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Review

Rice Cultivation in Bangladesh: Present Scenario, Problems, and Prospects

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Abstract. Bangladesh has an agrarian economy in which rice is the dominant crop. Rice is the staple food, reflected in the high per capita rice consumption in this country. The nutritional demand of the majority of people is met with rice. Over its long history, rice production in Bangladesh has gradually changed in terms of yield potentials, cultivation techniques, and cropping patterns. Despite pressure from overpopulation, the country has reached self-sufficiency in rice production. In this review, we focus on the present status and future prospects of rice cultivation in Bangladesh.

1. Introduction

Bangladesh is an agrarian country. About 76% of the people live in rural areas, and 47.5% of the total manpower is involved in agriculture. In Bangladesh, agriculture contributes 19.3% of the gross domestic product (GDP) of the country (Bangladesh Finance Bureau, 2014).

Bangladesh has a long history of rice cultivation. Rice is grown throughout the country except in the southeastern hilly areas. The agroclimatic conditions of the country are suitable for growing rice year-round. However, the national average rice yield is much lower (2.94 t/ha) than that of other rice-growing countries (BBS, 2012).

Rice is the staple food for about 156 million people of the country. The population growth rate is 2 million per year, and if the population increases at this rate, the total population will reach 238 million by 2050. An increase in total rice production is required to feed this ever-increasing population. At the same time, the total cultivable land is decreasing at a rate of more than 1% per year owing to the construction of industries, factories, houses, roads, and highways. On the other hand, due to urbanization, food habits tend to change, demanding the cultivation of new crops that must share land used for rice cultivation. Therefore, attempts should be made to increase the yield per unit area of rice. Moreover, due to climate change, agriculture is facing different adverse conditions, such as drought, flood, salinity, extreme temperature stress, and low soil fertility. In these circumstances, policies should be implemented to increase rice production in a sustainable manner for the food and nutritional security of this highly populated country.

2. Present status of rice cultivation in Bangladesh

2.1. Agroclimatic conditions: rainfall and temperature

Bangladesh has a tropical climate with considerable variation in climatic parameters, such as temperature and rainfall. The total area of the country is 14.86 million ha (147,570 square kilometers), and the cultivable area is 8.52 million ha. The cropping intensity of the country is 191%.

The country receives plenty of rainfall, although it is not evenly distributed across region or season. The average annual rainfall is about 2,320 mm and varies between 1,110 mm in the northwest and 5,690 mm in the northeast (FAO, 2010). Most of the rains occur during the monsoon season, between mid-June and September (Fig. 1A). There is very little rain between November and March, and the period between April and May has pre-monsoon rain with thunderstorms.

Bangladesh has distinct summer and winter seasons. Maximum summer temperatures range between 35–41°C during the months of April and May. In May 2014, the temperature reached 42.5°C, the highest temperature recorded in 60 years. December to February are the cooler months with average daily temperatures of around 15–20°C and night temperatures of 10–12°C. However, in north, the temperature drops below 10°C.

2.2. Rice growing seasons and crop calendar

There are three rice-growing seasons in Bangladesh: *aus, aman,* and *boro*. *Aus* is the pre-monsoon upland rice-growing season under rainfed conditions. The *aus* rice is direct or broadcast seeded during March and April after the pre-monsoon shower and harvested between July and August (Fig. 1B). Some areas under *aus* cultivation have shifted to irrigated *boro* rice because of the high yield potential of the latter.

The monsoon-season rainfed rice is the *aman,* which is the most widespread, including along the coastal areas. *Aman* is planted in two ways: direct seeding with *aus* in March and April and transplantation between July and August. Both types are harvested from November through December. However, late flooding can reduce the area of *aman*, and the absence of rain during summer also reduces *aus* growing area.

Boro is the dry-season irrigated rice planted from December to early February and harvested between April and June. Earlier, *boro* was grown in the very low-lying areas with residual water from the wet season and irrigated manually using surface water in times of water shortage (Fujita, 2010). Such traditional *boro* rice was transplanted after the recession of floodwater in November and harvested from April to May. In the mid-1960s, the modern high-yielding rice variety IR-8 was introduced into Bangladesh agriculture, primarily for *boro* using irrigation. Then, beginning in 1970, another International Rice Research Institute (IRRI) bred variety IR-20 was introduced to farmers for the *aman* season. Since 1973, the Bangladesh Rice Research Institute (BRRI), in partnership with IRRI, has been engaged in adaptive research to evaluate elite genetic lines under the IRRI-managed International Network for Genetic Evaluation of Rice (INGER). Under the brand

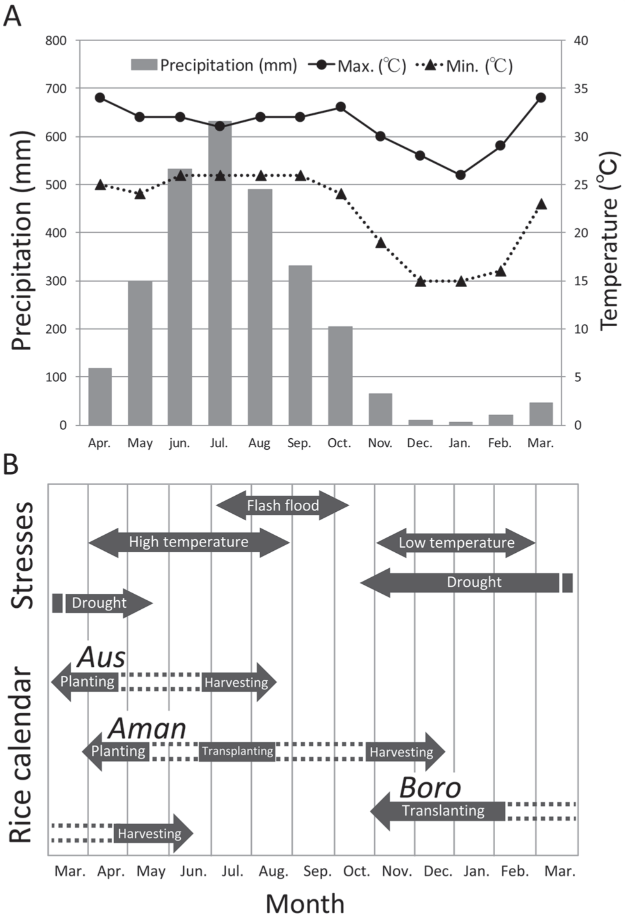

Fig 1. Agroclimatic conditions and rice calendar of Bangladesh.

A. The line graph (continuous line) shows monthly maximum temperature (°C) and the broken line shows monthly minimum temperature (°C); the bar graph showing the mean monthly precipitation (mm) throughout the year.

B. The above block arrows indicate the different kinds of stresses induced by the agroclimatic parameters throughout the year and the lower block arrows with dashes represents the rice crop calendar of Bangladesh.

name BR, and later BRRI dhan, it has released varieties that suit the agro-ecological conditions in Bangladesh (Hossain *et al*., 2013). Many IRRI lines were well suited in Bangladesh for the *boro* season, such as BR1, BR3, BR14, BRRI dhan28, and BRRI dhan29. However, IRRI varieties did not perform well in the *aman* season; therefore BRRI scientists crossed international elite lines with traditional land races and developed many reliable varieties, BR11 being one of the most popular.

Simultaneously, irrigation systems have been developed gradually in Bangladesh since the 1960s. Surface-water irrigation using low-lift pumps began in the mid-1960s and continued until the mid-1970s. After this period, the development of groundwater irrigation by tube wells accelerated, and the rapid diffusion of shallow tube wells throughout the 1980s boosted the cropped area and yield of dry-season *boro* rice dramatically (Fujita, 2010). With the introduction of ground water irrigation systems and the incorporation of modern high-yielding varieties, dry-season *boro* rice gained popularity (Fig. 2). The rice-cropping pattern of Bangladesh has changed—areas once occupied by the rainfed *aus* gradually shifted to *boro* cultivation (Fig. 3B). As a result, the contribution from each season also changed—*aman* rice previously contributed a major portion of total rice, but *boro* is now the major contributor to total rice production in the country, despite *aman* coverage area being greater (Fig. 3A). *Aus*, *aman,* and *boro* rice were recently reported to account for 7%, 38%, and 55%, respectively, of the total rice production in Bangladesh (Risingbd, 2014). In the year 2013–2014, rice production was 34.3 million t (Bangladesh Finance Bureau, 2014). Bangladesh has made notable progress in sustaining respectable growth in rice production, and this growth in production has originated mostly from the shift from low-yielding traditional to high-yielding modern varieties when irrigation facilities were developed (Hossain *et al*., 2006).

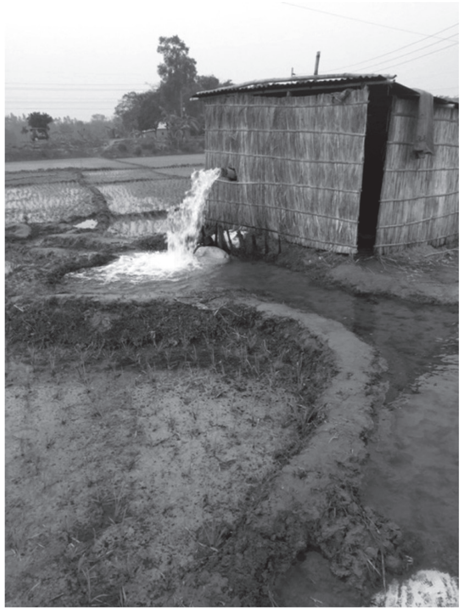

Fig 2. Ground water irrigation system in Bangladesh.
Watering the rice fields by shallow tube-well for dry season high yielding *boro* rice cultivation.

Another factor contributing to the increase in total rice production by irrigation and modern rice varieties is the change in the rural economy. In neighboring countries, the Green Revolution occurred during the 1960s and 70s. Bangladesh's green revolution occurred only during the 1980s owing to the rapid diffusion of shallow tube wells for the irrigation of dry-season *boro* and modern rice varieties. The development of the rural economy, driven by the full-scale diffusion of the Green Revolution, led to an increase in agricultural wage (Fujita, 2010). However, Hossain *et al.* (2006) showed that by the year 2001–2002, the coverage of modern rice varieties reached 65% of the rice-cropped area—80% for the dry season and 51% for the wet season; thus, the Green Revolution in rice cultivation is not yet complete in Bangladesh.

2.3. Rice cultivars

The BRRI, Bangladesh Institute of Nuclear Agriculture (BINA), and the Bangladesh Agricultural University (BAU) and other universities are trying to improve rice cultivars with high yield potential and resistance to different biotic and abiotic stresses (Table 1). BRRI has developed 69 rice varieties, BINA 17, and BAU 2. In addition to these

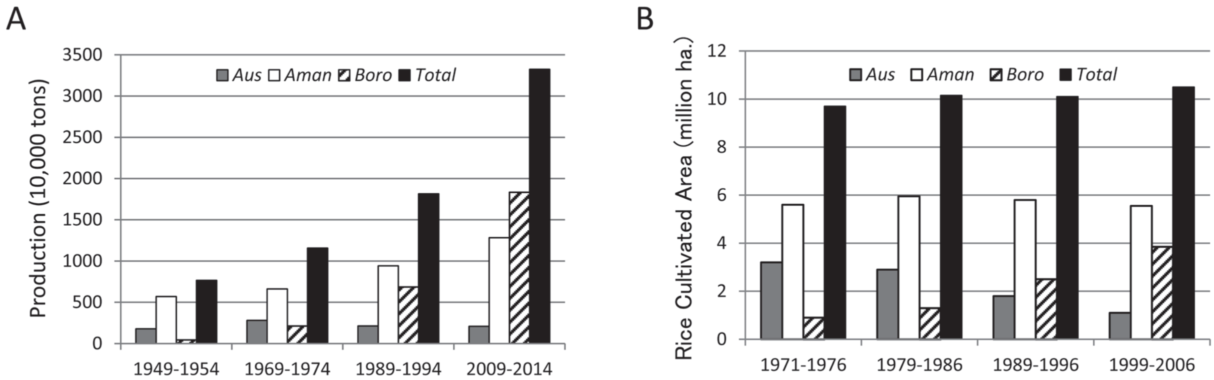

Fig 3. Trends of rice production and rice cultivated area over time in Bangladesh.
A. Production of rice in different growing seasons i.e., *aus*, *aman,* and *boro* and total production of rice for the period 1949 to 2014.
B. Trend of rice cultivated area in different growing seasons and total cultivated area for the period 1971 to 2006.
(From Fujita, 2010; Different issues of Gain reports, 2010-2015).

Table 1. Modern rice varieties of Bangladesh

Boro		*Aus*		*Aman*	
BR3		BR20		BR4	
BR14		BR21		**BR5**	Aromatic rice
BR16		BR24		BR10	
BR17		BR26		BR11	
BR18		BRRI dhan27		BR22	
BR19		BRRI dhan42	Drought tolerant	BR23	
BRRI dhan28		BRRI dhan43	Drought tolerant	BR25	
BRRI dhan29		**BRRI dhan48**	Drought tolerant	BRRI dhan30	
BRRI dhan36	Cold tolerant	BRRI dhan55		BRRI dhan31	
BRRI dhan45		**BRRI dhan65**	Drought tolerant	BRRI dhan32	
BRRI dhan47	Salt tolerant			**BRRI dhan33**	Drought tolerant
BRRI dhan50	Aromatic rice			BRRI dhan34	Aromatic rice
BRRI dhan55	Drought tolerant			BRRI dhan37	Aromatic rice
BRRI dhan58				BRRI dhan38	Aromatic rice
BRRI dhan59				BRRI dhan39	
BRRI dhan60				BRRI dhan40	Salt tolerant
BRRI dhan61	Salt tolerant			BRRI dhan41	Salt tolerant
BRRI dhan63				BRRI dhan44	
BRRI dhan64	Zn-enriched			BRRI dhan46	
BRRI dhan67	Salt tolerant			BRRI dhan49	
BRRI dhan68				**BRRI dhan51**	Submergence tolerant
BRRI dhan69				**BRRI dhan52**	Submergence tolerant
BRRI hybrid dhan2				BRRI dhan53	Salt tolerant
BRRI hybrid dhan3				BRRI dhan54	Salt tolerant
Iratom-24				**BRRI dhan56**	Drought tolerant
Binadhan-5				**BRRI dhan57**	Drought tolerant
Binadhan-6				**BRRI dhan62**	Zn-enriched
Binadhan-8	Salt tolerant			**BRRI dhan66**	Drought tolerant
Binadhan-10	Salt tolerant			BRRI hybrid dhan4	
Binadhan-14				Binashail	
				Binadhan-1	
				Binadhan-7	
				Binadhan-9	Aromatic rice
				Binadhan-11	Submergence tolerant
				Binadhan-12	Submergence tolerant
				Binadhan-13	Aromatic rice
				Binadhan-17	
				Baudhan2	

← Photo insensitive →
Binadhan-15, Binadhan-16

Salt tolerant; Submergence tolerant; Drought tolerant; Aromatic rice; Zn-enriched; Cold tolerant

modern high-yielding varieties, there are many traditional rice cultivars in Bangladesh with wide adaptability for the diverse agro-ecological conditions. However, with the increase in population, much more rice is needed, and modern rice should replace many of the traditional varieties to achieve this. More than 1000 traditional rice cultivars are now being grown in Bangladesh and are maintained by farmers due to their wide adaptability, superior grain quality, and resistance to abiotic and biotic stresses (Hossain and Jaim *et al*. 2009). However, these rice cultivars have very low yield (less than 2.0 t/ha) and are mostly grown in *aus* and *aman* seasons. These traditional cultivars are usually grown in less suitable areas, such as coastal areas, lands that have no irrigation system, and under deep-water conditions.

Irrigation is widely used throughout Bangladesh except in salt-affected areas. The precondition for growing high-yielding varieties in *boro* season is proper water management. In favorable ecological areas, about 92% of the farmers use irrigation; of these, only 28% own irrigation equipment, while 62% buy irrigation water (Hossain *et al.,* 2013). In 2008, the national irrigation coverage was

5.05 million ha, about 60% of total cultivable land, with groundwater covering 79% and surface water 21% (FAO, 2010). Different kinds of irrigation systems prevail in the country, such as deep-tube well, shallow-tube well, low-lift pumps, and also some traditional irrigation systems. A detailed account of irrigation systems in Bangladesh has been described by Fujita (2010).

Little scope now exists to increase total rice production by increasing irrigated areas. However, we could increase the irrigated area by at most about 70% because of salinity and land elevation constraints. The farmers of salinity-affected areas prefer to use traditional rice varieties because they tolerate salinity. Although Bangladesh has an agrarian economy, about 89% of total farm-holdings are below 2.49 acres in size (Kashem, 2013). However, socioeconomic factors, such as the predominance of small and marginal farmers and tenancy cultivation in agrarian structure, did not impede the adoption of modern rice varieties in Bangladesh (Asaduzzaman, 1979; Mandal, 1980; Hossain *et al.,* 2003; Alauddin and Tisdell, 1996). Moreover, the major constraints to the adoption of rice modern varieties were in fact logistic factors such as a lack of irrigation facilities in the dry season and the topography, which affects flood depth and salinity of the soil in coastal areas (Hossain *et al.*, 2006).

3. Factors affecting rice cultivation

3.1. Drought

Drought is one of the major abiotic constraints for rice grown under rainfed conditions in Bangladesh and causes a substantial reduction in yield. The retardation in crop growth caused by water stress at the seedling stage can be overcome, but water stress at the reproductive stage can cause substantial reduction in rice yield. Transplanted *aman* usually suffers from water stress at the reproductive stage or at early ripening phases, reducing crop yield phases (Fig. 1B). A crop growth simulation model showed a yield potential of 7.218 t/ha with early transplanting on 1 June, under low water stress during flowering and maturity stage, while high water stress during flowering, maturity, and both flowering and maturity stages results in yield reduction of 46%, 37%, and 73%, respectively (Mahmood *et al*., 2004). *Aus* rice could suffer from drought any time from the seedling to reproductive stages, as the crop is direct-seeded and grown under rainfed upland conditions (Biswas, 2014). However, the traditional *aus* varieties have some tolerance to drought and can overcome drought if some rain occurs in June. The yield potential of these rice varieties, however, is very low.

3.2. Flood

Flash floods affect 24% of rainfed lowland *aman* rice areas, mainly at the seedling stage. The unpredictable rainfall often affects *aman* transplanting. Heavy rainfall and flood causes *aman* crop damage at the seedling stage and also delays planting. Flood affects *aus* rice during harvesting. Partial or complete crop losses were common for *aus* rice production due to pre-harvest sprouting and submergence of the crop field. Flash floods also affect *boro* rice production in the low-lying Haor area during harvesting.

3.3. Salinity

The coastal area covers about 20% of the country, which is about 30% of the net cultivable area (Haque, 2006). In the dry season, soil and river water salinity increase, while it decreases during the monsoon season. Land use varies temporally and spatially with season. Due to salinity, the coastal area remains fallow during winter. Wet-season *aman* is the main crop, and farmers mostly use traditional rice varieties, which can withstand salinity but have a poor yield. Moreover, nutrient deficiencies, especially those of N and P, imposed by salinity are quite dominant. Among the micronutrients, Cu and Zn are limited in saline soils, causing a substantial reduction in yield.

3.4. Extreme temperature stresses

Rice grows normally between a critical temperature range of 20°C and 35°C, and varies with genotype, duration of critical temperature, diurnal changes, and physiological status of the plant (Yoshida, 1981). Surprisingly, rice plants encounter both low and high temperature stresses in the different growing seasons in Bangladesh (Fig. 1B). The stage most sensitive to low-temperature injury is the panicle initiation stage, causing spikelet sterility. The stage most sensitive to high-temperature is the flowering stage, also causing spikelet sterility. However, both low- and high-temperature stresses at the vegetative stage affect growth and development of the rice plant, which can be recoverable at later stages.

In Bangladesh, early *boro* rice often faces low-temperature stress at the vegetative as well as reproductive stage (Nahar *et al*., 2009a). Late *aman* faces low-temperature stress at the reproductive stage that causes increased spikelet sterility, subsequently decreasing yield (Nahar *et al.*, 2009b). In contrast, late *boro* and *aus* often encounter high temperature stress at the reproductive stage. Simulated crop model studies showed that an increase in air temperature would significantly decrease the productivity of *boro* rice in Bangladesh (Mahmood, 1998).

3.5. Soil fertility

Soil fertility is declining in Bangladesh due to intensive agriculture, imbalanced use of chemical fertilizers, limited addition of crop residues, and limited practice of green-manure cropping. The rate of organic matter depletion is also high because of the hot and humid climate. Bangladesh soils are deficient in some essential elements such as N, P, K, and S, which are limiting factors, among which N is the most limiting factor. With time, new elements are added as limiting nutrients in Bangladesh soil. Recently, Mg, Zn, and B were also reported to be limiting in many areas (Jahiruddin and Satter, 2010). Rice production without fertilizer has been declining over time in Bangladesh (BRRI, 2007–08); supplemental fertilization is essential to keep up the rice production.

3.6. Pests: insects, pathogens and weeds

Rice plants are often infested by various pests. Insects are a major constraint of rice production. The brown plant hopper (*Nilaparvata lugens*), rice stem borer (*Sciropophaga* spp.), green leaf hopper (*Nephotettix* spp*.)*, white-backed plant hopper (*Sogatella furcifera*), rice gall midge (*Orseolia oryzae*), rice hispa (*Dicladispa armigera*), and rice leaf folder (*Cnaphalocrocis medinalis*) are common insect pests of rice in Bangladesh (Alam, 2013, Nasiruddin and Roy, 2012, Fatema *et al*., 1999, Kamal *et al*., 1993, Alam, 1981, BRRI 1997, 2000, 2001, 2007, 2009). Bacterial leaf blight, sheath blight, leaf blast, sheath blast, tungro, and stem rot are major diseases. Weed infestation is high in *aus* rice. Sometimes rodents also attack *aman* rice during the harvesting period, substantially reducing the yield. In contrast, *boro* is the best rice-growing season, in which pest infestation is lower and which gives the highest yield under irrigation.

3.7. Multiple stresses

Multiple stresses are prevalent in rice cultivation in Bangladesh. Farmers of Bangladesh practice year-round farming, often limiting land available for the timely planting of the next crop. An early monsoon and excessive rainfall can cause flooding, which is harmful to young seedlings, while a late arrival usually leads to severe water stress (Mahmood *et al*., 2004). In addition, delayed transplanting of *aman* decreases spikelet fertility and reduces yield due to cold stress at the flowering stage (Nahar *et al*., 2009b). In the case of *boro*, early-planted crops face low-temperature stress at vegetative as well as reproductive stages and late-planted ones face high-temperature stress at the reproductive stage. In addition, the fertility status of most saline soils is low to very low with respect to organic matter content and N, P, Cu, and Zn availability (Haque, 2006).

4. Strategies to overcome problems associated with rice cultivation

4.1. Management and cultural practices

Rice productivity and total rice production in Bangladesh still have scope to increase if the proper crop management systems are followed. Farmers do not follow the integrated use of improved management practices such as time of planting, use of quality seeds, balanced use of fertilizers, and control of weeds and pest. There is a yield gap between the farmer's field and the yield potential of a particular variety. A CERES-Rice model showed that rainfed *aman* rice BR11 planted at planting dates of 1 June, 1 July, 15 July and 15 August had yield potential of 6.9, 5.0, 3.6, and 1.8 t/ha, respectively, from 1975 to 1987 (Mahmood *et al.,* 2003). The results also reveal that regional yield variations and yield vulnerability for a particular transplanting date exist. The main reason for the yield reduction due to delayed transplanting is the water stress at flowering and maturity stages (Mahmood *et al*., 2003). Another study was conducted to elucidate the effects of moisture stress on rainfed *aman* rice productivity. The average yield potential for a 1 June transplanting date and under low-water stress at flowering and maturity stages is 7.2 t/ha; potential yield reduction is 37%, 46%, and 73% for high water stress during maturity, flowering, and both flowering and maturity stages, respectively (Mahmood *et al.*, 2004).

Moreover, global climate is changing; researchers are trying to understand the possible effects of climate change on rice yield in Bangladesh using crop simulation models in different growing seasons. For example, irrigation-dependent *boro* rice is vulnerable to changes in temperature (Mahmood, 1997). A DSSAT model study reveals that, due to increases in daily maximum and minimum temperature, *boro* rice yield will reduce 20% and 50% for the years 2050 and 2070, respectively (Basak *et al.*, 2010). A comparative study of YIELD and CERES-Rice models showed that the rice productivity at Mymensingh predicted by YIELD is higher than that predicted by CERES-Rice, while the productivity estimates for Barisal by these two models are almost identical (Mahmood *et al*., 1998). The author mentioned that inconsistent management practices, differences in soil characterization procedures, method of dry matter estimation, and the range of diurnal temperature variation played an important role in productivity estimates. For the Mymensingh region, the CERES-Rice model estimates a decrease in productivity by 9.7% and 22.7% for a 2 and 4°C increase in air temperature, while the YIELD model estimates a yield reduction of 14.1% and 21.6%, respectively, for these temperature increases (Mahmood *et al*., 1998).

During the dry season, *boro* rice is grown under a constant stagnant-water condition in the field. The main source of water for irrigation is groundwater. The groundwater of Bangladesh is now under threat—the water table in some regions of the country, such as in Dhaka, is depleting each year by as much as 3 m (BADC, 2006). In the near future, it will be a significant threat for the country. The introduction of water-saving technology in rice production is an efficient method to keep the underground water table in a safe zone. Instead of flood irrigation, alternate wet and dry (AWD) methods of irrigation can be used. In addition, surface water should be reserved in ponds and small rivers in the rainy season and used for *aman* rice cultivation, especially at the flowering stage. BRRI has developed rainwater harvest technology for rainfed *aman* cultivation during the flowering stage to mitigate drought (Biswas, 2014). This technology should be disseminated to farmers throughout the country.

The fertility of Bangladesh soil is deteriorating day by day. Fertilizers should be applied based on soil tests. With the intensification of crop production, farmers use more fertilizers without an understanding of the actual requirements of the soil. Instead of the use of the normal urea, the urea super granule is an effective to reduce fertilizer use for optimum yield (Paul *et al*., 2013; Qurashi *et al*., 2013).

To prevent organic matter depletion, we should incorporate crop residues with soil and need to grow short-duration green-manure crops. For sustainable crop production, we need to use organic and inorganic fertilizers in the soil in a balanced manner.

Fig 4. Labour-intensive rice farming activities in Bangladesh.

A. *Aman* rice harvesting by the farmers.
B. Straw carrying after threshing.

Agriculture in Bangladesh is labor-intensive (Fig. 4). During both planting harvesting, laborers are scarce, which often affects the timely planting and harvesting of crops. Farmers sometimes fail to remove weeds before the critical stage of crop-weed competition, which may cause substantial reductions in the ultimate yield. Crop damage also occurs in rice during the post-harvest period owing to dependence on the weather. Improved post-harvest technology can reduce crop loss as well.

4.2. Genetic approaches to the improvement of rice cultivars

Available seeds, fertilizers, irrigation water, and pesticides are the major inputs for rice production. More than 50% of the farmers in Bangladesh use seeds from their own harvest. The Bangladesh Agricultural Development Corporation (BADC), the main government organization in charge of producing and marketing quality seeds, contributes only about 25% of the seeds planted (Hossain *et al.,* 2012). Moreover, the socioeconomic conditions of the farmers of Bangladesh are not stable. Therefore, it is very difficult for small farmers to afford the cost of seeds, fertilizers, pesticides, and irrigation water. The availability of these agricultural inputs is also sometimes restricted in the market.

As mentioned above, high-temperature and drought stresses can be avoided by changing the transplanting date or growth period. Sometimes it is difficult to plant rice at the optimum sowing time owing to lack of water, or excess water in the case of *aman*. As described in section 3.7, multiple stresses occur simultaneously in the field as well. Researchers therefore must create new rice varieties tolerant to multiple stresses.

No rice variety so far developed in Bangladesh can withstand temperature stresses. Spikelet sterility is a common phenomenon in rice cultivation in Bangladesh. It was prevalent in the past but was not rectified. With climate change, high temperature has become a major concern to crop production worldwide. In Bangladesh, temperature influences rice production in all growing seasons (Fig. 1A). Therefore, we need to take necessary action as soon as possible. The development of cold tolerant and high-temperature tolerant rice varieties is recommended.

The researchers at BRRI, BINA, BAU, and DU are working to improve rice cultivars by incorporating tolerance to drought, flood, and salinity. Scientists at BRRI and BINA have developed numerous rice varieties with some tolerance to submergence (BRRI dhan51, BRRI dhan52, Binadhan-11, and Binadhan-12 for *boro*), drought (BRRI dhan55 for *boro*; BRRI dhan42, BRRI dhan43, and BRRI dhan48 for *aus*; BRRI dhan33, BRRI dhan56, and BRRI dhan57 for *aman*), and salinity (BRRI dhan40, BRRI dhan41, BRRI dhan47, Binadhan-8, and Binadhan-10 for *boro* and BRRI dhan53 and BRRI dhan54 for *aman*, Table 1). Some premium rice varieties, such as aromatic rice (BRRI dhan50 for *boro* and BR5, BRRI dhan34, BRRI dhan37, BRRI dhan38, Binadhan-9, and Binadhan-13 for *aman*) and, recently, Zn-enriched rice (BRRI dhan62 for *aman* and BRRI dhan64 for *boro*), have also been developed by the researchers of BRRI by a cross-breeding method using local traditional varieties.

Of the different growing seasons, *boro* gives the highest average yield of 4 t/ha, which is still much lower than those of leading rice-growing countries like Japan and China. We need to increase the yield of *boro*. On the other hand, the water table is depleting and, in the near future, will be a significant threat for *boro* rice cultivation under flooded irrigation conditions. Therefore, we should further introduce drought tolerance in the popular *boro* varieties as well as find new high-yield lines that can tolerate drought. At the same time, we need to introduce low-temperature tolerance for early *boro* and high-temperature tolerance for late *boro*.

Aman is the second largest contributor to total rice production. BR11 is the most popular variety, but it is susceptible to drought and low temperature. A major QTL (quantitative trait locus), *SUB1* (*Submergence tolerence1*), explaining about 70% of phenotypic variation in submergence tolerance, has been identified and fine-mapped onto chromosome 9 in the submergence-tolerant *indica* rice cultivar RF13A (Xu and Mackill, 1996; Nandi *et al*, 1997; Xu *et al*., 2000). The *SUB1* locus has been introduced in popular varieties of southeast Asia by the backcrossing method and marker assisted selection (Neeraja *et al*., 2007, Iftekharuddaula *et al.*, 2011). The *SUB1* gene has been introduced into BR11 and was released as BRRI dhan52 for flood tolerance. This variety is very important for early planting and, by its use, farmers could reduce the cost of replanting and acquire a high yield even with complete submergence for two weeks (Ismail *et al*., 2013). In contrast, in regions in which early planting is not possible owing to lack of rain, late planting is an obvious solution. To overcome the water and low-temperature stress at flowering and maturity, we need to introduce drought and cold tolerance. In this aspect, gene pyramiding is important to overcome multiple stresses.

Enhancement of upland rice cultivation with high yield potential is another important approach to increase rice production. In Bangladesh, some traditional rice varieties are grown in the *aus* season as upland rice, but their yield is very low. We can improve this widely adaptable upland rice by cross-breeding with high-yielding varieties and selection in local field conditions via marker-assisted techniques and by QTL analysis. A survey revealed that many traditional popular varieties are under threat of extinction owing to their lower yield and profitability than those of the improved varieties (Hossain *et al*., 2013). The improvement in the yield potential of upland rice may increase production and reduce its cost.

Besides this, many traditional aromatic rice varieties with fine grain are grown in the *aman* season. This rice has extra value for consumers, but its yield is also very low. If we can incorporate high yield potential in these varieties, it will contribute to increase total rice production as well as meet consumer demand.

Researchers are trying to identify useful traits and use them for the improvement of rice. Recently, iron-enriched rice lines have been identified from local traditional rice varieties (Jahan *et al*., 2013). These iron-rich lines can be utilized in a breeding program, and their use can also reduce malnutrition in Bangladesh. Therefore, these traditional rice varieties are important genetic resources that could be used in breeding for the improvement of rice in Bangladesh.

Further, farmers demand the incorporation of high yield, quality consumption, and early maturity traits in an improved variety (Hossain, 2012). However, when researchers consider improving a variety, they emphasize a particular trait. To meet the demands of farmers, we need to accumulate many desirable traits in a single line. For this purpose, gene pyramiding is an efficient technique that might facilitate the incorporation of multiple desirable characteristics in the same line.

4.3. Strengthening communication between researchers and farmers

The agricultural knowledge and information system integrates agricultural education, farmers, researchers, and extension workers to harness knowledge and information from various sources for better farming and improved livelihood (Kashem, 2013). Strengthening the linkage between research and extension is important to disseminate the available technologies to farmers and also to understand the farmers' demands for technology. The spread of modern varieties has contributed to a growth in rice yield of 2.3% per year over the last three decades, which has helped Bangladesh achieve favorable food security despite high population growth (Hossain, 2006). When researchers are aware of the actual needs of the farmers of a particular region, they can set their research objectives accordingly. In addition, technologies developed by researchers should be transferred efficiently to the farmers through extension workers. Moreover, regional and international cooperation is needed to exchange knowledge and technology to increase rice production in a sustainable manner.

In conclusion, although Bangladesh is self-sufficient in rice production, yield is low. Bangladesh has the potential to boost rice production and export, which can contribute to the national economy. Targeted breeding is essential to accommodate the diverse environments of Bangladesh. The development of more high-yielding, early-maturing, drought-resistant, salt-tolerant, disease-resistant, submergence-resistant, cold-tolerant, high-temperature-tolerant, and nutrient-rich varieties will further boost rice production and nutrition. In addition, proper crop management strategies will enhance rice production.

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