International Journal of Agricultural Technology 2022Vol. 18(5):1961-1972
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Performance of high yielding boro rice varieties in Khagrachhari district of Bangladesh

Gupta, R.[1*], Faruquee, M.[2] and Sarkar, M. J.[3]

[1]Plant Breeding Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh, Bangladesh; [2]Assistant Scientist- Breeding, International Rice Research Institute, Dhaka, Bangladesh; [3]Horticulture Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh, Bangladesh.

Gupta, R., Faruquee, M. and Sarkar, M. J. (2022). Performance of high yielding boro rice varieties in Khagrachhari district of Bangladesh. International Journal of Agricultural Technology 18(5):1961-1972.

Abstract The entire varietal performance including grain quality is a crucial element for sustainable production when recommending a variety for cultivation. The performance of six popular boro rice (*Oryza sativa* L.) varieties was evaluated using yield and growth characteristics to determine which varieties were the top performers. Plant height (PH), days to flowering (DTF), days to maturity (DTM), number of total tillers per hill (NTH), number of effective tillers per hill (ETH), number of non-effective tillers per hill (NETH), panicle length (PL), number of filled grains per plant (FG), number of unfilled grains per plant (UFG), thousand grain-weight (TGW), grain yield (GY), dry straw weight (DSW), and % harvest index (HI) revealed the significant differences among the varieties. Maximum GY was noted in Binadhan-10 (6.72 t/ha) followed by Binadhan-12 (6.64 t/ha), BRRI dhan29 (6.55 t/ha) and these three varieties were significantly identical. For grain characteristics, the highest TGW was found in Binadhan-10 (28.74 g) and the lowest was in Binadhan-12 (16.07 g). Among the varieties, Binadhan-12 is getting popular due to its short grain characteristics and higher GY. Therefore, it should be recommended that in Chattogram Hill Tracts especially in the Khagrachhari districts the variety with short-medium grain characteristics and higher GY is preferable for boro season.

Keywords: Performance, Yield, Growth parameters, HYV, Boro rice

Introduction

Bangladesh's economy is based on agriculture, with rice serving as the country's main staple food, hence the country's high per capita consumption. It

[*] **Corresponding Author:** Gupta, R.; **Email:** rigyan2008@gmail.com

meets the nutritional needs of the average person. Over the course of its long history, rice production in Bangladesh has developed in terms of yield potential, growing practices, and cropping patterns (Shelly *et al*., 2016). The Boro rice system takes advantage of the moisture left over after harvesting Aman/Kharif rice. Water is retained in areas near canals, chaurland / Tal land, Haor, and other similar locations. Due to advances in irrigation facilities, boro rice is now being grown outside of its traditional bounds, and a new cropping pattern is evolving in a few sections of Khagrachhari districts. Boro rice is a photo-insensitive, transplanted rice that helps farmers cultivate a Rabi season crop that they would not otherwise be able to grow. It is grown with supplemental watering over the winter season (Singh, 2002). The development of irrigation facilities in Bangladesh's Khagrachhari districts has resulted in a remarkable growth in boro rice production. The fundamental benefit of growing boro rice is that the winter temperature is lower during the early phases of crop development, allowing photo-synthates to accumulate and carbon:nitrogen to aggregate. The ripening process accelerates as the temperature rises. Differences in yields between boro growing locations are explained by variations in these features. Increased boro rice production both within and outside of its traditional boundaries aided in the adoption of a variety of local cropping patterns, and thus, planting boro rice will help farmers better their economics (Singh, 2002).

Despite the pressures of overcrowding, the country has attained self-sufficiency in rice production (Shelly *et al*., 2016). In Bangladesh, there are three rice-growing seasons: aus, aman, and boro. Boro is a type of irrigated rice that is sown in the dry season from December to early February and harvested between April and June. Previously, boro was produced in very low-lying places with residual water from the rainy season and manually irrigated with surface water during water shortages (Fujita, 2010). Boro rice production has become possible due to the availability of groundwater irrigation via shallow tube wells (STWs) and deep tube wells (DTWs). Since 2000, rice output has increased at a higher rate than population growth, making agriculture a key contributor to Bangladesh's poverty reduction efforts (World Bank, 2016). The Northwestern Region (NW) of Bangladesh produces more than 25% of the country's total rice despite covering just 23.5 % of the country's total land (BBS, 2019), with 40% of the total irrigated area and 30% of the country's net cultivable area (NCA) (BADC, 2015). It has also the greatest average rice production (Mainuddin *et al*., 2019), and the average cropping intensity in this region (205 %) is greater than the national average (194 percent) (BBS, 2019). As a result, growing Boro rice in all parts of Bangladesh is vital, particularly in the Chattogram Hill Tracts (CHT), where it may thrive under the correct

conditions. Bangladesh's population is predicted to grow to 202 million by 2050, up from the current 168 million (Timsina *et al*., 2018). To meet the rising demand for food, an increase in Boro rice yield is required (Mainuddin and Kriby, 2015). For this region and other parts of Bangladesh, irrigation's positive benefits on crop output and agricultural revenue have been well established (Kirby *et al.* 2015). As a result, the government of Bangladesh has made it a national priority to maintain the current growth in irrigated rice production in NW Bangladesh (GED, 2018). Increasing food production from a declining resource base, especially water and land resources, in conjunction with an increasing population, will be a major problem for the country in the future (Mainuddin and Kriby, 2015).

The CHT includes 70% of Bangladesh's hilly terrain and covers 13,18,400 acres (10% of the country's total size), with 90% of the land being sloped (Hossain *et al.*, 2017). For Boro rice cultivation, there was no local cultivar in the complete CHT territories, therefore farmers had to rely on high yielding varieties (HYV) and hybrids. In 2018-19, the total land used for HYV Boro rice cultivation in CHTs areas was 14,912 hectares, with a production of 51,452 MT. The Khagrachhari districts had the most boro rice cultivation areas, with 7013 ha and a total production of 23,974 MT, out of the three CHT districts (BBS, 2019).

BRRI dhan28, BRRI dhan29 and Binadhan-12 are the three most popular varieties in boro seasons of Khagrachhari districts of Bangladesh and in case of low-lying land like Mohalchari upazilla’s of Khagrachhari i.e., the Lake land which is dried in dry season specially in boro season the farmer is used to cultivate the short duration BRRI dhan28, Binadhan-14 and some hybrid varieties. Chowhan *et al.* (2019) reported that, the single seedling performs better than two or three seedling per hill to get the desire yield of the boro varieties.

The performance of the varieties is necessary to pick the best performing varieties and their features. The experiment was carried out to analyze the performance of six common rice (*Oryza sativa* L.) varieties based on yield and growth parameters to identify the best performing varieties appropriate for cultivation in Bangladesh's Khagrachhari area.

Materials and methods

The field experiment was carried out at farmer's field, Anandanagar, Sadar Upazila, Khagrachhari hill district, Bangladesh during the Boro seasons of 2018-19 (December’18 to May’19) following randomized complete block design (RCBD) with four replications. The area is under the agro-ecological

zone (AEZ) 29, i.e., Northern and Eastern hills (Ahmmed *et al*., 2018) which are characterized by low rainfall and temperature in the rabi season (November to February). In this study, six varieties viz., Binadhan-5 (grains are long and slender), Binadhan-10 (grains are medium long and slender), Binadhan-12 (grains are medium short), Binadhan-18 (grains are long and slender), BRRI dhan28 (medium slender grain) and BRRI dhan29 (medium slender grain) were used that covered 208 m^2 (13m ×16m) areas where each plot size was 2×2 m^2. The pre-emergence seeds were sown in the seed bed and 35 days after sowing (DAS) old seedlings were transplanted at in the main field using 2-3 seedlings per hill. The fertilizer was applied following @210-100-150-80-6 kg/ha urea, triple superphosphates (TSP), muriate of potash (MOP), gypsum, and zinc. During the period of final land preparation, the full dose of TSP, MOP, and gypsum was applied and one-third of nitrogen and zinc were applied at 12 (days after transplanting (DAT) and the residual doses of nitrogen were applied in two splits at 40 and 55 DAT. Row to row and plant to plant distance was maintained 20×15 cm. To control initial weeds, pre-emergence weedicide Rifit 500 EC @ 988 mL/ha was applied. Later, two hand weeding was done at 30 and 45 DAT. When the upper soil completely dried and cracked, irrigation was applied. To reduce the stemborer and other systemic insect infestation 10kg of granular Carbofuran-5G per hectare was applied with first-time top dressing of urea. Fungal diseases were checked by applying Amistar Top @500 mL/ha and Nativo 75 wp @1g/L and for controlling sucking/biting type insects Ripcord 10 EC @ /988 mL/ha were applied.

Crops were harvested when 80% of the grains became mature and golden in color. Randomly five competitive plants from each plot were selected and data were recorded on plant height (PH) in cm, number of total tiller per hill (NTH), number of effective tiller per hill (ETH), number of non-effective tiller per hill (NETH), panicle length (PL) in cm, number of filled grain per plant (FG), number of unfilled grain per plant (UFG), thousand grain-weight (TGW), days to maturity (DTM), days to 50% flowering (DTF), grain yield (GY) and dry straw weight (DSW) data were recorded plot basis. Finally, GY and DSW was converted to t/ha, % HI was calculated based on adjusted GY and DSW using the following formula (Munshi *et al.,* 2016)-

$$\text{HI}\ (\%) = \frac{\text{Grains yield}}{\text{Grains yield} + \text{dry straw yield}} \times 100$$

GY was adjusted at 14% moisture content and straw yield at the sun-dry basis (IRRI, 2009).

All the collected data were statistically analyzed by using analysis of variance (ANOVA) technique and comparisons test (significance of mean difference was compared by Tukey Pairwise) by Minitab 17 statistical software (Minitab, 2015).

Results

The performance of different Boro rice varieties for GY and different yield contributing traits were evaluated and showed significant variations among the traits such as plant height (PH), days to 50% flowering (DTF), days to maturity (DTM), number of total tiller per hill (NTH), number of effective tiller per hill (ETH), number of non-effective tiller per plant (NETH), panicle length (PL), number of filled grain per plant (FG), number of unfilled grain per plant (UFG), thousand grain-weight (TGW), grain yield (GY), dry straw weight (DSW), and % harvest index (HI) (Table 1).

The highest PH was observed in Binadhan-5 (115.20 cm) followed by Binadhan-10 (107.25 cm) and there was significant difference in height to other varieties. The medium PH was recorded in Binadhan-12 (94.70 cm) followed by Binadhan-18 (93.50 cm) and BRRI dhan28 (92.25 cm). The lowest PH was observed in BRRI dhan29 (91.25 cm) which was statistically differed from others (Table 2).

It is shown that BRRI dhan29 required maximum DTF (134 days) which was significantly differ from other varieties (Table 2). The second highest DTF was found in Binadhan-18 (130 days) which was significantly differed from other varieties. Binadhan-12 and Binadhan-5 both required medium DTM (126 and 127 days) whereas the minimum DTF were recorded in Binadhan-10 (106 days) followed by BRRI dhan28 (120 days).

It is observed that BRRI dhan29 required maximum DTM (167 days) which was significantly differed from other verities (Table 2). The second highest DTM was found in Binadhan-5 (161) and Binadhan-12 (159) which was significantly differed from other varieties. Binadhan-18 and BRRI dhan28 both required medium DTM (144 and 151) whereas the minimum DTM were recorded in Binadhan-10 (139 days).

Total number of tillers per hill was significantly higher were produced by Binadhan-12 (14.3) and Binadhan-18 (14.1) followed by BRRI dhan28 (13.6), BRRI dhan29 (12.75) and Binadhan-10 (12.65); whereas Binadhan-5 (11.0) gave the lowest NTH. ETH was highest in Binadhan-12 (13.85) followed by BRRI dhan28 (11.65) and lowest in Binadhan-18 (10.00). ETH was lowest in Binadhan-12 (0.45) which was statistically different to the other cultivar/varieties (Table 2). On the other hand, highest number of NETH was

produced by Binadhan-18 (4.10) and then BRRI dhan29 (2.30) followed by BRRI dhan28 (1.95), Binadhan-10 (1.15) and Binadhan-5 (0.80).

The PL (24.35 cm) was found longest in Binadhan-12, which was statistically identical to Binadhan-5 (23.58 cm) and Binadhan-10 (22.96 cm). Shortest length was observed in Binadhan-18 (20.12 cm) followed by BRRI dhan28 (20.90 cm) where both were statistically similar (Table 2). The medium PL was found in BRRI dhan29 (22.27 cm).

FG was highest in Binadhan-12 (1262.75) followed by BRRI dhan29 (1001.50) which were statistically different from others (Table 2). The medium number of filled grains per plant (FG) were found in Binadhan-10 (835.74) and followed by Binadhan-5 (888.13). The lowest FG was found in BRRI dhan28 (693.75) followed by Binadhan-18 (722.50).

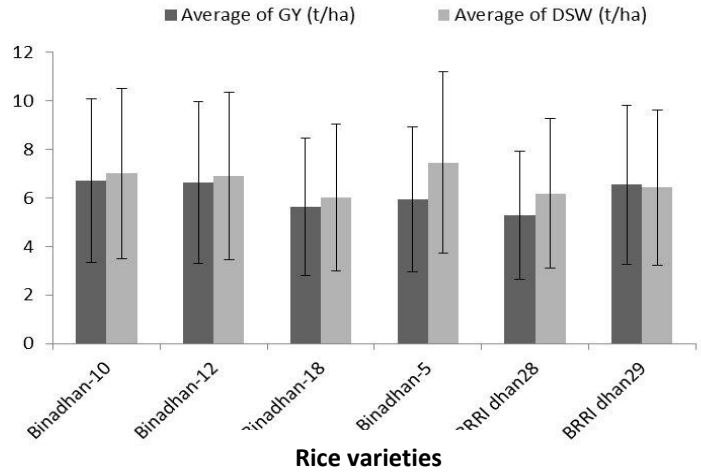

Figure 1. Showing the average GY (t/ha) and average dry straw weight (t/ha) of the rice varieties. Bar indicates mean value ± standard error of means (SEM)

There were significant differences amongst varieties in UFG (Table 1). BRRI dhan28 showed the lowest UFG (160.37) followed by Binadhan-10 (180.83) which both are statistically similar. On the other hand, the highest UFG were found in Binadhan-12 (379.75) followed by Binadhan-5 (347.00) and BRRI dhan29 (288.75). The medium UFG was observed in Binadhan-18 (258.50).

Table 1. Analysis of variance for plant characters of six popular Boro rice varieties

Items	df	PH (cm)	DTF	DTM	NTH (no.)	ETH (no.)	NETH (no.)	PL (cm)	FG (no.)	UFG (no.)	TGW (g)	GY (t/ha)	DSW (t/ha)	HI (%)
Varieties	5	142.64***	233.76***	384.38***	3.58**	6.76***	16.15***	21.54***	27..80***	25.37***	851.58***	31.24***	26.47***	14.43***
Replication	3	1.24	10.20***	9.13***	2.83*	2.45	2.06	1.76	2.36	2.08*	9.02***	5.33**	1.07	2.47
Error	15	4.14***	*	*	2.03*	1.70	1.02	0.97	3.86***	2.85***	2.75***	*	*	*

*, ** and *** indicates significant at 0.05, 0.01 and 0.001 probability, respectively.
Plant height (PH), days to 50% flowering (DTF), days to maturity (DTM), number of total tiller per hill (NTH), number of effective tiller per hill (ETH), number of non-effective tiller per hill (NETH), panicle length (PL), number of filled grain per plant (FG), number of unfilled grain per plant (UFG), thousand grain-weight (TGW), grain yield (GY), dry straw weight (DSW) and % harvest index (HI).

Table 2. Mean performance of six varieties based on different morphological traits related to yield

Varieties	PH (cm)	DTF	DTM	NTH (no.)	ETH (no.)	NETH (no.)	PL (cm)	FG (no.)	UFG (no.)
Binadhan-5	115.20 a	127.50 c	161.00 b	11.05 b	10.25 b	0.80 cd	23.58 ab	888.13 bc	347.00 ab
Binadhan-10	107.25 b	106.25 e	139.00 d	12.65 ab	11.50 b	1.15 bcd	22.96 ab	835.74 cd	180.83 d
Binadhan-12	94.70 c	126.00 c	159.00 b	14.30 a	13.85 a	0.45 d	24.35 a’	1262.75 a	379.75 a
Binadhan-18	93.50 cd	130.75 b	151.00 c	14.10 a	10.00 b	4.10 a	20.12 d	722.50 d	258.50 c
BRRI dhan28	92.25 cd	119.75 d	143.75 c	13.60 ab	11.65 ab	1.95 bc	20.90cd	693.75 d	160.37 d
BRRI dhan29	91.25 d	134.25 a	166.50 a	12.75 ab	10.45 b	2.30 b	22.27 bc	1001.50 b	288.75 bc
P value									
Varieties	0.000	0.000	0.000	0.135	0.012	0.000	0.000	0.000	0.000
Replication	0.738	0.288	0.441	0.233	0.236	0.154	0.188	0.490	0.295
CV (%)	9.82	6.72	7.65	23.32	24.59	106.32	9.51	29.05	41.66
SEM	0.89	0.87	0.95	0.28	0.25	0.17	0.19	23.9	10.2
Mean	99.03	124.08	154.88	13.08	11.28	1.79	22.36	900.70	269.20

The same letter indicates no significant differences and different letter indicates significant differences among the varieties for each traits. Again, plant height (PH), days to 50% flowering (DTF), days to maturity (DTM), number of total tiller per hill (NTH), number of effective tiller per hill (ETH), number of non-effective tiller per hill (NETH), panicle length (PL), number of filled grain per plant (FG) and number of unfilled grain per plant (UFG).

Highest TGW was found in Binadhan-10 (28.74 g) and lowest was in Binadhan-12 (16.07 g). Highest TGW of Binadhan-10 may be due to medium and slender grain and lowest weight of Binadhan-12 may be due to medium short grain, fine structure (Figure 2).

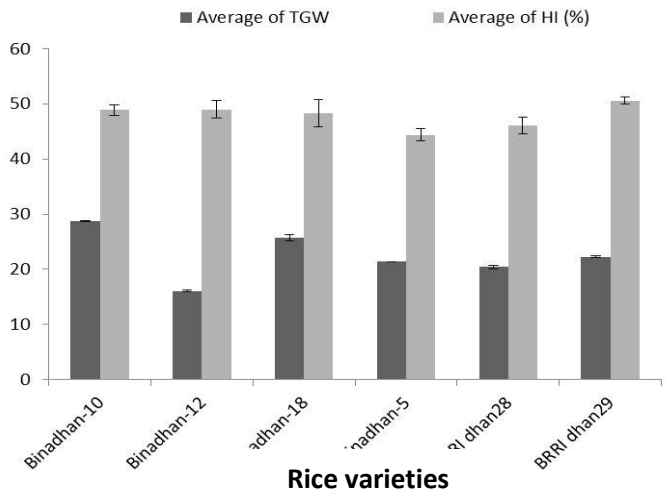

Figure 2. Showing the average thousand grain weight (g) and average harvest index (%) of the rice varieties. Bar indicates mean value ± standard error of means (SEM)

Maximum GY was recorded in Binadhan-10 (6.72 t/ha) followed by Binadhan-12 (6.64 t/ha), BRRI dhan29 (6.55 t/ha) and these three varieties were significantly identical. The lowest GY was found in BRRI dhan28 (5.27 t/ha) which was significantly different from other varieties (Figure 1) and the others were yielded Binadhan-5 (5.95 t/ha) and Binadhan-18 (5.64 t/ha).

Varieties differed significantly in DSW (Table 1). The highest DSW was recorded in Binadhan-5 (7.46 t/ha) which was statistically different from others. Then, the DSW were recorded in Binadhan-10 (7.01 t/ha) and Binadhan-12 (6.91 t/ha) which were both statistically similar (Figure 1). The lowest DSW was found in Binadhan-18 (6.03 t/ha) followed by BRRI dhan28 (6.19 t/ha) and BRRI dhan29 (6.43 t/ha) where three varieties were statistically similar.

BRRI dhan29 had significantly highest HI (%) (50.53) followed by Binadhan-12 (48.97), Binadhan-10 (48.86), Binadhan-18 (48.34) and these four varieties were statistically similar. Binadhan-5 showed significantly lowest harvest index (44.36) followed by BRRI dhan28 (46.07) which were statistically identical (Figure 2).

Discussion

PH is a one of the main growth parameters for any crop and GY production is correlated with this parameter either positively or negatively. It depends on the result of various genetically controlled elements, which is based on the number of internodes and length of internodes characterized by the varieties itself (Rahman *et al*., 2018). So, it may be concluded that the difference in PH is due to varietal genetic characters and the same result was stated by Sarkar *et al*. (2016). When the panicle is fully visible rice is said to be at the 'heading' stage. A day after heading has completed the flowering begins and it can continue even 7 days. A cubic relationship was reported by Ranawake *et al*. (2014) was the DTF on GY where DTF with a minimum and a maximum value which is fitted with the equation. The observation in this study is supported by Ghosh *et al.* (2015) who recorded variation of DTM due to different varieties. Haque *et al.* (2016) reported wide genotypic variation in phenological events among 14 Aus cultivars. The cause of the variability in the number of effective tillers per plant is the diversity in the genetic makeup of the variety. Varietal variation affected the quantity of tillers which is similar result found by Ramasamy *et al.* (1987).

Tillering ability is heavily influenced by rice GY. Less tillers produced fewer panicles, whereas higher number of tillers produces high tiller mortality, undersized panicles, poor grain filling, and thereby reduced GY (Peng *et al.*, 1994). ETH is one of the most important yield components, which determined by the number of panicles bearing tillers per unit area (Roy *et al.*, 2014). Jisan *et al.* (2014) established that, deviation in the NTH might be due to varietal characters. PL is different among the varieties because it is genetically controlled, and some variations were found in nature due to environmental variations. This result is reliable with results of Sarkar *et al.* (2016) who stated that PL significantly different among varieties. The differences in grain filling may have ensued due to genetic, environmental, or implemented cultural management practices. Dutta *et al.* (2002) perceived that yield was affected by the FG. Kiani and Nematzadeh (2012) reported that FG significantly correlated with GY. Sarkar *et al*. (2016) observed that number of FG due to variety influenced significantly. Sohel *et al.* (2009) reported that variation in spikelet sterility different significantly by variety and plant spacing. Roy *et al.* (2014) studied on 12 rice varieties and found difference in TGW due to morphological and varietal variation. Mondal *et al.* (2005) reported that TGW varied significantly among the 17 Aman cultivars studied. Dutta *et al.* (2002) reported that yield was affected by the FG. FG correlated significantly with GY which was reported by Kiani and Nematzadeh (2012). Due to varietal difference the

yields of the varieties were different from each other (Biswas *et al.*, 1998). Although, the genotype Binadhan-12 contributed 6.64 t/ha GY due to its grain characteristics i.e., short grain which TGW is 16.07g only that's why these variety is getting popularity day by day in Khagrachhari districts of Bangladesh.

PH and tiller number may have direct effect on the accumulation of biomass such as DSW. Pheloung and Siddique (1991) stated that straw yield could be dispersed to PH. DSW differed significantly due to varieties (Sarkar *et al*., 2016). Dry matter partitioning to economic yield was superior in BRRI dhan29 compared to the other varieties. Kusutani *et al.* (2000) reported the impact of high % HI to yields. Miah *et al.* (1990) observed that high yield is firmed by the physiological process which leading to a high net accumulation of photosynthates and dry matter partitioning. Jisan *et al.* (2014) highlighted that % HI is significant influenced by variety.

From the performance among the six varieties, it might be established that Binadhan-10, Binadhan-12 and BRRI dhan29 were the best performing varieties based on GY performance and Binadhan-12 is getting popularity due to its short grain characteristics and higher GY. Therefore, in Chattogram Hill Tracts (CHT) especially in the Khagrachhari district of Bangladesh for recommending varieties for cultivation should have the short-medium grain, higher GY and better harvest index and these indicated traits are recommended for further GY improvement.

Acknowledgements

The authors would like to express sincere appreciation and gratitude to Mr. Ongkio Marma, Field Man, BINA Sub-station, Khagrachari and Mr. Dolan Kanthi Mallick, Sub Assistant Agriculture Officer of the Department of Agricultural Extension, Sadar, Khagrachhari, Bangladesh for their helpful cooperation throughout the entire research work which was funded by Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh.

References

Ahmmed, S., Jahiruddin, M., Sultana, R., Begum, R. A., Biswas, J. C., Rahman, A. S. M. M. (2018). Fertilizer Recommendation Guide-2018. ISBN: 984-500-029-1, Bangladesh Agricultural Research Council (BARC), Farmgate, Dhaka, 1215:01-223.

BADC (2015). Minor Irrigation Survey Report 2014-15. Bangladesh Agricultural Development Corporation (BADC), Ministry of Agriculture, Government of the People's Republic of Bangladesh.

BBS (Bangladesh Bureau of Statistics) (2019). Bangladesh Bureau of Statistics. Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh. Retried from http://www.bbs.gov.bd/site/page/453af260-6aea-4331-b4a5-7b66fe63ba61/Agriculture

Biswas, J. K., Hossain, M. A., Sarker, B. C., Hassan, M. and Haque, M. Z. (1998). Yield performance of several rice varieties seeded directly as late aman crops. Bangladesh Journal of Life Science, 10:47-52.

Chowhan, S., Imdadul Hoque, M., Rani Ghosh, S., Islam, M. and Babul Akter, M. (2019). Effect of Variety and Seedling Number on the Growth and Yield of Boro Rice in Bangladesh. Journal of Experimental Agriculture International, 41:1-15.

Dutta, R. K., Mia, M. A. B. and Khanam, S. (2002). Plant architecture and growth characteristics of fine grain and aromatic rices and their relation with GY. International Rice Communication & Newsletter, 51:51-56.

Fujita, K. (2010). Re-thinking Economic Development. The Green Revolution, Agrarian Structure and Transformation in Bangladesh. Kyoto University Press, Kyoto, Japan.

GED (General Economics Division). (2018). Bangladesh Delta Plan 2100 (Abridged Version). Bangladesh Planning Commission, Government of the People's Republic of Bangladesh. Retried from https://oldweb.lged.gov.bd/UploadedDocument/UnitPublication/1/756/BDP%202100%20Abridged%20Version%20English.pdf

Ghosh, U. K., Khan, A. R. and Karim, M. A. (2015). Growth performance of aus rice varieties under rainfed condition. International Journal of Advanced Multidisciplinary Research, 2:29-35.

Haque, K. M. S., Karim, M. A., Bari, M. N. and Islam, M. R. (2016). Genotypic variation in the effect of drought stress on phenology, morphology and yield of aus rice. International Journal of Bioscience, 8:73-82.

Hossain, M. A., Jashimuddin, M., Nath, T. K. and O'Reilly, P. (2017). Spiny coriander (*Eryngium foetidum* L.) cultivation in the Chittagong Hill Tracts of Bangladesh: Sustainable agricultural innovation by indigenous communities. Indian Journal of Traditional Knowledge, 16:59-67.

IRRI (2009). How much water does rice need? Rice Today. International Rice Research, 8:28-29. http://books.irri.org/RT8_1_content.pdf

Jisan, M. T., Paul, S. K. and Salim, M. (2014). Yield performance of some transplant aman rice varieties as influenced by different levels of nitrogen. Journal of Bangladesh Agricultural University, 12:321-324.

Kiani, G. and Nematzadeh, G. (2012). Correlation and path coefficient studies in F2 populations of rice. Notulae Scientia Biologicae, 4:124-127.

Kirby, M., Ahmad, M. D., Mainuddin, M., Palash, W., Qadir, M. E., Shah-Newaz, S. M. (2015). The impact of irrigation development on regional groundwater resources in Bangladesh. Agricultural Water Management, 159:264-276.

Kusutani, A., Tovata, M., Asanuma, K. and Cui, J. (2000). Studies on the varietal differences of harvest index and morphological characteristics of rice. Japanese Journal of Crop Science, 69:359-364.

Mainuddin, M. and Kirby, M. (2015). National food security of Bangladesh to 2050. Food Security, 7:633-646.

Mainuddin, M., Alam, M. M., Maniruzzaman, M., Islam, M. T., Kabir, M. J. and Hasan, M. (2019). Irrigated agriculture in the northwest region of Bangladesh. CSIRO, Australia. Retried from https://dsi4mtf.usq.edu.au/wp-content/uploads/2019/09/No-18-CSIRO-DSI4MTF-BD-Final-Report_Final_Standard.pdf

Miah, M. H. N., Karim, M. A., Rahman, M. S. and Islam, M. S. (1990). Performance of Nizersail mutants under different row spacing. Bangladesh Journal of Training and Development, 3:31-34.

Minitab, I. (2015). Minitab Statistical Software, Release 17. Pennsylvania: State College.

Mondal, M. M. A., Islam, A. F. M. S. and Siddique, M. A. (2005). Performance of 17 modern transplant aman cultivar in the north region of Bangladesh. Bangladesh Journal of Crop Science, 16:23-29.

Munshi, M. K., Mazumder, S. H., Hossain, M. F., Rahman, M., Salim, M. and Paul, S. K. (2016). Effect of different growth factors on transplant Aman rice cv. Brri dhan51 during harvest. International Journal of Agriculture and Crop Sciences, 9:24-32.

Peng, S., Khush, G. S., Cassman and K. G. (1994). Evaluation of a new plant ideotype for increased yield potential. P.5-20 K.G. Cassman (Ed.), Breaking the Yield Barrier: Proceedings of a Workshop on rice Yield Potential in Favorable Environments, Los Banos, Philippines. 29 Nov-4 Dec. 1994, International Rice Research Institute, Los Banos, Philippines.

Pheloung, P. C. and Siddique, K. H. M. (1991). Contribution of system dry matter to GY in wheat cultivars. Australian Journal of Plant Physiology, 18:53-64.

Rahman, S., Jahan, T., Rahman, S. M. M., Rahman, M., Haque, M. M. and Khan, M. A. A. (2018). Evaluation of Some Transplanted AUS Rice Genotypes for Morphology, Yield and Disease Incidence. European Academic Research. p.295.

Ramasamy, S., Chandrasekaran, B. and Sankaran, S. (1987). Effect of spacing and seedlings hill-1on rice yield. International Rice Research, Newsletter, IRRI, Philippines, 12:49.

Ranawake, L., Amarasinghe, U., Hewage, M. J. and Pradeepika, N. G. J. (2014). Effect of Days to Flowering on Plant Height and Yield of Rice (*Oryza sativa* L.). International Journal of Plant & Soil Science, 3:1143-1152.

Roy, S. K., Ali, M. Y., Jahan, M. S., Saha, U. K., Ahmad-Hamdani, M. S., Hasan, M. M. and Alam, M. A. (2014). Evaluation of growth and yield attributing characteristics of indigenous Boro rice varieties. Life Science Journal, 11:122-126.

Sarkar, S. C., Akter, M., Islam, M. R. and Haque, M. M. (2016). Performance of Five Selected Hybrid Rice Varieties in Aman Season. Journal of Plant Sciences, 4:72-79.

Shelly, I. J., Nosaka, M. T., Nakata, M. K., Haque, M. S., Inukai, Y. (2016). Rice Cultivation in Bangladesh: Present Scenario, Problems, and Prospects. Journal of International Cooperation for Agricultural Development, 14:20-29.

Singh, U. P. (2002). Boro Rice in Eastern India. Rice-Wheat Consortium Regional Technical Coordination Committee Meeting. 10-14 February 2002. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Sohel, M. A. T., Siddique, M. A. B., Asaduzzaman, M., Alam, M. N. and Karim, M. M. (2009). Varietal performance of transplant aman rice under differnt hill densities. Bangladesh Journal of Agricultural Research, 34:33-39.

Timsina, J., Wolf, J., Guilpart, N., van Bussel, L. G. J, Grassini, P. and van Wart, J. (2018). Can Bangladesh produce enough cereals to meet future demand? Agricultural System, 163: 36-44.

World Bank (2016). Dynamics of rural growth in Bangladesh: Sustaining Poverty Reduction.

(Received: 27 October 2021, accepted: 30 June 2022)