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Source-Sink Relationship and Yield Performance of Hybrid Rice Varieties in *Boro* Season

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Abstract

The source-sink relationship and its impact on the yield performance of five hybrid rice varieties (BRRI hybrid dhan3, Heera4, Sonarbangla3, Moyna and Jagoron) was conducted in *Boro* season and two inbred rice varieties (BRRI dhan28 and BRRI dhan45) were used as test crop. The result showed that all the studied hybrid varieties exhibited superiority in respect of growth characters, yield and yield attributes such as plant height, tillers hill^{-1}, leaf area index, total dry matter hill^{-1}, shoot dry matter at pre-anthesis and maturity period, changes in shoot dry matter, shoot reserve translocation, total spikelets panicle^{-1}, spikelets fertility, weight of 1000 grains, biological yield and harvest index over the inbred. Highest shoot reserve translocation (15.58%), highest ratio of spikelets no. to LA (0.31 cm^{-2}) and yield sink to LA (14.09 mg cm^{-2}) were observed in Heera 4, while the lowest value (9.59%), lowest ratio of spikelets no. to LA (0.22 cm^{-2}) and yield sink to LA (11.09 mg cm^{-2}) were observed in BRRI dhan28. Heera4 (83.19%) accumulated significantly highest percentage of dry matter from current photosynthate in grain, while BRRI dhan45 showed the lowest value (75.79%). Heera 4 provided the highest grain yield (7.80 t ha^{-1}) which was closely followed by Jagoron (7.08 t ha^{-1}). While BRRI dhan28 showed the lowest grain yield (4.23 t ha^{-1}) closely followed by BRRI dhan45 (4.55 t ha^{-1}). Hybrid Heera 4 had the superiority over the test varieties in respect of post heading photosynthetic assimilation per unit leaf area and grain yield.

Keywords

Source-Sink Relationship, Hybrid Rice, Inbred Rice, Yield Performance, *Boro* Season

1. Introduction

Rice is the most important food grain in the world. It is the most important cereal crop in the developing world [1]. Ninety percent of rice is grown and consumed in Asia [2, 3]. Rice feeds more than a half of the people in the world [4]. It is the staple food for more than two billion people in Asia [5]. The current level of annual rice production of around 545 million tons could be increased to about 700 million tons to feed an additional 650 million rice eaters by 2025 using less land indeed the great challenge in Asia [6]. The population of Bangladesh is increasing at an alarming rate and the cultivable land is reducing due to urbanization and industrialization resulting in more shortage of food. The population of Bangladesh will increase to 173 million in 2020 which is 31 percent higher than the present level [7]. However, the national average yield (2.34 t ha^{-1}) is very low compared to that of other rice growing countries as the average rice yield in China is about 6.3 t ha^{-1}, Japan is 6.6 t ha^{-1} and Korea is 6.3 t ha^{-1}[8]. About 75% of the total cropped area and more than 80% of the total irrigated area of Bangladesh is planted to rice [9] and there are three diverse growing seasons of rice namely *Aus*, *Aman* and *Boro*.

Hybrids are generally more vigorous and larger in size than the parent stock. Different varieties perform differently in a particular environment. [10] Reported that although farmers got about 16% yield advantage in the cultivation of hybrids compared to the popularly grown inbred varieties, the yield gains were not stable. For developing the high yielding varieties, Japan initiated first breeding program in 1981 [11]. IRRI also started super rice breeding program to give up to 30% more rice yield (13-15 t ha^{-1}) than the current modern high yielding plant types [12]. Hybrid rice technology has been introduced in Bangladesh during the last ten years (Masum, 2009). In our country BRRI has started breeding program for the development of super high yielding varieties with large panicles and high yield potentialities. Several scientists reported that hybrid rice had higher productivity after heading but the more dry matter in vegetative organ at heading contributes little to the grain due to poor transportation and remobilization of stored assimilates. Slow senescence and more strong photosynthetic capability of flag leaf, higher LAI at grain filling period and higher post heading-CGR are the pre-requisites for higher yield in hybrid rice So, the available information on source activities, shoot reserve remobilization, and its influence on the yield formation of hybrid rice varieties are controversial. In this situation, clear information on the source-sink relation in hybrid rice would help to obtain desirable (sustainable) grain yield through the manipulation of agronomic cultural management practices. Under these circumstances, the research work was designed to evaluate source-sink relationship and yield performance of hybrid rice varieties in *Boro* season.

2. Materials and Methods

The experiment was conducted in the experimental farm, Sher-e-Bangla Agricultural University, Dhaka during the period from November, 2013 to March 2014, to study the source-sink relationship and its contribution to the yield performances of hybrid rice varieties in *Boro* season. The location of the experimental site is $23^{0}74^{/}$N latitude and $90^{0}33^{/}$E longitude and at an elevation of 8.4 m from sea level (Anon., 1989). The single factor experiment was laid out in Randomized Complete Block Design with three replications. The layout of the experiment was prepared for distributing the advanced line. There were 21 plots of size 4.0 m × 2.5 m in each. Seven rice varieties were assigned randomly into 7 plots of each replication. The materials and methods include a short description of the soil and climate condition of the experimental area, materials used for the experiment, data collection and data analysis procedure.

2.1. Characteristics of Soil and Climate

The soil of the experimental area belongs to the Modhupur Tract under AEZ No. 28. The selected plot was medium high land and the soil series was Tejgaon [7, 14]. Its top soil is clay loam in texture and olive gray with common fine to medium distinct dark yellowish brown mottles. The soil pH ranged from 6.0 to 6.6 and organic carbon content is 0.84%. Soil samples from 0-15 cm depths were collected from experimental field. The analysis was done by Soil Resource and Development Institute (SRDI), Dhaka. The experimental site was under the subtropical climate, characterized by three distinct seasons, winter season from November to February and the pre-monsoon or hot season from March to April and the monsoon period from May to October [15].

2.2. Experimental Materials

Table 1. *Name of rice variety.*

#	Rice variety	#	Rice variety
01	V_1: BRRI dhan28	02	V_2: BRRI hybrid dhan3
03	V_3: Heera 4	04	V_4: Sonarbangla 3
05	V_5: Moyna	06	V_6: Jagoron
07	V_7: BRRI dhan45		

2.3. Seed Collection and Sprouting

Seeds were collected from BRRI (Bangladesh Rice Research Institute), Gazipur and some were procured from respected company just 20 days ahead of the sowing of seeds in seed bed. Seeds were immersed in water in a bucket for 24 hours. Then the seeds were taken out of water and kept in gunny bags. The seeds started sprouting after 48 hours which were suitable for sowing in 72 hours.

2.4. Fertilizers and Manure

The fertilizers N, P, K, S, Zn and B in the form of urea, TSP, MP, gypsum, zinc sulphate and borax, respectively were applied. The entire amount of TSP, MP, gypsum, zinc sulphate and borax were applied during the final preparation of plot land. Mixture of cowdung and compost was applied at the rate of 10 t ha^{-1} during 15 days before transplantation. Urea was applied in three equal installments at after recovery, tillering and before panicle initiation. The dose and method of application of fertilizers are shown in Table 2.

Table 2. *Dose and method of fertilizers application.*

Fertilizers	Dose	Application (%)			
	(kg ha^{-1})	Basal	1st installment	2nd installment	3rd installment
Urea	150	--	33.33	33.33	33.33
TSP	100	100	--	--	--
MP	100	100	--	--	--
Zinc sulphate	10	100	--	--	--
Gypsum	60	100	--	--	--
Borax	10	100	--	--	--

Source: BRRI, 2012, AdhunikDhanerChash, Joydevpur, Gazipur

2.5. Data Recording

Data were recorded on physiological characters and yield components in each replication as follows-

2.5.1. Plant Height

The height of plant was recorded in centimeter (cm) at the time of 30, 50, 70 and 90 DAT (Days after transplanting) and at harvest. The height was measured from the ground level to the tip of the plant of five hills and finally the average value was calculated.

2.5.2. Tillers Hill^{-1}

The number of tillers hill^{-1} was recorded at the time of 30, 50, 70 and 90 DAT by counting total tillers of five respective hills and finally the average value was calculated to hill^{-1} basis.

2.5.3. Leaf Area Index

Leaf area index (LAI) was measured manually at the time of 30, 50, 70 and 90 DAT and at harvest. Data were recorded as the average of 05 plants selected at random the inner rows of each plots. The final data were calculated multiplying by a correction factor 0.75 as per Yoshida [16].

2.5.4. Stem and Leaf Dry Matter Hill^{-1}

Stem and leaf dry matter hill^{-1} was recorded at 30, 50, 70 and 90 DAT and at harvest from 10 randomly collected stems hill^{-1} of each plot from inner rows leaving the boarder row. Collected stems were oven dried at 70°C for 72 hours then transferred into desecrator and allowed to cool down at room temperature; final weight was taken and converted into stem dry matter content hill^{-1}.

2.5.5. Shoot Dry Matter Accumulation and Its Remobilization to Grain

Plants from 1 m^2 were sampled from each plot at pre-anthesis and maturity. The harvested plants were separated into leaf blades (leaf), culm and sheath (stem) and panicles. Dry matter of each component was determined after drying at 72°C for 72 hours. The shoot reserve translocation was calculated by net loss in dry weight of vegetative organs between pre-anthesis and maturity using the following:

$$\text{Shoot reserve translocation (\%)} = \frac{A-M}{A}\times 100 \qquad (1)$$

Where,
A = Total shoot dry matter at pre-anthesis, g m^{-2}
M = Total shoot dry matter at maturity, g m^{-2}

2.5.6. Days to Maturity

Days to maturity were recorded by counting the number of days required to harvest in each plot.

2.5.7. Panicles Hill^{-1}

The total number of panicles hill^{-1} was counted as the number of panicle bearing hill plant^{-1}. Data on effective tillers hill^{-1} were counted from 5 selected hills at harvest and average value was recorded.

2.5.8. Effective and Ineffective Tillers Hill^{-1}

The total number of effective and ineffective tillers hill^{-1} was counted as the number of panicle and no-panicle bearing tillers plant^{-1}. Data were counted from 5 selected hills at harvest and average value was recorded. Finally the total tillers hill^{-1} was counted by adding effective tillers and ineffective tillers hill^{-1}.

2.5.9. Panicle Length

The length of panicle was measured with a meter scale from 10 selected panicles and the average value was recorded.

2.5.10. Filled and Unfilled Spikelets Panicle^{-1}

The total number of filled and unfilled spikelets was counted randomly from selected 10 panicles of a plot on the basis of grain in the spikelet and then average number of filled and unfilledspikelets panicle^{-1} was recorded. Finally the total spikelets panicle^{-1} was counted by adding filled and unfilled spikelets panicle^{-1}.

2.5.11. Spikelets Fertility

Spikelets fertility was computed using the formula:

$$\text{Spikelets fertility (\%)} = \frac{\text{Filled spikelets panicle}^{-1}}{\text{Total spikelets panicle}^{-1}}\times 100 \qquad (2)$$

2.5.12. Thousand Grains Weight

One thousand grains were counted randomly from the total cleaned harvested grains of each individual plot and then weighed in grams and recorded.

2.5.13. Yield

Grains obtained from each unit plot were sun-dried and weighed carefully and finally adjusted to 14% moisture basis using a digital moisture meter. Straw obtained from each unit plot were sun-dried and weighed carefully. The dry weight of grains and straw of each plot from harvested area was measured and converted to t ha^{-1}. Grain yield and straw yield together were regarded as biological yield and expressed in t ha^{-1}.

$$\text{Biological yield} = \text{Grain yield} + \text{Straw yield}. \qquad (3)$$

2.5.14. Harvest Index

Harvest index was calculated from the grain and straw yield of rice for each plot and expressed in percentage.

$$\text{HI (\%)} = \frac{\text{Economic yield (grain weight)}}{\text{Biological yield (Total dry weight)}}\times 100 \qquad (4)$$

2.5.15. Source-Sink Relation

Ratio of spikelets number to leaf area (at heading), yieldsink to leaf area (at heading) and accumulated grain dry matter from current photosynthate (GDMCPn) to average leaf area (heading to maturity)reflect source -sink relations. Ratio of spikelets number to leaf area (at heading) and yield sink to leaf area (at heading) were estimated as follows-

$$\text{Ratio of spikelets no to LA (cm-2)} = \frac{\text{Spikelets number cm}^{-2}}{\text{LAI at heading}} \quad (5)$$

$$\text{Ratio of Yield sink to LA (mg cm-2)} = \frac{\text{Yield sink mg cm}^{-2}}{\text{LAI at heading}} \quad (6)$$

Where,

$$\text{Yield sink (mg cm}^{-2}) = \frac{\text{Panicles wt.hill}^{-1}}{\text{Hill area}} \times 100 \quad (7)$$

Ratio of accumulated grain dry matter from current photosynthate to average leaf area (heading to maturity) expresses the actual assimilate supply to grain from each unit post-heading leaf area and was calculated as follows-

Ratio of accumulated grain dry matter from current photosynthate (GDMCPn) to average leaf area,

$$\text{LA (mg cm}^{-2}) = \frac{\text{Yield sink – (panicle dry weight at heading + remobilization)}}{\text{Average LAI from heading to maturity}} \quad (8)$$

2.5.16. Grain Dry Matter Percent from Current Photosynthate

Percentage of grain dry matter from current photosynthate (GDMCPn%) was estimated using following formula-

$$\text{GDMCPn(\%)} = \frac{\text{Yield sink} - \text{(panicle dry weight at heading + remobilization)}}{\text{Grain weight}} \times 100 \quad (9)$$

2.6. Statistical Analysis

The data obtained for different characters were statistically analyzed using MSTAT-C software to observe the significant difference among the varieties. The mean values of all the characters were calculated and analysis of variance was performed. The significance of the difference among the treatment means was estimated by the Least Significant Difference (LSD) test at 5% level of probability [17].

3. Results and Discussion

3.1. Plant Height

Statistically significant variation was recorded for plant height for different varieties at 30, 50, 70 and 90 days after transplanting (DAT). Data revealed that at 30, 50, 70 and 90 DAT, the tallest plant heights (37.29, 56.49, 79.23 and 98.83 cm respectively) were recorded from Jagoron which were statistically similar (35.34, 55.69, 77.69 and 99.03 cm respectively) to Heera 4, whereas the shortest plant heights (29.28, 47.68, 71.12 and 87.30 cm respectively) were recorded from BRRI dhan28 (Figure. 1). [18] Earlier study reported that H_1 hybrid rice variety surpassed other varieties in terms of plant height. Previous study reported earlier significant effects on plant height at maturity for different rice variety [19].

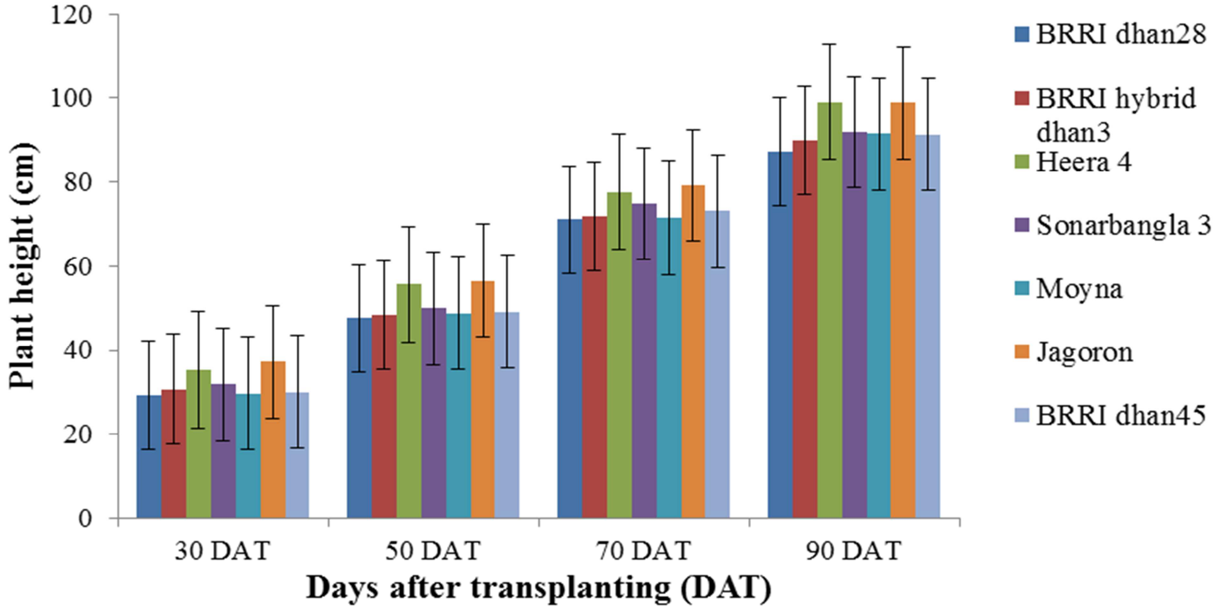

Figure 1. *Plant heights at different days after transplanting (DAT) in the test rice varieties.*

3.2. Tillers Hill^{-1}

At 30, 50, 70 and 90 DAT, the maximum tillers hill^{-1} (6.83, 10.52, 17.31 and 19.27 respectively) were found in Heera 4 which were statistically similar (6.03, 10.12, 16.69 and 17.46 respectively) to Jagoron, while the minimum tillers hill^{-1} (4.07, 7.27, 11.07 and 14.41 respectively) were observed in BRRI dhan28 (Table 3). [19] Recommended hybrid rice varieties because it produced more productive tillers. [20]Also reported that Rice Hybrid-2 (KRH2) produced highest tiller number than the other varieties.

3.3. Leaf Area Index

At 30, 50, 70 and 90 DAT, the highest leaf area index (0.279, 1.164, 3.48 and 5.97 respectively) was observed in Heera 4 which was statistically similar (0.257, 1.147, 3.48 and 5.68 respectively) to Jagoron and the lowest leaf area index (0.213, 0.921, 2.74 and 5.03 respectively) was found in BRRI dhan28 (Table 3). The result indicated that hybrid rice produced higher LAI than the check variety and the increase in LAI with time could be attributed to increase in number of tillers consequently higher number of leaves hill^{-1}.

3.4. Stem and Leaf Dry Matter Hill^{-1}

Statistically significant variation was recorded for stem dry matter hill^{-1} for different varieties at 30, 50, 70 and 90 days after transplanting (DAT). At 30, 50, 70 and 90 DAT, the highest stem dry matter hill^{-1} (2.75, 3.95, 8.22 and 6.47 g respectively) were found in Heera 4 which were statistically similar (2.46, 3.82, 7.70 and 6.10 g respectively) to Jagoron, while the lowest stem dry matter hill^{-1} (2.02, 2.69, 5.79 and 5.12 g respectively) were attained from BRRI dhan28 (Figure 2). Similar results were also reported by [21-23] from their earlier experiments. Significant variation was observed in terms of leaf dry matter hill^{-1} for different varieties at 30, 50, 70 and 90 DAT. At 30, 50, 70 and 90 DAT, the highest leaf dry matter hill^{-1} (1.74, 2.93, 6.52 and 5.98 g respectively) were recorded from Heera 4 which were statistically similar (1.68, 2.82, 6.34 and 5.12 g respectively) to Jagoron, whereas the lowest leaf dry matter hill^{-1} (1.37, 2.31, 5.25 and 4.35 g respectively) were recorded from BRRI dhan28 (Figure 3).

Table 3. *Tillers hill^{-1} and Leaf area index at different days after transplanting for different rice varieties in Boro season.*

Rice variety	Tillers hill^{-1} at				Leaf area index at			
	30 DAT	50 DAT	70 DAT	90 DAT	30 DAT	50 DAT	70 DAT	90 DAT
BRRI dhan28	4.07 d	7.27 d	11.07 c	14.41 b	0.213 cd	0.921 b	2.74 c	5.03 b
BRRI hybrid dhan3	5.57 b	8.23 c	11.32 c	14.39 b	0.235 c	0.957 b	3.32 b	5.32 b
Heera 4	6.83 a	10.52 a	17.31 a	19.27 a	0.279 a	1.164 a	3.48 a	5.97 a
Sonarbangla 3	5.36 b	9.17 b	14.72 b	17.72 a	0.217 cd	0.898 b	3.02 bc	5.36 b
Moyna	5.01 c	8.02 c	11.82 c	14.38 b	0.212 cd	0.963b	3.01 bc	5.11 b
Jagoron	6.03 a	10.12 a	16.69 a	17.46 a	0.257 b	1.147 a	3.48 a	5.68 a
BRRI dhan45	5.00 c	8.12 c	12.02 c	15.67 b	0.223 cd	0.892 b	2.98 bc	5.07 b
$LSD_{(0.05)}$	0.474	0.842	1.446	1.498	0.018	0.056	0.245	0.509
CV (%)	5.82	5.98	6.62	5.37	3.95	6.78	3.37	5.43

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

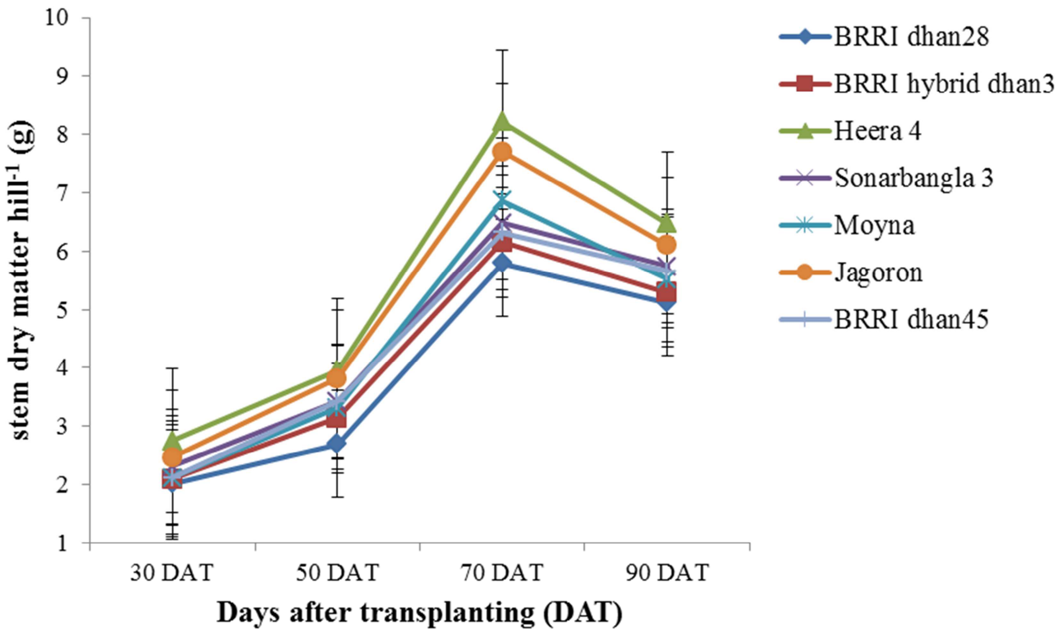

Figure 2. *Stem dry matter hill^{-1} at different days after transplanting (DAT) in the test rice varieties.*

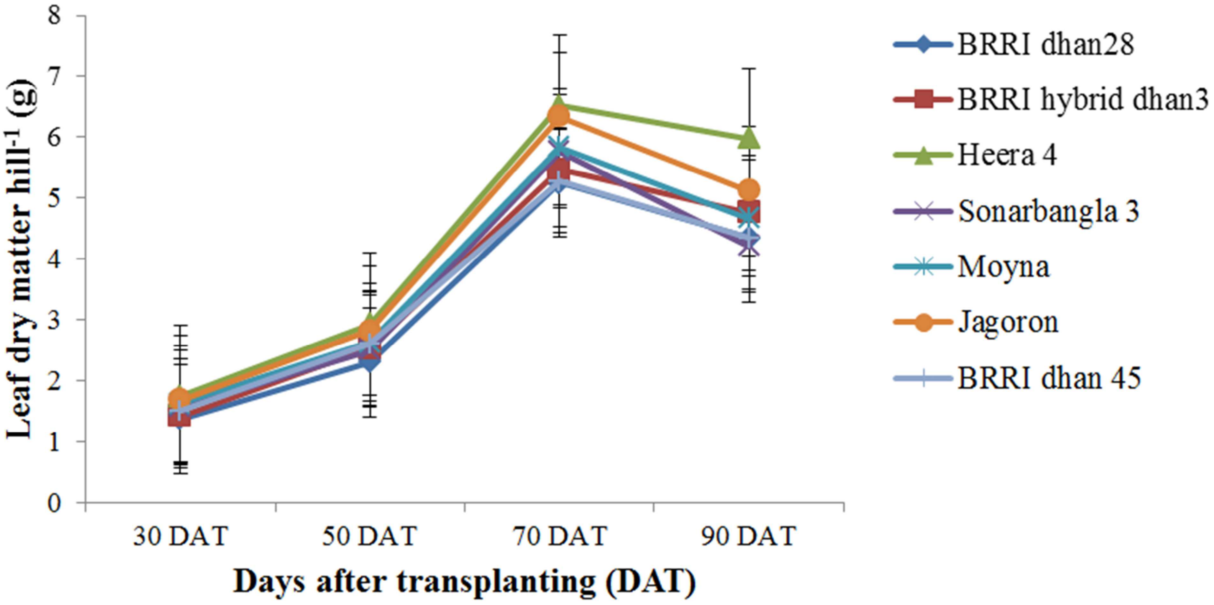

Figure 3. *Leaf dry matter hill^{-1} at different days after transplanting (DAT) in the test rice varieties.*

3.5. Shoot Dry Matter Accumulation and Its Remobilization to Grain

Statistically significant variation was recorded for shoot dry matter at pre-anthesis, shoot dry matter at maturity, change in shoot dry matter and shoot reserve translocation.

3.5.1. Shoot Dry Matter at Pre-anthesisPeriod

For shoot dry matter at pre-anthesis period, the highest value (30.88 gm^{-2}) was recorded from Heera 4 which was statistically similar (29.97 and 29.90 gm^{-2} respectively) to Jagoron and Sonarbangla 3. Again the lowest value (24.93gm^{-2}) was found in BRRI dhan28 (Table 4).

3.5.2. Shoot Dry Matter at Maturity Period

In consideration of shoot dry matter at maturity period the highest value (26.07 gm^{-2}) was recorded from Heera 4 which was statistically similar (25.52 and 25.51 gm^{-2} respectively) to Jagoron and Sonarbangla 3, again the lowest value (22.54 gm^{-2}) was found in BRRI dhan28 (Table 4).

3.5.3. Changes in Shoot Dry Matter

For changes in shoot dry matter the highest value (4.81 gm^{-2}) was recorded from Heera 4 which was statistically similar (4.45, 4.39 and 4.30 gm^{-2} respectively) to Jagoron, Sonarbangla 3 and Moyna, again the lowest value (2.39 gm^{-2}) was found in BRRI dhan28 (Table 4).

3.5.4. Shoot Reserve Translocation

Consideration of shoot reserve translocation, the highest shoot reserve translocation (15.58%) was recorded from Heera 4 which was statistically similar (14.85%, 14.76% and 14.68% respectively) to Jagoron, Moyna and Sonarbangla 3, while the lowest (9.59%) was found in BRRI dhan28 which was followed (11.40%) by BRRI dhan45 (Table 4). This result revealed that the test hybrid variety had the advantage of shoot reserve translocation to the grains.

3.6. Days to Maturity

The maximum days to maturity (145.04 days) was observed in Sonarbangla 3 which was closely followed (140.19 days and 139.01 days respectively) by BRRI dhan45 and BRRI dhan28, while the minimum days to maturity (114.57) was found in Jagoron (Table 5).

3.7. Panicles Hill^{-1}

The maximum number of panicles hill^{-1} (14.82) was recorded from Heera 4 which was closely followed (13.57) by Jagoron and the minimum number (10.29) was recorded from BRRI dhan45 which was statistically similar (10.45, 10.53 and 10.62) to BRRI dhan 28, BRRI hybrid dhan3 and Moyna (Table 5). [22] vreported that panicle length was longest in hybrid Hb_2 than Hb_1.

3.8. Effective and Ineffective Tillers Hill^{-1}

The maximum number of effective tillers hill^{-1} (14.83) was found in Heera 4 which was statistically similar (13.64) to Jagoron, while the minimum number (10.43) was observed in BRRI dhan45 (Table 5). The minimum number of ineffective tillers hill^{-1} (1.93) was found in Heera 4 which was statistically similar (2.03) to Jagoron, while the maximum number (3.29) was observed in Moyna which was followed (2.86 and 2.55 respectively) by Sonarbangla 3 and BRRI hybrid dhan 3 (Table 5).

3.9. Panicle Length

The longest panicle (23.63 cm) was found in Jagoron which was statistically similar (23.51 cm and 23.23 cm) to Heera 4 and Sonarbangla 3 respectively, while the shortest panicle length (18.77 cm) was attained from BRRI dhan28 which was statistically similar (18.79 cm) to BRRI dhan45 (Table 5). [20]In a study with hybrid rice cultivar KRH2 and

1R20 as a check variety and reported that the increased grain yield of KRH2 was mainly attributed to the tallest panicle length.

Table 4. *Pre-anthesis dry matter accumulation in shoot and its translocation to the grain of different rice varieties in Boro season.*

Rice variety	Shoot dry matter atpre-anthesis (g m^{-2})	Shoot dry matter at maturity (g m^{-2})	Changes in shoot dry matter (g m^{-2})	Shoot reserve translocation (%)
BRRI dhan28	24.93 d	22.54 c	2.39 d	9.59 c
BRRI hybrid dhan3	28.04 b	24.32 b	3.72 b	13.27 b
Heera 4	30.88 a	26.07 a	4.81 a	15.58 a
Sonarbangla 3	29.90 a	25.51 a	4.39 a	14.68 a
Moyna	29.14 b	24.84 b	4.30 a	14.76 a
Jagoron	29.97 a	25.52 a	4.45 a	14.85 a
BRRI dhan45	27.37 c	24.25 b	3.12 c	11.40 bc
$LSD_{(0.05)}$	1.722	1.175	0.573	2.081
CV (%)	6.89	8.43	6.39	8.36

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

3.10. Filled and Unfilled Grains Panicle^{-1}

The highest number of spikelets grains per panicle (88.60) were recorded from Heera 4 which was statistically similar (87.87, 83.40 and 82.80) with Jagoron,Sonarbangla 3 and Moyna, again the minimum number of filled spikelets panicle^{-1} (70.27) was recorded from BRRI dhan28 which was statistically similar (74.80 and 75.53) to BRRI dhan45 andBRRI hybrid dhan 3 (Table 5). [24] Recorded different number of filled spikelets for different varieties. The lowest number of unfilled grains panicle^{-1} (6.61) was recorded from Heera 4 which was statistically similar (7.02 and 7.32) to Jagoron and Sonarbangla 3, while the highest number (9.62) was recorded from Moyna which was statistically similar (9.42, 9.12 and 8.82) to BRRI dhan28, BRRI dhan45 and BRRI hybrid dhan3 respectively (Table 5). (BINA,1993) conducted an experiment with four varieties/advanced lines and reported significant variation in unfilled grains panicle^{-1}.

3.11. TotalSpikelets Panicle^{-1}

The maximum number of total spikeletspanicle^{-1} (95.30) was recorded from Heera 4 which was statistically similar (95.00, 92.53 and 90.83) to Jagoron, Moyna and Sonarbangla 3. On the other hand the minimum number of total spikelets panicle^{-1} (79.80) was observed in BRRI dhan28 (Figure 4). [26, 27] observed that the restorer lines showed more spikelets than maintainer lines.

3.12. SpikeletsFertility

The highest spikelets fertility (92.97%) were recorded from Heera 4 which was statistically similar (92.49% and 91.82%) to Jagoron and Sonarbangla 3, while the lowest spikelets fertility (88.06%) was observed in BRRI dhan28 (Figure 5).

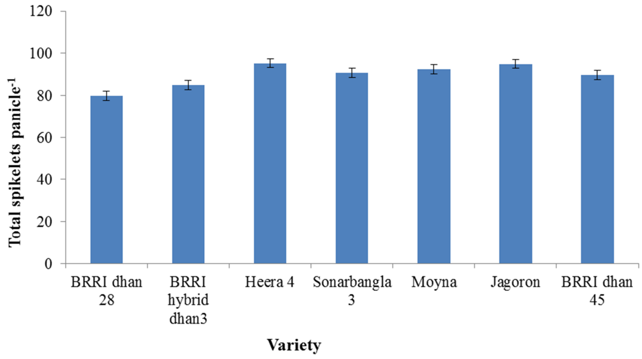

Figure 4. *Total spikelets panicle^{-1} in the test rice varieties.*

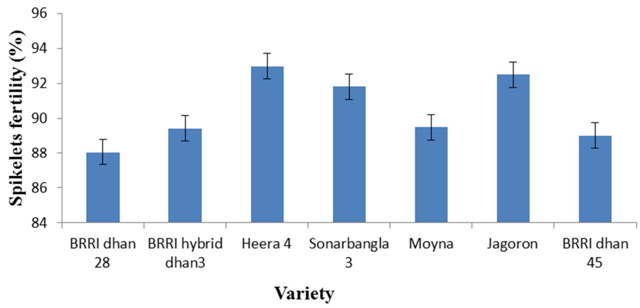

Figure 5. *Spikelets fertility (%) in the test rice varieties.*

3.13. 1000 Grains Weight

The highest weight of 1000 grains (23.26 g) was found in Heera 4 which was statistically similar (23.11 g) to Jagoron, while the lowest weight of 1000 grains (19.69 g) was recorded from BRRI dhan28 which was statistically similar (20.14 g, 20.40 g and 20.53 g respectively) to Moyna, BRRI dhan45 and BRRI hybrid dhan3 (Table 5). [28] Conducted an experiment with two hybrids (CNHR2 and CNHR3) and two high yielding varieties (IR36 and IR64) of rice and five levels of nitrogenous fertilizers and observed that IR36 gave the highest 1000-grain weight (21.07g).

Table 5. Yield contributing characters of different rice varieties in Boro season.

Rice variety	Days to maturity	Panicles hill^{-1} (No.)	Effective tillers hill^{-1} (No.)	Ineffective tillers hill^{-1} (No.)	Panicle length (cm)	Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)	Weight of 1000-grains (g)
BRRI dhan28	139.01 ab	10.45 d	10.48d	2.39 bc	18.77 c	70.27e	9.42 a	19.69 c
BRRI hybrid dhan3	129.33 c	10.53 d	10.72d	2.55 b	20.65 b	75.53d	8.82 a	20.53 bc
Heera 4	137.00 b	14.82 a	14.83a	1.93 c	23.51 a	88.6a	6.61 b	23.26 a
Sonarbangla 3	145.04 a	12.07 c	11.64c	2.86 b	23.23 a	83.4b	7.32 b	21.61ab
Moyna	138.12 b	10.62 d	10.66d	3.29 a	19.72 b	82.8b	9.62 a	20.14 bc
Jagoron	114.57 d	13.57 b	13.64b	2.03 c	23.63 a	87.87a	7.02 b	23.11 a
BRRI dhan45	140.19 ab	10.29 d	10.43d	2.30 bc	18.79 c	74.80d	9.12 a	20.40 bc
$LSD_{(0.05)}$	7.236	0.765	0.264	0.775	2.249	5.48	0.961	1.094
CV (%)	5.63	4.76	8.89	16.76	6.57	5.35	7.55	8.83

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

3.14. Grain and Straw Yield

The highest grain yield (7.80 t ha^{-1}) was observed in Heera 4 which was statistically similar (7.08 t ha^{-1}) to Jagoron and closely followed (6.35 t ha^{-1} and 6.18 t ha^{-1}) by Sonarbangla 3 and Moyna. On the other hand, the lowest grain yield (4.23 t ha^{-1}) was recorded from BRRI dhan28 (Figure 6). [29]reported different yield for different variety. The highest straw yield (9.39 t ha^{-1}) was found in Jagoron which was statistically similar (9.21 t ha^{-1} and 8.86 t ha^{-1}respectively) to Heera 4 and Sonarbangla 3, while the lowest straw yield (6.24 t ha^{-1}) was attained from BRRI dhan28 which was closely followed (6.46 t ha^{-1}) by BRRI dhan45 (Figure 7).

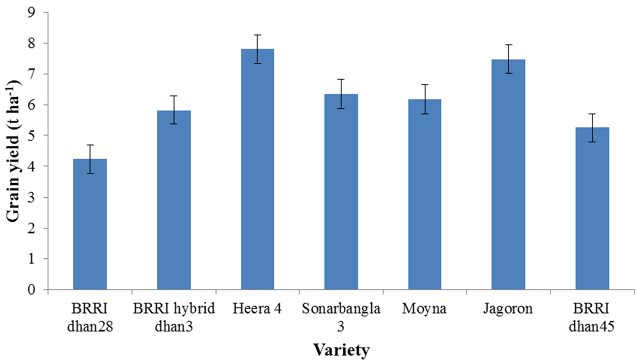

Figure 6. Grain yield in the test rice varieties.

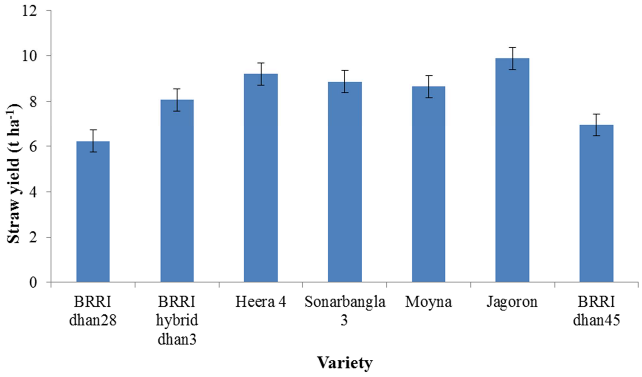

Figure 7. Straw yield in the test rice varieties.

3.15. Biological Yield

The highest biological yield (17.01 t ha^{-1}) was observed in Heera 4 which was statistically similar (16.47 t ha^{-1}) to Jagoron and closely followed (15.21 t ha^{-1} and 14.84 t ha^{-1}) by Sonarbangla 3 and Moyna, whereas the lowest biological yield (10.47 t ha^{-1}) was found in BRRI dhan28 which was statistically similar (11.01 t ha^{-1}) to BRRI dhan45 (Figure 8).

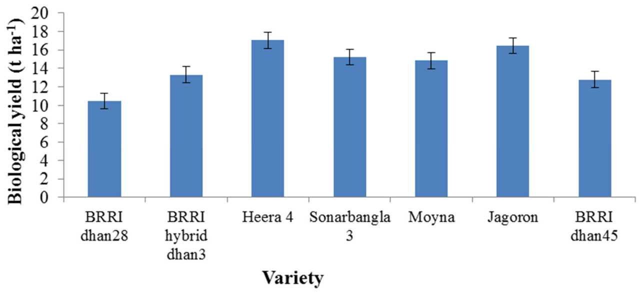

Figure 8. Biological yield in the test rice varieties.

3.16. Harvest Index

The highest harvest index (45.86%) was found in Heera 4 which was followed (42.99%, 41.75% and 41.64% respectively) by Jagoron, Sonarbangla 3 and Moyna. Again the lowest harvest index (40.40%) was recorded from BRRI dhan28 (Figure 9).

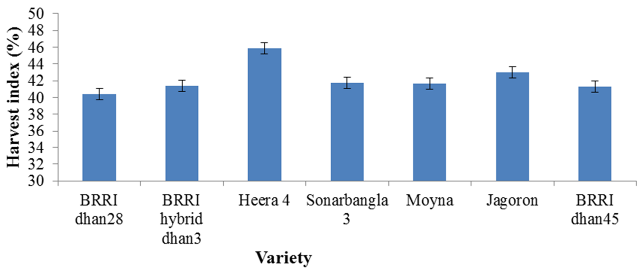

Figure 9. Harvest index in the test rice varieties.

3.17. Source-Sink Relationship

Ratio of spikelets number to leaf area (at heading), yield sink to leaf area (at heading) and grain dry matter accumulated from current photosynthetic assimilation to leaf area (heading to maturity) reflected source-sink relation

(Table 6). Heera 4 (0.31 no. cm^{-2}), Jagoron (0.30 no. cm^{-2}) and Sonarbangla 3 (0.27 no. cm^{-2}) varieties maintained considerable higher ratio of spikelets number to leaf area (at heading) compared to inbred BRRI dhan28 (0.22 no. cm^{-2}) in *Boro* season. In addition, the highest ratio of yield sink to Leaf Area (At heading) was recorded from Heera 4 (14.09 mg cm^{-2}) which was followed (13.88, 13.39, 13.02 mg cm^{-2} respectively) by Jagoron, Sonarbangla 3 and Moyna, while the lowest value was recorded from BRRI dhan28 (11.09 mg $cm^{-2)}$. This result indicated that the test hybrid varieties had higher source use efficiency from panicle initiation (PI) stage to heading stage. Tabulated data of *Boro* season showed that ratio of grain dry matter accumulated from current photosynthetic assimilation to leaf area (heading to maturity) was significantly higher in Heera 4 (11.01 mg cm^{-2}) than all studied varieties. These results suggested that Heera 4 had the genotypic superiority over the test varieties in respect of post heading photosynthetic assimilation per unit leaf area (higher source use efficiency). Higher yield sink per unit leaf area in all the studied hybrids indicated that the shoot reserve remobilization played substantial role in its higher yield over inbred varieties.

3.18. Grain Dry Matter from Current Photosynthate(GDMCPn)

Percentage of grain dry matter accumulated from current photosynthate (GDMCPn %) varied significantly among the studied hybrid and inbred varieties (Table 6). Grain dry matter accumulated from current photosynthate ranged from 75.79% to 83.19% in *Boro* season respectively among the varieties. Heera 4 (83.19%) accumulated significantly higher percentage of dry matter from current photosynthate in grain compared to all the studied varieties in *Boro* season. This value was closely followed (82.99%, 80.95%, 79.93% and 78.66% respectively) by Jagoron, Sonarbangla 3, BRRI hybrid dhan3 and Moyna, while the lowest value (75.79%) was recorded from BRRI dhan45.

Table 6. *Source-sink relation of the hybrid and inbred rice varieties in Boro season.*

Rice variety	Ratio of spikelets no. to LA (at heading)No.cm^{-2}	Ratio of yield sink to LA (at heading)mg. cm^{-2}	Ratio of GDMCPn to average LA (heading to maturity)mg. cm^{-2}	GDMCPn (%)
BRRI dhan28	0.22d	11.09c	8.80bc	75.95c
BRRI hybrid dhan3	0.23cd	12.98bc	10.04b	79.93bc
Heera 4	0.31a	14.05a	11.01a	83.19a
Sonarbangla 3	0.27b	13.39b	10.14ab	80.95b
Moyna	0.26b	13.02b	9.62b	78.66b
Jagoron	0.30a	13.88ab	10.79a	82.99a
BRRI dhan45	0.24c	11.37c	8.68c	75.79c
$LSD_{(0.05)}$	0.152	1.352	0.734	3.217
CV (%)	5.67	7.75	4.54	8.94

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05level of probability. DM= dry matter, LA =leaf area, GDMCPn= Grain dry matter from current photosynthate

4. Conclusion

At 30, 50, 70 and 90 DAT, the tallest plant heights (37.29, 56.49, 79.23 and 98.83 cm respectively) were recorded from Jagoron, whereas the shortest heights (29.28, 47.68, 71.12 and 87.30 cm respectively) were recorded from BRRI dhan28. The maximum number of tillers $hill^{-1}$, highest LAI and highest dry matter $hill^{-1}$ were found in Heera 4, while the minimum tillers $hill^{-1}$, lowest LAI and lowest dry matter $hill^{-1}$ were observed in BRRI dhan28. The highest shoot reserve translocation (15.58%) was recorded from Heera 4, while the lowest (9.59%) was found in BRRI dhan28. The maximum days to maturity (145.04 days) was observed in Sonarbangla 3, while the minimum days to maturity (114.57) was found in Jagoron. The longest panicle length (23.63 cm) was found in Jagoron while the shortest panicle length (18.77 cm) was attained from BRRI dhan28. The maximum number of effective tillers $hill^{-1}$, total spikelets $panicle^{-1}$ spikelets and fertility highest weight of 1000 grains was found in Heera 4, while the minimum number was observed in BRRI dhan45. The highest biological yield (17.01 t ha^{-1}) with harvest index (45.86%) was observed in Heera 4 whereas the lowest biological yield (10.47 t ha^{-1}) and (40.40%) was found in BRRI dhan28. In addition, Heera 4 maintained highest ratio of spikelets number to LA (0.31 no. cm^{-2}) (at heading), while the lowest value (0.22 no. $cm^{-2)}$ was observed in BRRI dhan28. The highest ratio of yield sink to LA (At heading) was recorded from Heera 4 (14.09 mg cm^{-2}), while the lowest value (11.09 mg cm^{-2}) was recorded from BRRI dhan28. Heera 4 (83.19%) accumulated significantly higher percentage of dry matter from current photosynthate in grain, while the lowest value (75.79%) was recorded from BRRI dhan45. These results suggested that Heera 4 had the genotypic superiority over the tested varieties in respect of post heading photosynthetic assimilation per unit leaf area (higher source use efficiency). From the findings, it is observed that all the studied hybrids showed better performance in case of tillering, leaf area development pattern, source use efficiency and yield performance compared to inbred varieties. Among all test rice varieties Heera 4 hybrid rice was the best among the test varieties in consideration of source-sink relationship and yield performance.

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