New Zealand Journal of Crop and Horticultural Science

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tnzc20

Comparative analysis of growth, yield and nutrient content in six rice varieties under slightly saline conditions in southwest coastal Bangladesh

Syed Sazidul Islam, Md. Rakib Hasan, Md. Tangimul Islam, Monowara Khatun & Md. Yamin Kabir

NEW ZEALAND JOURNAL OF CROP AND HORTICULTURAL SCIENCE
https://doi.org/10.1080/01140671.2025.2454609

RESEARCH ARTICLE

Comparative analysis of growth, yield and nutrient content in six rice varieties under slightly saline conditions in southwest coastal Bangladesh

Syed Sazidul Islam [a], Md. Rakib Hasan [a], Md. Tangimul Islam [b], Monowara Khatun [a] and Md. Yamin Kabir [c]

[a]Soil, Water and Environment Discipline, Khulna University, Khulna, Bangladesh; [b]Biotechnology and Genetic Engineering Discipline, Khulna University, Khulna, Bangladesh; [c]Agrotechnology Discipline, Khulna University, Khulna, Bangladesh

ABSTRACT

Considering the threats of climate change to rice production in Bangladesh, one of the most climate-vulnerable countries, initiatives to boost rice production and improve grain nutrition are crucial. To identify the best rice variety, a field experiment was conducted with a Randomised Complete Block Design in slightly saline soil from December 2019 to April 2020. Six rice varieties (*Black rice, Violet rice, BRRI dhan47, BRRI dhan28, BRRI dhan67 and Hybrid Hera dhan-6*) were tested to evaluate growth, yield and nutrient content. *Black rice* was the tallest one; however, it produced the lowest tillers, leaves and shoots dry weight. Conversely, *Hybrid Heradhan-6* was one of the shortest varieties and produced the highest tiller number and shoot dry weight. *Hybrid Hera dhan-6* also yielded a higher grain yield, biological yield and harvest index and *Black rice* did the opposite. There was a negative linear relationship of plant height with tiller number and shoot dry weight and tiller number and biological yield served as the major contributors to the grain yield. *Hybrid Hera dhan-6* also extracted the maximum amount of P and K. Therefore, *Hybrid Hera dhan-6* was the best rice variety in terms of growth, yield and nutrient uptake.

ARTICLE HISTORY
Received 17 August 2024
Accepted 9 December 2024

KEYWORDS
Black rice; *Violet rice*; *Hybrid Hera dhan-6*; tiller number; biological yield; food security

Introduction

Rice (*Oryza sativa* L.) is a vital grain crop that serves as the principal calorie supplier for more than 50% of the world's population, particularly in Asia (Adenle et al. 2019). In Bangladesh, rice is a strategic commodity as it is crucial for food security, income, employment and socio-political stability (Salam et al. 2019). Food security in Bangladesh largely depends on rice as it provides 70% calories and 58% protein for its people (BBS 2019). Rice covers about three-fourths of the cultivable land in Bangladesh and contributes 46% to the agricultural gross domestic product (GDP) and 5% to the overall GDP of the country (BER 2019, 2023). Bangladesh produces rice in three seasons e.g. *Aus*, *Aman*,

CONTACT Md. Yamin Kabir kabiryamin@gmail.com; yaminkabir@ku.ac.bd
Supplemental data for this article can be accessed online at https://doi.org/10.1080/01140671.2025.2454609.

and *Boro* in a year and ranks third among the rice-producing countries in the world. The total rice production was 41.57 million metric tons in 2022–2023, with the contribution of 3.69, 16.35 and 21.53 million metric tons from *Aus*, *Aman* and *Boro* seasons, respectively (BER 2023) indicating the dominance of *Boro* rice. Farmers are increasingly motivated to cultivate *Boro* rice due to its shorter duration and higher profitability compared to *Aus* and *Aman* rice (Mainuddin et al. 2021). Over the last decade, rice production particularly *Boro rice* has increased (BER 2023). However, Bangladesh is a small country with an area of 148,460 square kilometres and it inhabits more than 174.4 million people as of 24 November 2024 (https://www.worldometers.info/world-population/bangladesh-population/). Although rice production has been increased, it is not sufficient and Bangladesh imports rice to support domestic demand and stabilise market prices (USDA 2021). Moreover, there are diverse environmental and socio-economic challenges that pose a risk to rice availability in the country (Jamal et al. 2022).

Southwest coastal Bangladesh is facing challenges like salinity intrusion, poor drainage, flood, cyclone, water stagnation and atypical rainfall pattern for rice production (Kabir and Golder 2017). Moreover, rice production in coastal areas has been affected by drought, sea-level rise, waterlogging and unfertile land formation (Islam and Hossain 2020). Therefore, resilient rice production is required to ensure food security (Mondal et al. 2019). Although there is limited or no scope to increase the area under rice cultivation, rice production must be increased to meet the increasing demand. It is predicted that Bangladesh will require >47 million tons of rice for 215 million people in 2050 and the Government of Bangladesh declared 'Rice Vision 2050' for ensuring resilient rice production (BDP 2018). However, rice production has been hindered by diversified environmental (rising temperature, irregular rainfall, salinity, flood, cyclone, water logging, drought, freshwater scarcity and drawdown groundwater) and socio-economic (increasing population, decreasing cultivable land, small farms, low adaptive capacity, consumer behaviour, price fluctuations and labour shortage) challenges (Jamal et al. 2023). To overcome these challenges, strategies such as increasing yield, increasing area under rice cultivation, decreasing yield gap, adapting hybrid/high yielding varieties, stabilise input prices and stabilise the rice market are required (Jamal et al. 2023). Bangladesh has to ensure required rice production through growing high-yielding varieties, adopting improved cultural practices, land reclamation and boosting cropping intensity (Golder et al. 2014). In Batiaghata Upazila (southwestern part of Bangladesh) of Khulna, farmers used to cultivate hybrid and local varieties as well as IRRI- and BRRI-developed rice varieties. However, the production of cultivated varieties is not satisfactory due to climate change, decreased pest resistance, the emergence of new pests and salinity (Alotaibi 2023). To overcome this issue, farmers started cultivating new varieties. Among them, the performance of six rice varieties, e.g. *Black rice*, *Violet rice*, *BRRI dhan28*, *BRRI dhan47*, *BRRI dhan67* and *Hybrid Hera dhan-6* has been evaluated. Although there is plenty of research information available on the particular rice varieties, there is limited documentation on the comparative study of growth and yield attributes along with the nutrient content of these rice varieties during the *Boro* season in the coastal area of Bangladesh. Therefore, this study aimed to compare the growth, yield, and nutrient content of six selected rice varieties in the southwest coastal area of Bangladesh.

Materials and methods

Field selection and soil analysis

The experiment was conducted from December 2019 to April 2020 at Batiaghata (south-western coastal area) of Bangladesh, with GPS coordinates of 22°43′49.4″ N and 89° 28′00.5″E (Figure 1). The soil samples were collected from the field for analysis before tillage. The samples were air-dried, ground and sieved using a 2 mm sieve. Soil properties including texture (Gee and Bauder 1986), pH (Jackson 1973), EC (Allison and Richards 1954), soil organic carbon (Walkley and Black 1934), available phosphorus (Olsen 1954), available sulphur (Hunt 1980) and exchangeable sodium and potassium (Benton 2001) were determined in the laboratory of Khulna University (https://ku.ac.bd/), Bangladesh.

Experimental design and cultural practices

Six rice varieties, namely *BRRI dhan28*, *Black rice*, *Violet rice*, *BRRI dhan47*, *BRRI dhan67* and *Hybrid Hera dhan-6,* were put to test in the experiment. *BRRI dhan28* has been cultivated in this area for the past few years and *Black rice* and *Violet rice* were selected for their high nutritional content. Seeds of *BRRI dhan28*, *BRRI dhan47* and *BRRI dhan67* were obtained from BADC, Khulna (https://badc.gov.bd/). Seeds of *Hybrid Hera dhan-6* (Supreme Seed Company, Bangladesh) were sourced from the market and *Black rice*

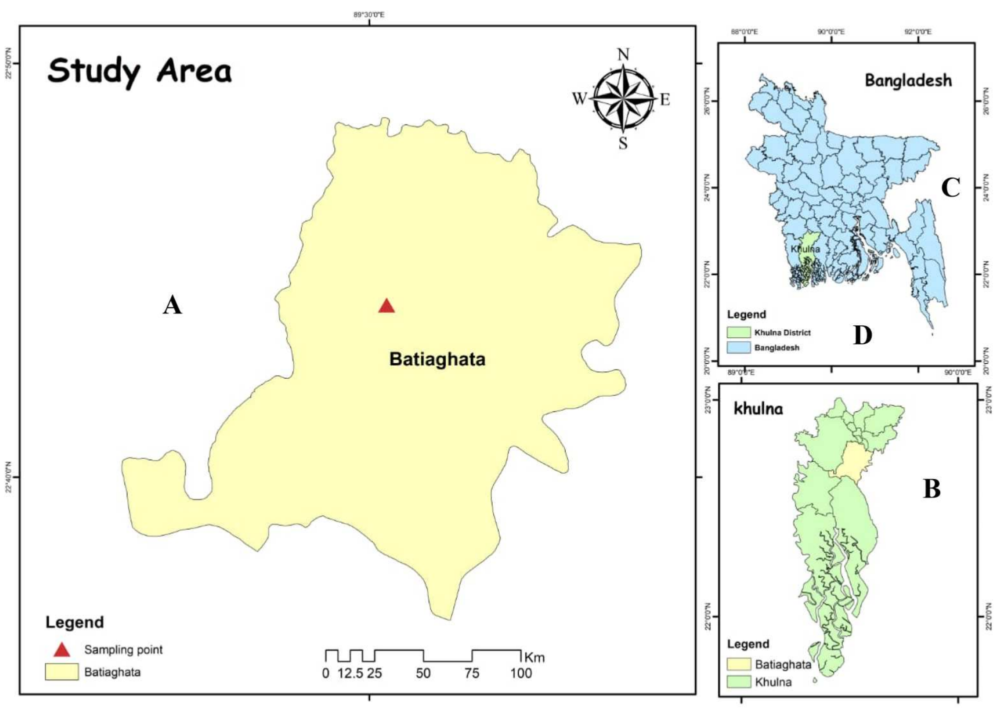

Figure. 1. Map of the study area pointing to the location of the study field at Batiaghata **A**, Khulna of Bangladesh. The red triangle shows the exact location of the study area at Batiaghata (yellow) which is also shown within the map of Khulna **B** and the location of Khulna is also depicted within Bangladesh map **C**. The Bay of Bengal (part of the Indian Ocean) is located to the south of Bangladesh **D**.

and *Violet rice* from a farmer of Batiaghata. *Black rice* is named after its black grain (S1) which is rich in proteins, vitamins and minerals (Fe, Zn, Mn and P) (Suzuki et al. 2004) and contains higher minerals compared to white rice (Zhang 2000). The deep purple colour of *Black rice* is due to the presence of high anthocyanin in the pericarp of the seed (Ichikawa et al. 2001). The plant of the *Violet rice* is purple/violet with white grain (S1). This variety has been cultivated in the Sherpur district of Bangladesh. According to the farmers, this is *Boro* rice that requires relatively less amount of fertiliser. *Hybrid Hera dhan-6* is a high-yielding hybrid *Boro* rice and is marketed by the Supreme Seed Company (https://supremeseed.net/product/hybrid-hera-dhan-6/). *BRRI dhan28, BRRI dhan47 and BRRI dhan67* are high-yielding varieties released by Bangladesh Rice Research Institute (BRRI) (https://brri.gov.bd/). *BRRI dhan28* is a popular variety in southern Bangladesh and *BRRI dhan47* and *BRRI dhan67* are salt tolerant to some extent (http://krishi.gov.bd/variety/28; http://krishi.gov.bd/variety/32). First, rice seeds were carefully cleaned in fresh water, soaked in a gunny bag for a whole day and then allowed to sprout. Sprouted seeds were sown in the seed beds and one-month-old seedlings were transplanted in the field maintaining a 20 cm spacing between rows and 15 cm spacing between plants following a Randomised Complete Block Design where the varieties were replicated thrice. The unit plot was 12 m^2 (4 m × 3 m), with a 50 cm gap between plots.

Each experimental plot was treated with N, P and K at a recommended rate (120, 70 and 30 kg ha^{-1} respectively), with N (source: urea) administered in three stages [during tillage, 35 days after transplanting (DAT) and 80 DAT] and the other nutrients were applied twice (during tillage and at 80 DAT). Intercultural operations and pest control were carried out as per requirement. The field remained submerged with 3–8 cm of standing water until one week of harvesting.

Measurements of growth and yield attributes

Plant growth attributes (height, number of tillers and leaves and area of leaf) were measured during growth [30, 60 and 90 days after transplanting (DAT)] and at harvest. From each plot, five plants were selected at random and their heights were measured using a scale. The tiller number and leaf number were counted manually and the area of the leaf was estimated by multiplying the leaf length by the leaf width (mean of three estimations). The plants were harvested when the grains matured and approximately 90% got ripened. Yield attributes such as panicle no. $hill^{-1}$, panicle length (cm), filled, unfilled and total grain $panicle^{-1}$, 1000 grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (HI) were calculated at harvest from randomly selected three plants for every plot.

The grains were threshed, cleaned and counted to determine the grain number (filled-, unfilled- and total grains). Thousand-grain weight was determined at 13–14% moisture. Biological yield and shoot dry weight were also calculated. Grain yield (GY) and straw yield (SY) along with harvest index (HI) were estimated as follows.

$$\text{Grain/straw yield}(\text{t ha}^{-1}) = \frac{\text{GY or SY}\left(\frac{\text{kg}}{\text{m}^2}\right) \times 10,000}{1000} \quad (1)$$

$$HI(\%) = \frac{\text{Grain yield}}{\text{Grain yield} + \text{straw yield}} \times 100 \quad (2)$$

Grain nutrient analysis

To assess grain nutrient content, clean grains were dried in an oven at 60°C for 24 hours, ground and sieved. Total nitrogen (N) was estimated using the micro-Kjeldahl method (Jackson 1973). To determine potassium (K), phosphorus (P), sulphur (S) and sodium (Na), powdered specimens were digested in an acid mixture (HNO_3: $HClO_4$:: 2: 1) (Jackson 1973). Total P and S were determined following Murphy and Riley (1962) and Hunt (1980) methods, respectively and K and Na were determined following the Benton (2001) method. The grain nutrient uptake was calculated using the following formula.

$$\text{Grain nutrient uptake}(\text{kg ha}^{-1}) = \frac{\text{Nutrient content in grain } (\%) \times \text{Grain weight}\left(\frac{\text{kg}}{\text{ha}}\right)}{100} \quad (3)$$

Statistical analyses

Data were analysed following One-way analysis of variance (ANOVA) and F Test by the statistical software IBM SPSS Statistics for Windows (Version 26.0.0.0) [IBM Corp. (2020), Armonk, NY, USA]. The means were separated by the same statistical package with Tukey's HSD Test at a 5% level of probability. The figures have been constructed using MS Excel (Microsoft Office 2016).

Results

Soil and climate of the study area

The soil was silty clay loam having 0.78% organic carbon, 6.70 pH and 3.73 dS/m EC (Table 1) indicating the slight saline nature of the soil. The available N, P, K, S and Na

Table 1. Physicochemical properties of the studied soil.

Properties	**Values**[a]
Texture	Silty clay loam
Soil organic carbon (%)	0.78 ± 0.03
pH	6.7 ± 0.00
EC (dS/m)	3.73 ± 0.17
Available N (ppm)	41.46 ± 3.66
Available P (ppm)	21.17 ± 1.67
Available K (ppm)	311.12 ± 29.54
Available S (ppm)	31.37 ± 5.06
Available Na (ppm)	1427.10 ± 52.39

[a]The numerical values are the mean ± standard deviation of three measurements.

contents of the soil were 41.46, 21.17, 311.12, 31.37 and 1427.10 ppm, respectively (Table 1). During the study period (18 December 2019–30 April 2020), the morning (9:00 HR) minimum temperatures ranged from 6.50 to 27.30°C with a mean of 17.62°C and the evening (18:00 HR) maximum temperatures ranged from 19.00 to 37.00°C with a mean of 28.93°C (Figure 2). Similarly, the morning relative humidity (RH) varied from 42 to 100% with a mean of 74.62% and the evening RH varied from 35% to 98% with a mean of 61.68% (Figure 2). It rained 18 days out of 135 days and a total of 221 mm rainfall was recorded during the growing period and most of the rainfall (179 mm) occurred in April, particularly in the last week of the month (Figure 2).

Growth attributes of rice

Growth attributes of rice varied significantly on different days after transplanting (DAT) and at harvest. At 90 DAT, the tallest plant (114.89 cm) was recorded from *Black rice* preceded by *BRRI dhan67* (108.44 cm), *BRRI dhan28* (99.44 cm) and the shortest one from *Hybrid Hera dhan-6* (92.67 cm). At harvest, *Black rice* and *Violet rice* were the tallest (119.33 cm) and shortest (99.50 cm) rice plants, respectively (Table 2). *Hybrid Hera dhan-6* displayed the highest number of tillers (40.66) and the lowest number of tillers

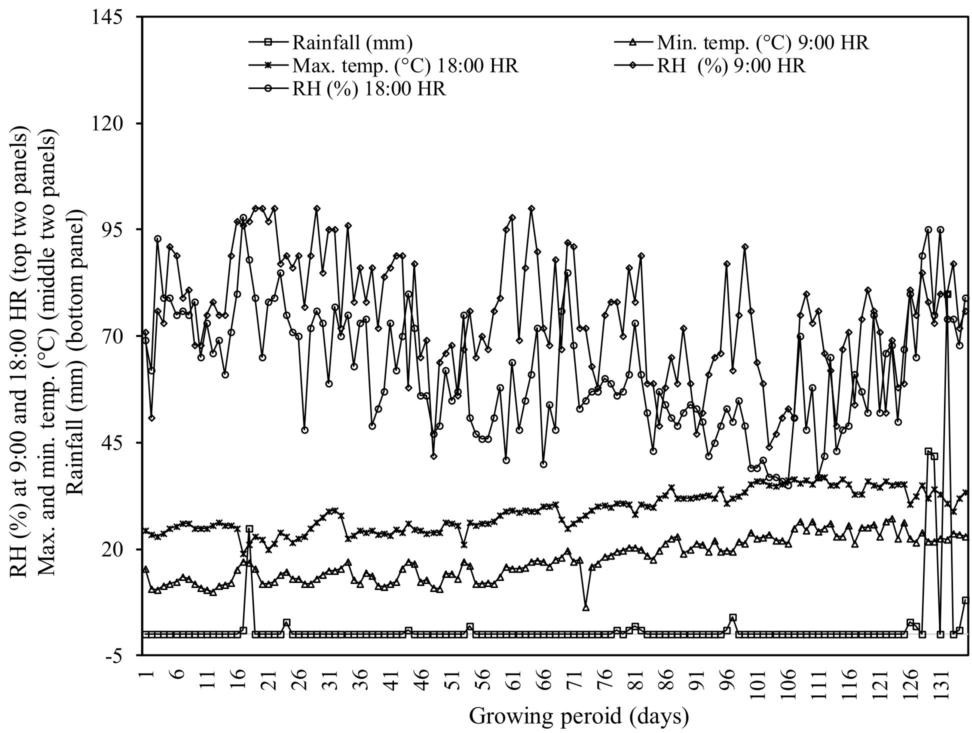

Figure. 2. Daily relative humidity (RH, %) at 9:00 and 18:00 HR (top two panels), minimal and maximal temperatures (°C) at 9:00 and 18:00 HR (local time, time zone: UTC + 6 HR), respectively (middle two panels), and daily rainfall (mm) (bottom panel) during the period of the experiment (18 December 2019–30 April 2020; the total growing period 135 days). Weather data were collected from Khulna Meteorological Station, the nearest weather station to the experimental site.

Table 2. Plant height of rice is affected by varieties on different days after transplanting (DAT).

Variety	[a]Plant height (cm)			
	30 DAT	60 DAT	90 DAT	At Harvest
Black rice	41.43 ± 2.90a	78.44 ± 1.54a	114.89 ± 3.22a	119.33 ± 9.09a
BRRI dhan47	31.60 ± 0.61b	70.22 ± 2.31b	99.22 ± 1.78c	111.17 ± 2.71b
Violet rice	31.73 ± 1.28b	73.11 ± 2.42ab	95.78 ± 1.18cd	99.50 ± 1.64d
BRRI dhan28	28.31 ± 1.47bc	59.78 ± 1.79c	99.44 ± 1.17c	103.17 ± 3.60cd
BRRI dhan67	31.18 ± 2.75b	68.22 ± 2.02b	108.44 ± 3.32b	108.00 ± 5.55bc
Hybrid Hera dhan-6	24.14 ± 0.94c	61.22 ± 1.75c	92.67 ± 2.15d	102.50 ± 7.40cd
p	<0.01	<0.01	<0.01	<0.01

[a]The value represents the mean (average of six measurements) ± SE (standard error). In each column, values not sharing the same letter(s) differ significantly at $p < 0.05$.

Table 3. The number of tillers per hill of rice as affected by varieties on different days after transplanting (DAT).

Variety	[a]Tiller $Hill^{-1}$			
	30 DAT	60 DAT	90 DAT	At Harvest
Black rice	2.25 ± 0.25	9.89 ± 0.35a	16.00 ± 1.34a	26.67 ± 2.94c
BRRI dhan47	2.25 ± 0.25	6.67 ± 0.73b	13.56 ± 1.04abc	28.17 ± 3.66bc
Violet rice	2.08 ± 0.08	7.44 ± 0.69b	11.00 ± 0.85c	30.16 ± 4.93bc
BRRI dhan28	2.25 ± 0.25	9.67 ± 0.50a	15.22 ± 1.35ab	33.30 ± 5.19b
BRRI dhan67	2.25 ± 0.25	9.56 ± 0.88a	14.00 ± 0.88abc	39.17 ± 4.83a
Hybrid Hera dhan-6	2.00 ± 0.00	7.33 ± 0.53b	12.00 ± 0.78bc	40.66 ± 5.54a
P	0.914	<0.01	0.016	<0.01

[a]The value represents the mean (average of six measurements) ± SE (standard error). In each column, values not sharing the same letter(s) differ significantly at $p < 0.05$.

obtained from *Black rice* (26.67) at harvest (Table 3). Leaf number per hill also varied significantly among the kinds of rice; the highest leaf number per hill (107.83) was obtained from *BRRI dhan47* and the lowest from *Black rice* (55.0) at harvest (Table 4). Similarly, the largest leaf area (46.24 cm^2) was measured for *BRRI dhan47* which was statistically similar to *Violet rice* (44.47 cm^2) and the smallest leaf area (32.18 cm^2) was recorded from *Hybrid Hera dhan-6* (Table 5). *Hybrid Hera dhan-6* resulted in the highest shoot fresh weight (334.65 g $hill^{-1}$) and shoot dry weight (104.91 g $hill^{-1}$) and lowest shoot fresh weight (232.65 g $hill^{-1}$) and shoot dry weight (72.93 g $hill^{-1}$) were obtained from *Black rice* (Figure 3). Plant height showed a negative linear relationship

Table 4. The number of leaves per hill of rice as affected by varieties on different days after transplanting (DAT).

Variety	[a]Leaf $hill^{-1}$			
	30 DAT	60 DAT	90 DAT	At Harvest
Black rice	5.33 ± 0.80b	28.11 ± 1.24	69.22 ± 6.42a	55.00 ± 6.72b
BRRI dhan47	3.91 ± 0.21b	22.00 ± 2.29	56.89 ± 4.93ab	107.83 ± 20.74a
Violet rice	7.42 ± 0.55a	25.44 ± 2.26	49.56 ± 4.66b	60.50 ± 13.07b
BRRI dhan28	7.17 ± 0.91a	28.67 ± 2.16	62.33 ± 3.67ab	102.67 ± 10.80a
BRRI dhan67	5.25 ± 0.63b	26.67 ± 2.41	70.78 ± 2.66a	98.50 ± 14.34a
Hybrid Hera dhan-6	3.75 ± 0.16b	22.11 ± 1.59	53.11 ± 4.59b	73.17 ± 20.98b
p	<0.01	0.233	<0.01	<0.01

[a]The value represents the mean (average of six measurements) ± SE (standard error). In each column, values not sharing the same letter(s) differ significantly at $p < 0.05$.

Table 5. The leaf area of rice is affected by varieties on different days after transplanting (DAT).

Variety	[a]Leaf area (cm^2)			
	30 DAT	60 DAT	90 DAT	At Harvest
Black rice	16.85 ± 2.39a	40.53 ± 1.27b	38.22 ± 2.44b	35.87 ± 3.40bc
BRRI dhan47	8.77 ± 0.51b	38.92 ± 1.56b	48.82 ± 3.19a	46.24 ± 5.20a
Violet rice	8.56 ± 0.57b	45.10 ± 1.26a	47.31 ± 2.97a	44.47 ± 4.68a
BRRI dhan28	6.77 ± 1.35b	38.40 ± 0.85b	31.94 ± 1.50b	34.42 ± 3.77bc
BRRI dhan67	8.18 ± 1.77b	41.36 ± 1.48b	46.99 ± 2.63a	38.57 ± 3.68b
Hybrid Hera dhan-6	5.00 ± 0.26b	26.95 ± 0.75c	39.25 ± 2.79b	32.18 ± 2.15c
P	<0.01	<0.01	<0.01	<0.01

[a]The value represents the mean (average of six measurements) ± SE (standard error). In each column, values not sharing the same letter(s) differ significantly at $p < 0.05$.

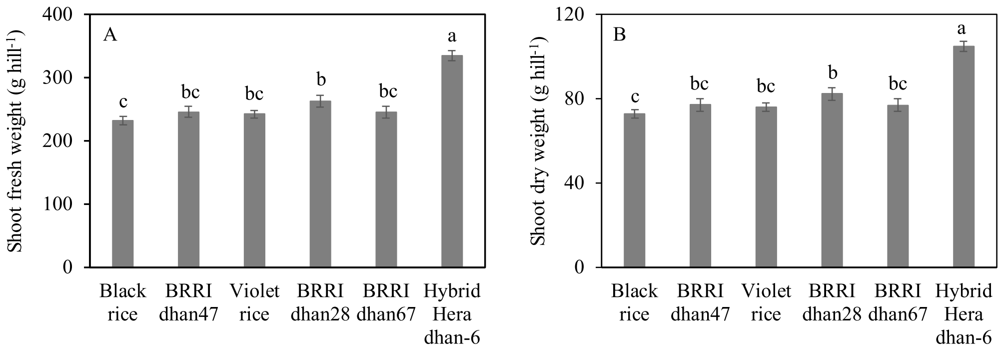

Figure. 3. Rice shoot fresh weight (g $hill^{-1}$) **A** and dry weight (g $hill^{-1}$) **B** as affected by varieties. A bar of a figure (e.g. Fig. A) having a dissimilar letter (s) varied statistically at a 5% level of probability. The error bar represents the mean ± standard error of three measurements.

with tiller number ($R^2 = 0.25$) and shoot dry weight ($R^2 = 0.21$). However, tiller number had a quadratic relation with shoot dry weight ($R^2 = 0.55$) and biological yield ($R^2 = 0.78$) (Figure 4).

Yield attributes of rice

The number of panicles, filled grain and total grain and weight of 1000 grain varied significantly among the varieties (Table 6). *Hybrid Hera dhan-6* produced the highest panicle no. $hill^{-1}$, filled grain $panicle^{-1}$ and total grain $panicle^{-1}$ except for *BRRI dhan67* which had statistically similar panicle number of *Hybrid Hera dhan-6*. *Black rice* produced the lowest number of panicles and the total number of grains in a panicle. However, *Violet rice* had the highest 1000-grain weight (27.9 g) and *BRRI dhan67* produced the lowest grain weight (20.4 g) (Table 6). The panicle length and unfilled spikelet $panicle^{-1}$ did not vary among the varieties. The variety *Hybrid Hera dhan-6* significantly yielded the highest economic (yield) and biological yields and, therefore, HI (Figure 5). However, the HI of *BRRI dhan67, BRRI dhan47* and *Violet rice* were statistically similar to *Hybrid Hera dhan-6*. Black rice generally had the lowest economic (grain) and biological yields, and consequently, the lowest HI (Figure 5). Grain yield

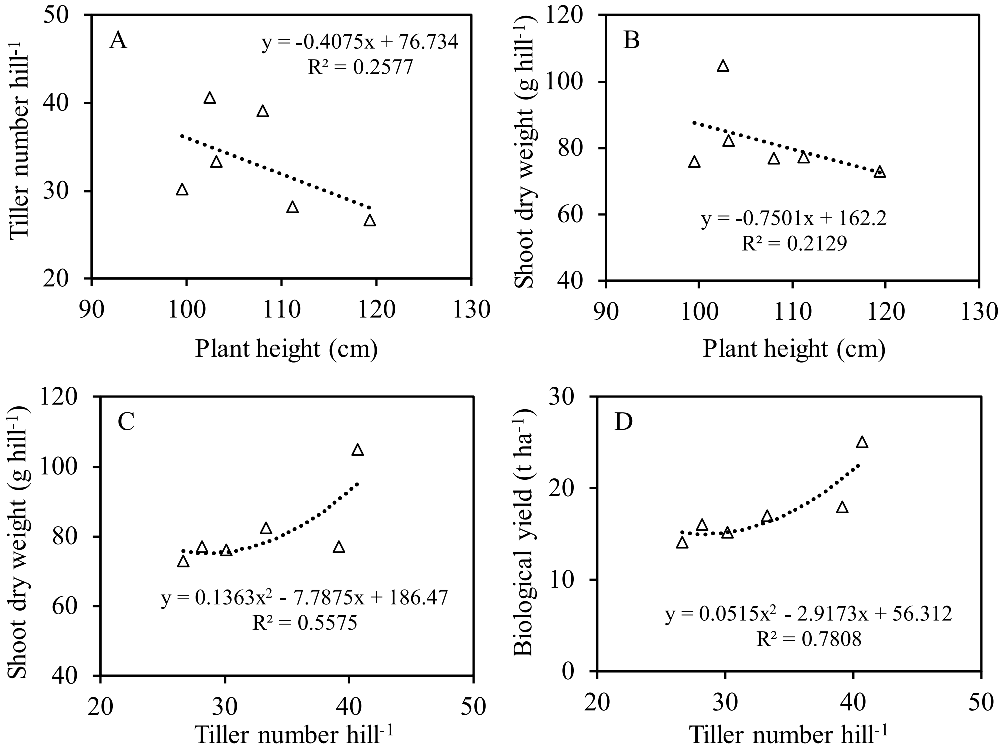

Figure. 4. Relationship of rice tiller number with plant height **A**, shoot dry weight with plant height **B**, shoot dry weight with tiller number **C** and biological yield with tiller number **D** as affected by varieties. The dotted lines are fit by either linear or quadratic regressions.

Table 6. Yield attributes of rice as affected by the varieties at harvest.

Variety[a]	Panicle no. hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Unfilled spikelet panicle^{-1}	Total grain panicle^{-1}	1000 grain weight (g)
Black rice	24.8 ± 1.2c	25.6 ± 0.2	154.3 ± 20.4b	10.7 ± 4.9	165.0 ± 15.6b	25.5 ± 0.3c
BRRI dhan47	25.5 ± 1.6bc	23.3 ± 0.4	134.0 ± 15.6b	41.0 ± 15.7	175.0 ± 22.5b	26.6 ± 0.2b
Violet rice	29.7 ± 2.0b	23.9 ± 0.6	171.3 ± 14.4b	21.3 ± 0.9	192.7 ± 13.5b	27.9 ± 0.2a
BRRI dhan28	30.3 ± 2.9b	28.1 ± 0.6	153.7 ± 2.7b	19.3 ± 2.7	173.0 ± 1.2b	20.9 ± 0.2e
BRRI dhan67	36.5 ± 1.7a	25.8 ± 0.4	164.0 ± 6.2b	12.7 ± 2.9	176.7 ± 7.3b	20.4 ± 0.2e
Hybrid Hera dhan-6	36.8 ± 3.1a	25.1 ± 0.3	212.3 ± 8.7a	50.3 ± 19.4	262.6 ± 14.3a	24.7 ± 0.1d
p	<0.01	0.102	0.019	0.106	<0.01	<0.01

[a]The value represents the mean (average of three measurements) ± SE (standard error). In each column, values not sharing the same letter(s) differ significantly at $p < 0.05$.

showed a quadratic, decreasing trend with plant height ($R^2 = 0.37$) and a linear, increasing trend with shoot dry weight ($R^2 = 0.78$) (Figure 6A–B). Grain yield also exhibited a quadratic, increasing trend with tiller number, panicle number, filled grain number and biological yield (Figure 6C–F). The R^2 values were 0.87, 0.81, 0.76 and 0.96 for tiller number, panicle number, filled grain number and biological yield, respectively

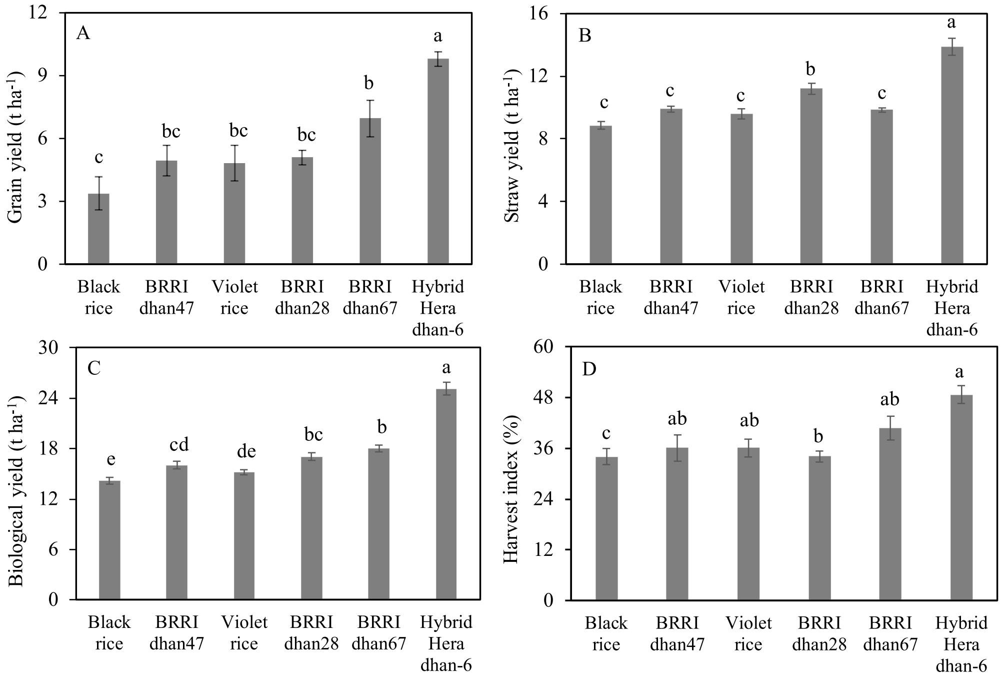

Figure. 5. Grain yield (t ha^{-1}) **A**, straw yield (t ha^{-1}) **B**, biological yield (t ha^{-1}) **C** and harvest index (%) **D** of rice as affected by varieties. The Bar of a figure (e.g. Fig. A) having a dissimilar letter (s) varied statistically at a 5% level of probability. The error bar represents the mean ± standard error of three measurements.

indicating that these attributes are important components for explaining the variations in grain yield and among them, the contribution of biological yield is the maximum (Figure 6).

Rice nutrient content and uptake

Rice grains varied in nutrient content and nutrient uptake. *Black rice* had the highest level of N (1.26%) and the lowest N (0.57%) was obtained from *Hybrid Hera dhan-6*. *Violet rice* contained the highest concentration of P (0.37%) and S (0.39%) and *BRRI dhan67* had the highest concentration of K (0.44%) and Na (0.28%) (Table 7). The highest amount of N (126.6 kg ha^{-1}) was extracted by the Black rice and the lowest by *BRRI dhan47* (62.7 kg ha^{-1}). However, *Hybrid Hera dhan-6* took up the highest amount of P (45.4 kg ha^{-1}) and K (65.9 kg ha^{-1}). Though all the varieties had taken up a similar amount of S, *Black rice* obtained the lowest amount of Na (15.6 kg ha^{-1}) and the highest Na was by the *Violet rice* (29.6 kg ha^{-1}) (Table 8).

Discussion

Soil and climate

The analyses confirmed that the studied soil is a silty clay loam textured with low organic carbon, high soil pH and slight saline (EC 3.73 dS/m). Similar findings were reported by

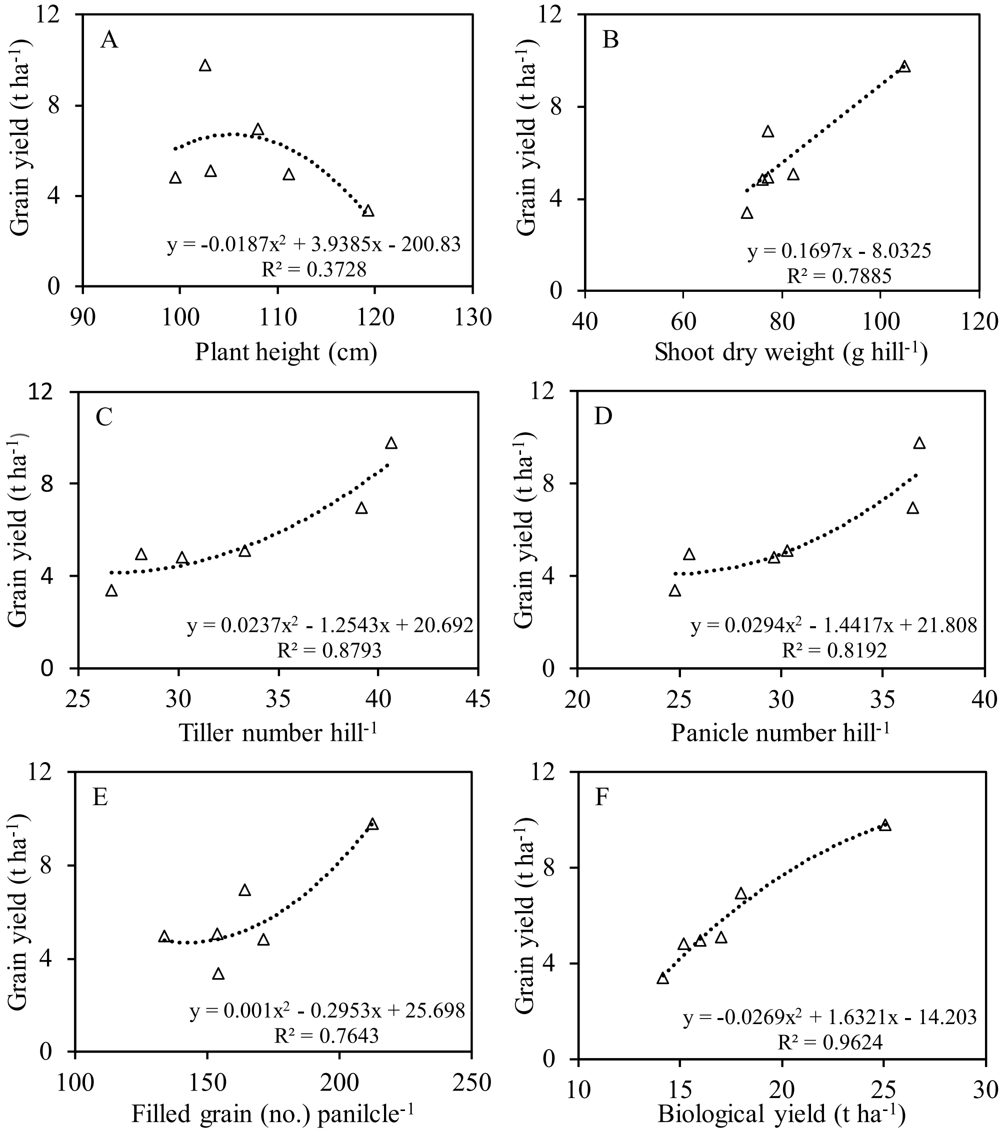

Figure. 6. Relationship of rice grain yield (t ha^{-1}) with plant height **A**, shoot dry weight **B**, tiller number hill^{-1} **C**, panicle number hill^{-1} **D**, number of filled grain panicle^{-1} **E** and biological yield (t ha^{-1}) **F** as affected by varieties. The dotted lines are fit by either quadratic or linear (shoot dry weight) regressions.

other studies (Hanif et al. 2013; Islam and Hossain 2020). The coastal soil of Bangladesh is characterised by low N and P but high Na content (Haque 2006; Hasan et al. 2019). The high average temperatures (18.29°C at 9:00 HR and 29.39°C at 18:00 HR) and high average RHs (74.59% at 9:00 HR and 60.39% at 18:00 HR) indicate the warm and humid nature of Bangladeshi weather (Nahida et al. 2024). The scanty rainfall during January and February shows the dry nature of Bangladeshi winter. However, more rainfall in the last week of April specifies a wet summer – the characteristic summer in Bangladesh.

Table 7. Grain nutrient content of rice is affected by the varieties.

	Grain nutrient content (%)[a]				
Variety	N	P	K	S	Na
Black rice	1.26 ± 0.01a	0.32 ± 0.01ab	0.33 ± 0.012bc	0.31 ± 0.02bc	0.16 ± 0.01c
BRRI dhan47	0.70 ± 0.01b	0.25 ± 0.01c	0.33 ± 0.02bc	0.35 ± 0.01ab	0.24 ± 0.01b
Violet rice	0.68 ± 0.00b	0.37 ± 0.05a	0.29 ± 0.01c	0.39 ± 0.02a	0.26 ± 0.00b
BRRI dhan28	0.67 ± 0.00b	0.29 ± 0.00b	0.41 ± 0.04ab	0.27 ± 0.04cd	0.14 ± 0.01c
BRRI dhan67	0.68 ± 0.01b	0.34 ± 0.01ab	0.44 ± 0.05a	0.34 ± 0.02abc	0.28 ± 0.01a
Hybrid Hera dhan-6	0.57 ± 0.0c	0.27 ± 0.01b	0.39 ± 0.02abc	0.22 ± 0.02d	0.15 ± 0.01c
p	0.000	0.026	0.038	0.002	0.000

[a]The value represents the mean (average of three measurements) ± SE (standard error). In each column, values not sharing the same letter(s) differ significantly at $p < 0.05$.

Table 8. Grain nutrient uptake rice of rice is affected by the varieties.

	[a]Nutrient uptake (kg ha^{-1})				
Variety	N	P	K	S	Na
Black rice	126.6 ± 3.3a	31.6 ± 1.8c	33.4 ± 3.1bc	31.2 ± 2.5	15.6 ± 0.6c
BRRI dhan47	62.7 ± 5.7c	22.9 ± 2.3d	30.2 ± 6.1c	31.7 ± 3.7	21.5 ± 2.2bc
Violet rice	78.1 ± 8.5bc	41.1 ± 3.8ab	33.5 ± 3.9bc	43.9 ± 3.2	29.6 ± 3.6a
BRRI dhan28	82.1 ± 7.2bc	35.8 ± 2.9bc	50.3 ± 6.1ab	33.6 ± 4.6	17.3 ± 0.4c
BRRI dhan67	63.1 ± 5.8c	31.5 ± 2.2c	41.3 ± 8.2bc	31.8 ± 7.1	26.1 ± 2.2ab
Hybrid Hera dhan-6	96.3 ± 7.8b	45.4 ± 1.6a	65.9 ± 2.1a	37.5 ± 1.7	25.1 ± 0.8ab
p	<0.01	<0.01	<0.01	0.285	<0.01

[a]The value represents the mean (average of three measurements) ± SE (standard error). In each column, values not sharing the same letter(s) differ significantly at $p < 0.05$.

Rice growth attributes

The height of the rice plants varied among the varieties and the tallest and shortest rice was *Black rice* and *Violet rice*, respectively. Variation in plant height is due to differences in inter-node length which is attributed to an increase in cell number and cell size (Mahmood et al. 2019; Chowhan et al. 2021). The tallest rice (*Black rice*) produced the lowest tillers and leaves resulting in the lowest shoot weights (fresh weight and dry weight). Conversely, one of the shortest kinds of rice (*Hybrid Hera dhan-6*, second to *Violet rice*) produced the highest tillers leading to cause highest shoot weight indicating a trade-off of rice plant height with tiller number and shoot dry weight (Figure 4). If rice is tall, it may produce a small number of tillers compared to a short statured-rice and vice-versa. Similarly, plant height was the inverse of rice tiller number (Liao et al. 2019). However, rice tiller number increased shoot dry weight and biological yield though the contribution to biological yield was more pronounced than shoot dry weight (Figure 4). The variations in tiller number and thus plant height, shoot dry weight and biological yield are mainly due to genetic makeup of the varieties (Yan et al. 2023). In the present study, *Hybrid Hera dhan-6* produced a maximum number of tillers which resulted in the highest shoot fresh weight and dry weight. Similarly, *Hybrid Hera dhan-6* performed better than other (local or non-hybrid) rice varieties regarding growth attributes of rice (Rahman et al. 2017; Mahmood et al. 2019) mainly through producing a maximum number of tillers.

Yield and yield contributing attributes of rice

Hybrid Hera dhan-6 was superior in terms of economic yield (grain) and biological yield and it showed the highest HI that established it as the best variety among the six rices in this study. *Hybrid Hera dhan-6* produced the highest grain yield by producing a maximum number of panicles in a hill, a maximum number of filled grains in a panicle and a maximum total grains per panicle. The highest tillers in a hill led to producing the maximum straw yield of *Hybrid Hera dhan-6*. The combination of the highest grain and straw yields resulted in the maximum biological yield which was mainly attributed to the tiller number of *Hybrid Hera dhan-6* (Figure 4D) and HI of this variety was the maximum as it is a ratio of grain yield and biological yield. HI reflects the transfer of dry matter to the economic part of a crop (Islam et al. 2008; Khan et al. 2023) and varies among the varieties (Jahan et al. 2014). The opposite results have been obtained for *Black rice* as it produced a minimum number of tillers, panicles and total grains that resulted in the lowest economic (grain) yield and subsequently, minimum HI. Yield and yield attributes of rice are mainly governed by the genetic constitution of a variety (Dutta et al. 2002; Chowhan et al. 2021). In the present study, the major contributor to grain yield is biological yield ($R^2 = 0.96$) followed by tiller number ($R^2 = 0.87$), panicle number ($R^2 = 0.81$), shoot dry weight ($R^2 = 0.78$) and filled grain number ($R^2 = 0.76$) (Figure 6). Similarly, biological yield was the major contributor ($R^2 = 0.93$) to the grain yield of six aromatic rice varieties (Islam et al. 2013) suggesting significant contribution of biological yield to the economic yield. Moreover, biological yield, number of filled grains and HI had a positive association with rice grain yield (Fentie et al. 2021). Now, the tiller number is a great contributor to the biological yield ($R^2 = 0.78$) establishing the tiller number as the main contributor to the grain yield. Similarly, the high grain yield of certain rice genotypes was often determined by a higher number of tillers and panicles (Feng et al. 2007; Huang et al. 2020) as was reported in the present study for *Hybrid Hera dhan-6* and tiller production served as a critical factor for panicle development in rice (Wang et al. 2017).

Variations in straw yield may be attributed to available carbohydrates, vegetative growth and genotypic differences (Hasanuzzaman et al. 2009; Norman et al. 2013). Plant height, duration of plant production, ineffective tiller production and foliage production of rice cultivars can result in variations in straw yields. Similarly, rice straw yield might vary because of the height of the plant and the weight of the straw and the variations were variety-dependent (Islam and Salam 2018). Thousand-grain weight of rice also varied due to varieties and the interaction of varieties and environments (Baral et al. 2020). Moreover, variations in the total number of grains and filled grains are dependent on genetics, environment and cultural management approaches (Kusutani et al. 2000; Sohel et al. 2010; Kiani and Nematzadeh 2012; Akram et al. 2013; Sarkar 2014; Chamely et al. 2015; Nahar et al. 2018). *Hybrid Hera dhan-6*, in the present study, produced the highest grain yield among the varieties by producing the highest number of panicles, filled grains and total grains and these results are supported by other studies which reported that *Hybrid Hera dhan-6* was superior regarding yield and yield attributes compared to the other varieties (Ashrafuzzaman et al. 2009; Roy et al. 2014; Mahmood et al. 2019).

Nutrient content and uptake of rice varieties

The nutrient content of rice grain varied among the varieties and it ranged from 0.25% to 0.37% for P, 0.29% to 0.44% for K, 0.22% to 0.39% for S and 0.15% to 0.28% for Na.

However, the N content of grains ranged from 0.57% (*Hybrid Hera dhan-6*) to 1.26% (*Black rice*) i.e. the N content of *Black rice* was more than twice (2.21 times) than that of *Hybrid Hera dhan-6*. However, *Hybrid Hera dhan-6* contains higher phosphorus and potassium that may contribute to its better grain yield compared to other varieties. The higher nitrogen uptake by *Black rice* is due to the existence of pigments in its grain (Karkee et al. 2019; Dhankhar and Kaur 2023). Moreover, *Black rice* contains high proteins, minerals, vitamins, antioxidants and polyphenols compared to common white rice (Das et al. 2023; Idrishi et al. 2024; Khatun and Mollah 2024). Nutrient uptake of rice depends on nutrient availability, photosynthesis, carbohydrate accumulation, dry matter production, enzyme activity, genetic potentiality and growth hormone. The translocation of dry matter from vegetative parts to the panicle resulted in fluctuations in nutrient uptake (Huang et al. 2017; Zeng et al. 2019). Among the varieties, *Violet rice* contains more sulphur and sodium which might be attributed to its genetic makeup and salt-tolerant capacity.

Conclusion

Hybrid Hera dhan-6 demonstrates the best growth and yield performances mainly through the production of a maximum number of tillers. A higher number of tillers leads to producing a higher number of panicles, a higher number of filled grains per panicle and a higher number of total grains per panicle that ultimately maximise the grain yield of this variety. A higher number of tillers also results in higher biological yield which also contributes to higher grain yield. *Hybrid Hera dhan-6* also results in the highest harvest index (48.7%). However, plant height is inversely linked with tiller number and shoot dry weight and *Hybrid Hera dhan-6* is one of the shortest (second only to *Violet rice*) rice in the study. *Hybrid Hera dhan-6* also contains a higher amount of P and K which may also contribute to the higher grain yield. Therefore, *Hybrid Hera dhan-6* with superior growth and yield potentialities can be chosen for rice production in the southwest coastal area of Bangladesh. However, further research needs to be conducted to get the final recommendation.

Acknowledgement

The authors are grateful to the Laboratory of Soil, Water and Environment Discipline, Khulna University, Khulna 9208, Bangladesh for their support during the experimental period.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Credit author statement

Syed Sazidul Islam: Supervision, Conceptualisation, Analysing, Writing – original draft, review & editing, Fund acquisition; Md. Yamin Kabir: Analysing, Writing – review & editing; Rakib Hasan: Data collection and chemical analyses; Md. Tangimul Islam: Data collection and management; Monowara Khtaun: Chemical analyses.

ORCID

Syed Sazidul Islam http://orcid.org/0000-0002-6508-5784
Md. Rakib Hasan http://orcid.org/0009-0000-6636-637X
Md. Tangimul Islam http://orcid.org/0000-0002-1447-9820
Monowara Khatun http://orcid.org/0000-0002-7304-0092
Md. Yamin Kabir http://orcid.org/0000-0001-9089-5837

References

Adenle AA, Wedig K, Azadi H. 2019. Sustainable agriculture and food security in Africa: the role of innovative technologies and international organizations. Technology in Society. 58:101143. doi:10.1016/j.techsoc.2019.05.007.

Akram HM, Ali A, Sattar A, Rehman HSU, Bibi A. 2013. Impact of water deficit stress on various physiological and agronomic traits of three Basmati rice (Oryza sativa L.) cultivars. Journal of Animal and Plant Sciences. 23(5):1415–1423.

Allison LE, Richards LA. 1954. Diagnosis and improvement of saline and alkali soils (No. 60). Soil and Water Conservative Research Branch, Agricultural Research Service, US Department of Agriculture.

Alotaibi M. 2023. Climate change, its impact on crop production, challenges, and possible solutions. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 51(1):13020. doi:10.15835/nbha51113020.

Ashrafuzzaman M, Islam MR, Ismail MR, Shahidullah SM, Hanafi MM. 2009. Evaluation of six aromatic rice varieties for yield and yield contributing characters. International Journal of Agriculture and Biology. 11(5):616–620.

Baral BR, Pande KR, Gaihre YK, Baral KR, Sah SK, Thapa YB, Singh U. 2020. Increasing nitrogen use efficiency in rice through fertilizer application method under rainfed drought conditions in Nepal. Nutrient Cycling in Agroecosystems. 118(1):103–114. doi:10.1007/s10705-020-10086-6.

BBS. 2019. Yearbook of agricultural statistics 2019. Dhaka, Bangladesh: Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh.

BDP. 2018. Bangladesh Delta plan 2100. Dhaka, Bangladesh: General Economic Division, Ministry of Planning, Government of the People's Republic of Bangladesh.

Benton JJ. 2001. Laboratory guide for conducting soil tests and plant analysis. New York: CRC Press LLC. p. 27–41.

BER. 2019. Bangladesh economic review 2019. Dhaka, Bangladesh: General Economic Division, Ministry of Planning, Government of the People's Republic of Bangladesh.

BER. 2023. Bangladesh economic review 2023. Dhaka, Bangladesh: General Economic Division, Ministry of Planning, Government of the People's Republic of Bangladesh.

Chamely SG, Islam N, Hoshain S, Rabbani MG, Kader MA, Salam MA. 2015. Effect of variety and nitrogen rate on the yield performance of Boro rice. Progressive Agriculture. 26(1):6–14. doi:10.3329/pa.v26i1.24508.

Chowhan S, Ali MKJ, Nahar K, Rahman MM, Ali MI, Islam M. 2021. Yield and morpho physical characters of some modern aus rice varieties at Khagrachari. Plant Science Today. 8(1):155–160. doi:10.14719/pst.2021.8.1.984.

Das M, Dash U, Mahanand SS, Nayak PK, Kesavan RK. 2023. Black rice: a comprehensive review on its bioactive compounds, potential health benefits and food applications. Food Chemistry Advances. 3:100462. doi:10.1016/j.focha.2023.100462.

Dhankhar MP, Kaur P. 2023. Black rice as potential superfood-a review. Journal for ReAttach Therapy and Developmental Diversities. 6(8s):900–903. doi:10.53555/jrtdd.v6i8s.2833.

Dutta RK, Mia MB, Sakina Khanam SK. 2002. Plant architecture and growth characteristics of fine grain and aromatic rices and their relation with grain yield.

Feng WANG, Cheng FM, Zhang GP. 2007. Difference in grain yield and quality among tillers in rice genotypes differing in tillering capacity. Rice Science. 14(2):135–140. doi:10.1016/S1672-6308(07)60019-5.

Fentie DB, Abera BB, Ali HM. 2021. Association of agronomic traits with grain yield of lowland rice (Oryza sativa L.) genotypes. International Journal of Agriculture Sciences. 8(3):2348–3997.
Gee GW, Bauder JW. 1986. Particle-size analysis. Methods of soil analysis: part 1. Physical and Mineralogical Methods. 5:383–411. doi:10.2136/sssabookser5.1.2ed.c15.
Golder PC, Sastry RK, Srinivas K. 2014. Research priorities in Bangladesh: analysis of crop production trends. SAARC Journal of Agriculture. 11(1):53–70. doi:10.3329/sja.v11i1.18375.
Hanif M, Rezoa K, Adhikary N, Nasrin S. 2013. Influence of soil texture and land use practices on aggregate stability and soil organic carbon stocks. Khulna University Studies. 11&12:129–138. doi:10.53808/KUS.2013.11and12.1209-L.
Haque SA. 2006. Salinity problems and crop production in coastal regions of Bangladesh. Pakistan Journal of Botany. 38(5):1359–1365.
Hasan MH, Rahman MR, Haque A, Hossain T. 2019, January. Soil salinity hazard assessment in Bangladesh coastal zone. In: Proceedings of the International Conference on Disaster Risk Management, Dhaka, Bangladesh. p. 12–14.
Hasanuzzaman M, Fujita M, Islam MN, Ahamed KU, Nahar K. 2009. Performance of four irrigated rice varieties under different levels of salinity stress. International Journal of Integrative Biology. 6(2):85–90.
Huang M, Shan S, Cao J, Fang S, Tian A, Liu Y, Cao F, Yin X, Zou Y. 2020. Primary-tiller panicle number is critical to achieving high grain yields in machine-transplanted hybrid rice. Scientific Reports. 10(1):2811. doi:10.1038/s41598-020-59751-4.
Huang M, Tang QY, Ao HJ, Zou YB. 2017. Yield potential and stability in super hybrid rice and its production strategies. Journal of Integrative Agriculture. 16(5):1009–1017. doi:10.1016/S2095-3119(16)61535-6.
Hunt J. 1980. Determination of total sulphur in small amounts of plant material. Analyst. 105(1246):83–85. doi:10.1039/an9800500083.
Ichikawa H, Ichiyanagi T, Xu B, Yoshii Y, Nakajima M, Konishi T. 2001. Antioxidant activity of anthocyanin extract from purple black rice. Journal of Medicinal Food. 4(4):211–218. doi:10.1089/10966200152744481.
Idrishi R, Singha S, Rangan L. 2024. Quality characterization, variety discrimination and correlations amongst twelve landraces of black rice of Assam and Manipur, India. Journal of Food Composition and Analysis. 130:106182. doi:10.1016/j.jfca.2024.106182.
Islam MM, Ismail MR, Ashrafuzzaman M, Shamsuzzaman KM, Islam MM. 2008. Evaluation of chickpea lines/mutants for high growth and yield attributes. International Journal of Agriculture & Biology. 10:493–498.
Islam N, Kabir MY, Adhikary SK, Jahan MS. 2013. Yield performance of six local aromatic rice cultivars. IOSR Journal of Agriculture and Veterinary Science. 6(3):58–62. doi:10.9790/2380-0635862.
Islam SS, Hossain M. 2020. Morphological and yield performance of rice varieties grown in moderately and strongly saline soils of Khulna, Bangladesh. Global Scientific Journal. 8(3):582–596.
Islam T, Salam MA. 2018. Effect of number of seedlings hill-1 on the yield and yield contributing characters of short duration Aman rice cultivars. Progressive Agriculture. 28(4):279–286. doi:10.3329/pa.v28i4.36367.
Jackson ML. 1973. Soil chemical analysis. Vol. 498. New Delhi, India: Pentice hall of India Pvt. Ltd. p. 151–154.
Jahan MS, Sultana S, Ali MY. 2014. Effect of different nitrogen levels on the yield performance of aromatic rice varieties. Bulletin of the Institute of Tropical Agriculture, Kyushu University. 37(1):47–56. doi:10.11189/bita.37.47.
Jamal MR, Kristiansen P, Kabir MJ, Lobry de Bruyn L. 2022. Cropping systems intensification and diversification: risk, vulnerability and adaptation in southwest coastal Bangladesh. International Journal of Sustainable Development & World Ecology. 29(8):677–694. doi:10.1080/13504509.2022.2073615.
Jamal MR, Kristiansen P, Kabir MJ, Lobry de Bruyn L. 2023. Challenges and adaptations for resilient rice production under changing environments in Bangladesh. Land. 12(6):1217. doi:10.3390/land12061217.

Kabir H, Golder J. 2017. Rainfall variability and its impact on crop agriculture in southwest region of Bangladesh. Journal of Climatology & Weather Forecasting. 5(1):1–20.

Karkee SS, Sah SK, Marhatta S, Dhakal S, Kandel M, Shrestha J. 2019. Nitrogen uptake and economics of black rice (Oryza sativa L. indica) under different crop geometries and nitrogen management practices. Archives of Agriculture and Environmental Science. 4(2):171–176. doi:10.26832/24566632.2019.040207.

Khan MAR, Mahmud A, Islam MN, Ghosh UK, Hossain MS. 2023. Genetic variability and agronomic performances of rice genotypes in different growing seasons in Bangladesh. Journal of Agriculture and Food Research. 14:100750. doi:10.1016/j.jafr.2023.100750.

Khatun S, Mollah MMI. 2024. Analysis of black rice and some other cereal grains for protein, sugar, polyphenols, antioxidant and anti-inflammatory properties. Journal of Agriculture and Food Research. 16:101121. doi:10.1016/j.jafr.2024.101121.

Kiani G, Nematzadeh G. 2012. Correlation and path coefficient studies in F2 populations of rice. Notulae Scientia Biologicae. 4(2):124–127. doi:10.15835/nsb427366.

Kusutani A, Tovata M, Asanuma K, Cui J. 2000. Studies on the varietal differences of harvest index and morphological characteristics of rice. Japanese Journal of Crop Science. 69(3):359–364. doi:10.1626/jcs.69.359.

Liao Z, Yu H, Duan J, Yuan K, Yu C, Meng X, Kou L, Chen M, Jing Y, Liu G, et al. 2019. Slr1 inhibits MOC1 degradation to coordinate tiller number and plant height in rice. Nature Communications. 10(1):2738. doi:10.1038/s41467-019-10667-2.

Mahmood R, Howlader MHK, Haque MZ. 2019. Performance of hybrid Boro rice in coastal area of Bangladesh. Progressive Agriculture. 30(2):186–193. doi:10.3329/pa.v30i2.42511.

Mainuddin M, Alam MM, Maniruzzaman M, Kabir MJ, Mojid MA, Hasan MM, Schmidt EJ, Islam MT. 2021. Yield, profitability, and prospects of irrigated Boro rice cultivation in the North-West region of Bangladesh. PLoS One. 16(4):e0250897. doi:10.1371/journal.pone.0250897.

Mondal MS, Islam MT, Saha D, Hossain MSS, Das PK, Rahman R. 2019. Agricultural adaptation practices to climate change impacts in coastal Bangladesh. In: Huq S., Chow J., Fenton A., Stott C., Taub J., Wright H., editor. Confronting climate change in Bangladesh: policy strategies for adaptation and resilience. Berlin/Heidelberg, Germany: Springer; p. 7–21.

Murphy J, Riley JP. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta. 27:31–36. doi:10.1016/S0003-2670(00)88444-5.

Nahar A, Mannan MA, Mamun MAA, Ghosh TK. 2018. Growth and yield performance of foxtail millets under salinity. Bangladesh Agronomy Journal. 21(1):51–59. doi:10.3329/baj.v21i1.39360.

Nahida N, Khan SAKU, Díaz-Pérez JC, Kabir MY. 2024. Plant growth, fruit yield, and quality of capsicum (*Capsicum annum* L.) as affected by nitrogen levels in the coastal soil of Bangladesh. Khulna University Studies. 21(1):187–194. doi:10.53808/KUS.2024.21.01.1187-ls.

Norman R, Roberts T, Slaton N, Fulford A. 2013. Nitrogen uptake efficiency of a hybrid compared with a conventional, pure-line rice cultivar. Soil Science Society of America Journal. 77(4):1235–1240. doi:10.2136/sssaj2013.01.0015.

Olsen SR. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate (No. 939). Washington, DC: US Department of Agriculture. US Government Printing Office.

Rahman MH, Naim MA, Matin MA, Anee TI, Hossain MA, Hasanuzzaman M. 2017. Variations of growth parameters in some aromatic rice verities under salt stress. Bangladesh Agronomy Journal. 19(2):1–10. doi:10.3329/baj.v19i2.31847.

Roy SK, Ali MY, Jahan MS, Saha UK, Ahmad-Hamdani MS, Hasan MM, Alam MA. 2014. Evaluation of growth and yield attributing characteristics of indigenous Boro rice varieties. Life Science Journal. 11(4):122–126.

Salam MU, Mahalder BK, Bhandari H, Kabir MS, Sarkar MAR, Nessa B, Ali MA. 2019. Chapter 44 - Policy directions toward increasing rice productivity—lessons from Bangladesh. In: Hasanuzzaman M, Fujita M, Nahar K, Biswas JK, editors. Advances in rice research for abiotic stress tolerance. Cambridge: Woodhead Publishing; p. 895–913. doi:10.1016/B978-0-12-814332-2.00044-7.

Sarkar SC. 2014. Performance of five selected hybrid rice varieties in Aman season [doctoral dissertation]. Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka-1207.

Sohel MAT, Siddique MAB, Asaduzzaman M, Alam MN, Karim MM. 2010. Varietal performance of transplant Aman rice under different hill densities. Bangladesh Journal of Agricultural Research. 34(1):33–39. doi:10.3329/bjar.v34i1.5750.

Suzuki M, Kimura T, Yamagishi K, Shinmoto H, Yamaki K. 2004. Comparison of mineral contents in 8 cultivars of pigmented brown rice. NIPPON SHOKUHIN KAGAKU KOGAKU KAISHI. 51(8):424–427. doi:10.3136/nskkk.51.424.

USDA. 2021. Grain: world market and trade. Washington, DC, USA: United State Department of Agriculture.

Walkley A, Black IA. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science. 37(1):29–38. doi:10.1097/00010694-193401000-00003.

Wang Y, Lu J, Ren T, Hussain S, Guo C, Wang S, Cong R, Li X. 2017. Effects of nitrogen and tiller type on grain yield and physiological responses in rice. AoB Plants. 9(2):plx012. doi:10.1093/aobpla/plx012.

Yan Y, Ding C, Zhang G, Hu J, Zhu L, Zeng D, Qian Q, Ren D. 2023. Genetic and environmental control of rice tillering. The Crop Journal. 11(5):1287–1302. doi:10.1016/j.cj.2023.05.009.

Zeng Y, Tan X, Zeng Y, Xie X, Pan X, Shi Q, Zhang J. 2019. Changes in the rice grain quality of different high-quality rice varieties released in southern China from 2007 to 2017. Journal of Cereal Science. 87:111–116. doi:10.1016/j.jcs.2019.03.015.

Zhang MW. 2000. Specialty rice and its processing techniques. Beijing: China Light Industry Press. 47–83.