Morpho-physiological Basis of Yield Performance of Early Maturing Rice Varieties in Bangladesh

ABSTRACT

A considerable progress in plant breeding for higher yield is attained mainly through selection of morpho-physiological attributes in rice. The field experiments were conducted at three different locations under sub-tropical conditions with four early maturing rice varieties *viz.,* Binadhan-7, Binadhan-17, BRRI dhan33, and BRRI dhan39 during kharif rice season (July-October) of 2016 to find out the natural variation in the morpho-physiological attributes contributing to higher grain yield in rice. Morphological parameters on plant height, root structure, tillering ontogeny, internode elongation pattern, flag leaf length, flag leaf width, flag leaf angle, number of primary & secondary rachis branches and also physiological traits on chlorophyll content, photosynthesis rate, total dry mass, growth rate, number of vascular bundles, harvest index with yield and yield contributing characters were studied. Results indicated that plants having rapid growth and development at early growth stages showed higher chlorophyll content, photosynthesis rate, long flag leaf, number of vascular bundles in 1st internode and also exhibited the increase in the number of grains per panicle resulting higher grain yield. Among the test varieties, Binadhan-17 showed superiority in the most morpho-physiological criteria and higher number of vascular bundles manifesting in higher grain yield. This information may help breeders to identity and develop high yielding rice variety.

Key words: Morpho-physiology, Early maturing, Yield and Rice varieties

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops in the world especially in Asia and African countries (FAO 2011). More than 50% of the world's population took rice as a staple food that provides 45-60% of the dietary calories (Yang and Zhang 2010). In the last half-century, world rice production has dramatically increased due to genetic and morpho-physiological improvement of traditional varieties or development of high yielding rice varieties. However, rapid population growth and economic development are creating pressures for increase food production. Yield and yield associated traits of different field crops are complex, controlled by various genes and are highly influenced by environmental conditions (Shi et al. 2009)**.** It is important that further improvements will be required to fulfill the demand of increasing world populations. Accordingly, improving crop productivity by selecting yield-contributing characters has been an important factor for higher rice production (Wang and Li 2008). However, rice grain yield production depend on tiller number per plant, grain number per panicle, grain size, grain fertility, panicle length and rachis branching of the panicle (Yan et al. 2013).

The utilization of heterosis and variation in plant architecture are considered to be important components in high yielding rice production (Wu 2009). Studies have been conducted to increase the fundamental understanding on morpho-physiological attributes of the grain yield of rice by many breeders and physiologists, and based on their results they formulated different selection criteria for yield improvement. Thus, their applications have been associated with increased yield. Effect of yield attributing traits on the final grain yield of rice has been extensively studied (Selvaraj et al. 2011; Puteh et al. 2013).Of them, number of panicles per plant, number of grains per panicle and grain weight directly contribute to the final yield of rice (Akter et al. 2014; Babu et al. 2012; Berahim et al. 2014). Besides, there are some other characters like plant height, days to maturity, panicle length etc. also contribute to grain yield (Xue et al. 2008). Rice genotypes classified into six groups based on the elongation patterns of the internodes which support the plant to stand (Takeda 1977).

The degree of grain filling in rice spikelet greatly affect by leaf position and orientation. Besides, grain yield in rice was positively associated with physiological attributes such as net assimilation rate (NAR), leaf area index (LAI), photosynthesis, specific leaf weight (SLW) and total dry matter, however, in path co-efficient analysis TDM and Photosynthesis were found most important (Sharma and Singh 2000; Islam 2010). Further, the variety with higher dry matter production come from the roots and shoots which constitute the plant structure that helped in higher grain yield production. The optimum proportion of dry mass production between different parts should be properly partitioned for maximizing the grain yield (Gorney and Larson 1989). Several researchers reported that the genotypes with higher TDM also produced higher yield due to large root system and leaf area (Flood et al. 1995; Mondal et al. 2012).

In addition, morphological and physiological traits also have the important role on the major improvements in rice yield potential, which ultimately improve the efficiency of resource capture. The high-yielding rice varieties showed higher leaf photosynthetic rates and chlorophyll content (Peng et al. 2008) and their metabolism regulates the plant development (Masuda and Fujita 2008). Photosynthesis is the major factor that makes variation in biomass production and yield (Saragih et al. 2013; Yoshida and Horie 2009) which stimulus the response of photosynthesis to light such as chlorophyll, flag leaf length, width and angle. Besides, it has been clear that leaf photosynthesis increases 20-30% grain yield in rice (Ambavaram et al. 2014). However, recent studies indicate that growth rate during heading stage is critically related with final yield in rice (Takai et al. 2013) and a positive relationship between leaf photosynthesis and leaf chlorophyll content has been widely observed in rice (Huang et al. 2015). However, about 90% of biomass production is derived from photosynthetic products in crop that increased yields (Makino 2011). The leaf length, width and angle are determinant the shape and size of a leaf which control photosynthesis (Peng et al. 2008). Flag leaf plays important roles for grain yield through greater carbohydrate translocation from leaf to the spikelet during the grain filling (Davood et al. 2009).It is predicted that many of the mechanisms used to improve rice yield potential such as canopy architecture, HI and total biomass production (Chang et al. 2016; Badger 2013).

The trait effect on grain yield is important for plant breeders to recognize promising traits to be selected that can make variations in rice yield production (Togay et al. 2008; Ali et al. 2009).The present study was carried out under sub-tropical condition to know the morphophysiological causes of yield variation in similar durated modern rice varieties.

2. MATERIALS AND METHODS

2.1 Site description, plant materials and design

Field experiments were performed at three agro-ecological zones of Bangladesh such as Mymensingh, Magura and Pabna districts in Kharif (July-October) season of 2016. Four early maturing rice varieties such as Binadhan-7 (110-120 days), Binadhan-17 (112-118 days), BRRI dhan33 (118 days) and BRRI dhan39 (120 days) were used in this study . Average temperature during the cropping season was around 32±3°C (Source: Bangladesh Meteorological Department).The soil status of Mymensingh, Magura and Pabna experimental land is presented in Table 1.

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replicates. The unit plot size was 3.0 m ×3.0 m. Thirty-five days old seedlings were transplanted on 05 August, 2016. Plant to plant and row to row distance were maintained at 15 cm and 20 cm, respectively.

2.2 Fertilizer application and cultural methods

Urea, triple super phosphate (TSP), muriate of potash (MP) and gypsum were applied at the rate of urea 120, TSP 80, MP 60 and gypsum 45 kg ha^{-1} (BARC 2012). All the fertilizers were applied at basal doses during final land preparation except urea. Half of urea was applied at 15 days after transplanting (DAT) and remaining half urea was applied at 45 DAT as top dress. Intercultural operations were done when needed for ensuring proper growth and development of the rice.

2.3 Parameters measured

To study ontogenetic growth characteristics, five harvests were made and the first crop sampling was done at 30 DAT and continued at an interval of 10 days until the crop maturity. Ten plants were randomly selected per plot and uprooted for obtaining data of different parameters. The separated plants were collected and the corresponding dry weights were recorded after oven drying at 80 ± 2 ^{0}C for 72 hours (Kato et al. 2007). Leaf chlorophyll was measured by SPAD meter (Konica Minolta Sensing Inc., Japan) at different DAT. Leaf photosynthesis was measured by Portable Photosynthesis System (Li-Cor LI-6400XT, LICOR Inc. Nebraska, USA). The rice plants were harvested when 90% of the grains became golden yellow in color. At harvest, yield contributing characters and seed yield were recorded from 10 representative plants.

2.4 Anatomical features of peduncle tissues

Peduncles were sampled at the ripening stage. The 1st internodes were cut and fixed in FAA solution (50 % ethanol, 5 % acetic acid, 3.7 % formaldehyde) and stored at 4^{0}C following the methods described by Akter et al. (2015). The sample was cut using a sharp blade and the sections were stained with 1 %

safranin in 30 % ethanol for 30 s, followed by two washes with sterile water, then mounted on Superfrost-plus glass slides (Fisher Scientific, Pittsburgh, PA, USA) using glycerin. Finally, the cross sections of peduncle were observed by optical microcopy at 100 magnifications (BX53M/BXFM system microscope, OLYMPUS).

2.5 Statistical analysis

The collected data were analyzed statistically following the analysis of variance (ANOVA) technique and the mean differences were adjusted with Duncan's Multiple Range Test (DMRT) using the statistical computer package program, MSTAT-C (Russell 1986).

3. RESULTS AND DISCUSSION

3.1 Morphological traits

Improvement of rice yield potential controlled by different mechanisms through canopy architecture, HI and total biomass production (Chang et al. 2016; Badger 2013). We evaluated different growth and development of early maturing rice varieties, which make variations in different yield contributing characters. The phenotypic developments were compared from the vegetative to the maturity stage. At the seedling stage, BRRI dhan39 displayed apparently shorter plant than other studied varieties, whereas plant height was almost similar at tillering stage in all varieties. (Figs. 1 A&B) and at maturity, Binadhan-17 was the shortest (Fig. 1C &Table 2). Binadhan-7 and BRRIdhan33 exhibited long and profuse fibrous roots (Fig 1D) but almost similar heading date was recorded (Table 2). Binadhan-7 produced increased tiller numbers at all growth stages and BRRI dhan39 always produced fewer numbers of tillers (Fig 2 and Table 2). Finally, Binadhan-17 produced higher grain yield as well straw yield with increased harvest index (Table 2). This suggests that several variations were noted among the early maturing varieties. The harvest index (HI) increased the plant capacity to allocate assimilates into the developed reproductive parts (Gutam, 2011; Mazid et al, 2013) that may be useful in selecting crop varieties for higher grain yield (Fageria 2007). Our observations suggest that Binadhan-17 had more ability to allocate biomass in developing organs for higher yield production.

The relative lengths of each internode of the culm in four varieties are shown in Fig. 3A. All internodes were evenly shortened for all varieties that fit with dn-type of internode elongation pattern, based on the classification by Takeda (1977). Among them, the 2nd internode of Binadhan-17 was mostly shortened (Fig. 3A&B) that may reduce the culm length.

All the tested cultivars showed significant difference in flag leaf length and width (Table 3). Amongst varieties, Binadhan-17 displayed the longest flag leaf comparing to other varieties, whereas narrow flag leaves were observed in Binadhan-7 (Fig. 4A&B and Table 3). The flag leaf structure and position of a cultivar determines the amount of photosynthetic activity (Prakash et al, 2011). It significantly affects grain yield adjusting the canopy structure and other important production parameters (Davood et al, 2009; Prakash et al, 2011). In the present study, Binadhan-17 had the long and narrow leaves that might help in capturing resource and producing sufficient assimilates.

3.2 Physiological traits

The pattern of chlorophyll content and photosynthesis rate was significantly different among the varieties during the different growth periods. The leaf chlorophyll was higher at tiller start stage (30 DAT) followed by declined at 40 DAT, thereafter leaf chlorophyll gradually increased with age until 60 DAT followed by a decline until maturity in all varieties (Fig. 5). The highest leaf chlorophyll content and photosynthetic rate was observed in Binadhan-17 at all growth stages and Binadhan-7 contained the lowest chlorophyll (Fig. 5). The rice yield depends on various processes including photosynthesis rate, conversion of assimilates to biomass and assimilates partitioning (Jeng et al. 2006; Puteh et al. 2014). Chlorophyll content and photosynthesis rates during plant growth and development are related with high yield (Ohsumi et al. 2007) that support the insight of increased grain yield production in Binadhan-17.

The total dry matter (TDM) production in rice varieties increased with age up to maturity but TDM accumulation was rapid up to 70 DAT followed by slowly increase up to physiological maturity (Fig. 6). Binadhan-17 maintained the highest TDM and the lowest TDM was recorded in BRRI dhan39 at all growth stages that was probably due to better photosynthesis rate and chlorophyll content in leaves (Mondal et al, 2013). In contrast, Binadhan-17 showed rapid growth and development at different growth stages (Fig. 7) except 40-50 DAT accumulates dry matter in shortest possible time for higher grain yield. Considering the dry matter and absolute growth rate, results indicated that Binadhan-17 showed positively and significantly higher dry matter production and rapid growth which might help in increased higher grain yield.

The difference of large vascular bundles of the uppermost internodes and pith cavity among different varieties was perceived by microscopic observation. The numbers of large vascular bundles were increased along with the increased diameters of the 1st internodes and pith cavity in Binadhan-17 followed by BRRI dhan33 (Fig.8 a&b) that improved stem strength and reduced lodging risk. The vascular bundle system of the culms provides stronger mechanical support in shorter rice plants (Teale et al. 2006; Aohara et al. 2009) that may help against the lodging and inhibit assimilates translocation. These results indicated that the meristematic activity and cell proliferation enhances plant growth for better photosynthesis and dry matter accumulation of Binadhan-17 which ultimately contributes to yield.

3.3 Yield and yield contributing traits

The variation in yield and yield attributes of the varieties were significant. It was reported that rice production increased due to selecting yield and yield contributing characters during the course of rice cultivation (Wang and Li 2008) and can be estimated on the performance of panicle length, grain number per panicle, grain size, grain fertility, 1000-seed weight and rachis branches of the panicle (Yan et al. 2013). Variations of yield contributing characters such as panicle length, number of fill and un-fill grains/panicle and 1000-grain weight was significant (Table 4). BRRIdhan39 produced the longest panicle and Binadhan-17 had shorter panicles with greater number of grains per panicle. The lowest unfilled grains/panicle was recorded in Binadhan-7 followed by Binadhan-17 and the highest number of unfilled grain was recorded in BRRI dhan33 (Table 4). BRRI dhan33 produced comparatively coarse grains as compared to others, whereas Binadhan-17 produced fine grain. Besides, Binadhan-17 showed higher number of rachis branches as compared to other three varieties (Fig. 9). The highest grain yield was recorded in Binadhan-17 at all three locations. Binadhan-7 and BRRI dhan39 produced the lowest mean grain yield. The grain yield was higher in Binadhan-17 might be due to increase grain number/panicle, higher number of secondary rachis branches (Fig 9 and Table 4). These data suggests that the yield can be increased with the increased grains per panicle and secondary branches in rice.

Dry matter allocation per spikelet from heading to maturity was important for higher grain yield in rice. The poor grain filling might be related to poor partitioning of assimilates to the grain in rice (Puteh et al, 2014). Total dry mass production and its distribution into seed yield per plant were found in Binadhan-17 followed by BRRI dhan33. Besides, BRRI dhan39 produced comparatively the low yield with lowest TDM over its growth period (Fig. 6).It is observed that the grain yield increased with increased total dry matter production and grain yield strongly correlated with total dry mass production (Fig. 10).These results indicated that higher dry matter production during grain filling is helpful for grain filling in rice that also previously reported by Yang et al. 2002.

3.4 Conclusions

The variety, which had rapid growth and development at early growth, stages, better dry matter partitioning to economic yield also showed higher grain yield. Binadhan-17 showed superiority in early growth and development resulting from higher number of vascular bundles that promotes dry matter accumulation. In addition, grain yield is increased mainly due to increase grain number per panicle, higher number of secondary rachis branches. This information may be helpful for breeders for developing superior rice varieties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Fig. 1. Morphological appearance; A: seedling stage, B: tillering stage, C: maturity stage, D: roots of early maturing rice varieties from left to right; Binadhan-7, Binadhan-17, BRRI dhan33 and BRRI dhan39 respectively.

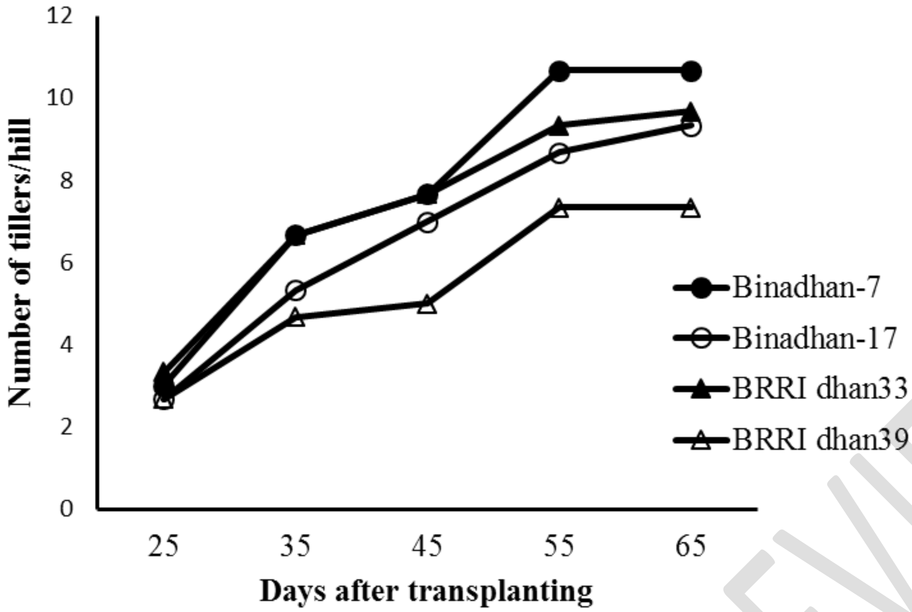


Fig.2. Ontogenetic tillering pattern of early maturing four rice varieties

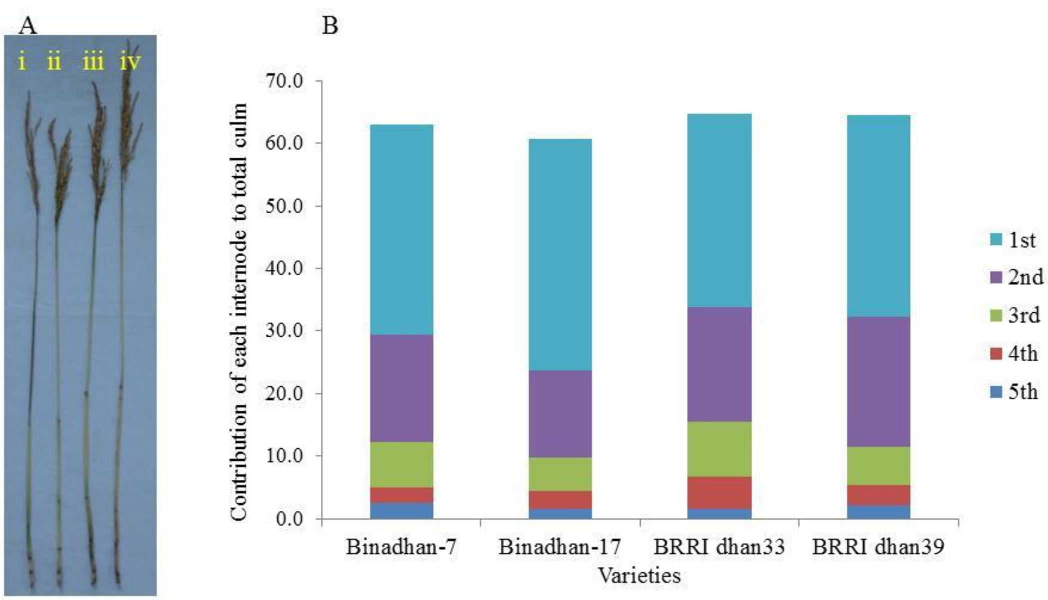


Fig.3. Internodes elongation patterns; **a** schematic representation of the upper five internodes of four rice varieties i) Binadhan-7, ii) Binadhan-17, iii) BRRI dhan33 and iv) BRRI dhan39 respectively; **b** relative contribution of each internode to the total culm length

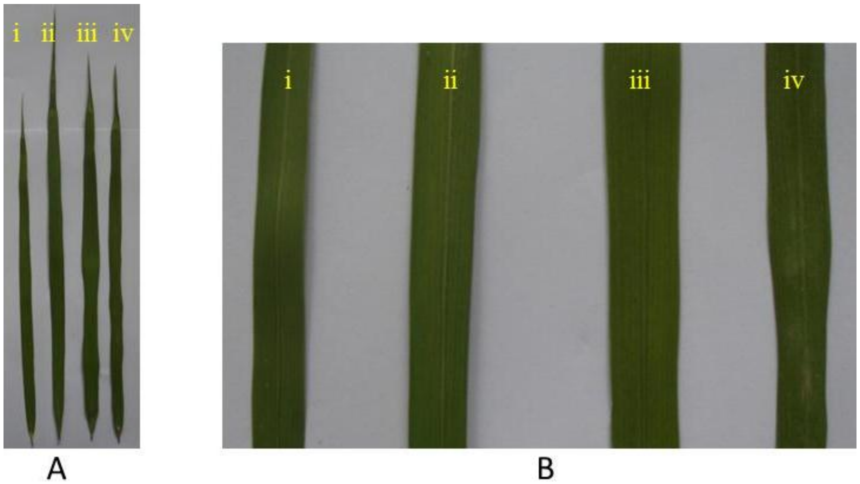
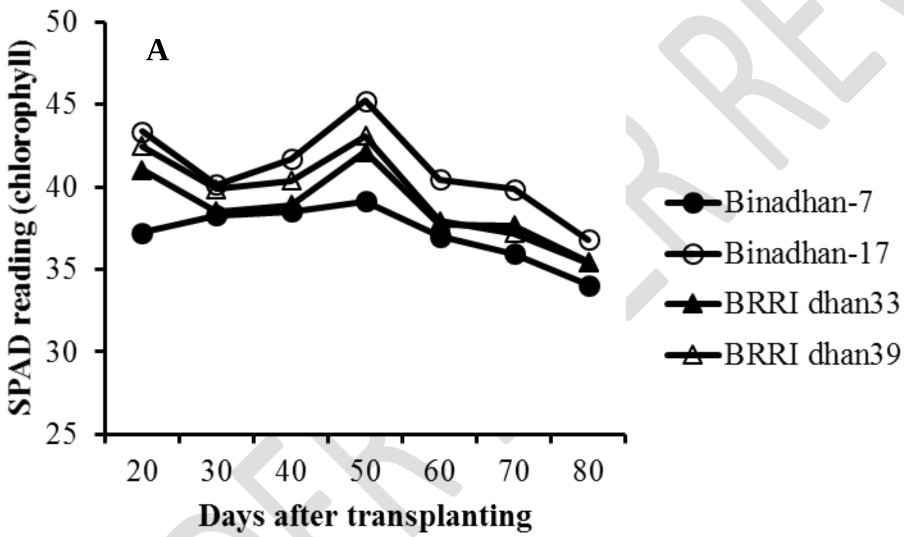


Fig.4. Variations in flag leaf length and breadth; **a** leaf length **b** leaf width of four rice varieties i) Binadhan-7, ii) Binadhan-17, iii) BRRI dhan33 and iv) BRRI dhan39 respectively



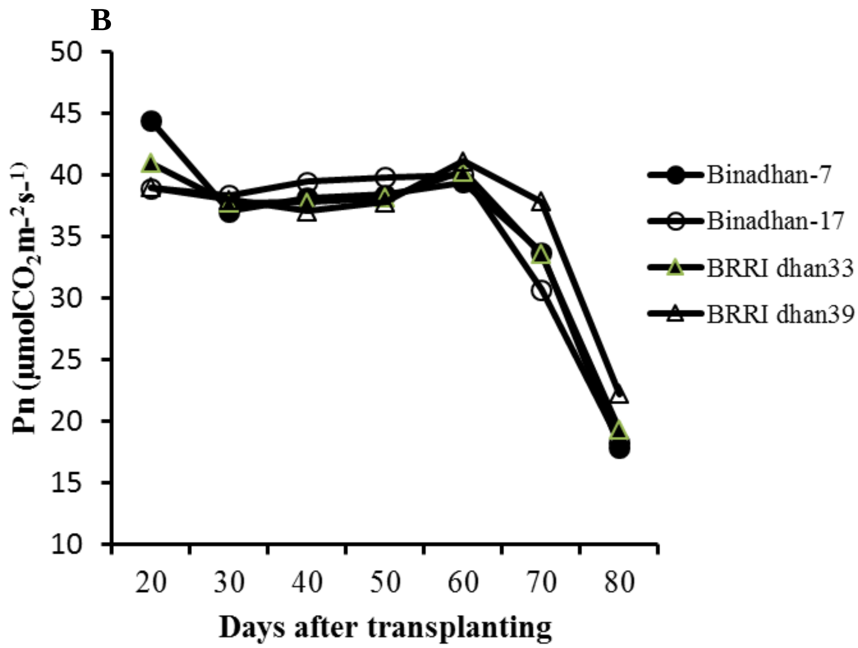


Fig.5. Ontogenetic **a** chlorophyll content **b** photosynthetic rate at different DAT of four rice varieties at Mymensingh.

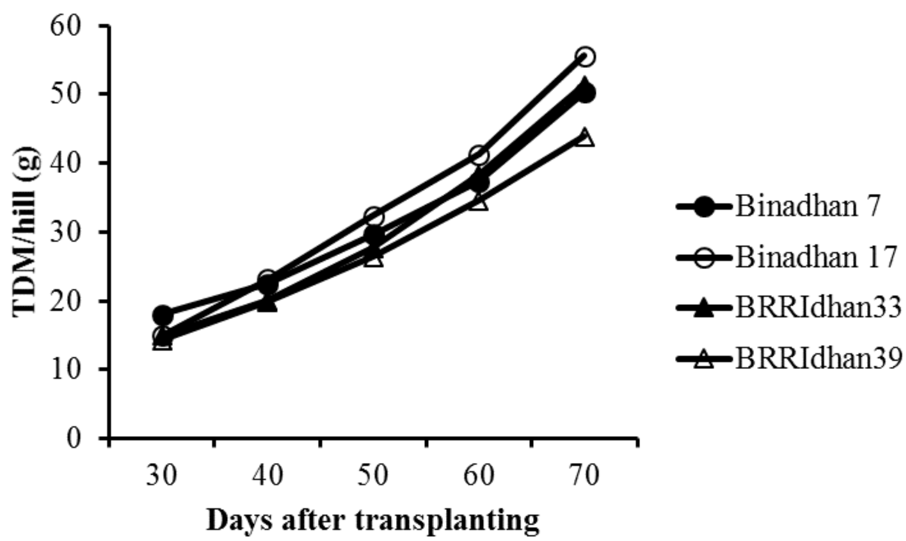


Fig.6. Total dry mass production at different growth stages in four rice varieties

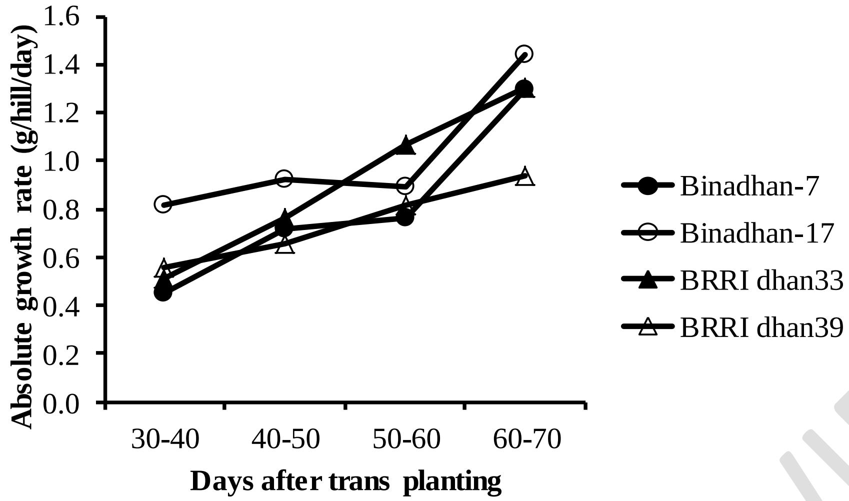
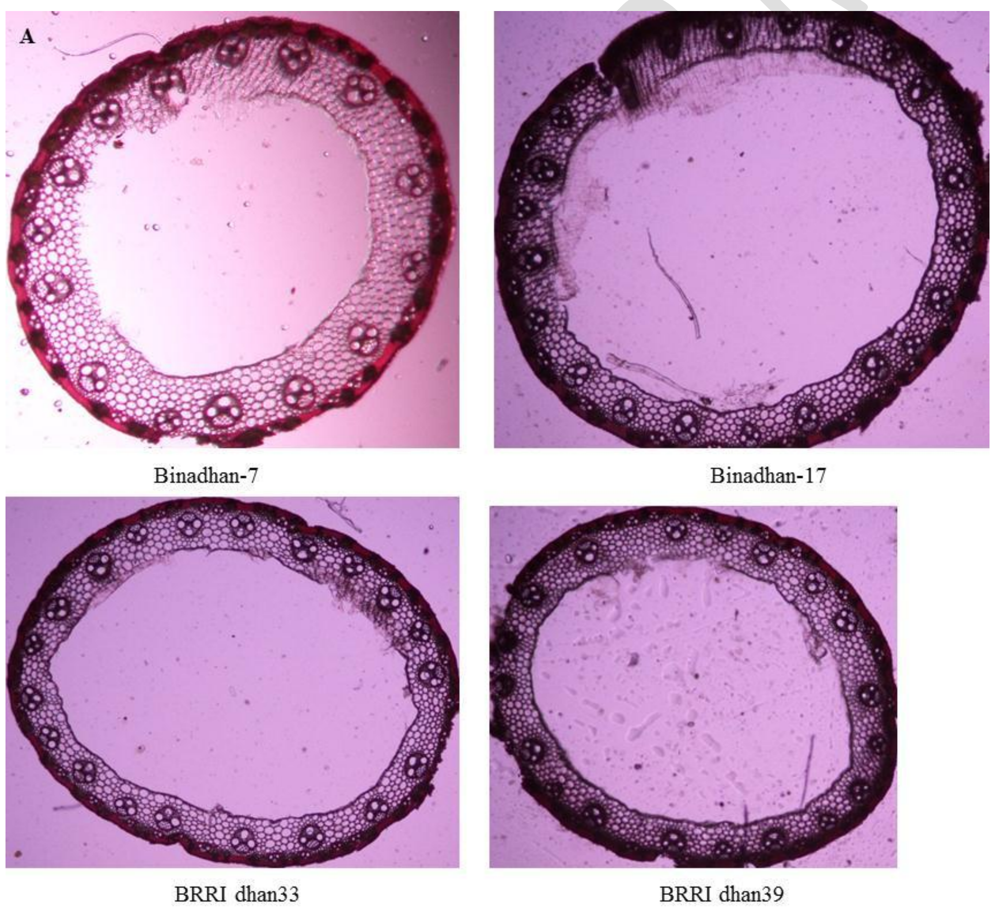


Fig.7. Plant growth rate per day at different growth stages in four early maturing rice varieties



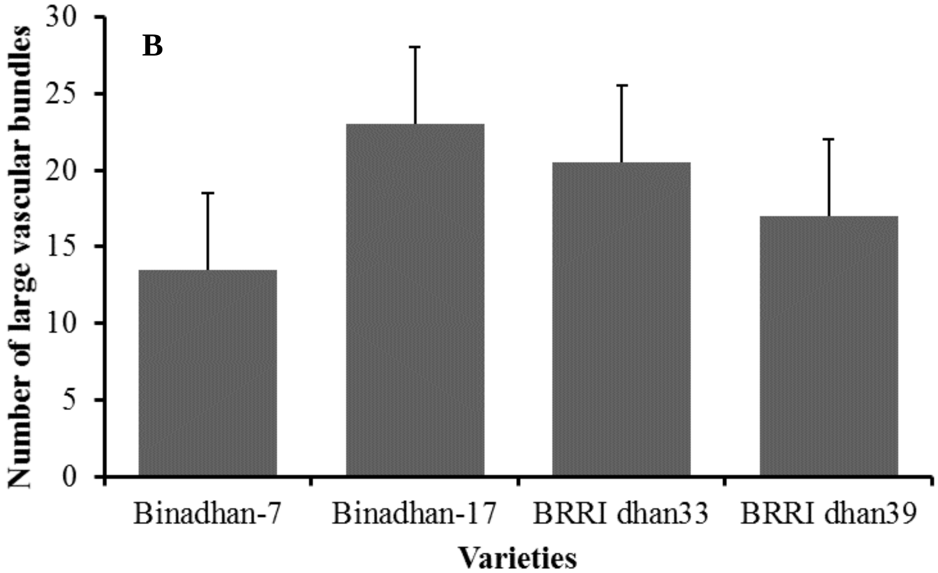


Fig.8. Microscopic observations; **a** cross-section of the 1st internode **b** the number of large vascular bundles

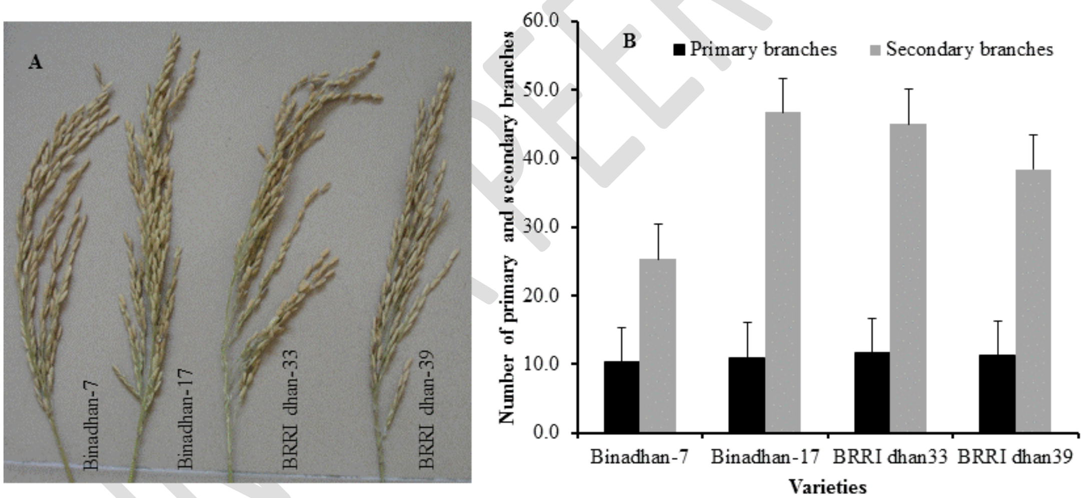


Fig.9. Panicle characterization; **a** Panicle architecture **b** Variations in primary and secondary branches of early maturing four rice varieties

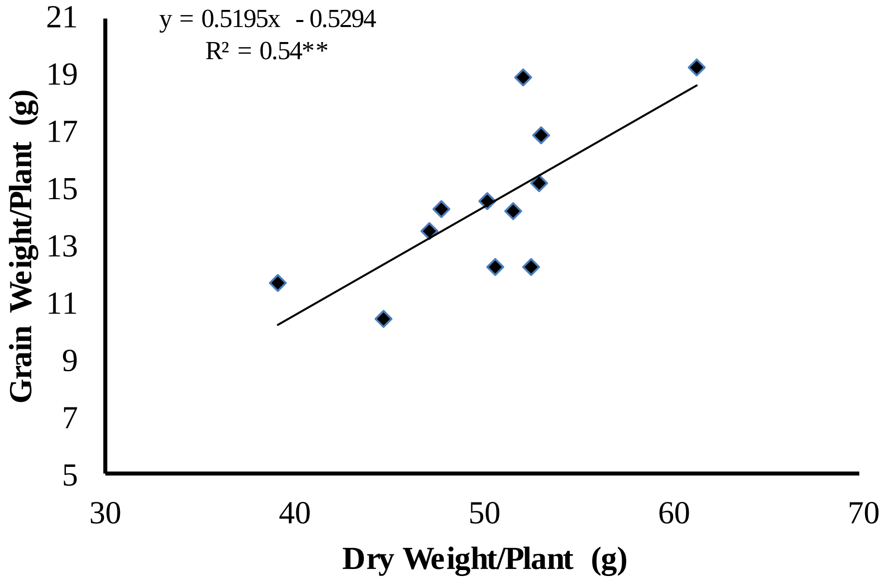


Fig.10. Relationship between dry weight and grain weight per plant

Table 1. General characteristics of soil at three different locations

Soil characteristics	Mymensingh	Magura	Pabna
Textural class	Sandy loam	Silty clay loam	Silty clay loam
Organic matter (%)	0.84/1.17	1.30	1.47
Total nitrogen (%)	0.07	0.06	0.12
Available phosphorus (ppm)	18.5	15.2	14.6
Exchangeable potassium (emol kg^{-1})	0.12	0.11	0.11
Available sulphur	18.62	18.9	19.3
pH	6.8	7.3	6.5

Table 2. Morphological and yield contributing characters of early maturing four rice varieties

Variety	Heading date	Plant height (cm)	Tillers plant^{-1} (no)	Effective tillers plant^{-1} (no)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest Index (%)
Binadhan-7	October 2	94.1 b	10.59 a	9.58 a	4.22 b	5.23 c	44.66 a
Binadhan-17	October 1	89.1c	9.58 b	8.41 b	5.07 a	5.85 ab	46.43 a
BRRI dhan33	October 2	102.6 a	7.74 c	7.37 b	4.83 a	5.77 b	45.57 a
BRRI dhan39	October 4	103.7 a	8.99 b	8.12 b	4.20 b	6.10 a	40.78 b
CV%	-	3.38	10.94	12.96	4.70	5.15	7.31

Common letter(s) in a column on specific treatment do not differ significantly at 5% level as per DMRT

Table 3. Comparison of flag leaf in early maturing four rice varieties

Variety	Leaf angle (^{0})	Leaf length (cm)	Leaf width (cm)
Binadhan-7	9.33 a	39.28 bc	1.09 b
Binadhan-17	10.00 a	48.07 a	1.38 a
BRRIdhan33	9.83 a	37.18 c	1.48 a
BRRIdhan39	9.8 a	40.76 b	1.38 a
CV%	3.73	2.67	5.79

Common letter(s) in a column on specific treatment do not differ significantly at 5% level as per DMRT

Table 4. Yield and yield contributing characters of four early maturing rice varieties

Varieties	Panicle Length (cm)	Grains panicle^{-1}	Unfilled grains panicle^{-1}	1000-grain weight (g)	Seed yield (t ha^{-1})			
					Mymensingh	Ishurdi	Magura	Mean
Binadhan-7	24.37 b	122.1 c	20.89 c	21.72 c	3.90 b	4.77 c	3.99 b	4.22 c
Binadhan-17	22.86 c	175.2 a	26.89 b	20.28 d	4.32 a	6.17 a	4.73 a	5.07 a
BRRI dhan33	25.38 ab	136.3 b	36.00 a	24.10 a	4.33 a	5.57 b	4.60 a	4.83 b
BRRI dhan39	26.47 a	143.4 b	35.56 a	23.11 b	4.16 ab	4.97 c	3.47 c	4.20 c
CV%	4.82	7.83	11.07	4.44	4.70	5.10	6.54	5.45

Common letter(s) in a column on specific treatment do not differ significantly at 5% level as per DMRT