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Research paper

Source-sink manipulation influences the grain-filling characteristics associated with the grain weight of rice

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Source-sink and translocation capacity of assimilate can plays an important role during the grain formation. An experiment was conducted to investigate the effect of source-sink manipulation on grain weight of rice using two rice varieties viz. BRRI dhan49 and Balam. Seven treatments were employed in the experiment and analyzed the data by randomized complete block design (RCBD) with three replications. Considering yield and yield contributing characters, BRRI dhan49 performed better than Balam. The grain weight of BRRI dhan49 was increased when the half spikelets were removed. Manipulation on grains number which had strong effects on grain yield might be the main reason causing the lower grain yield. However, the individual grain weight increased in the 25% and 50% spikelet removal in between two rice varieties. When 50% or full flag leaves were removed, the grain size and percentage of filled grain were drastically reduced, resulting the ultimate lower yield. Moreover, the results suggested that the grain yield of BRRI dhan49 and Balam were limited by the sink activity, more than source capacity.

Key words: *source-sink, manipulation, rice grain-filling, grain weight*

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food of Bangladesh. Among the world top most rice growing countries, Bangladesh ranked the 4th position regarding its production (FAOSTAT, 2021). But Bangladesh has been facing acute shortage of rice to feed it's over population. And total rice production is continuously declining due to country's urbanization and industrialization. The horizontal expansion of rice area in Bangladesh is not possible due to high rate of its population growth. Moreover, some rice growing areas are now being used as ponds for raising fishes to meet up the protein demand of its over-crowded people. So, the production of higher yield in per unit area maybe one of the important way to ensure the food security of the country. Rice grain yield depends on both the source and the sink capacity of the plant (Shi et al., 2017). In the rice plant, the most critical and development stage is the grain filling (Hossain et al., 2010; Niknejad et al., 2007; Tabassum et al., 2020b; Yang et al., 2008) which enhance its production. In this phase, source supply occurs either from pre-heading carbohydrate reserves or from post-heading photosynthates, which is crucial to fill sink adequately for getting higher and good quality yield (Aye et al., 2020; Godarzi et al., 2015). To study its grain filling process, manipulation of source-sink ratio is the suitable methods have been reported by many researchers (Asli et al., 2011; Bai et al., 2016; Shahruddin et al., 2014). For developing grains, artificial reduction of grain number in each inflorescence is one of the best techniques to increase the photo-assimilate supply while removal of flag leaf or its parts can reduce the photo-assimilate (Bai et al., 2016). Generally, rice plant assimilates higher photosynthetic products before anthesis and store in vegetative organs to fill grains properly (Murchie et al., 2002). However, the photosynthetic assimilation and grain filling also depends on the post-anthesis of rice. Wu et al. (2018) noticed the greater yield due to the genotypic effects of rice which leads to higher dry matter accumulation as well as expanded sink capacity.

In the crop physiology, changes in assimilate supply at different phenological stages is the major advancement regarding the yield improvement of a particular crop (Hossain et al., 2017; Tabassum et al., 2020a). The primary photosynthate sink like florets, and the top three leaves on a stem, especially the flag leaf, are marked as the primary source. The flag leaf has great importance on panicle length, grains number per panicle as well as the total grain yield (Akter et al., 2016; Aye et al., 2020; Shahruddin et al., 2014). A negative correlation between percent of sterility and yield of rice has been reported by Moncada et al. (2001) and reduce its sterility or boost up its fertility would be the valuable option for higher yield production. Moreover, rice varieties comprising compact and short panicle with high grain density can increase 8 to 20% more yield rather than other traditional rice varieties (Bai et al., 2016; Zhang, 2007). Therefore, larger sink size along with adequate transport of photo-assimilate from leaves and stems is essential to produce higher yield.

The aim of this study was to examine the performance of sink and source interactions at pre-and post-anthesis to evaluate the possible factors limiting grain yield in the two rice cultivars. Artificial manipulations of the sink and source ratio and evaluation of the variation in two rice cultivars was used to assess the existence of genotypic differences in the response. Now this topic is not clearly understood by the entire researcher but we can see in this experiment when the flag leaf or spikelets removed then the grain yield may be increased or decreased due to source or sink limitation. Considering this, the study was undertaken to determine the genotypic differences in the response of availability of photo-assimilates in rice as well as to improve the understanding of grain weight determination and its key associated traits in both local and high yielding of rice varieties.

MATERIALS AND METHODS

Topography of the experimental site and materials

An experiment was carried out at the Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh during the transplant aman season (July to December 2016) to the effect of source-sink manipulation on grain weight of rice. Geographically the experimental site is located at 24°25"N latitude and 90°50"E longitude. The experimental field was medium high land with loamy soil having pH value of 5.7. The land was flat, well drained and above the flood level. Soil of the experimental field was more or less neutral in reaction, low in organic matter content and its general fertility level was also low. Soil contained 1.29% organic matter, 0.10% total nitrogen, 16.72 ppm available phosphorus, 0.12 ppm exchangeable potassium and 14.12 ppm available sulphur (Measured data are not shown). The experimental area is under the sub-tropical climate having high humidity, high temperature and heavy rainfall with occasional gusty winds in Kharif season (April-September) and scanty rainfall with moderately low temperature during the Rabi season (October-March). The experiment comprised two varieties viz. BRRI dhan49 and Balam. Seeds were collected from the Bangladesh Rice Research Institute, Joydebpur, Gazipur and Agronomy Field Laboratory, Mymensingh, Bangladesh.

Treatments and design

Seven treatments were applied during the experiment viz. control (No manipulation) (T_1), removal of one sided spikelets at heading(T_2), full flag leaf removal at heading(T_3), half flag leaf removal at heading(T_4), upper half spikelets removal at heading(T_5), lower half spikelets removal at heading(T_6) and upper half spikeletes removal at 10 DAA(T_7). The experiment was laid out in a randomized complete block design (RCBD) with three replications. The total numbers of unit plots were 42. The size of each unit plot was 5m^2 (2.5m x 2 m). The spaces between blocks and plots were 1 m and 0.75 m, respectively.

Cultural Practices

The land was prepared well by ploughing and cross-ploughing using rotavetor to produce good environment of seed germination and plant growth. The experimental plots were fertilized with urea (200 kg ha^{-1}), triple super phosphate (100 kg ha^{-1}), mutiate of potash (70 kg ha^{-1}), gypsum (60 kg ha^{-1}) and zinc sulphate (10 kg ha^{-1}). Seedlings were uprooted carefully from the nursery bed. Before uprooting the seedlings, nursery bed was slightly irrigated for easier uprooting. Uprooted seedlings were transplanted in the unit plots on 21 July, 2016 respectively at the rate of three seedlings hill^{-1} maintaining spacing of 25 cm × 15 cm. Irrigation, weeding, pest control, mulching and other intercultural operations were done as per requirement.

Collection of experimental data

Five hills (excluding order hills) were selected randomly from each experimental plot to record necessary data. An area of 1 m^2 was selected in the middle portion of each plot to record the yield of grain and straw. The data on the following parameters were collected such as plant height (cm), number of total tillers m^{-2}, number of effective tillers m^{-2}, number of non-effective tillers m^{-2}, panicle length (cm), number of grains panicle^{-1}, number of sterile spikelets panicle^{-1}, 1000-grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}), harvest index (%), primary rachis number $panicle^{-1}$, primary rachis density cm^{-1}, grain morphology(length, height, width) and superior-inferior grains per panicle.

Biological yield (t ha^{-1}) was measured using grain yield and straw yield and was calculated using the following formula:
Biological yield = Grain yield (t ha^{-1}) + Straw yield (t ha^{-1})

Harvest index (%) was calculated using the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Statistical Analysis

The collected data were compiled and tabulated in proper form and subjected to statistical analysis. Data were analyzed using the analysis of variance technique with the help of computer package program MSTAT-C and mean differences were adjudged by Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Panicle length

Panicle length was significantly influenced by the two varieties (Table 1). The highest panicle length (25.61cm) was found in Balam rice variety. Such variation was observed due to genotypic effect of the two rice cultivars. A big- or/and erect panicle produced a greater variation in grain weight and quality than those of small- or/and curve one (Kato, 2004). Similarly, source-sink manipulation had significant effect on panicle length by different treatment (Table 2). In the interaction effect of variety and treatment, panicle length also showed the significant effect (Table 3). The largest panicle length (25.61cm) was found in control (no manipulation) of Balam and the shortest panicle length (22.76cm) was obtained in upper half spikelets removal at heading of BRRI dhan49. Akter et al. (2016) noticed 23.63 cm longest panicle in Jagoron rice cultivar after the sink-source effect.

Number and density of primary rachis

Primary rachis no. $panicle^{-1}$ was significantly influenced by different varieties (Table 1). And the highest number of primary rachis per panicle (12.73) was found in BRRI dhan49 rice variety. The treatment effect also significantly influenced on primary rachis number per panicle (Table 2). The maximum number of primary rachis $panicle^{-1}$(12.73) was found in control (no manipulation) and the minimum number of primary rachis $panicle^{-1}$(7.33) was obtained at removal of one sided spikelets at heading stage. Analysis of variance showed that the primary rachis number $panicle^{-1}$ was significantly influenced by different variety and treatment (Table 3). The maximum number of primary rachis $panicle^{-1}$ (12.73) was found in control (no manipulation) of BRRI dhan49 rice variety.

Higher density of primary rachis cm^{-1}(4.40cm) was found in BRRI dhan49 rice variety (Table 1). The highest density of primary rachis cm^{-1} (4.40cm) was found in upper half spikelets removal at heading stage and the lowest density of primary rachis cm^{-1} (2.18cm) was obtained from control (no manipulation) (Table 2). The interaction of variety and source-sink manipulation had significant effect on primary rachis density cm^{-1} (Table 3). The maximum density of primary rachis per cm (4.40cm) was found in upper half spikelets removal at heading stage of BRRI dhan49.

Grain morphology

Grain density in primary branch cm^{-1} was not significantly influenced by different varieties as well as treatment. However, numerically higher density in primary branch per cm (1.39) was found in Balam rice variety. Numerically the maximum grain density in primary branch cm^{-1} (1.40) was found in control (no manipulation) and the minimum density of primary rachis per cm (1.12) was obtained from upper half spikeletes removal at 10 DAA. Interaction effect of variety and treatment also showed insignificant result (Table 3). Grain length was significantly influenced by different varieties. The highest grain length (7.90 mm) was found in BRRI dhan49 rice variety. Analysis of variance reveals that the grain length was significant among the different treatments. The highest grain length (8.00 mm) was found in upper half spikelets removal at heading stage and the lowest grain length (7.43 mm) was obtained from control (no manipulation) (Figure 4). Grain length was significantly influenced by different variety and treatment (Figure 6). Grain height was not significantly influenced by different varieties but significantly influenced by source-sink manipulation. The result showed that the grain height ranged from 1.50 mm to 1.98 mm. The highest grain height (1.98 mm) was found on removal of one sided spikelets at heading stage and the lowest grain height (1.50 mm) was obtained from half flag leaf removal at heading stage (Figure 4). A significant variation in grain height was come upon due to the interaction between variety and treatment. The highest grain height (1.98 mm) was found in Balam on removal of one sided spikelets at heading stage (Figure 6). Shahruddin et al. (2014) illustrated that removal of 25 and 50% spikelet produced a significant higher individual grain size. Grain width was significantly influenced by different varieties, ranged from 2.23 mm to 2.66 mm. The highest grain width (2.66) was found in BRRI dhan49 rice variety (Figure 2). The result showed that the effect of manipulations ranged from 2.26 mm to 2.66 mm. The highest grain width (2.66 mm) was found on the lower half spikelets removal at heading stage and the lowest grain width (2.26 mm) was obtained from control (no manipulation) (Figure 4). Grain width was significantly influenced by different varieties and treatments (Figure 6). Usually the rain weight has more pronounced effects on grain yield. Asli et al. (2011) reported the significant variation of grain weight among the studied cultivars.

Superior and inferior grain $panicle^{-1}$

The highest superior grain $panicle^{-1}$ (10.71) was found in Balam on lower half spikelets removal at heading stage and the lowest superior grain $panicle^{-1}$ (7.70) was obtained from

Table 1. Effect of variety on panicle and grain morphology of rice

Variety	Panicle length (cm)	Primary rachis no. panicle^{-1}	Primary rachis density cm^{-1}	Grain den. In prim. Bra. cm^{-1}	Superior grain no. panicle^{-1}	Inferior Grain no. panicle^{-1}	Grain no. panicle^{-1}	Total spikelets panicle^{-1}(no.)	Filled spikelets panicle^{-1}(no.)	Unfilled spikelets panicle^{-1}(no.)	1000 grain weight(g)	Grain yield (t ha^{-1})	Straw yield(t ha^{-1})	Biological yield(t ha^{-1})	Harvest index (%)
BRRIdhan 49	22.76b	12.73a	4.40a	1.08	7.70b	36.00a	249.56a	135.93a	105.43a	30.50	23.88a	5.35a	7.21	13.53	39.53a
Balam	25.61a	8.76b	2.15b	1.39	10.71a	18.49b	145.77b	124.83b	94.00b	30.83	17.23b	3.00b	11.46	14.47	20.73b
CV (%)	2.76	8.11	14.67	19.96	7.79	6.00	0.67	5.95	5.95	7.30	1.35	3.89	18.07	11.40	5.95
Sig. level	*	*	*	NS	*	**	**	**	**	NS	**	**	NS	NS	**

In a column, figures with the same letters do not differ significantly as per DMRT, **=significant at 1% level of probability; *=significant at 5% level of probability; NS=Non significant

Table 2. Effect of source-sink manipulation on panicle and grain morphology of rice

Treatments	Panicle length (cm)	Primary rachis no. panicl^{-1}	Primary rachis density cm^{-1}	Grain den. in prim. Bra.cm^{-1}	Superior grain no. panicle^{-1}	Inferior Grain no. panicle^{-1}	Grain no. panicle^{-1}	Total spikelets panicle^{-1}(no.)	Filled spikelets panicle^{-1}(no.)	Unfilled spikelets panicle^{-1}(no.)	1000 grain weight(g)	Grain yield (t ha^{-1})	Straw yield(t ha^{-1})	Biological yield(t ha^{-1})	Harvest index (%)
T_1	25.61a	12.73a	2.18f	1.40	9.06b	36.00a	249.56a	119.80a	105.14a	14.66b	21.33c	5.35a	11.46	14.47	36.97a
T_2	23.88bc	7.33b	3.45bc	1.22	10.46a	30.23b	102.30d	75.23de	62.92e	12.31b	21.92bc	2.72d	11.09	12.78	21.41b
T_3	23.72bc	11.90a	2.72de	1.23	10.33a	29.43b	143.50c	105.33b	77.73c	29.46a	20.85c	4.10c	10.40	12.68	32.32a
T_4	24.43ab	11.73a	3.85b	1.39	10.40a	23.96c	156.30b	103.83b	89.83b	25.18a	21.76c	4.66b	9.81	12.93	36.06a
T_5	22.76c	8.21b	4.40a	1.39	0.00c	26.50bc	83.03e	69.16e	64.83de	4.33c	23.13ab	2.80d	9.84	11.59	24.24b
T_6	23.51bc	8.56b	3.23cd	1.15	10.71a	0.00d	80.80e	76.30d	72.46cd	4.77c	23.49a	2.91d	10.15	11.9	24.87b
T_7	23.20c	8.61b	2.70e	1.12	0.00c	25.86bc	82.36e	86.50c	76.88c	5.38c	23.88a	2.78d	10.01	11.61	23.94b
CV (%)	2.80	7.52	9.04	16.33	6.701	12.26	4.48	3.79	6.32	20.34	3.29	3.86	14.06	10.90	11.54
Sig. level	**	**	**	NS	**	**	**	**	**	**	**	**	NS	NS	**

In a column, figures with the same letters do not differ significantly as per DMRT. **=significant at 1% level of probability; NS=Non significant' T_1=Control (No manipulation); T_2=Removal of one sided spikelets at heading; T_3=Full flag leaf removal at heading; T_4=Half flag leaf removal at heading; T_5=Upper half spikelets removal at heading; T_6=Lower half spikelets removal at heading.T_7=Upper half spikeletes removal at 10 DAA

Table 3: Interaction effect of variety and treatment on panicle and grain morphology of rice

Variety x Treatment	Panicle length (cm)	Primary rachis no. panicle^{-1}	Primary rachis density cm^{-1}	Grain density in primary branch cm^{-1}	Superior grain no. panicle^{-1}	Inferior Grain no. panicle^{-1}	Grain no. panicle^{-1}	Total spikelets panicle^{-1}(no.)	Filled spikelets panicle^{-1}(no.)	Unfilled spikelets panicle^{-1}(no.)	1000 grain weight(g)	Grain yield (t ha^{-1})	Straw yield(t ha^{-1})	Biological yield(t ha^{-1})	Harvest index (%)
V_1T_1	25.14ab	12.73a	1.98f	1.403	9.06bc	36.00a	249.56a	117.07a	105.14a	11.93cd	21.33bc	5.35a	8.18cd	13.53ab	39.53a
V_1T_2	23.88cd	7.33de	2.08f	1.120	7.70c	30.23b	102.30d	71.48efg	61.68hi	9.86d	21.92b	2.72ef	8.23cd	10.96de	24.86e
V_1T_3	24.31bc	11.90ab	2.03f	1.226	8.46c	29.43bc	143.50b	105.33bc	77.73de	27.60ab	20.85c	4.10c	8.58bcd	12.68bcd	32.32c
V_1T_4	23.73cde	11.73ab	3.85b	1.230	8.66c	23.96d	156.30b	103.83cgh	89.83c	14.00c	21.76bc	4.66b	8.26cd	12.93abc	36.06b
V_1T_5	22.76eff	6.06f	4.40a	1.390	-	26.50bcd	83.03ef	69.16gh	64.83gh	4.33e	23.13a	2.80ef	7.21d	10.01e	28.00d
V_1T_6	23.10def	6.00f	3.23cd	1.156	8.93c	-	80.80ef	76.30e	72.46ef	3.83e	23.49a	2.91de	8.43bcd	11.35cde	25.68de
V_1T_7	22.46f	7.00def	2.18f	1.086	-	25.86cd	82.36ef	86.50d	81.83d	5.00e	23.88a	2.78ef	8.12cd	10.90de	25.58de
V_2T_1	25.61a	11.72ab	2.18f	1.120	9.06bc	17.76ef	145.77b	110.33b	95.66b	14.66c	18.50def	3.00d	11.46a	14.47a	20.97f
V_2T_2	23.02def	6.66ef	3.45bc	1.226	10.46a	18.49e	61.50gh	75.23ef	62.92hi	12.31cd	17.82efg	1.68h	11.09a	12.78abc	13.16h
V_2T_3	23.72cde	8.76c	2.72e	1.230	10.33ab	16.29ef	93.22de	85.28d	55.82j	29.46a	17.23g	2.10g	10.40a	12.50bcd	16.83g
V_2T_4	24.43bc	11.34b	2.15f	1.390	10.40ab	14.50f	124.11c	83.87d	58.68ij	25.18b	17.63fg	2.70f	9.81abc	12.51bcd	21.73f
V_2T_5	22.61	8.21cd	2.823de	1.156	-	9.85g	57.61h	65.44h	61.83hi	3.60e	18.66def	1.75h	9.84abc	11.59cde	15.23gh
V_2T_6	23.51cdef	8.56c	2.75e	1.086	10.71a	-	86.50ef	70.49fgh	65.71gh	4.77e	19.08d	1.80h	10.15bcd	11.95bcd	15.33gh
V_2T_7	23.20def	8.61c	2.70	1.120	-	14.16f	73.61fg	74.55efg	69.33fg	5.38e	18.75de	1.60h	10.01ab	11.61cde	13.92h
CV (%)	2.658	8.013	10.011	13.945	12.25	12.44	7.56	3.83	4.57	17.96	3.03	4.10	11.16	8.77	6.83
Sig. level	**	**	**	NS	**	**	**	**	**	**	**	**	**	**	**

In a column, figures with the same letters do not differ significantly as per DMRT. **=significant at 1% level of probability; NS=Non significant' T_1=Control (No manipulation); T_2=Removal of one sided spikelets at heading; T_3=Full flag leaf removal at heading; T_4=Half flag leaf removal at heading; T_5=Upper half spikelets removal at heading; T_6=Lower half spikelets removal at heading.T_7=Upper half spikeletes removal at 10 DAA

BRRI dhan49 on removal of one sided spikelets at heading stage (Table 1). In general, superior spikelets flower blooms earlier and are located at the top of primary branches, whereas inferior spikelets flower later and are located at the base of secondary branches. Superior spikelets usually exhibit a faster rate of increase in dry weight during the development stage (Asli et al., 2011). Inferior grain panicle^{-1} was significantly influenced by different varieties (Table 1). The highest inferior grain panicle^{-1}(36.00) was found in BRRI dhan49 rice variety. A limitation of carbohydrate supply was noticed with slow grain filling and low grain weight of inferior spikelets (Maqueira-López et al., 2019; Wang, 1981). Source-sink manipulation had significant effect on inferior grain panicle^{-1} (Table 2).The result showed that the effect of manipulation ranged from 23.96 to 36. The highest inferior grain panicle^{-1} (36) was found on control (no manipulation) and the inferior grain panicle^{-1} (23.96) was obtained from half flag leaf removal at heading stage. There were significant differences in the effect of source-sink manipulation in respect of variety (Table 3).

Number and weight of grain panicle^{-1}

The result showed that the grain number panicle^{-1} was significantly influenced by different varieties (Table 1). The highest grain number panicle^{-1}(249.56) was found in BRRI dhan49 rice variety. Grain number panicle^{-1} defers due to the genetic variation among the rice genotypes. The result showed that the effect of source-sink manipulation ranged from 80.80 to 249.56 (Table 2). The highest grain number panicle^{-1} (249.56) was found on control (no manipulation) and the grain number panicle^{-1} (80.80) was obtained from the lower half spikelets removal at heading stage. There were significant difference in effect of interaction of variety and source-sink manipulation (Table 3). The highest individual grain weight (24.86mg) was found in BRRI dhan49 on upper half spikelets removal at heading stage and the lowest individual grain weight (17.16mg) was obtained from Balam on full flag leaf removal at heading stage (Figure 5). The present study suggests that the grain number decreased when removed the full flag leaf at heading stage. In the previous studies on the sink-source manipulation on rice, Asli et al. (2011) & Lubis et al. (2003) demonstrated that higher grain numbers leads to higher yield production.

The individual grain weight was significantly influenced by different varieties, ranged from 17.16 to 24.86 mg. The highest individual grain weight (24.86mg) was found in BRRI dhan49 rice variety (Figure 1). The highest individual grain weight (24.86 mg) was found on upper half spikelets removal at heading stage and the lowest individual grain weight (22.46mg) was obtained from full flag leaf removal at heading stage (Figure 3). The highest individual grain weight (24.86mg) was found in BRRI dhan49 on upper half spikelets removal at heading stage (Figure 5). In the present study, the higher grain weight increased when removed upper half spikelets at heading stage, resulting the higher yield production. Other researchers also noticed the similar findings; the higher single grain weight is positively correlated with higher total yield (Asli et al., 2011; Lubis et al., 2003; Shahruddin et al., 2014).

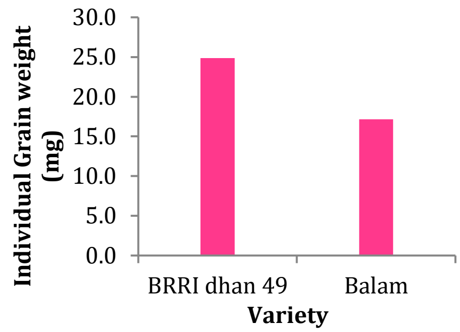

Figure 1. Effect of variety on individual grain weight of rice

Analysis of spikelets panicle^{-1}

Total spikelets panicle^{-1} was significantly influenced by different varieties at 1% level of probability, ranged from 124.83 to 135.93 (Table 1). The highest total spikelets panicle^{-1} (119.8) was found on control (no manipulation) and the lowest total spikelets panicle^{-1} (69.16) was obtained from the upper half spikelets removal at heading stage. Interaction of variety and source-sink manipulation exerted significant influence on total spikelets panicle^{-1} (Table 3). And the highest total spikelets panicle^{-1} (117.07) was found in BRRI dhan49 on control (no manipulation). Lubis et al. (2003) showed that yield of rice cultivar Takanari was the highest among the cultivars used because of higher spikelet number.

Filled spikelets panicle^{-1} was significantly influenced by different (Table 1). The higest filled spikelets panicle^{-1}(105.43) was found in BRRI dhan49 rice variety and lower total spikelets panicle^{-1} (94) was obtained from Balam. Filled spikelets panicle^{-1}was significantly influenced by different source-sink manipulation and the highest filled spikelets panicle^{-1} (105.14) was found on control (no manipulation) and the lowest filled spikelets panicle^{-1} (62.92) was obtained from removal of one sided spikelets at heading stage. Interaction of variety and source-sink manipulation exerted significant influence on filled spikelets panicle^{-1} (Table 3). Higher effective spikelets per panicle in japonica conventional inbred rice have been reported by Wei et al. (2018). Unfilled spikelets panicle^{-1} was not significantly influenced by different varieties (Table 1) but significantly influenced by different treatments (Table 2). The highest unfilled spikelets panicle^{-1} (29.46) was found on full flag leaf removal at heading stage and the lowest unfilled spikelets panicle^{-1} (4.33) was obtained from the upper half spikelets removal at heading stage. Interaction of variety and source-sink manipulation exerted significant influence on unfilled spikelets panicle^{-1} (Table 3). The highest unfilled spikelets panicle^{-1} (29.46) was found in Balam on full flag leaf removal at heading stage and the lowest unfilled spikelets panicle^{-1} (3.83) was obtained from BRRI dhan49 on the lower half spikelets removal at heading stage. In the different source-sink limitation levels, the most and the least unfilled spikelet also noticed by Godarzi et al. (2015) in the rice panicle in control plants.

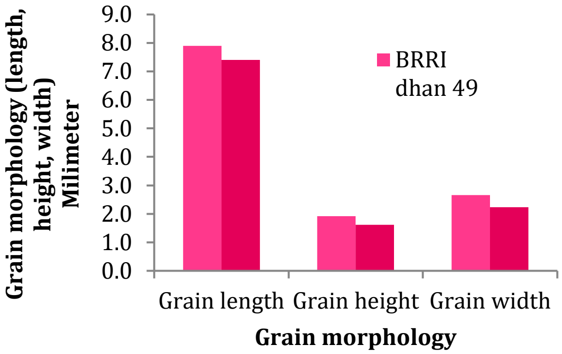

Figure 2. Effect of variety on grain morphology of rice

1000 grain weight (g)

Variety showed significant differences in respect of 1000 grain weight (Table 1). The difference was occurred may be due to genotypic variation. The highest 1000 grain weight (23.88 g) was found in BRRI dhan49 rice variety and the lowest 1000 grain weight (17.23 g) was obtained from Balam. 1000 grain weight was significantly influenced by different treatments, ranged from 20.85 g to 23.88 g (Table 2). 1000 grain weight (23.88 g) was found on upper half spikeletes removal at 10 DAA and the lowest 1000 grain weight (20.85 g) was obtained from full flag leaf removal at heading stage. 1000 grain weight was significantly influenced by different varieties and treatments (Table 3). Bu-hong et al. (2006) reported that1000-grain weight were decreased when the flag were removed which was mainly associated with its lower seed setting rate and filling degree.

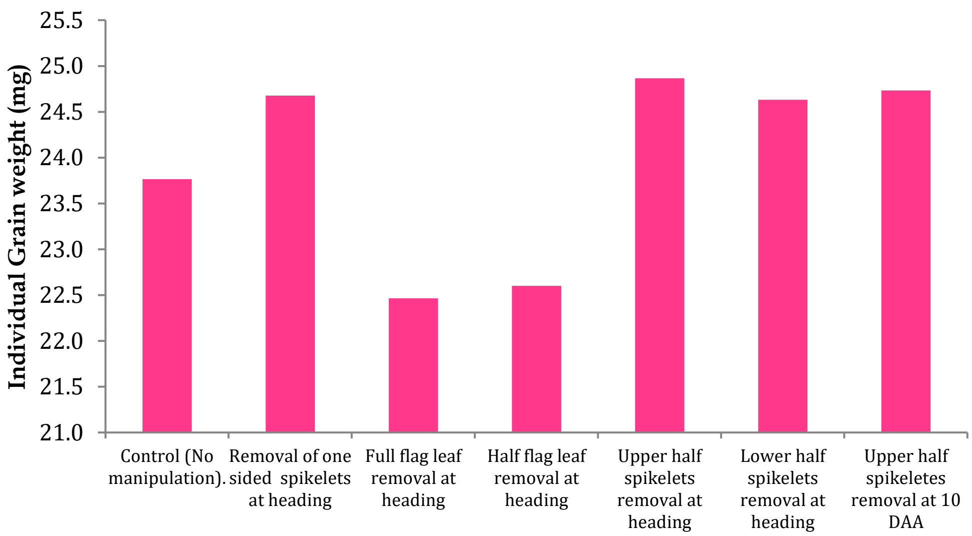

Figure 3. Effect of source-sink manipulation on individual grain weight of rice

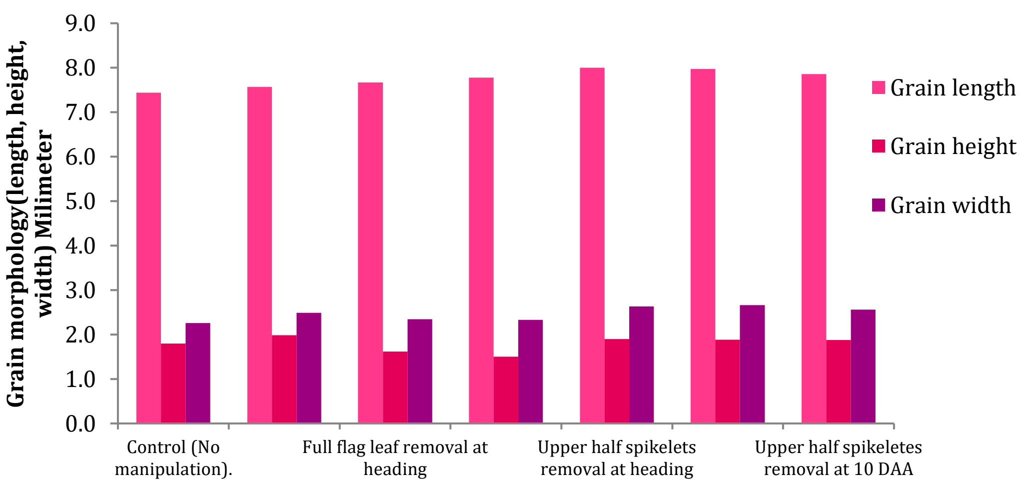

Figure 4. Effect of source-sink manipulation on grain morphology of rice

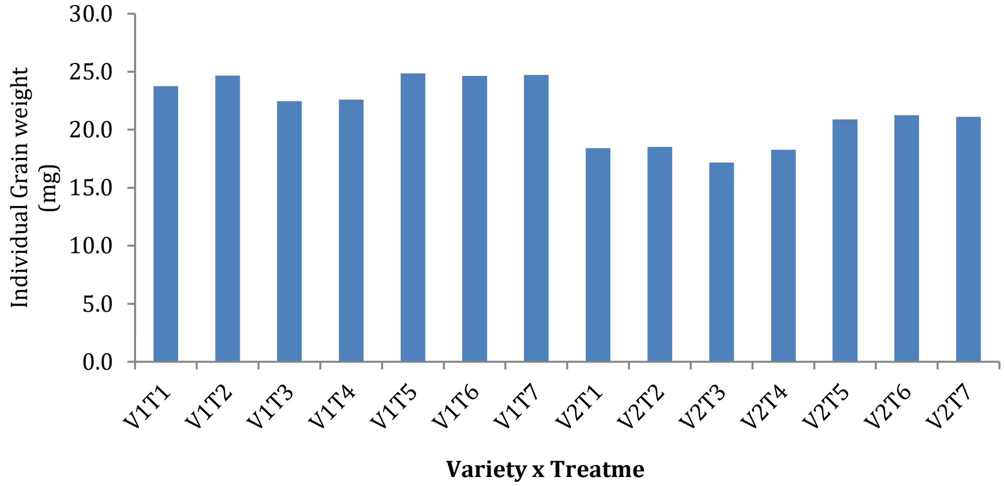

Figure 5. Interaction effect of variety and source-sink manipulation on individual grain weight of rice

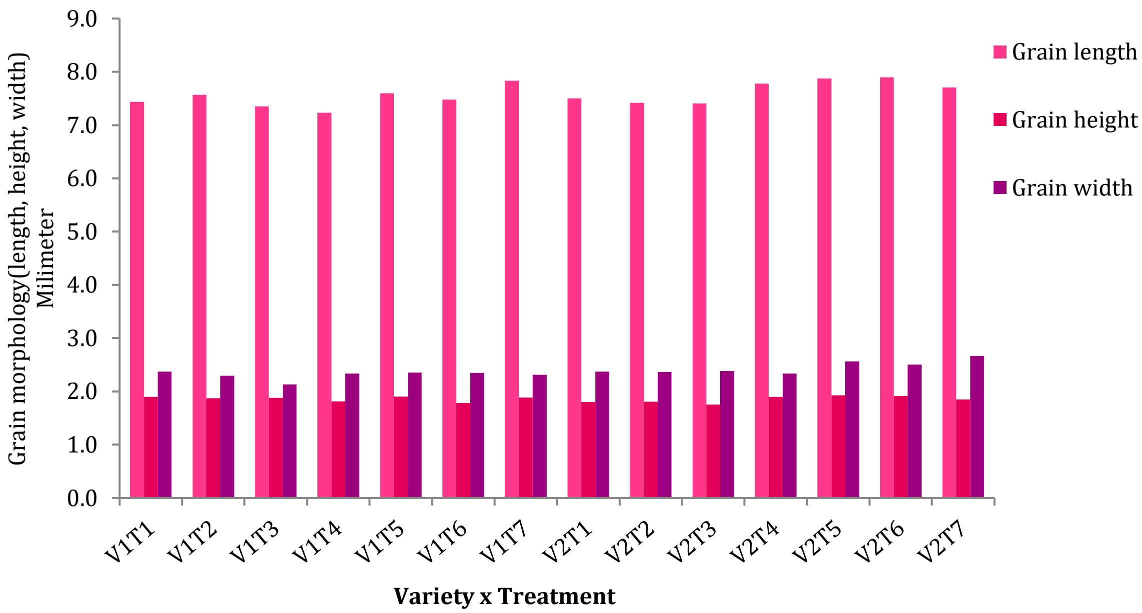

Figure 6. Interaction effect of variety and source-sink manipulation on grain morphology of rice

Grain yield (t ha^{-1})

Grain yield was significantly influenced by different varieties (Table 1). And the highest grain yield (5.35 t ha^{-1}) was found in BRRI dhan49 rice variety. Differences of grain yield were obtained due to the genetic variation of two rice varieties. Grain yield was significantly influenced by different treatments (Table 2) where the highest grain yield (5.35t ha^{-1}) was found on control (no manipulation). The interaction of variety and source-sink manipulation exerted significant influence on grain yield (Table 3). The highest grain yield (5.35 t ha^{-1}) was found in BRRI dhan49 on upper half spikelets removal at heading and the lowest grain yield (1.60t ha^{-1}) was obtained from Balam on upper half spikeletes removal at 10 DAA. The present study indicated that when removed 50% upper half spikelets at heading can increases the individual grain weight, grain size and percentage of filled grain in both the apical and basal spikelets. However, removal of 50% flag leaf drastically reduced its grain size and percentage of filled. These results are corroborated with the agreement of many authors those mentioned the larger sink size which is responsible for the production of higher yield (Godarzi et al., 2015; Lubis et al., 2003; Shahruddin et al., 2014).

Biological yield (t ha^{-1})

Biological yield was not significantly influenced by different variety and treatments. However, numerically the highest straw yield (14.47t ha^{-1}) was found on T control (no manipulation) and the lowest biological yield (11.57 t ha^{-1})

was obtained from upper half spikelets removal at heading stage. Biological yield was significantly influenced by different varieties and treatments at 1% level of probability (Table 3). The highest biological yield (14.47t ha^{-1}) was found in Balam on control (no manipulation) and the lowest biological yield (10.01 t ha^{-1}) was obtained from BRRI dhan49 on upper half spikelets removal at heading stage. Murchie et al. (2002) demonstrated that the manipulation of leaf by sink-source interaction obtained the greater biomass and seed production. And Smith et al. (2018) reviewed that the relationship between sources and sinks is very complex, because the sink strength is depends on the sink size and sink activities.

Harvest index (%)

Variety showed significant differences in respect of harvest index ranged from 21.73% to 39.53% (Table 1). The highest harvest index (39.53%) was found in BRRI dhan49 rice variety. Harvest index was not significantly influenced by different treatments (Table 2). There were significant differences in the effect of interaction of variety and source-sink manipulation on harvest index, ranged from 13.16% to 39.53% (Table 3). The highest harvest index (39.53%) was found in BRRI dhan49 on control (no manipulation) and the lowest harvest index (13.16%) was obtained from Balam on removal of one sided spikelets at heading stage. The present findings suggested that there is a significant positive correlation between sink size and straw yield. These findings are corroborated with the result of other researchers (Godarzi et al., 2015; Shahruddin et al., 2014) stated that sink-source manipulation played an important roles in the yield and yield attributing traits of rice.

CONCLUSION

Based on the present study, it may be concluded that the grain weight of BRRI dhan49 was increased when the upper half spikelets removal at heading stage. The grain size and percentage of filled grain were drastically reduced when the 50% or full flag leaf were removed. Therefore, flag leaf is played a very important role because of the production of photo-assimilate as a main source. Moreover, the results suggested that the grain yield of BRRI dhan49 and Balam were limited by the sink activity, more than source capacity.

AUTHOR CONTRIBUTIONS

This work was carried out in collaboration between authors. Authors Satyabrata Sarkar, Md. Romij Uddin and Ahmed Khairul Hasan planned the project, conducted experiment, collected data and performed statistical analysis. Authors Fakhrul Islam Monshi, Rehenuma Tabassum and Mohammad Joyel Sarkar performed statistical analysis and drafted the manuscript.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

ETHICS APPROVAL

Not applicable

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