	+7.0
T_5	74.3±1.76	+4.2	84.3±2.96	-2.0
T_6	75.3±0.67	+5.6	81.0±2.52	-5.8
T_7	71.7±1.45	+0.6	80.0±2.52	-7.0
T_8	74.0±1.53	+3.8	81.3±2.40	-5.5
T_9	71.0±1.00	-0.4	85.7±2.40	-0.3
Level of sig.	ns		ns	
CV (%)	3.58		3.11	

Here, data expressed as mean ± SE (standard error). ‘ns’ stands for non- significant and ‘CV’ stands for co-efficient of variance

T_1 = Control, T_2 = Pyrazosulfuron-ethyl, T_3 = Butachlor, T_4 = Pyrazosulfuron-ethyl + orthosulfamuron, T_5 = Butachlor + orthosulfamuron, T_6 = Pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil, T_7 = Butachlor fb orthosulfamuron fb butachlor + propanil, T_8 = Pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine and T_9 = Butachlor fb orthosulfamuron fb 2,4-D amine

Shoot length

Herbicides applied in preceding rice did not show any significant effect on shoot length of wheat and lentil at 25 days after sowing during 2013-14 (Fig. 2A and 2C) and 2014-15 (Fig. 2B and 2D). The tallest wheat seedling (31.4 cm) was found in 2013-14 from the plots that received pyrazosulfuron-ethyl followed by orthosulfamuron followed by 2,4-D amine and from the plots with pyrazosulfuron-ethyl followed by orthosulfmuron in 2014-15. Similarly, the tallest lentil seedling was recorded from pyrazosulfuron-ethyl treated plots and untreated control plots in 2013-14 and from butachlor followed by orthosulfamuron followed by butachlor + propanil treated plots in 2014-15.

Shoot lengths of wheat and lentil seedlings were also not affected by herbicide residue of rainy season rice and even some plots of wheat and lentil that received pyrazosulfuron-ethyl, orthosulfamuron or butachlor in the preceding rice had taller seedlings than the control plots. The reason behind of getting such results cannot be clearly defined but these results clearly indicated that application of those herbicides in the preceding rainy season rice crop might be safe for growth of the subsequently grown wheat or lentil. Similar results also reported by Zahan et al (2016) that herbicides applied in rice had no residual effect on shoot length and leaf chlorophyll content of the succeeding crops. Residual effects of pyrazosulfuron-ethyl and butachlor were also tested by PI et al (2015) through using an indicating crop like cucumber. Additionally they analyzed soil chemically to detect the presence of residue of those herbicides. After two consecutive year of study they revealed a complete absence of pyrazosulfuron-ethyl in soil and they claimed pyrazosulfuron-ethyl and butachlor had no adverse residual effect on germination and shoot and root length of cucumber.

SPAD value of leaf

SPAD values of wheat leaves at 25 days after sowing were not significantly affected by the residue of herbicides applied in the preceding rainy season rice during 2013-14 while the effect of herbicide residue on leaf SPAD value was found significant in 2014-15 (Table 4). However, result of in 2014-15 showed that leaves of all herbicide treated plots had identical SPAD value as control plots and leaves of pyrazosulfuron-ethyl treated plots also showed significant variation having 17.9% higher SPAD value than the control plots.

In case of lentil leaves, SPAD values were significantly varied due to the residue of herbicides applied in the preceding rainy season rice during 2013-14 while the values were not significantly differed in 2014-15 (Table 4). In 2013-14, lentil leaves of butachlor followed by orthosulfamuron followed by 2,4-D amine treated plots had the highest SPAD value and the lowest value was in butachlor treated plots, but leaves of both these treated plots had identical SPAD value with the control plots.

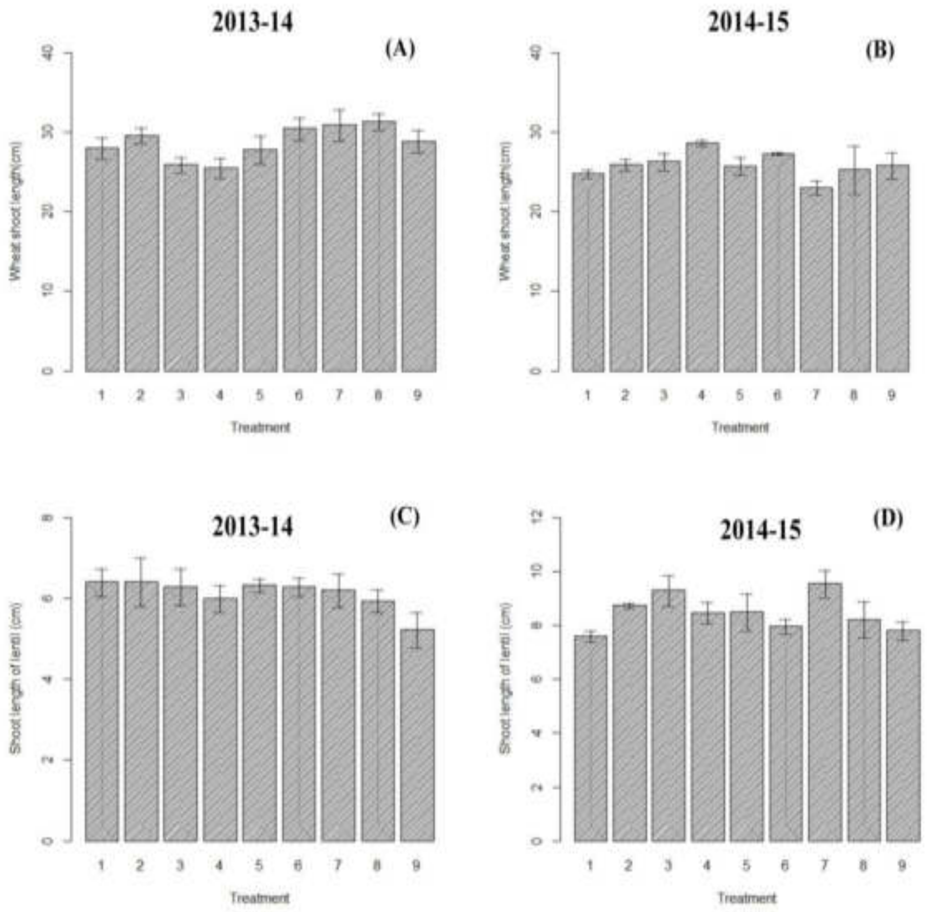

Fig. 2. Effect of herbicides applied in non-puddled transplanted rainy season rice on shoot length of the succeeding wheat at 25 days after sowing during (A) 2013-14 and (B) 2014-15 and of lentil during (C) 2013-14 and (D) in 2014-15 at Mymensingh, Bangladesh

Crop dry matter

Results demonstrated that dry matters of wheat seedlings were non-significantly varied in 2013-14 with the treatments of herbicides applied in the preceding rainy season rice whereas the differences in wheat dry matters among the treatments were significant in 2014-15 (Table 5). The greater dry matter content of wheat seedlings was obtained from pyrazosulfuron-ethyl followed by orthosulfamuron followed by 2,4-D amine treated plots which was closely identical with pyrazosulfuron-ethyl treated plots while the lowest dry matter content was found from control plots. Additionally, all herbicide treated plots had greater wheat dry matter than the control plots by 5.9-19.8% in 2013-14 and by 18.3-52.4% in 2014-15. On the other hand, dry matter content of lentil was non-significantly affected by the residue of rice herbicides during both years (Table 5).

Table 4. Effect of applied herbicides in non-puddled transplanted rainy season rice on SPAD value of leaves of the succeeding wheat and lentil at 25 days after sowing during 2013-14 and 2014-15

Treatment	Wheat		Lentil	
	2013-14	**2014-15**	**2013-14**	**2014-15**
T_1	42.5±0.87	30.8±1.38 b	21.1±0.19 a-d	20.3±1.25
T_2	46.8±0.95	36.3±0.55 a	19.4±1.88 cd	21.7±0.82
T_3	43.9±1.31	31.7±0.07 ab	18.1±0.68 d	17.8±0.76
T_4	45.4±2.69	32.3±0.58 ab	19.3±1.60 cd	17.5±1.62
T_5	45.8±2.42	34.7±0.88 ab	22.4±1.09 abc	19.0±0.73
T_6	45.2±1.49	35.1±1.17 ab	19.7±1.19 bcd	18.2±1.62
T_7	43.9±2.46	33.1±0.15 ab	22.5±1.74 abc	17.4±0.94
T_8	44.5±1.02	32.2±1.21 ab	23.4±1.42 ab	21.1±1.73
T_9	44.0±1.34	30.8±0.23 b	24.5±1.70 a	22.1±1.94
Level of sig.	ns	**	*	ns
CV (%)	5.61	7.59	9.58	10.41

Here, data expressed as mean ± SE (standard error). Means within a column followed by different letters are significantly different as per DMRT range at p=0.05.

'**' stands for significant at 1% level, '*' stands for significant at 5% level, 'ns' stands for non-significant and 'CV' stands for co-efficient of variance

T_1 = Control, T_2 = Pyrazosulfuron-ethyl, T_3 = Butachlor, T_4 = Pyrazosulfuron-ethyl + orthosulfamuron, T_5 = Butachlor + orthosulfamuron, T_6 = Pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil, T_7 = Butachlor fb orthosulfamuron fb butachlor + propanil, T_8 = Pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine and T_9 = Butachlor fb orthosulfamuron fb 2,4-D amine

Grain yield

Grain yields of wheat and lentil were non-significantly varied with treatments during both the year (Table 6). In case of wheat, the highest grain yield was obtained from pyrazosulfuron-ethyl treated plots in 2013-14 and from butachlor followed by orthosulfamuron treated plots in 2014-15. The highest grain yield of lentil was gained from butachlor treated plots during both years.

These results clearly expressed that herbicides applied in rainy season rice did not show any adverse effect on the succeeding wheat and lentil. Similar finding was reported by Hernández-Sevillano *et al.* (2001), Jettner *et al.* (1999), Moyer (1995), Kotoula-Syka (1993) and Hsiao and Smith (1983) that herbicides applied at their label rate had no residual effect on the succeeding crops; however they conducted research on other herbicides. Conversely, findings of Vargas and Wright (1994) opposed with the present study result that carryover of sulfonylurea herbicide applied in corn caused severe injury to the subsequently grown wheat crop. Some other previous studies also found sugar beet, sorghum, barley, pea or oilseed rape were injured in field when they were grown after wheat treated with sulfonylurea herbicides (Shinn *et al.*, 1999; Szmigielska *et al.*, 1998; Günther *et al.*, 1993). Therefore, several agronomic researches should be carried out on the residual effects of herbicides in various succeeding crops under different soil and environmental conditions.

Table 5. Effect of applied herbicides in non-puddled transplanted rainy season rice on dry matter of the succeeding wheat and lentil seedlings at 25 days after sowing during 2013-14 and 2014-15

Treat ment	Wheat dry matter (g m^{-2})				Lentil dry matter (g m^{-2})			
	2013-14	% change	2014-15	% change	2013-14	% change	2014-15	% change
T_1	10.1±0.8	-	8.2±0.0	-	2.8±0.2	-	4.1±0.1	-
T_2	12.1±1.1	+19.8	12.2±1.0	+48.8	3.3±0.3	+25.0	5.1±0.4	+24.4
T_3	11.3±0.6	+11.9	9.2±0.4	+12.2	2.8±0.2	0	4.8±0.6	+17.1
T_4	11.4±0.7	+12.9	10.9±0.9	+32.9	2.8±0.5	0	5.1±0.4	+24.4
T_5	10.7±1.0	+5.9	9.7±0.1	+18.3	3.2±0.2	+14.3	5.1±0.3	+24.4
T_6	11.1±0.5	+9.9	9.7±0.2	+18.3	3.3±0.3	+25.0	4.8±0.2	+17.1
T_7	11.0±0.8	+8.9	11.6±0.6	+41.5	2.9±0.3	+3.6	4.3±0.3	+4.9
T_8	11.9±0.6	+17.8	12.5±0.8	+52.4	2.7±0.3	-3.6	4.1±0.3	0
T_9	11.7±0.5	+15.8	11.4±0.6	+39.0	2.8±0.3	0	4.7±0.2	+14.6
Level of sig.	ns		**		ns		ns	
CV (%)	12.28		13.03		18.32		11.53	

Here, data expressed as mean ± SE (standard error). '**' stands for significant at 1% level, 'ns' stands for non-significant and 'CV' stands for co-efficient of variance

T_1 = Control, T_2 = Pyrazosulfuron-ethyl, T_3 = Butachlor, T_4 = Pyrazosulfuron-ethyl + orthosulfamuron, T_5 = Butachlor + orthosulfamuron, T_6 = Pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil, T_7 = Butachlor fb orthosulfamuron fb butachlor + propanil, T_8 = Pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine and T_9 = Butachlor fb orthosulfamuron fb 2,4-D amine

Table 6. Effect of herbicides applied in non-puddled transplanted rainy season rice on grain yield (t ha^{-1}) of the succeeding wheat and lentil during 2013-14 and 2014-15

Treatment	Wheat				Lentil			
	2013-14	**% change**	**2014-15**	**% change**	**2013-14**	**% change**	**2014-15**	**% change**
T_1	1.90	-	2.01	-	0.95	-	0.86	-
T_2	2.19	+15.3	1.92	-4.5	0.92	-3.2	0.89	+3.5
T_3	1.90	0	1.85	-7.9	1.07	+12.6	0.94	+9.3
T_4	2.06	+8.4	2.02	+0.5	1.05	+10.5	0.84	-2.3
T_5	1.97	+3.7	2.05	+2.0	0.91	-4.2	0.91	+5.8
T_6	2.10	+10.5	1.91	-5.0	0.97	+2.1	0.87	+1.2
T_7	2.14	+12.6	2.02	+0.5	0.87	-8.4	0.86	0
T_8	2.11	+11.1	1.90	-5.5	1.01	+6.3	0.94	+9.3
T_9	2.08	+9.5	2.01	0	0.99	+4.2	0.87	+1.2
Level of sig.	ns		ns		ns		ns	
CV (%)	11.00		11.47		11.20		12.27	

Here, data expressed as mean ± SE (standard error). 'ns' stands for non-significant and 'CV' stands for co-efficient of variance

T_1 = Control, T_2 = Pyrazosulfuron-ethyl, T_3 = Butachlor, T_4 = Pyrazosulfuron-ethyl + orthosulfamuron, T_5 = Butachlor + orthosulfamuron, T_6 = Pyrazosulfuron-ethyl fb orthosulfamuron fb butachlor + propanil, T_7 = Butachlor fb orthosulfamuron fb butachlor + propanil, T_8 = Pyrazosulfuron-ethyl fb orthosulfamuron fb 2,4-D amine and T_9 = Butachlor fb orthosulfamuron fb 2,4-D amine

Conclusion

The two-year study concluded that the tested five herbicides (pyrazosulfuron-ethyl, butachlor, orthosulfamuron, butachlor + propanil and 2,4-D amine) applied in rainy season rice under strip-tilled non-puddled field had no or very low residual adverse effect on subsequently grown wheat or lentil in sandy loam textured soil. Therefore, application of all the tested herbicides in rainy season rice is safe for growing of subsequent crop like wheat or lentil under similar environmental condition but recommended rate of application should be strictly followed.

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Pollinator Sanctuaries along with Integrated Habitat Development: A new model for successful bee conservation, ecosystem regeneration and biodiversity enrichment

S. K. Basu

Global bee populations are showing an alarming decline due to a number of factors like environmental pollution, indiscriminate use and over applications of various agro-chemicals, industrial agricultural practices detrimental to nature, changes in the land use patterns; and parasitic diseases of bees as well as lack of adequate supply of nectar and pollens for different bee species due to lack of suitable bee foraging plants and natural melliferous flora. The challenges are not just restricted to honey bees and/or native/indigenous bee species; but also to other insect pollinator like moths and butterflies; as well as certain species of pollinator-friendly flies and beetles. Under these circumstances it is important to conserve the endangered bee species and other pollinator insects, molluscs (snails and slugs), birds (certain humming bird species), mammals (bats) helping in the process of natural cross pollination.

The establishment of Pollinator Sanctuaries, Pollinator Gardens or Pollinator Habitats at suitable sites by using appropriate custom-designed Pollinator Mixes. Such Pollinator Mixes could include selected native wildflowers and grasses as well as pollinator friendly annual/biennial/perennial forage legumes and grasses in different proportions suitable for various agro-climatic zones. Plant species selected for the mix must be flowering in sequence, one after another, to extend the pollinator (bee) foraging period; and provide them with adequate supply of nectar and pollen. Pollinator Mixes need to be developed based on appropriate agronomic parameters of the target growing region based on local agro-climatic conditions; and keeping in mind the local pollinator diversity and their foliage preferences.

Pollinator Mixes constituting of native wildflowers only, currently available commercially, are not a viable option due to their poor adaptability to local agronomic conditions, high yield fluctuations (based on locality and annual production variation), as well as high management and production cost. Suitable Pollinator Mixes could be used to create Pollinator Sanctuaries along farm perimeters, hard to access and unused areas of a farm, forest fringes, adjoining highways, boulevards and wetlands, city and municipal parks and gardens, golf courses, unused or agronomically unsuitable areas, remediation sites, and unused available sites in both rural and urban areas. Development of suitable eco-friendly Pollinator Mixes for different agro-climatic regions could therefore have both positive ecological and economic implications in terms of ecological services and environmental cost-benefit ratio.

The long term benefits of establishing Pollinator Sanctuaries could be summarized as follows:[1]

1. Establishment of low cost, low maintenance, highly affordable dynamic natural ecosystems that can cater to the nesting and foraging needs of a wide diversity of insect pollinators including honey bees and native bees.

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2. Long term production benefits for local and/or regional agriculture, forestry and apiculture industries.
3. Pollinator Sanctuaries, once established, can slowly develop into highly biodiverse, complex, natural ecosystems.
4. Well established Pollinator Sanctuaries will also attract several other local invertebrates and vertebrates (like small reptiles, amphibians, birds and mammals) helping to conserve not just insect pollinators (like bees) but local biodiversity in general.
5. Pollinator Sanctuaries, especially along roadways, would create natural pathways between various remaining natural "islands" so that species could move from one natural habitat to another and, thus, find food, nesting habitats and breeding partners to continue genetic diversity within species.
6. Since forage species are included in the proposed Pollinator Mixes they could be used by ranchers as pastures for late fall grazing of animals.
7. Pollinator sanctuaries, integrated with wetland development, can develop into suitable aquatic habitats for aquatic birds, especially if the accompanying water body is well stocked with fishes.
8. Mixtures of long and short grasses in the mix can attract both small passerine and ground nesting birds to Pollinator Sanctuaries over time which would add to the local biodiversity.
9. The forage legumes in the mix would enrich soil quality through biological nitrogen fixation.
10. Species like different Brassica members and salt tolerant grasses would help in phytoremediation of previously agronomically unsuitable areas.

It is important to note that a large number of global food and industrial/commercial crops, forage crops, wildflowers, ornamentals, vegetables and forest species are dependent on biological agents or vectors of cross pollination for their successful reproduction and survival. The yield loss due to lack of suitable pollinators for cross pollination is a serious threat to the future of global agriculture as well as for maintaining the balance of our natural ecosystems. Loss of honey bees are having detrimental socio-economic impacts on the apiculture industry; and thereby impacting the livelihood and social security of millions of individuals around the planet.

Establishing suitable pollinator (bee) gardens or habitats or sanctuaries at suitable sites could prove to be instrumental in both bee and other pollinator insect conservation from a long term, ecological perspective. Using suitable Pollinator Mixes comprising of native grasses, wildflowers as well as annual, biennial, perennial forage crops (forage grasses, legumes, different Brassica family members) can help in establishing Pollinator gardens or habitats or sanctuaries in perimeters of forested areas, under used or unsuitable agronomic lands, unused and available rural locations, city and municipal parks and gardens, lawns, kitchen gardens, unused or hard to farm areas, in sites adjacent to natural or artificial waterbodies like ponds, pools, ditches, swamps, bogs, streams, irrigation canals etc

Freshwater wetland habitats need to be protected to conserve the aquatic ecosystems, the rich biodiversity associated with it and to protect nature for our future generations.

Protecting freshwater wetlands may not necessarily involve huge expertise, funding and high level of technology applications; but simple innovation, creativity, awareness and the desire to develop comprehensive multi-layer conservation strategy in the line of Multiple Tier Conservation Model (MTCM). A well managed and carefully planned freshwater aquatic habitat conservation strategy could be establishing Integrated Ecological Habitat Development for Bees, Birds and Fishes (IEHD-BBF). This proposed model targets multiple trophic levels within a dynamic natural or artificial freshwater ecosystem to conserve multiple species simultaneously.

Natural or artificial aquatic habitats like pools, ponds, ditches, swamps, bogs, lakes, canals etc could be targeted for ecological restoration by planting short or high grasses, salt tolerant aquatic plant species and grasses along with Pollinator mixes comprising of annual and/perennial legumes, wildflowers and related pollinator friendly plant species or melliferous flora around target fresh water habitats. Such mixes will not only restore aquatic habitats; but, also attract small and medium sized land birds and a wide diversity of pollinator insects like honey bees, native bees, moths, butterflies, certain species of pollinator beetles and flies for nectar foraging, nesting and breeding purposes.

If the water bodies are well stocked with indigenous fish species, well protected grassy aquatic habitats will also attract a wide diversity of aquatic birds to nest, forage and breed in such unique environmentally restored ecosystems. Such an integrated Bees, Birds and Fishes Conservation Model (BBFCM) can be extremely useful in securing conservation protection to multiple species at the same time and location.

Grasses in the mixes can help in soil erosion and restoration, phytoremediation; while legumes will enrich the soil with natural nitrogen resources without application of any synthetic fertilizers. Care must be taken to avoid sparing any pesticides in such habitats to avoid chemical pollution. Over the time, such aquatic habitats will also attract local wildflowers and aquatic plants to grow and thrive in these ecosystems attractive to various species of both terrestrial and aquatic insects including active pollinators (like bees, moths, butterflies and pollinator beetles and flies); along with small to medium sized terrestrial and aquatic birds to nest and forage in such restored aquatic habitats. Well stocked water bodies with indigenous fish species will promote indigenous fish conservation and at the same time provide a stable food source for a number of aquatic birds. Grasses are amazing cover crops and if suitable varieties are properly selected, they could do an amazing job of efficient ground cover. An experimental batch of salt tolerant grass mix can grow rapidly and cover the barren and non-agronomic salinity impacted land surface efficiently. Grasses could be used as important constituent of Pollinator Mixes for successful stand establishment, soil cover, preventing soil erosion, weed competition, help in phytoremediation and as a forage crop can be used in grazing in tamed and untamed pastures.

Small and medium ranged mammals, reptiles and amphibians will also be able to establish in such ecosystem utilizing the growing complex food chains and food webs over time. Overall, the innovative and multi-trophic level Integrated Ecological Habitat Development for Bees, Birds and Fishes (IEHD-BBF) model has huge potential for restoration and reestablishment of natural and artificial aquatic ecosystems with minimal care, attention, management and funding. Such ecological restoration using the IEHD-BBF model can serve the needs of dwindling bees and insect pollinator populations to thrive back along with local resident and migratory birds, indigenous fishes to successfully multiply in an integrated multi-species catering dynamic ecological system.

Bangladesh with her unique location in south Asia has a wide diversity of agro-climatic regions within her borders and a rich biodiversity. It may be beneficial for establishing Pollinator Mix and Pollinator Sanctuary use and application as an educational program in the country to train and attract farmers to use this new technology platform. The participation of farmers and crop producers together with apiculture workers in utilizing the establishment of Pollinator Sanctuaries in non-agriculturally productive lands, forest fringes, in city and municipality lawns, parks, gardens and boulevards, unused space in both urban and rural areas could help in bee conservation significantly. The Integrated Habitat Development involving local wetlands in habitat creation can be a significant, low maintenance and inexpensive technology boost in recreation and establishment ecological niches and in the enrichment of local biodiversity in various agro-climatic regions across the country.

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Image 1: A showy milkweed (*Asclepias speciosa* Torr.; Family-Asclepiadaceae) plant in bloom. Milkweed plants across North America attracts a wide diversity of local natural insect pollinators like moths, butterflies, honeybees, native bees, some pollinator friendly beetles and flies in large numbers. As an integral component of the natural ecological habitat they play an important role in helping to conserve indigenous insect pollinators like bees that are currently showing an alarming decay in their numbers across North America due to a number of anthropogenic factors like pollution, diseases, stress and lack of suitable foraging plants for collecting nectar and pollen. Photo credit: S. K. Basu

Image 2: A Looper moth (*Autographa* sp., Family-Noctuidae, Order-Lepidoptera) foraging on pollinator friendly plant Scorpion weed/Heliotrope (*Phacelia* sp., Family-Boraginaceae)]. Photo credit: S. K. Basu

Image 3: An orange belted bumblebee or tricoloured bumblebee (*Bombus ternarius* Say, 1837) foraging on a glandular globe thistle flower (*Echinops sphaerocephalus*, Family-Asteraceae), a member of the sunflower family in a municipal garden of the city of Lethbridge, Alberta. Globe thistle is a glandular herbaceous non-native plant found in the Canadian Prairies varying in height between 80-250 centimetres and is know to attract a wide diversity of natural unset pollinators like honeybees, native bees (bumble bees), moths and butterflies, native (indigenous) bees, honeybees, some pollinator friendly species of beetles and flies.Photo credit: S. K. Basu

Image 4: A drone fly [*Eristalis tenax* (Linnaeus, 1758] foraging on purple cone flower [*Echinaceae purpurea* L., Family Astercaeae (L.) Moench]. Photo credit: S. K. Basu

Image 5: Integrated Habitat Development include bee or pollinator insect habitat development along or adjacent to water bodies have demonstrated excellent results with respect to enrichment of local biodiversity. Photo credit: S. K. Basu

Image 6: Pollinator Sanctuaries have been showing great promise if integrated with local shelterbelt developments at farm perimeters Photo credit: S. K. Basu

Image 7: The area around water bodies are excellent sites for establishing low cost, low maintenance and long tern sustainable Pollinator Sanctuaries. Such unique artificially created habitats not only attracts pollinator insects like bees; but also attracts wide diversity of other farmer-friendly insects, small passerine and ground nesting birds, waterfowls, fishes, reptiles, amphibians and small mammals Photo credit: S. K. Basu

Image 8: A pollinator insect visiting flax (*Linum usitattissimum* L.) flower. One of the greatest attribute of the proposed Pollinator Mix has been the use of locally adapted annual and/or perennial crops that has varying flowering periods thereby extending the nectar and pollen foraging period of insect pollinators like bees increasing their chance of survival in their natural ecosystems. Photo credit: S. K. Basu

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Morphological Variability of the Isolates of *Sclerotium Rolfsii* Causing Foot and Root Rot Disease of Betelvine

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Abstract

Morphological characters of nineteen isolates of *Sclerotium rolfsii* Sacc. collected from various localities of major betelvine growing areas of Bangladesh were studied. The mycelial growth, colony colour, colony consistency, formation of sclerotia and number, shape, size, colour and test weight of the sclerotial bodies varied remarkably among the isolates. The colony diameter of the isolates varied from 58-88 mm at 60 hours of incubation with growth rate ranged 0.96-1.47 mm per hour. Colony of the isolates showed embeded, fluffy or wooly growth on the surface of the culture medium with thin to profusely thick consistency. Sclerotia were formed after 9-15 days of incubation depending on different isolates. Number of sclerotia produced by different isolates varied 14-288 per plate. The sclerotial colour ranged from light brown to brown and dark brown. Sclerotial shape was round or irrigular or spherical to irrigular in different isolates. The average size of the sclerotia of different isolates varied 1.0-2.2 mm in diameter. The weight of 100 sclerotia ranged 72-553 mg representing significant variability among the isolates.

Key words: Betelvine, foot and root rot, morphological variations, *Sclerotium rolfsii*

Introduction

Betelvine (*Piper betle* L.) is a kind of dioecious perennial creeper vine belonging to the family Piperaceae. It is cultivated largely for its leaves. It is an important cash crop of Bangladesh. Betelvine leaves have a strong pungent aromatic flovour and are widely used as a masticatory substance. Mature leaves are used for chewing with smeared hydrated lime plus catechu, areca nut, cardamom, clove etc. Betelvine leaf chewing is considered as a good and cheap source of dietary calcium. Usually the people of South-Asia, South-east Asia, Gulf States and Pacific Islands chew betel leaves. All classes of people of Bangladesh chew not only as a habit but also as an item of rituals, etiquette and manners.

Diseases are one of the important factors limiting the productivity of betel leaf. Among them foot and root rot caused by *Sclerotium rolfsii* is a major constraint for cultivation of the betelvine crop (Goswami *et al.,* 2002). In India, stem rot caused by *S. rolfsii* is a major problem in most of the states accounting for 10-11 percent yield loss (Prasad *et al.,* 2012). In severely infected field, loss ranges from 10 to 25 percent and sometimes, it reaches up to 80 percent (Mehan and McDonald, 1990).

Sclerotium rolfsii Sacc. is a well-known ubiquitous soil inhabiting and most destructive soil borne fungus; that was initially described by Rolfs (1892) on tomato. The *Sclerotium*

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rolfsii is widely distributed and causes severe damage to more than 500 crops (Aycock, 1966). *S. rolfsii* is predominantly distributed throughout tropical and subtropical regions where, the temperature reaches higher levels during the rainy season. Having a saprophytic activity in soil, *S. rolfsii* can survive in soil for many years by producing sclerotial bodies (Webber, 1931). These sclerotia constitute the primary inoculum for host infection and resistant propagules for dispersal and survival of the fungus under adverse environmental conditions. The typical symptom of the disease is rapid wilting and sickly appearance of plants with brownish lesion at the stem base near the soil level which later girdles the stem. White mycelial growth forms over the infected tissue and often radiates over the soil surface.

Understanding the variability of a pathogen in a geographical region is a pre-requisite for appropriate disease management programme and also for documenting the changes occurring in the pathogen population (Akram *et al*., 2007). However, a limited work has been done on the variability of *S. rolfsii* in betelvine. The present studies were conducted during 2015 to determine the morphological variabilities of *S. rolfsii* isolates causing foot and root rot disease of betelvine in Bangladesh.

Materials and Methods

The fungus associated with the foot and root rot disease of betelvine were isolated from the diseased samples collected from major betelvine growing areas of five selected upazillas of Bangladesh following tissue planting method (Tuite, 1969; Mian,1995). The upazillas were Gouranadi, Kaligonj, Mirpur, Mohanpur and Sitakunda under the districts of Barisal, Jhenaidah, Kushtia, Rajshahi and Chattagram, respectively. The diseased basal stems were thoroughly washed with tap water to remove soil and sand particles. After washing infected plant parts were cut into small pieces (5 cm) from advancing end of the lesions. The cut pieces were surface sterilized with 1.0% Clorox (NaOCl) for 5 minutes, and rinsed with sterilized water for 3 times. Surface sterilized plant pieces were plated on PDA medium in 90 mm petri-dishes and incubated at room temperature (25±2° C) for 3-5 days and examined daily for any fungal growth. Growing cottony mycelium was transferred to PDA plates to purify and multiply.

Pure cultures of the isolates were prepared following hyphal tip method (Islam *et al.,* 2001; Tuite, 1969; Mian, 1995) and subsequently transferred to fresh PDA plates and were characterized for morphological features at room temperature (25±2°C). The characteristics were compared with appropriate key book (Barnett and Hunter, 1999) and identified as isolates of *S. rolfsii*. The isolates were designated based on the location and source (Host) as suggested by Aminuzzman *et al.* (2010). Petridishes containing pure culture of *S. rolfsii* isolates were labelled properly and stored at 4°C for use when necessary.

Pure cultures of the isolates were grown on fresh PDA by placing 5 mm culture blocks at the centre of petridishes and each of the isolates replicated four times and data on mycelial growth with colony and sclerotial characters were recorded. Radial growth of colony was recorded at 12 hours intervals upto 96 hours of incubation. Consistency and colour of colony were recorded as the important identifying characteristics for the isolates of *S. rolfsii*. Days to sclerotia formation, number of sclerotia per plate, size and shape of sclerotia and arrangement of sclerotia in petri-plate were also recorded. Sclerotial size of an isolate was recorded based on the assessment of diameter randomly counted sclerotia in each petridish. Data on radial growth, and sclerotial size, number and weight were analysed statistically and means were compared by LSD. The studies were conducted in the laboratory of the Department of Plant Pathology at Sher-e-Bangla Agricultural University, Dhaka.

Results and Discussion

The fungus isolated from diseased betelvine samples was identified as *Sclerotium rolfsii* based on typical symptoms on infected plant parts and key mycological characteristics (Plate 1). Microscopic examination of the fungal culture showed hyaline, thin walled, septate and profusely branched mycelium with clamp connections.

Mycelial growth of the isolates of *Sclerotium rolfsii*

The isolates of *S. rolfsii* grown on PDA plates revealed different mycelial growth rates in different isolates before full coverage of the petridish. The colony diameter of the isolates varied 58-88 mm at 60 hours of incubation with growth rates ranged 0.96-1.47 mm per hour. The maximum mycelial growth (1.47 mm/hr) was recorded in isolate-16 followed by isolate-15 (1.41 mm/hr). The minimum mycelial growth (0.96 mm/hr) was observed in isolate-2 (Table 1).

Colony characters of the isolates of *Sclerotium rolfsii*

Among the isolates, colony of isolates-1, 2, 7, 11, 13, 14, 18 and 19 showed embedded growth on the surface of the culture medium with thin to profusely thick consistency. Fluffy colony consistency was found in isolates-3, 4, 6, 8, 12, and 17. In other isolates the colony consistency was wooly. The colony colour was off white in isolates-11, 12, 17 and 18, white in isolates-1, 13, 14, 15, 16 and 19, and brightly white in rest of the isolates (Table 2 and Plates 2). Based on growth morphology, the isolates of *S. rolfsii* were grouped into 3 categories viz, a. Embeded, b. Fluffy and c. Wooly with thin to profusely thick colony consistency representing all the isolates collected from the major belelvine growing areas of Bangladesh.

Sclerotium characters of the isolates of *Sclerotium rolfsii*

When the colony attained maturity (within 9-15 days of culture), small mycelial knots were formed, which turned into mustard seed like sclerotia. The isolate-9 produced sclerotia within 9 days; isolate-2, 4, 5, 12, 17, 18 and 19 within 10 days; isolate-10 within 12 days; isolate-11 within 13 days; isolate-1, 3, 6, 13, 15 and 16 within 14 days and isolate-7, 8 and 14 within 15 days of culture age. The colour of fully matured sclerotia varied in different isolates as light brown, brown and dark brown. Colour of sclerotia was light btown in isolates-5, 6 and 7, brown in islates-2, 3, 4, 3, 9, 11, 14 and 19, while rest of the isolates produced dark brown sclerotia in culture (Table 2 and Plate 3).

The arrangement of sclerotia was scattered in most of the isolates, while the sclerotia in isolate-7 and 15 were clustered at the periphery of the petridishes and those in isolates-3, 9 and 12 were found in both scattered and cluster forms.

Number of sclerotia produced by different isolates on culture plates varied 14-288 per plate. The highest number of sclerotia was produced by isolate-16 followed by isolate-1 (270 no./plate). The lowest number of sclerotia was produced by isolate-10. Sclerotial shape was round or irregular or spherical to irregular in different isolates. Sclerotia of isolates-4, 5 and 6 were spherical to irregular and isolate-18 produced round to irregular sclerotia. Isolate-7 and 10 showed sclerotia of irregular shape, while round shaped sclerotia were found in rest of the isolates. The average size of the sclerotia produced by different isolates varied 1.0-2.2 mm in diameter. The biggest sclerotium was produced by isolate-10 followed by isolate-7 (2.0 mm). The smallest sclerotium was observed in isolate-3 and 9. The weight of 100 sclerotia ranged 72-553 mg. The highest 100 sclerotial weight was found in isolate-7 and the lowest in isolate-15 (Table 3 and Plate 3). Altogether 19 isolates of *S.rolfsii* were identified considering characteristics of colony and sclerotia (Tables 2 and 3).

The variabilities identified among the isolates of *S. rolfsii* were based on the growth behabiour and characteristics of colony and sclerotia observed in different isolates.

Findings of the present studies revealed that most of the morphological characteristics of the cultures of *S. rolfsii* isolated from foot and root rot infected betelvine plants showed clear variations. Based on those variations in morphological characteristics, the 19 isolates demonstrate that these were independent 19 isolates.

Findings on characterisistics of isolates of *S. rolfsii* realised from the present investigation are in agreement with the findings of the previous investigations (Manu *et al*., 2018). Manu *et al*. (2018) found morphological and cultural variability among different pathogenic isolates of *S. rolfsii*. He reported the variations in colony diameter, sclerotial number, sclerotial colour and sclerotial weight among the isolates of *S. rolfsii,* where the sclerotial number ranged from 261.7 to 1048.7 and the sclerotial size from 1.10 to 2.10 mm with light to dark brown colour.

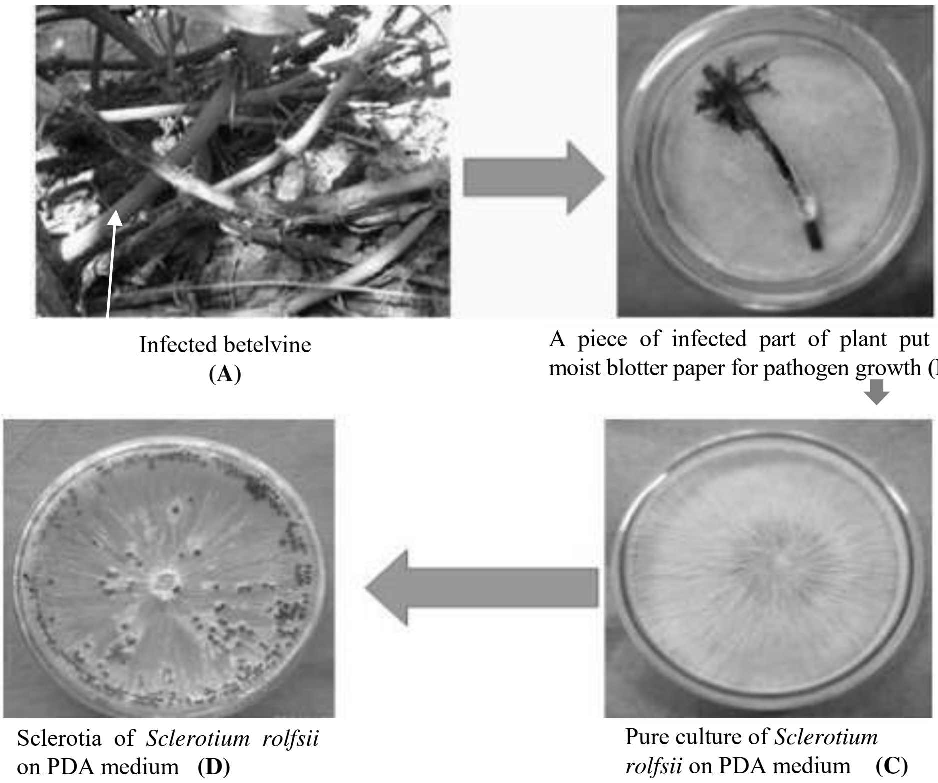

Plate 1. Infected betelvine vines (A), infected vine piece on moist blotter (B), pure culture (C) and sclerotia (D) of *Sclerotium rolfsii*

Table 1. Growth of the 19 isolates of *Sclerotium rolfsii* on PDA plates at room Temperature (25±2°C)

Isolates	Radial mycelial growth (mm) at the incubation period (hr.)								Growth rate mm h^{-1} at 60 hr.
	12	24	36	48	60	72	84	96	
Isolate-1 (BGPBSr-1)	12 f	22 de	42 de	56 de	80 c	87	90	NM	1.33 c
Isolate-2 (BGPBSr-2)	13 ef	17 f	32i	41 k	58 j	66	83	90	0.96 j
Isolate-3 (BGPBSr-3)	14 d-f	22 de	40 ef	50 hi	68 h	75	90	NM	1.13 h
Isolate-4 (BGPBSr-4)	17 a-d	23 c-e	38 fg	51 g-i	67 h	75	87	90	1.11 h
Isolate-5 (BGPBSr-5)	18 a-c	25 b-d	45 b-d	58 cd	78 cd	85	90	NM	1.30 cd
Isolate-6 (BGPBSr-6)	17 a-d	26 bc	47 b	60 bc	80 c	87	90	NM	1.33 c
Isolate-7 (BGPBSr-7)	13 ef	23 c-e	42 de	57 de	77 de	84	90	NM	1.28 de
Isolate-8 (JKPBSr-1)	13 ef	20 ef	39 fg	52 gh	74 fg	84	90	NM	1.23 fg
Isolate-9 (JKPBSr-2)	14 d-f	21 e	37 gh	49 i	67 h	76	88	90	1.11 h
Isolate-10 (JKPBSr-3)	15 c-f	25 b-d	43 cd	55 ef	75 ef	85	90	NM	1.25 ef
Isolate-11 (KMPBSr-1)	20 a	26 bc	45 bc	61 b	80 c	88	90	NM	1.33 c
Isolate-12 (KMPBSr-2)	13 ef	22 de	43 cd	56 de	78 cd	88	90	NM	1.30 cd
Isolate-13 (KMPBSr-3)	14 d-f	21 e	44 cd	57 de	80 c	90	NM	NM	1.33 c
Isolate-14 (RMPBSr-1)	16 b-e	25 b-d	45 bc	62 b	80 c	87	90	NM	1.33 c
Isolate-15 (RMPBSr-2)	20 a	28 ab	51 a	66 a	85 b	90	NM	NM	1.41 b
Isolate-16 (RMPBSr-3)	19 ab	30 a	52 a	68 a	88 a	90	NM	NM	1.47 a
Isolate-17 (CSPBSr-1)	18 a-c	25 b-d	42 de	56 de	75 ef	82	90	NM	1.25 ef
Isolate-18 (CSPBSr-2)	15 c-f	21 e	35 h	45 j	63 i	71	85	90	1.05 i
Isolate-19 (CSPBSr-3)	16 b-e	28 ab	40 ef	53 fg	72 g	78	90	NM	1.20 g

Values within the same column with a common letter(s) do not differ significantly (P=0.01)

Note: NM = No measurement after petri-plate had been covered

BG = Barisal-Gouranadi, PB = *Piper betle,* Sr = *Sclerotium rolfsii,* CS = Chattagram-Sitakunda, JK = Jhenaidah-Kaligonj, KM = Kushtia-Mirpur and RM = Rajshahi-Mohanpur

Table 2. Morphological characteristics of colony and sclerotia of the 19 isolates of *Sclerotium rolfsii* on PDA at room temperature (25±2°C)

Isolates	Colony consistency	Colony colour	Days to sclerotia formation	Colour of sclerotia
Isolate-1 (BGPBSr-1)	Embeded and thick	White	14	Dark brown
Isolate-2 (BGPBSr-2)	Embeded and thick	More white	10	Brown
Isolate-3 (BGPBSr-3)	Fluffy and thick	More white	14	Brown
Isolate-4 (BGPBSr-4)	Fluffy and thick	More white	10	Brown
Isolate-5 (BGPBSr-5)	Wooly	More white	10	Light brown
Isolate-6 (BGPBSr-6)	Fluffy	More white	14	Light brown
Isolate-7 (BGPBSr-7)	Embeded and thick	More white	15	Light brown
Isolate-8 (JKPBSr-1)	Fluffy at the pheripheral area	More white	15	Dark brown
Isolate-9 (JKPBSr-2)	Wooly	More white	09	Brown
Isolate-10 (JKPBSr-3)	More wooly	More white	12	Dark brown
Isolate-11 (KMPBSr-1)	Embeded and thin	Off white	13	Brown
Isolate-12 (KMPBSr-2)	Fluffy	Off white	10	Dark brown
Isolate-13 (KMPBSr-3)	Embeded and thick	White	14	Dark brown
Isolate-14 (RMPBSr-1)	Embeded profuse and thick	White	15	Brown
Isolate-15 (RMPBSr-2)	Wooly at the pheripheral area	White	14	Dark brown
Isolate-16 (RMPBSr-3)	Wooly at the pheripheral area	White	14	Dark brown
Isolate-17 (CSPBSr-1)	Fluffy	Off white	10	Dark brown
Isolate-18 (CSPBSr-2)	Embeded and thick	Off white	10	Dark brown
Isolate-19 (CSPBSr-3)	Embeded and thick	White	10	Brown

Table 3. Characteristics of sclerotia of the 19 isolates of *Sclerotium rolfsii* on PDA at room temperature (25±2°C)

Isolates	Characteristics of Sclerotia				
	Arrangement on culture plate	numbe r/ plate	Shape	Size (mm)	Wt. of 100 sclerotia (mg)
Isolate-1 (BGPBSr-1)	Scattered	270 b[α]	Round	1.06 gh	85.5 l
Isolate-2 (BGPBSr-2)	Scattered	60 k	Round	1.03 gh	105 i
Isolate-3 (BGPBSr-3)	Cluster and scattered	50 l	Round	1.00 h	100 j
Isolate-4 (BGPBSr-4)	Scattered	83 j	Spherical to irregular	1.05 gh	106 i
Isolate-5 (BGPBSr-5)	Scattered	63 k	Spherical to irregular	1.72 c	282.5 d
Isolate-6 (BGPBSr-6)	Scattered	25 m	Spherical to irregular	1.67 c	304.11 c
Isolate-7 (BGPBSr-7)	Cluster at the side of petri-plates	48 l	Irregular	2.00 b	553 a
Isolate-8 (JKPBSr-1)	Scattered	249 c	Round	1.42 d	154 g
Isolate-9 (JKPBSr-2)	Scattered and cluster at the periphery	230 d	Round	1.00 h	102 j
Isolate-10 (JKPBSr-3)	Scattered	14 n	Irregular	2.20 a	473 b
Isolate-11 (KMPBSr-1)	Scattered	89 i	Round	1.13 g	96 k
Isolate-12 (KMPBSr-2)	Scattered but cluster at peripheral ring	147 f	Round	1.70 c	245 e
Isolate-13 (KMPBSr-3)	Scattered	118 h	Round	1.09 gh	73.5 m
Isolate-14 (RMPBSr-1)	Scattered one side	132 g	Round	1.10 gh	74 m
Isolate-15 (RMPBSr-2)	Cluster at peripheral ring	209 e	Round	1.25 f	72 m
Isolate-16 (RMPBSr-3)	Scattered	288 a	Round	1.40 de	130 h
Isolate-17 (CSPBSr-1)	Scattered	79 j	Round	1.62 c	280.5 d
Isolate-18 (CSPBSr-2)	Scattered	51 l	Round to irregular	1.50 d	212 f
Isolate-19 (CSPBSr-3)	Scattered	213 e	Round	1.30 ef	131 h

[α]Values within the same column with a common letter(s) do not differ significantly (P=0.01).

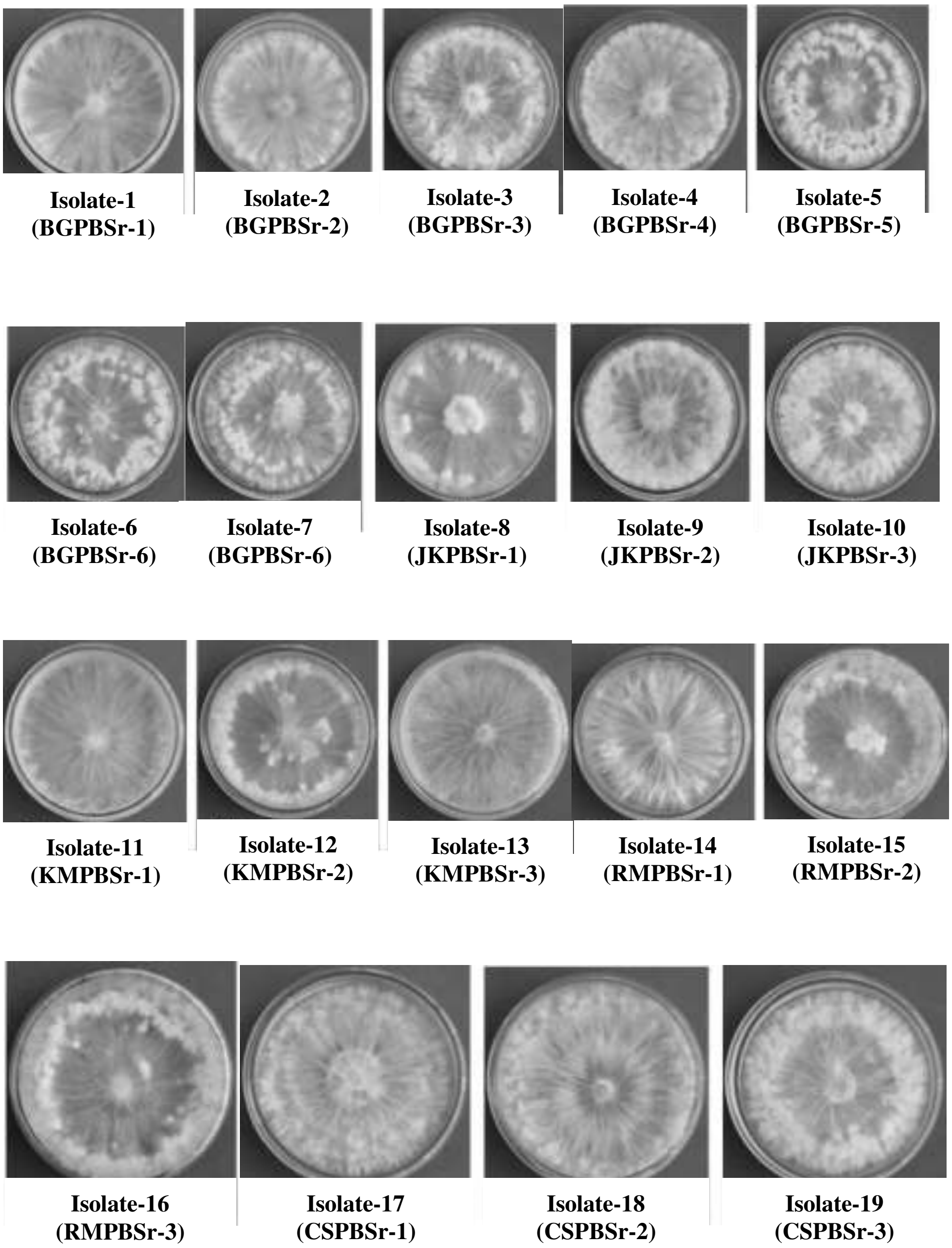

Plate 2. Culture plates showing mycelial growth of the isolates of *Sclerotium rolfsii* on PDA medium

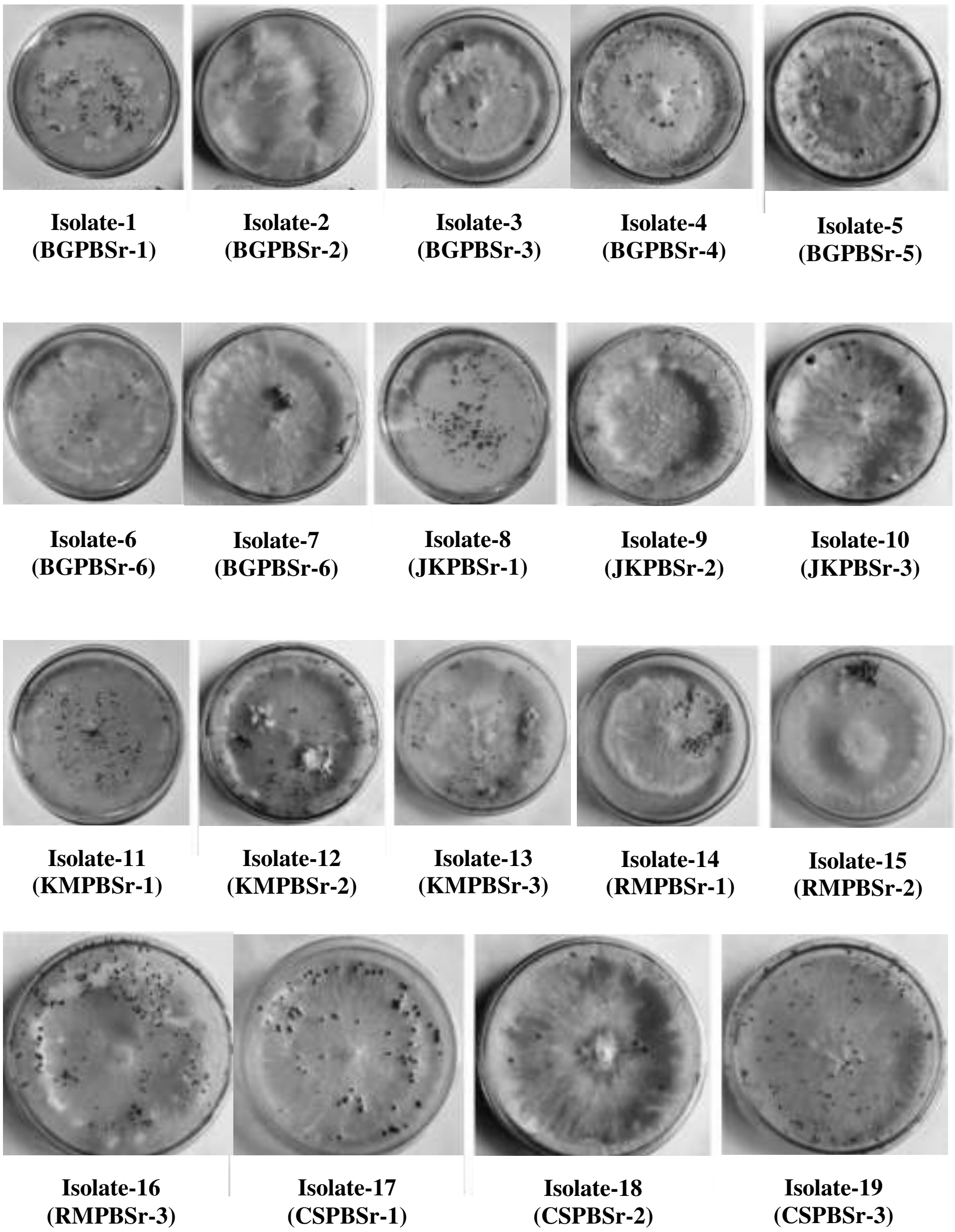

Plate 3. Mycelia and sclerotia of the different isolates of *Sclerotium rolfsii* on PDA medium

Conclusion

The findings of the present study reveal variabilities exist among the isolates of *S. rolfsii* associated with foot and root rot of betelvine in Bangladesh. The existence of physiological races of the pathogen might be the reasons for diversified severity of the disease and yield losses in different betelvine growing regions of the country.

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Participatory Carbon Measurement from Understory Layer in a Selective Village Common Forests in Khagrachhari, Bangladesh

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Abstract

Climate change is a recent global phenomenon that is anthropogenic and influences the characteristics of the global atmosphere. REDD+ is acting worldwide as a mitigation strategy to minimize the climate change consequences by reducing deforestation, forest degradation and emission of greenhouse gases. The study was conducted in Komolchori village common forests in Khagrachhari to estimate understory carbon concentration through a participatory approach. The study estimated that total biomass of herbs, grasses, and litters analyzed from the data collected by forestry professionals and local participants were 4.03±0.37 tha^{-1}, and 4.02±0.36 tha^{-1}, respectively. Likewise, the total carbon from herbs, grasses, and litters was 1.89±0.17 $tCha^{-1}$ and 1.89±0.17 $tCha^{-1}$, respectively. There was no significant difference between the values of biomass and carbon estimated by forestry professionals and local participants. The result confirms the possibility of implementing a participatory approach in carbon estimation from the understory layer. The study can assist the researchers and policymakers in implementing REDD+ projects in Bangladesh. It also opens the scope of reducing transaction costs while implementing REDD+ projects.

Key Words: Herbs, Grasses, Litters, Biomass, Carbon.

Introduction

Global climate change is a serious concern of the world communities nowadays. It has been globally regarded as an anthropogenic event caused by an excessive concentration of greenhouse gases (GHG) in the atmosphere (Costello *et al.*, 2009). The Reducing Emissions from Deforestation and forest Degradation and supporting the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (REDD+) has been suggested as an essential means to reduce the atmospheric GHG at low cost (Corbera and Schroeder, 2011). Additionally, it supports forest biodiversity conservation by retarding forest degradation and deforestation (Stickler *et al.*, 2009).

To gain carbon credit and to reduce the rate of greenhouse gas emission, forest carbon is measured. Among the six forest pools, the understory layer contains a small amount of forest carbon. The understory layer consists of all the plants of lower canopy levels of a forest ecosystem, mainly herbs, shrubs, grasses, and litters. The understory layer may not sequester much carbon to the land, but it is ecologically significant to the soils (Salunkhe *et al.*, 2014). Its estimation is not only useful for total carbon measurement in the forests but also needed for understanding the ecosystem functions of the forests (Litton *et al.*, 2007).

Participatory carbon measurement and monitoring carried out with local and indigenous communities are aimed at testing the feasibility of community involvement in forest

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carbon measurement. The participatory carbon measurement program in Indonesia has proved its effectiveness in measuring carbon by community people (WWF, 2014). Participatory carbon monitoring and measurement make the communities understand the environmental values of forest regarding climate change and improving forest management by indigenous knowledge and skill. It may be a collaborative work promoting cooperation between local communities, local governments, and national institutions (Huy *et al.*, 2013). It has been found that carbon assessment by professionals needs a very high cost where there is a chance of having the same quality work carried out by local community people at a low cost (Mukama *et al.*, 2012). So, participatory carbon measurement and monitoring are appreciated regarding low transaction costs in the context of gaining carbon credit. A participatory carbon measurement and monitoring process by using GPS in Nepal shows that it is less time consuming to boundary mapping and minimize systematic and personal errors than using compass survey (Rana *et al.*, 2008).

This study was conducted to estimate carbon from the understory layer of Komolchori Village Common Forests (VCF) in the Chittagong Hill Tracts (CHT). Though they represent an essential pool of forest carbon estimation, they are omitted in many cases due to the lack of accurate methodology and difficulty in estimation (Salunkhe *et al.*, 2014). Many studies measured carbon content from herbs (Cao and Chen, 2015, Peichl and Arain, 2006, Pibumrung *et al.*, 2008, Salunkhe *et al.*, 2014), and litters of a forest (Cao and Chen, 2015, Chen *et al.*, 2007, Ordóñez *et al.*, 2008, Patenaude *et al.*, 2003, Salunkhe *et al.*, 2014, Wolde *et al.*, 2014) in many countries, but the study of participatory measurement system to estimate carbon from the understory layer is insufficient. Notably, in the context of Bangladesh, there was no study about the participatory measurement system in forest carbon estimation. The present study measured carbon contents in herbs, grasses, and litters through a participatory process- involving local people. From the literature, it is clear that understory vegetation and litters are critical carbon pool of a forest (Du *et al.*, 2015, Patenaude *et al.*, 2003, Salunkhe *et al.*, 2014) and it contains 5-20% of the total stand-carbon depending on various site conditions (Karjalainen, 1996). To reduce the transaction cost and to increase the profit in carbon trading, participatory carbon measurement and monitoring is a practical approach (Mukama *et al.*, 2012, Skutsch, 2005). The specific objectives of this study were to measure carbon contents from herbs, grasses, and litters in the Komolchori VCF under the CHT; and to measure the effectiveness of carbon measurement by local community people. This study was conducted to enrich the knowledge pool about the involvement of the local community in carbon measurement in CHT in Bangladesh. This study can play a vital role in the implementation of national REDD+ programs in Bangladesh.

Materials and Methods

The study was conducted in the wet mixed forests of Komolchori VCF in the Khagrachhari Sadar Upazila of Khagrachhari District under the CHT.

Description of the study area

Khagrachhari district is situated on the southeast of Bangladesh under the CHT. The geographical location is between latitude 22°38′ to 23°44′ N and longitude 91°42′ to 92°11′ E (Fig. 1). Khagrachhari district is bordered by Tripura (Indian state) to north, Rangamati, and Chittagong district to the south, Rangamati district to the east, Chittagong district, and Tripura to the west. The human population of the Khagrachhari district is 6,13,917, including male and female sex ratio 105:100, tribal and non-tribal ratio 52:48. The average literacy rate is 26.3% in the district. Khagrachhari is a valley that has three rivers, and most of the lands are hilly areas, including the total area of 2,749.16 km^2 with the mean annual rainfall 3031 mm, the maximum temperature 34.6°C, and minimum 13°C.

The Komolchori VCF is locally called 'Reserve' situated in Buarchari Mouza (Mouza no-264) in Khagrachhari Sadar Upazila. It is, of 128 hectares, managed by a local ethnic community as a co-management agent. The VCF is about 5 km away from the Komolchori village (Fig. 1). Plots were distributed between the latitudes ranging from N 23°05.006' to N 23°05.988' and longitudes from E 92°01.774' to E 92°02.206'.

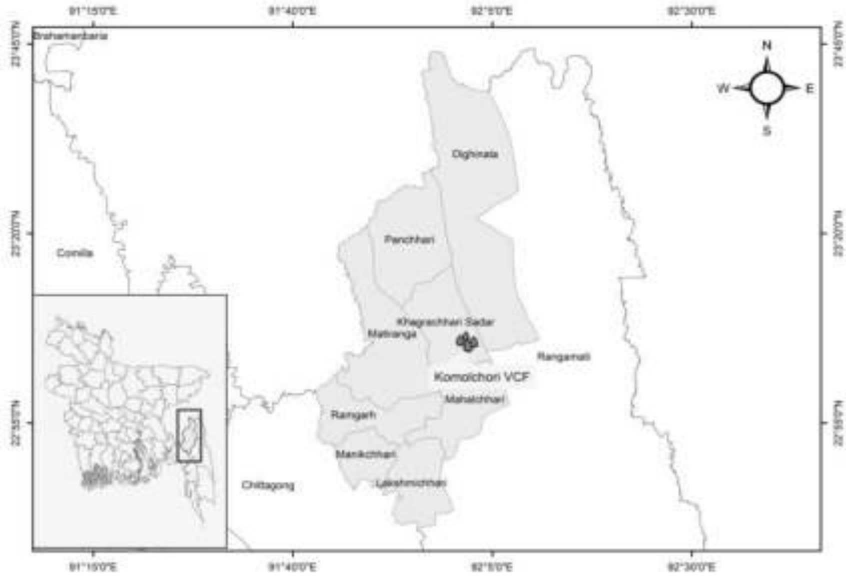

Fig. 1: Map of Khagrachhari district indicating the Komolchori village common forests

Sample design

The Komolchori VCF was selected purposively as a medium growth natural forest in the CHT to measure the carbon in the understory layer through a participatory approach. Human resource management, i.e., team formation, orientation (theoretical and practical), detail training of the local community members, was the first task of the research work. Participation in permanent plot marking, and data collection by the local trained crews and its comparison with the data collection by the forestry professionals were the major activities of the research work.

A total of 15 trainees, selected from the forest-dependent Chakma community of the Komolchori village, were selected purposively. With the discussion of the *Karbary* (leader of the social organization), active and 18 years+ old trainees (11 male and 4 female) were selected purposively. After selecting the participants, they were put under a training scheme, of 15 days, including the theory of forest inventory and its corresponding practical in the field. The 15 trained crews are defined as the local participants in this study.

The local participants took part in permanent plot demarcation, sample collection, weighing the samples, and packaging the samples. From the same permanent plot, the data were collected by the forestry professionals. However, the local participants did not have any role in laboratory procedures and data analysis. The study was conducted from March 2014 to August 2015.

From the VCF, a total of 57 permanent sample plots were selected (Fig. 2) for biomass and carbon study. The plots were selected randomly using the superimposed grids on the VCF map through the local peoples' participation. The plots were circular in shape of 10 m-radius. The total number of permanent mother plots was estimated using the formula of MacDicken (1997) as follow;

$N = (CV*t)^2/E^2$

Where

N = maximum number of sample plots

CV = Coefficient of variation of biomass

T = value of t obtained from the student's t-distribution table at n-1 degrees of freedom of the pilot study at 10% probability

E= sampling error at 10%.

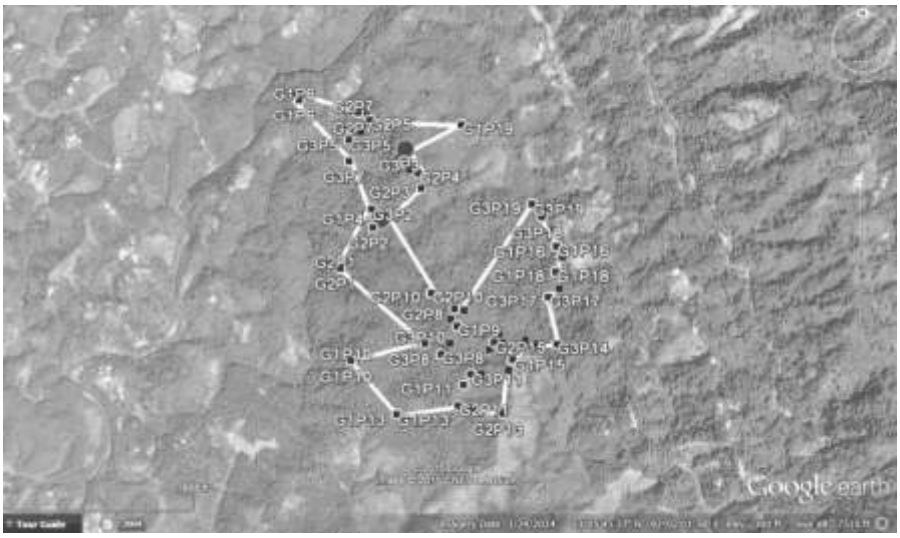

Fig. 2: Plots for measuring carbon from the understory layer in the Komolchori village common forests under the Chittagong Hill Tracts

A 1m-radius sub-plot was taken at the center point of every mother plot for measuring herb, grass, and litter. The mother plot was delineated for measuring the other pools of carbon. The other pools were tree, sapling, and soils. The 10m-radius mother plot was for studying trees, 5m-radius sub-plot was for saplings, and 1m-radius sub-plot was for herbs, grasses, and litters (Fig. 3). The center of the plot was recorded as the global coordinates (latitude, longitude) assisted by the Global Positioning System (GPS). For further monitoring of the same plot, the coordinates of the center of the plots were put in the system of proximity alarm of the GPS.

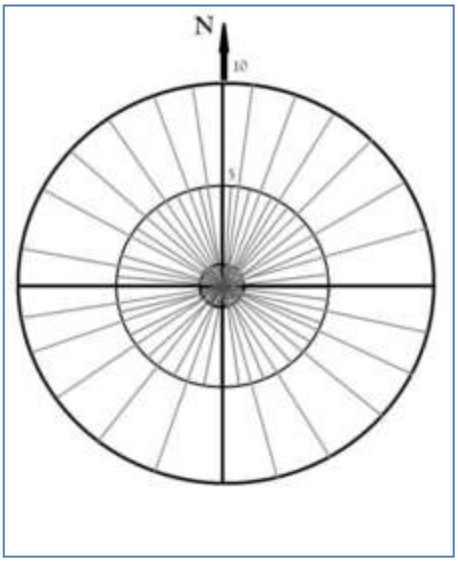

Fig. 3: Demarcation of circular plots for sampling in the Komolchori village common forests of Khagrachchari under the Chittagong Hill Tracts

For a convenient demarcation of the boundary of the plot, a nylon rope of 6.28m length for a 1m-radius plot was used. For measuring the radius of the plot, a 1m-length nylon rope was used. For collecting the data, the local participants were distributed in three groups having 5 in each. Each group collected data independently followed by the data collection by the forestry professionals.

Measurement of biomass

To measure biomass-carbon in the herbs and grasses, a destructive method was used. For this, a 1m-radius circular plot was allocated for measuring the total biomass from herbs, grasses, and litters. All the herbs and grasses were rooted out and weighed by the measuring scale in the field. For this, garden-hoes and garden-shovel were used. All the litters also were collected and weighed in the same manner. Weights of the fresh samples were recorded in the datasheet. A subsample of herbs, grasses, and litters from the first-hand samples was weighed in the field and brought to the laboratory for drying by the oven. The participants collected a total of 57 sub-samples, including herbs and grasses, and another 57 samples of litters. The forestry professionals collected the same number of sub-samples of herbs, grasses, and litters from the same circular plot. The herbs, grasses, and litters were oven-dried at 105°C unless getting the constant weight. Finally, the constant data was recorded in the structured datasheet.

Data Analysis

The biomass of litters, grasses, and herbs (LGH) per hectare was calculated using the following formula, and the carbon content in LHG was calculated by multiplying LHG with the default carbon fraction of 0.47 (Gibbs *et al.*, 2007).

$$\text{LHG} = \frac{W_{field}}{A} \times \frac{W_{subsample,dry}}{W_{subsample,wet}} \times \frac{1}{10000}$$

Where,

LHG = Biomass of leaf litter, herbs and grass [t ha^{-1}]

W_{field} = Weight of the fresh field sample of leaf litter, herbs and grass, destructively sampled within an area of size A [g]

A = Size of the area in which leaf litter, herbs, and grass were collected [ha]

$W_{subsample,dry}$ = Weight of the oven-dry sub-sample of leaf litter, herbs and grasses have taken to the laboratory to determine moisture content [g]

$W_{subsample,wet}$ = Weight of the fresh sub-sample of leaf litter, herbs and grass have taken to the laboratory to determine moisture content [g]

Above formula was used in Joshi *et al.* (2012) while describing carbon assessment in community-managed forests in Nepal.

After the estimation of the biomass and carbon of the understory layer from the data collected by the local participants' group and the forestry professionals, a comparison by unpaired 't' test among the results was conducted. As the data were normally distributed, there was no problem with using 't' test even though the sample size was 57.

Results and Discussion

Biomass in herbs, grasses, and litters

The mean biomass in herbs and grasses was 0.32±0.08 tha^{-1}, in litters 3.71±0.30 tha^{-1}, and the total biomass in herbs, grasses, and litters was 4.03±0.37 tha^{-1} from the data collected by the forestry professionals (Table 1). It was 0.29±0.056 tha^{-1}, 3.73±0.31 tha^{-1} in herbs and grasses, and litters, respectively, while the total biomass including herbs, grasses and litters was 4.02±0.36 tha^{-1} from the data collected by the participants.

Table 1: Biomass and carbon of herbs, grasses, and litters in the Komolchori village common forests in the Chittagong Hill Tracts

Forest understory pool	Measuring group			
	Forestry professionals		Participants	
	Biomass (tha^{-1})	Carbon (tCha^{-1})	Biomass (tha^{-1})	Carbon (tCha^{-1})
Herbs and grasses	0.32±0.08	0.15±0.04	0.29±0.06	0.14±0.03
Litters	3.71±0.30	1.74±0.14	3.73±0.31	1.75±0.15
Total	4.03±0.37	1.89±0.17	4.02±0.36	1.89±0.17

The distribution of biomass data in the graph over forestry professionals and local participants shows no significant dispersion evident by the unpaired t-test.

Herbaceous biomass was found 4.18±4.04 tha^{-1} in the 2-year old white pine stands, and 0.003±0.005 tha^{-1} in 15 years old white pine stands of a temperate pine plantation forest (Peichl and Arain, 2006). This study is showing around 0.3 tha^{-1} biomass amount from herbs and grasses. From the study conducted by Peichl and Arain (2006), it indicates that biomass in the understory layer can differ depending upon the age of the forest. From a study conducted in Brazilian native woodland, biomass in the litter layer ranged from 0.64 to 8.63 tha^{-1} (Dias *et al.*, 2006). In the present study, biomass found from the litter layer has a similarity with that study conducted in Brazil. The litter biomass depends on the climate, water availability, season, altitude, and microbial activity (Saatchi *et al.*, 2007). However, the recent studies are not showing the pattern of the mean biomass and carbon density in the litter with altitude clearly (Wolde *et al.*, 2014).

Carbon in herbs, grasses, and litters

The mean carbon in herbs and grasses and litters was 0.15±0.04 $tCha^{-1}$ and 1.74±0.14 $tCha^{-1}$, while the total carbon was 1.89±0.17 $tCha^{-1}$ estimated from the data collected by the forestry professionals (Table 1). The estimation from the data collected by the local participants was 0.14±0.03 $tCha^{-1}$ in herbs and grasses, and 1.75±0.15 $tCha^{-1}$ in litters while the total carbon was 1.89±0.17 $tCha^{-1}$.

The distribution of carbon data in the graph over forestry professionals and local participants shows no significant dispersion evident by the unpaired t-test.

Carbon from herbs, grasses, and litters contains a small but significant amount of total forest carbon. This understory pool of forest possesses 5-20% of the total stand-carbon depending on various site conditions (Karjalainen, 1996). Litter layer effects to determine the soil organic carbon accumulation (Du *et al.*, 2015). A study, conducted upon the estimation of carbon in a tropical dry deciduous forest, calculated 5.23 $tCha^{-1}$ from herbs (Salunkhe *et al.*, 2014). In a Chinese cork oak forest of Qinling Mountain, 0.19±0.04 $tCha^{-1}$ carbon from herbs was found (Cao and Chen, 2015). Carbon from herbs was 1.92±1.85 $tCha^{-1}$ in a temperate pine plantation in China (Peichl and Arain, 2006). In the case of carbon from the litter layer, 1.28 $tCha^{-1}$ was estimated in Arbaminch groundwater forest of Ethiopia (Wolde *et al.*, 2014). In a tropical dry deciduous forest of India, carbon from litter layer was 0.66 $tCha^{-1}$ (Salunkhe *et al.*, 2014). Carbon from the litter layer was found 3.00 $tCha^{-1}$ in a semi-natural woodland of England (Patenaude *et al.*, 2003). In Chinese cork oak forest, carbon from litters was 2.18±0.44 $tCha^{-1}$ (Cao and Chen, 2015). Carbon in the understory layer can vary depending on their age and microbial activity (Peichl and Arain, 2006, Groffman *et al.*, 2015). Hence, the findings of the present study on carbon estimation from herbs, grasses, and litters do not show any extraordinary status.

Brown and Corbera (2003) confirmed that "the greater the number of stakeholders and actors in the process, the less of the eventual profit will remain in the hands of the local community." The transaction costs of the forest carbon project include planning with a baseline, measuring and monitoring carbon sequestered, validating these measurements with standard verification system, and marketing the carbon stocks (Skutsch, 2005). All the activities professionally outsourced can be a significant factor in reducing the profitability of carbon trading. Only community-based carbon measurement and monitoring can reduce transaction costs, increasing the profitability of carbon marketing at the supply side (Skutsch, 2005). The present study confirmed that there was no significant difference in the casrbon measurements between the local participants and the forestry professionals. Only a 15-days training turned out an effective measurement practice of the local participants. In Bangladesh, there is no REDD+ pilot project yet, but there is an opportunity to implement pilot projects to reduce forest degradation and deforestation by minimizing forest dependency of local communities (Miah *et al.*, 2014). Estimating carbon in all the pools of forests is crucial for REDD+ implementation where carbon in the understory layer is an important complimentary stock. The participatory approach of measuring the carbon under this study can be a learning to other carbon forestry in Bangladesh.

Conclusion

The present study estimating the carbon amount from herbs, grasses, and litters are representing an essential pool of forest carbon. This study revealed that participatory carbon measurement by participants shows nearly the same result as the result of the forestry professionals. There was no significant difference between their performances. A 15-day training effectively turned out this performance of the local participants. It can be excellent learning to the other carbon forestry projects in Bangladesh. However, it should be clear that the participation of local people was only in the field. They had no participation in laboratory work. This study will be helpful in implementing REDD+ projects in Bangladesh by reflecting a way to reduce transaction costs.

Acknowledgment

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The topics will cover current and future scenarios for improvement of sustainability of the fragile eco-system, food security, natural resource management, input distribution & management, nutrition, agribusiness, climatic risk management, human resource development and economic implications of rapid globalization obtaining since the recent past. The retrospects and prospects of agricultural improvement *vis-à-vis* the constraints hindering progress of agricultural development etc, are burning topics needing elaborate analysis and synthesis for the policy makers , teachers, researches, extensonists, service providers, marketing agents, NGOs and private sector entrepreneurs.

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