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Impact of Different Varieties and Biochar on Rice Productivity

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THEPURPOSE of the investigation was to determine how biochar affected the yield of Boro rice cultivars, including growth dynamics, and yielding characteristics. The investigation was performed at Sher-e-Bangla Agricultural University in Dhaka. Two elements made up the experiment's treatments, such as factor A: Biochar treatment (B_0=No Biochar, B_1= Rice husk + cowdung Biochar, B_2= Mango Biochar, and B_3= Mehogoni Biochar) and Factor B: (V_1= BRRI Dhan100, V_2= BRRI Dhan89, V_3= BRRI Dhan84, and V_4= BRRI Dhan69). Three replications were used in the tests, which were conducted according to the RCBD design. Prior to boro transplanting, biochar was added to the soil. Plant height, tillers and leaf number, leaf length, leaf breadth, leaf area index at 40, 60, and 80 DAT, as well as harvest and effective and non-effective tillers, panicle length, filled and unfilled grains, weight of 1000 grains, grain yield, straw yield, and harvest index of rice are all greatly impacted by the variety, the biochar and its interaction effect. Variety V_3 (BRRI dhan89) outperformed the other four varieties in terms of rice yield, growth qualities, and yield attributes. The results showed that compared to other biochar treatments, applying the appropriate dose of biochar B_3 (Mehogoni biochar) demonstrated increased growth and yield potential. In conclusion, using variety V_3 and biochar B_3 together can be regarded as an effective agricultural technique for enhancing rice development and grain yield.

Keywords: Impact, Varieties, Mehogoni biochar, Mango biochar, Rice yield.

Introduction

The principal staple grain, rice (*Oryza sativa* L.), provides 50% of the world's population with calories, and demand is expected to rise by 28% by 2050 (**Zhu et al., 2018**). **Kabir et al. (2021)** studied and found that rice production in Bangladesh could increase from the baseline of 35.29 MT in 2015 to 46.90 MT in 2030, 54.09 MT in 2040, and 60.85 MT in 2050 with the combined influence of yield improvements by enhancing varietal potential, reducing the current yield gap for rice. Asia produces and consumes almost 90% of the world's rice (**Wassmann et al., 2009**). The production of rice in Asia (China and India in particular), has a significant impact on global food security. Together, the two Asian superpowers China and India are responsible for 49% of global rice output and have 37% of the world's population. Therefore, in order to fulfill the increasing demand of grain from the global population, rice production needs to be greatly boosted. About 13 million farm families in Bangladesh, which is regarded as the world's third-largest producer of rice, depend on the grain for their livelihood. About 11.42 million hectares of land are used for rice cultivation, which has stayed relatively constant over the previous three decades. Rice is grown on around 78% of the total cropped area of Bangladesh (**Al Mamun et al., 2021**).

There has been a major reduction in the amount of hunger that exists around the world in recent decades as a result of improvements in agricultural productivity and food production (**Pingali, 2012**; **Khoury et al., 2014**; **Godecke et al., 2018**). Nearly half of the world's population relies on rice as their primary source of nutrition, particularly in less developed countries (**Ainsworth, 2008**; **Shimono, 2011**). Rice is classified as a staple food. Consequently, increasing rice production and productivity is one of the most important things that can be done to ensure food security, reduce hunger, and serve as a necessary prerequisite for achieving sustainable economic growth (**O'Donnell, 2010**). There are a number of technologies that have been identified as having the potential to increase rice production. These technologies include high-yielding rice varieties, efficient agronomic

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management approaches, enhanced accessibility to nutrients and water, and weed control (**Hazel, 2010**; **Nhamo et al., 2014**). A particularly effective intervention for increasing yields is represented by enhanced or high-yielding cultivars (**Oni et al., 2009**; **Chen et al., 2010**). These technologies are among the technologies that have been developed. **Anwar et al. (2007), Xiao et al. (2008), Oni et al. (2009)**, and **Chen et al. (2010)** have all contributed significantly to the boost in rice yield that has occurred since 1980 (Liu et al., 2013). Another factor that has contributed greatly to this increase is the development of new kinds of rice. It has been demonstrated through empirical research that high-yield varieties (HYV) have a positive impact on agricultural yield (**Faltermeier and Abdulai, 2009; deGraft-Johnson et al., 2014; Abdulai & Huffman, 2014; Shideed** and **El Mourid, 2015**). Additionally, it has been demonstrated that the utilization of HYV can maintain yield despite a reduction in input **(Peng et al., 2009; Adewuyi, 2012**).

The pyrolysis of various agricultural farm leftovers (such as stover, husks, livestock and poultry wastes, and forest wastes like bamboo, mahogany, and so on) results in the production of biochar (BC), which contains a substantial quantity of organic carbon in addition to calcium, magnesium, and organic carbonates. Biochar (BC) is a product of the pyrolysis of agriculture, was reported by **Leng et al. (2019)**; **Semida et al. (2019)**. By increasing the soil's permeability, carbon sequestration capacity, microbial activity, water-holding capacity, and porosity, biochar promotes plant growth and increases yields (**Zhu et al., 2017**). Applications of biochar are being explored as a way to improve plant performance and sequester carbon. Applying biochar is rarely used in contemporary agriculture, and its agronomic value in terms of crop response and soil health advantages has not yet been determined (**Fahad et al., 2016**). According to experimental data thus far, adding biochar often promotes plant growth, especially when paired with the addition of N or P fertilizers in poor soils (**Blackwell et al., 2009**; **Major et al., 2010**). It also reduces nutrient leaching (**Laird et al., 2009**). Applying biochar improves the cation exchange capabilities of the soil (**Liang et al., 2006**), especially when the functional groups oxidize with time (**Cheng et al., 2006**). According to **Liu et al. (2013)**, the biochar amendment increased crop yield by an average of 13% overall. **Vijay et al. (2021)** claim that biochar is essential for improving the physical, chemical, and biological characteristics of soil, which is why crop yields in various field crops have increased. In order to ascertain the impact of various cultivars and biochar on rice productivity, the study was conducted.

2. Materials and Methods

The field experiments was carried out at the experimental field, Department of Agronomy at Sher-e-Bangla Agricultural University in Dhaka, Bangladesh between November 2021 and May 2022. The testing region was 8.6 meters above sea level and located at 23°77´N latitude and 90°33´E longitude.

One component (V_1 = BRRI Dhan100, V_2 = BRRI Dhan89, V_3 = BRRI Dhan84, and V_4 = BRRI Dhan69) and one factor (B_0 = No Biochar, B_1 = Rice Husk + Cowdung Biochar, B_2 = Mango Biochar, and B_3 = Mehogoni Biochar) made up the experiment's treatments. Three replications using a randomized complete block design (RCBD) were used for the trials. The size of each of the 48 plots was 5.76 m^2 (4 m × 2.5 m). Plots were spaced 0.75 meters apart, while replications were spaced 0.75 meters apart.

According to their sources of urea, triple super phosphate (TSP), muriate of potash (MoP), zypsum, and zinc sulphate, the appropriate dosages of NPKS and Zn were applied as per the fertilizer recommendation guide. As a base fertilizer dose, the whole amount of TSP, two-thirds of the Muriate of Potash (MoP), zinc sulphate, and gypsum were administered. Before panicle initiation, the urea was applied in three equal installments at 10 DAT, 30 DAT (together with the remaining muriate of potash), and 45 DAT. Before the seedlings were transplanted, the soil was directly treated with 100% of thenecessary amount of biochar (5.0 t ha^{-1},which is mostly used in many countries worldwide).

At crop harvest, the following variables were measured: plant height, tillers, number of leaves, length, breadth, and area index at 20, 40, 60, and 80; harvest and effective and non-effective tillers; panicle length; filled and unfilled grains; weight of 1000 grains; grain yield; straw yield; and harvest index. To ascertain variation resulting from the experimental treatments, Statix-10 software was used to statistically evaluate the recorded data on various parameters. A Least Significance Difference (LSD) test was used to assess the variations in the treatment means at a 5% probability level.

3. Results and Discussion

There was a significant difference in plant height at 40, 60, and 80 days after transplanting (DAT) and harvest, but there was no significant difference at 20 DAT (Table 1). This was due to the effect of cultivars, biochar, and their interactions. It was discovered that variety V_2 (BRRI dhan89) had the highest plant height (17.97, 39.24, 72.36, 86.05, and 102.00 cm) at 20, 40, 60, and 80 days after transplanting (DAT), followed by variety V1, and the variety V_4 (BRRI dhan67) had the lowest plant height overall. Both **Akter et al. (2018)** and **Chamely et al. (2015)** came to the same conclusions. They reported that the height of the plant is a varietal characteristic as well as a genetic component of the cultivar; hence, the height of the plant varied from cultivar to cultivar. It was discovered that B_3 (Mehogoni Biochar) had the highest plant height (17.81, 37.51, 69.17, 82.25, and 98.73 cm) at 20, 40, 60, 80 DAT, and harvest, respectively. When it came to plant height, B_0 (No Biochar) had the lowest plant height. The interaction $V_2 \times B_3$ was observed to have the maximum plant height, whereas the interaction $V_4 \times B_0$ was observed to have the lowest plant height. According to **Kamara et al. (2015)** and **Zhou et al. (2017)**, the height of rice plants given biochar was greater than those that did not receive biochar. Application of biochar results in an improvement in the physicochemical qualities of the soil, which is reflected in the development of plants and the generation of biomass. According to the findings of the earlier research conducted by **Chen et al. (2021)**, the utilisation of biochar treatment resulted in an increase in rice plant height of up to 8%. In the current investigation, the plants that had been treated with biochar ended up having the maximum plant height. As a result of the experiments conducted by **Lakitan et al. (2018)**, it was discovered that the application of varying concentrations of biochar resulted in a notable rise in the height in rice plants.

The effect varieties, biochar, and interaction resulted in remarkable variation in the number of tiller hill^{-1} at 40, 60, and 80 DAT but non-significant at 20 DAT (Table 1). Variety V_2 (BRRI dhan89) found the highest number of tiller hill^{-1} 6.14, 15.92, 16.56 at 40, 60 and 80 DAT followed by V_1 and the lowest was found in V_4 (BRRI dhan67). The variation of tiller number hill^{-1} is probably due to the genetic makeup of the cultivars. Similar results were also observed by **Rahman and Bulbul (2014)** and **Chamely *et al*. (2015)**. The highest number of tiller hill^{-1} (5.87, 15.22, and 15.87) at 40, 60, and 80 DAT, respectively, were found in B_3 (Mehogoni Biochar), and the lowest was found in B_0 (No Biochar) (Table 2). Tiller number hill^{-1} increased when plants were treated with biochar. According to **Chen *et al.* (2021)**, tiller no. hill^{-1} increased by 12 and 9% with the use of 20 and 40 t ha^{-1} biochar compared to the control treatment, which was corroborated with the present study. In another experiment, **Thavanesan and Seran (2018)** reported that the use of rice-husked biochar (1 t ha^{-1}) with rice straw improved tiller no. hill^{-1} over control as biochar application improved soil fertility significantly. The highest plant height was observed in interaction $V_2 \times B_3$ and the lowest in $V_4 \times B_0$.

At 60 and 80 days after transplanting, as well as at harvest, the single and interaction effects of cultivars and biochar had a significant influence on the quantity of leaves, while at 20 and 40 days after transplanting, these effects were not significant (Table 1). Throughout all of the observations, the variety V_2 had the highest leaf count, whereas the variety V_4 (BRRI dhan67) had the lowest leaf count. The maximum leaf count was observed in B3 (Mehogoni Biochar), whereas the lowest leaf count was recorded in B_0 (No Biochar) throughout all of the observations. For instance, the interaction $V_2 \times B_3$ yielded the highest leaf count (9.42, 32.81, 63.74, 60.98, and 59.87), while the interaction $V_4 \times B_0$ yielded the lowest leaf count (6.52, 20.16, 39.15, 37.46, and 36.78) at 20, 40, 60, 80 DAT, and harvest, respectively.

The effects of varieties and biochar, individually and in interaction, significantly impacted leaf breadth at 40, 60, and 80 DAT and harvest; however, these effects were insignificant at 20 DAT (Table 2). Variety V_2 (BRRI dhan89) displayed the most extended leaf breadth, whereas variety V_4 (BRRI dhan67) showed the shortest leaf breadth in all studied observations. The highest leaf measurements were noted in B_3 (Mehogoni Biochar), whereas the lowest was recorded in B_0 (No Biochar) throughout all observations. In interaction, the maximum leaf breadth measurements (1.04, 2.05, 2.40, 2.48, and 2.43 cm) were observed in the interaction of $V_2 \times B_3$, whereas the minimum values (0.74, 1.46, 1.74, 1.81, and 1.78 cm) were recorded in $V_4 \times B_0$ at 20, 40, 60, 80 DAT, and harvest, respectively.

The LAI of rice at 40, 60, and 80 DAT and harvest was significantly impacted by the individual effects of cultivars, biochar, and their combination, but not at 20 DAT (Table 2). Variety V_2 (BRRI dhan89) had the highest LAI (0.28, 3.07, 11.46, 12.09, 11.49), while Variety V_4 (BRRI dhan67) had the lowest LAI (0.20, 1.50, 5.74, 6.16, 5.85) at 20, 40, 60, 80 DAT, and harvest, respectively. In biochar, B_3 (Mehogoni Biochar) had the highest LAI (0.29, 2.80, 10.50, 11.09, 10.54), whereas B_0 (No Biochar) had the lowest (0.18, 1.71, 6.35, 6.75, 6.40) at 20, 40, 60, 80 DAT, and harvest, respectively. From this experiment, it was found that LAI was better in case of plant treated with mehogoni biochar. It might be due to adequate supply of nutrient form mehogoni biochar which help better leaf area and better LAI. According to Islam et al. (2018), biochar with a maximum LAI of 7 t ha^{-1} showed the changes of increasing LAI up to 100 DAS. Using biochar greatly increased the leaf area plant^{-1} (171.99 cm^2) and the leaf area index (6.48) (**Ahmad et al., 2021**). **Viger et al. (2015)** found that applying biochar enhanced plant growth in both species (the crop plant *Lactuca sativa* L. and the model plant *Arabidopsis*).

Table 1. Plant height tiller number and number of leaves of rice as influenced by different varieties and biochar.

Treatments	Plant height (cm)					Tiller number $hill^{-1}$				Number of leaves				
	20 DAT	40 DAT	60 DAT	80 DAT	Harvest	20 DAT	40 DAT	60 DAT	80 DAT	20 DAT	40 DAT	60 DAT	80 DAT	At harvest
Effect of varieties														
V_1	17.57	37.43b	69.03b	82.09b	97.30b	2.24	5.92b	15.23b	15.85b	8.37b	29.21b	56.31b	53.87b	52.90b
V_2	17.97	39.24a	72.36a	86.05a	102.00a	2.25	6.14a	15.92a	16.56a	8.72a	30.41a	59.02a	56.47a	55.45a
V_3	17.05	33.67c	62.13c	73.11c	89.92c	2.16	5.22c	13.39c	13.93c	8.09c	25.31c	49.17c	47.04c	46.18c
V_4	16.89	29.92d	55.16d	65.31d	76.33d	2.06	4.61d	12.01d	12.44d	7.36d	22.77d	44.82d	42.61d	41.84d
CV (%)	6.11	4.75	4.73	5.79	4.70	11.95	4.63	5.70	4.70	8.94	3.45	4.56	3.47	2.76
$LSD_{(0.05)}$	0.912	0.832	1.580	2.16	3.47	0.230	0.142	0.357	0.256	0.213	0.635	0.853	0.693	0.552
Effect of biochar														
B_0	17.25	32.19c	59.37c	70.28d	83.30c	2.11	4.99c	12.78d	13.19d	7.31d	24.37d	46.86d	44.83d	44.02d
B_1	17.21	34.92b	64.43b	75.88c	90.88b	2.25	5.46b	14.04c	14.60c	8.10c	26.70c	52.27c	49.82c	48.92c
B_2	17.21	35.64b	65.72b	78.15b	92.63b	2.17	5.57b	14.52b	15.10b	8.34b	27.53b	53.48b	51.16b	50.24b
B_3	17.81	37.51a	69.17a	82.25a	98.73a	2.17	5.87a	15.22a	15.87a	8.80a	29.10a	56.71a	54.17a	53.19a
CV (%)	6.11	4.75	4.73	5.79	4.70	11.95	4.63	5.70	4.70	8.94	3.45	4.56	3.47	2.76
$LSD_{(0.05)}$	0.912	0.832	1.580	2.16	3.47	0.230	0.142	0.357	0.256	0.213	0.635	0.853	0.693	0.552
Interaction effects of varieties and biochar														
V_1B_0	17.45	33.72ef	62.19ef	73.95ef	87.65ef	2.24	5.52ef	13.86eff	14.43e	7.54	26.99	50.72f	48.53f	47.65f
V_1B_1	17.55	37.19d	68.58d	81.56cd	96.67cd	2.26	5.82cd	15.09d	15.69d	8.32	28.80	55.94d	53.52d	52.55d
V_1B_2	17.19	38.40cd	70.81cd	84.22bc	99.82bc	2.13	6.01c	15.58cd	16.21c	8.58	29.74	57.77c	55.27c	54.26c
V_1B_3	18.10	40.42b	74.54b	88.65ab	105.07ab	2.31	6.33b	16.40b	17.06a	9.04	31.30	60.81b	58.17b	57.12b
V_2B_0	17.45	35.34e	65.18e	77.52de	91.88de	2.02	5.53e	14.34e	14.91e	7.85	27.48	53.17e	50.87e	49.95e
V_2B_1	17.45	38.98bc	71.88bc	85.49bc	101.33bc	2.23	6.10bc	15.82bc	16.45c	8.66	30.19	58.64c	56.10c	55.08c
V_2B_2	18.02	40.25b	74.23b	88.28ab	104.63ab	2.30	6.30b	16.33b	16.98c	8.95	31.17	60.55b	57.93b	56.88b
V_2B_3	18.97	42.37a	78.13a	92.92a	110.14a	2.42	6.63a	17.19a	17.88a	9.42	32.81	63.74a	60.98a	59.87a
V_3B_0	17.52	31.49g	58.09g	68.91g-i	86.03ef	2.16	4.83hi	11.98i	12.45g	7.31	22.86	44.41h	42.48h	41.71i
V_3B_1	17.09	34.20ef	63.19ef	72.18fg	89.30ef	2.39	5.26e-g	13.35fg	13.89f	8.06	25.21	48.97g	46.85g	46.00gh
V_3B_2	16.65	33.62f	61.99f	73.73e-g	87.38ef	2.10	5.24fg	13.88ef	14.44e	8.23	25.76	50.05fg	47.88fg	47.01fg
V_3B_3	16.91	35.38e	65.25e	77.60de	96.98cd	2.00	5.54de	14.36e	14.93e	8.76	27.40	53.23e	50.93e	50.01e
V_4B_0	16.58	28.21i	52.02i	60.72j	67.65h	2.01	4.07hi	10.92j	10.98h	6.52	20.16	39.15i	37.46i	36.78j
V_4B_1	16.75	29.32hi	54.07hi	64.30ij	76.22g	2.12	4.64i	11.90i	12.37g	7.35	22.59	45.54h	42.81h	42.03i
V_4B_2	16.99	30.28gh	55.83gh	66.40hi	78.70g	2.15	4.74hi	12.29hi	12.77g	7.59	23.45	45.55h	43.57h	42.78i
V_4B_3	17.24	31.85g	58.74g	69.82f-h	82.74fg	1.96	4.98hi	12.92gh	13.62f	7.99	24.88	49.05fg	46.62g	45.78h
CV (%)	6.11	4.75	4.73	5.79	4.70	11.95	4.63	5.70	4.70	8.94	3.45	4.56	3.47	2.76
$LSD_{(0.05)}$	1.824	1.665	3.161	4.32	6.947	0.460	0.284	0.714	0.512	0.426	1.270	1.706	1.387	1.105

In a column, figure(s) followed by same letter do not differ significantly at 5% level.

Table 2. Leaf length, Leaf breadth and Leaf area index of rice as influenced by different varieties and biochar.

Treatments	Leaf length (cm)					Leaf breadth (cm)					Leaf area index (LAI)				
	20 DAT	40 DAT	60 DAT	80 DAT	At harvest	20 DAT	40 DAT	60 DAT	80 DAT	At harvest	20 DAT	40 DAT	60 DAT	80 DAT	At harvest
Effect of varieties															
V_1	12.76a	20.04b	32.96b	35.26b	34.73b	0.93	1.81b	2.12b	2.19b	2.15b	0.25b	2.68b	9.96b	10.52b	10.01l
V_2	13.28a	21.01a	34.46a	36.87a	36.31a	0.96	1.90a	2.23b	2.29a	2.25a	0.28a	3.07a	11.46a	12.09a	11.49a
V_3	11.74b	17.80c	29.02c	30.79c	30.33c	0.92	1.60c	1.87c	1.93c	1.90c	0.22c	1.80c	6.67c	7.05c	6.70c
V_4	10.72c	15.80d	25.84d	27.64d	27.23d	0.84	1.48d	1.74d	1.80d	1.77d	0.20c	1.50d	5.74d	6.16d	5.85d
CV (%)	5.18	2.87	4.76	3.71	5.53	6.54	4.80	6.00	3.60	4.53	3.87	5.98	7.56	3.45	3.98
$LSD_{(0.05)}$	0.593	0.276	0.523	0.316	0.306	0.092	0.021	0.023	0.027	0.029	0.021	0.044	0.176	0.271	0.256
Effect of biochar															
B_0	10.91c	16.78d	27.58d	29.28d	29.33d	0.82	1.56d	1.83d	1.89d	1.86d	0.18d	1.71d	6.35d	6.75d	6.40d
B_1	12.14b	18.48c	30.10c	32.43c	32.30c	0.91	1.68c	1.96c	2.02c	1.99c	0.23b	2.15c	8.06c	8.55c	8.13c
B_2	12.37b	19.23b	31.54b	33.48b	33.39b	0.94	1.73b	2.03b	2.10b	2.06b	0.25b	2.39b	8.92b	9.42b	8.97b
B_3	13.08a	20.16a	33.05a	35.37a	35.23a	0.99	1.82a	2.13a	2.20a	2.17a	0.29a	2.80a	10.50a	11.09a	10.54a
CV (%)	5.18	2.87	4.76	3.71	5.53	6.54	4.80	6.00	3.60	4.53	3.87	5.98	7.56	3.45	3.98
$LSD_{(0.05)}$	0.593	0.276	0.523	0.316	0.036	0.092	0.021	0.023	0.027	0.029	0.021	0.044	0.176	0.271	0.256
Interaction effect of varieties and biochar															
V_1B_0	11.76	18.05f	29.94f	32.04f	31.39f	0.84	1.63f	1.91f	1.97f	1.94fg	0.19	1.99g	7.26g	7.67f	7.25f
V_1B_1	12.59	19.91d	32.66d	34.94d	34.42d	0.93	1.80d	2.10d	2.17d	2.14d	0.24	2.58e	9.61e	10.17d	9.67d
V_1B_2	13.00	20.56c	33.72c	36.08c	35.71c	0.96	1.86c	2.17c	2.24c	2.20c	0.27	2.84d	10.59d	11.19c	10.68c
V_1B_3	13.68	21.64b	35.50b	37.98b	37.41b	1.01	1.96b	2.29b	2.36b	2.32b	0.31	3.31b	12.38b	13.07b	12.42b
V_1B_0	11.96	18.93e	31.04e	33.21e	32.71e	0.86	1.71e	2.00e	2.07e	2.03e	0.20	2.22f	8.27f	8.74e	8.29e
V_2B_1	13.19	20.87c	34.23c	36.63c	36.08c	0.95	1.89c	2.21c	2.27c	2.24c	0.27	2.97c	11.09c	11.69c	11.12c
V_2B_2	13.62	21.55b	35.35b	37.82b	37.25b	0.99	1.95b	2.28b	2.35b	2.31b	0.30	3.27b	12.22b	12.90b	12.27b
V_2B_3	14.34	22.69a	37.21a	39.81a	39.21a	1.04	2.05a	2.40a	2.48a	2.43a	0.35	3.81a	14.26a	15.05a	14.28a
V_2B_0	10.65	16.22h	25.9	27.73i	27.32b	0.82	1.43h	1.67j	1.73i	1.70j	0.16	1.32b	4.81j	5.09i	4.84i
V_2B_1	11.68	17.43g	28.59f	30.59g	30.13g	0.93	1.61f	1.86g	1.90g	1.87gh	0.21	1.73i	6.47h	6.83g	6.49g
V_3B_2	11.99	18.60f	30.5	31.59f	31.11f	0.94	1.64f	1.94f	2.02ef	1.98ef	0.23	1.91gh	7.11g	7.51f	7.14f
V_3B_3	12.64	18.9	31.0	33.25e	32.75e	0.99	1.71e	2.00e	2.07e	2.03e	0.27	2.22f	8.29f	8.76e	8.32e
V_3B_0	9.26	13.93i	23.4	24.14j	23.78j	0.74	1.46h	1.74h	1.81h	1.78i	0.18	1.31k	5.06j	5.51i	5.24i
V_3B_1	11.10	15.70h	24.9	27.55i	27.14i	0.84	1.44h	1.68ij	1.73i	1.70j	0.17	1.30k	5.05j	5.52i	5.31i
V_3B_2	10.88	16.21h	26.58h	28.45h	28.02h	0.87	1.47h	1.72hi	1.77hi	1.74ij	0.20	1.54j	5.76i	6.08h	5.78
V_3B_3	11.65	17.34g	28.44g	30.43g	29.98g	0.92	1.54g	1.83g	1.91g	1.88gh	0.24	1.84h	7.07g	7.49f	7.14
CV (%)	5.18	2.87	4.76	3.71	5.53	6.54	4.80	6.00	3.60	4.53	3.87	5.98	7.56	3.45	3.98
$LSD_{(0.05)}$	1.186	0.552	1.046	0.632	0.612	0.190	0.042	0.043	0.045	0.059	0.042	0.087	0.353	0.542	0.512

In a column, figure(s) followed by same letter do not differ significantly at 5% level.
Here, V_1 = BRRI Dhan100, V_2 = BRRI Dhan89, V_3 = BRRI Dhan84 and V_4 = BRRI Dhan69, T_0 =No Biochar, T_1 = Rice husk + cowdung Biochar, T_2 = Mango Biochar and T_3 = Mehogoni Biochar

Table 3. Yield attributes and yield of rice as influenced by different varieties and biochar.

Treatments	Panicle length (cm)	Effective tillers hill^{-1} (No.)	Non-effective tillers hill^{-1} (No.)	Number of filled grains	Unfilled grains panicle^{-1}	1000 Grain weight	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
Effect of varieties									
V_1	25.80b	13.04b	0.96c	177.70b	9.14c	16.47d	8.31b	8.95b	48.13b
V_2	26.84a	13.67a	0.85d	186.28a	8.52d	24.16a	8.71a	9.07a	48.94a
V_3	22.64c	11.42c	1.07b	155.57c	10.44a	22.08b	7.04c	7.92c	47.04c
V_4	19.78d	10.05d	1.15a	137.30d	10.33b	21.82c	5.91d	7.55d	43.85d
CV (%)	7.33	4.58	5.13	6.21	7.56	2.88	7.12	6.79	2.99
$LSD_{(0.05)}$	0.468	0.212	0.030	1.262	0.036	0.425	0.024	0.98	0.284
Effect of biochar									
B_0	21.74	10.80d	1.08a	147.23d	10.36a	20.75	6.72d	7.67d	46.48c
B_1	23.50	11.97c	1.04b	163.09c	9.86b	21.09	7.44c	8.38c	46.85c
B_2	24.26	12.36b	1.01b	168.41b	9.55c	21.18	7.69b	8.56b	47.12b
B_3	25.56	13.04a	0.91c	178.13a	8.66d	21.50	8.11a	8.89a	47.50a
CV (%)	7.33	4.58	5.13	6.21	7.56	2.88	7.12	6.79	2.99
$LSD_{(0.05)}$	0.468	0.212	0.030	1.262	0.036	0.425	0.024	0.98	0.284
Interaction effect of varieties and biochar									
F_1B_0	23.84fg	11.74f	1.04de	160.08g	9.86e	16.28	7.48h	8.14e	47.89e
F_1B_1	25.44e	12.96d	0.96fg	176.54e	9.37f	16.35	8.25e	8.94c	48.01de
F_1B_2	26.27de	13.38cd	0.96fg	182.30d	9.08g	16.53	8.52d	9.18b	48.15c-e
F_1B_3	27.65b	14.08b	0.87h	191.90b	8.23j	16.71	8.97b	9.53a	48.49cd
F_1B_0	24.18f	12.31e	0.88h	167.80f	9.34f	23.78	7.84f	8.44d	48.17c-e
F_2B_1	26.67cd	13.58c	0.90gh	185.06c	8.69h	24.14	8.65c	9.12b	48.68bc
F_2B_2	27.53bc	14.02b	0.85h	191.09b	8.42i	24.20	8.93b	9.22b	49.21ab
F_2B_3	28.98a	14.76a	0.78i	201.15a	7.63k	24.51	9.40a	9.52a	49.69a
F_2B_0	21.10jk	10.28h	1.15bc	140.14j	11.27a	21.77	6.34l	7.21i	46.78f
F_2B_1	22.27hi	11.34fg	1.10cd	154.55h	10.71c	22.02	6.99j	7.85fg	47.12f
F_3B_2	22.99gh	11.71f	1.06de	159.59g	10.37d	22.08	7.22i	8.10e	47.13f
F_3B_3	24.21f	12.33e	0.97fg	167.99f	9.40f	22.47	7.61g	8.53d	47.13f
F_3B_0	17.86m	8.87i	1.25a	120.90l	10.99b	21.17	5.21o	6.89j	43.09i
F_3B_1	19.62l	10.00h	1.19ab	136.20k	10.66c	21.87	5.88n	7.61h	43.58hi
F_3B_2	20.26kl	10.32h	1.15c	140.64j	10.32d	21.93	6.07m	7.72gh	44.01h
F_3B_3	21.38ij	10.99g	1.01ef	151.48i	9.36f	22.30	6.46k	7.99ef	44.71g
CV (%)	7.33	4.58	5.13	6.21	7.56	2.88	7.12	6.79	2.99
$LSD_{(0.05)}$	0.937	0.425	0.060	2.52	0.072	0.850	0.048	0.187	0.568

In a column, figure(s) followed by same letter do not differ significantly at 5% level.
Here, V_1 = BRRI Dhan100, V_2 = BRRI Dhan89, V_3 = BRRI Dhan84 and V_4 = BRRI Dhan69, T_0 =No Biochar, T_1 = Rice husk + cowdung Biochar, T_2 = Mango Biochar and T_3 = Mehogoni Biochar

In Arabidopsis, they found that applying biochar promoted leaf cell expansion and significantly increased leaf area by 130%. The interaction of $V_2 \times B_3$ had the highest LAI, while $V_4 \times B_0$ had the lowest values across all observations. The findings demonstrated that the LAI rose quickly until 60 DAT, at which point it grew gradually until declining.The panicle length of rice showed a considerable impact, whereas biochar had no discernible effect (Table 3). Variety V_2 and biochar B_3 had the longest panicles (26.84 cm), while variety V_4 had the shortest (19.78 cm). Similar findings by **Hossain et al. (2016)**, **Chamely et al. (2015)**, and **Diaz et al. (2000)** confirmed the current study and stated that panicle length varied among varieties. The use of biochar in rice fields greatly increased panicle length; however, **Lakitan et al. (2018)** found that higher yield at higher rates of biochar application was not related to panicle length but was very significantly related to number of tillers hill^{-1}, productive tillers hill^{-1}, number of grains per panicle^{-1}, and percentage of filled grain. Varieties and biochar had a substantial interaction effect on panicle length; the interaction of V_4B_3 produced the longest panicle (28.98 cm), whereas the interaction of V_4B_0 produced the shortest (17.86 cm).

The types, biochar, and their interaction effect all had a substantial impact on the number of tillers that were effective and ineffective (Table 3). At harvest, the interaction of V_2 produced the highest effective and lowest non-number of effective tillers hill^{-1} (13.67 and 0.85), while V_4 produced the lowest effective and highest non-effective tillers hill^{-1} (10.05 and 1.15). The results of the current investigation were consistent with those of **Latif et**

al. (2020), who found that BRRI dhan29 produced the greatest number of effective tillers hill^{-1} (17.64). Regarding the biochar effect, the similar pattern was seen in B_3 and B_0, respectively. Significant impacts of biochar on rice on several tillers hill^{-1} were found by **Lakitan et al. (2018)**. At harvest, the interaction of F_2B_1 produced the greatest effective and lowest non-number of effective tillers hill^{-1} (14.76 and 0.78), while F_1B_0 produced the lowest effective and highest non-effective tillers hill^{-1} (8.87 and 1.25).

The types, biochar, and their interaction effect all had a substantial impact on the quantity of filled and unfilled grains (Table 3). The variety V_2 and Biochar B_3 generated the maximum filled and lowest non-number of effective tillers hill^{-1} (186.28, 8.52 and 178.13, 8.66) in a single effect. The current study's results were consistent with those of **Ullah et al. (2016)**, who found that the Heera (V_4) variety had the most full grains among the types, while the BRRI dhan58 (V_2) variety had the fewest. The current investigation confirmed that applying biochar enhanced prospective rice output by boosting full grains and drastically reducing the number of empty grains. At 60 DAP, the number of filled grains panicle^{-1} was significantly higher in plants treated with rice straw (1.0 t ha^{-1}) and rice husked biochar (1.0 t ha^{-1}) than in plants that were not treated (**Thavanesan and Seran, 2018**). The interaction of V_2B_3 produced the highest filled grain (201.15), while V_3B_0 produced the lowest filled and greatest unfilled grain (120.90).

The 1000 grain weight was significantly impacted by variety (Table 3). While variety V_4 had the lowest harvest index (21.82), variety V_2 had the greatest harvest index (24.16). According to **Latif et al. (2020)**, the varietal performance caused a considerable difference in the weight of 1000 grains. 1000 grain weight had no discernible effect on the biochar effect. The interaction effects of variety and biochar showed a similar outcome.

Rice grain production is greatly impacted by variety, biochar, and their interaction (Table 3). The interaction of V^2 produced the highest grain and straw yield (8.71 and 9.07 t ha^{-1}) in the variety effect, whereas V_4 produced the lowest grain yield (5.91 and 7.55 t ha^{-1}). The interaction of B3 produced the maximum grain yield (8.11 and 8.89 t ha^{-1}) in the biochar effect, while B_0 produced the lowest grain yield (6.72 and 7.67 t ha^{-1}). Compared to the control, the use of biochar improved grain yield. **Farhangi-Abriz et al. (2021)** reported similar results, demonstrating that the use of biochar (1-10 t ha^{-1}) boosted the yield of grain and straw. The interaction of V_2B_3 produced the maximum grain yield (9.40 and 9.52 t ha^{-1}), while V4B0 produced the lowest grain yield (5.21 and 6.89 t ha^{-1}).

The rice harvest index was greatly impacted by variety, biochar, and their interaction (Table 3). Variety V_2 and biochar B_3 had the highest harvest index (48.94 and 47.50) in the single effect, while variety V_4 and biochar B0 had the lowest harvest index (5.91 and 46.48). Additionally, Chowhan et al. (2019) discovered notable variations in the harvest index between the various types of rice and stated that hybrid rice continued to have a higher harvest index. According to **Akter et al. (2018)**, BRRI dhan29 had a higher harvest index (42.86%) than BRRI dhan74 (39.28%). **Shah and Shah (2018)** showed in a prior work that the use of biochar (40 t ha^{-1}, 60 t ha^{-1}, and 80 t ha^{-1}) increased HI in comparison to the absence of biochar treatment. By enhancing soil qualities, the use of biochar considerably raised the rice harvest index (**Qin et al., 2016**). The interaction of V_2B_3 had the greatest harvest index (49.69), whereas the interaction of V_4B_0 had the lowest (43.09).

Conclusion

The effect of different varieties, different biochar, and their interaction resulted remarkable variation in all the growth and yield parameters of rice. Based on the results of the present study, it can be concluded that the application of B_3 (Mehogani biochar) showed higher growth, yield attributes, and yield of rice variety V_3(BRRI dhan89).

Consent for publication:

All authors declare their consent for publication.

Author contribution:

The manuscript was edited and revised by all authors.

Conflicts of Interest:

The author declares no conflict of interest.

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References

Abdulai, A., Huffman, W. (2014) The adoption and impact of soil and water conservation technology: an endogenous switching regression application. *Land Economics,* **90**(1): 26–43. doi.org/10.3368/le.90.1.26

Adewuyi, S. (2012) Resource-use productivity of rural farmers in KWARA–state, Nigeria. *Asset*, **1**(1):123–31.

Ahmad, S., Ghaffar, A., Rahman, M.H.U., Hussain, I., Iqbal, R., Haider, G., Khan, M.A., Ikram, R.M., Hussnain, H., Bashir, M.S. (2021) Effect of application of biochar, poultry and farmyard manures in combination with synthetic fertilizers on soil fertility and cotton productivity under arid environment. *Communications in Soil Science and Plant Analysis,* **52**(17): 2018-2031. doi.org/10.1080/00103624.2021.1908324.

Ainsworth, E.A. (2008) Rice production in a changing climate: a meta-analysis of responses to elevated carbon dioxide and elevated ozone concentration. *Global Change Biology*, **14**(7):1642–1650. doi.org/10.1111/j.1365-2486.2008.01594.x

Akter, M.S., Yeasmin, S., Hasan, A. (2018) Effect of integrated nitrogen application on the yield of two *Boro* rice varieties: BRRI dhan29 and BRRI dhan74. *Archives of Agriculture and Environment Science*,

3(4): 410-415. doi.org/10.26832/24566632.2018.0304014

Al Mamun, M.A., Nihad, S.A.I., Sarkar, M.A.R. et al. (2021) Growth and Trend Analysis of Area, Production and Yield of Rice: A Scenario of Rice Security in Bangladesh. *PLoS One*, **16**(12): e0261128. doi.org/10.1371/journal.pone.0261128.

Anwar, M.R., O'Leary, G., McNeil, D., Hossain, H., Nelson, R. (2007) Climate change impact on rainfed wheat in south-eastern Australia. Field Crop Research, **104**(1–3):139–47. doi.org/10.1016/j.fcr.2007.03.020

Blackwell, P., Riethmuller, G., Collins, M. (2009) Biochar application to soil. In: Biochar for environmental management: science and technology. Earth scan, London. pp. 207–226.

Chamely, S.G., Islam, N., Hoshain, S. Rabbani, M.G., Kader, M.A., Salam, M.A. (2015) Effect of variety and nitrogen rate on the yield performance of *Boro* rice. *Progressive Agriculture,* **26**(1): 6-14.

Chen, C., Wang, E., Yu, Q., Zhang, Y. (2010) Quantifying the effects of climate trends in the past 43 years (1961–2003) on crop growth and water demand in the North China Plain. *Climatic*

Change, **100**(3–4):559–78. doi.org/10.1007/s10584-009-9690-3

Chen, X., Yang, S., Ding, J., Jiang, Z., Sun, X. (2021) Effects of biochar addition on rice growth and yield under water-saving irrigation. *Water,* **13**(2):209. doi.org/10.3390/w13020209

Cheng, C.H., Lehmann, J., Thies, J.E., Burton, S.D. and Engelhard, M.H. (2006). Oxidation of black carbon by biotic and abiotic processes. *Org. Geochem.* **37**(11): 1477-1488.

Chowhan, S., Hoque, M.I., Ghosh, S.R., Islam, M., Akter, M.B. (2019). Effect of Variety and Seedling Number on the Growth and Yield of *Boro* Rice in Bangladesh. *Journal of Experimental Agriculture International***,** **41**(6): 1-15. doi.org/10.9734/jeai/2019/v41i630436

deGraft-Johnson, M., Suzuki, A., Sakurai, T., Otsuka, K. (2014) On the transferability of the Asian rice green revolution to rainfed areas in sub-Saharan Africa: an assessment of technology intervention in Northern Ghana. *Agricultural Economics*, **45**(5): 555–570.

Diaz, S, Castro, R., Morejon, R. (2000) Morpho-agronomic characterisation of varieties of rice. *Cultivos Tropicales*, **21**(3): 81-86.

Evenson, R.E., Gollin, D. (2003) Assessing the impact of the Green Revolution, 1960 to 2000. *Science*, 300(5620):758–762.

Fahad, S., Hussain, S., Saud, S., Tanveer, M., Bajwa, A.A., Hassan, S., Shah, A.N., Ullah, A., Wu, C., Khan, F.A., Shah, F. (2016) A biochar application protects rice pollen from high-temperature stress. *Plant Physiology and Biochemistry*, **96:** 281-287.

Faltermeier, L., Abdulai, A. (2009) The impact of water conservation and intensification technologies: empirical evidence for rice farmers in Ghana. *Agriculture Economics*, **40**(3):365–79. doi.org/10.1111/j.1574-0862.2009.00383.x

Farhangi-Abriz, S., Torabian, S., Qin, R., Noulas, C., Lu, Y., Gao, S. (2021) Biochar effects on yield of cereal and legume crops using meta-analysis. *Science of the Total Environ*ment, **775**: 145869. doi.org/10.1016/j.scitotenv.2021.145869

Gödecke, T., Stein, A.J., Qaim, M. (2018) The global burden of chronic and hidden hunger: trends and determinants. *Global Food Security*, **17**: 21–29. doi.org/10.1016/j.gfs.2018.03.004

Haddad, L. (2017) The global nutrition report 2017. Washington, DC: IFPRI; 2017.

Hazel, P.B.R. (2010) The Asian Green Revolution. Proven Success in Agricultural Development, International Food Policy Research Institute, Washington DC, pp. 67–97.

Hossain, M.E., Haque, A. N.A., Haque, M.E., Lee, H. (2016) Performance and productivity of *Boro* rice varieties cultivated in saline area of Satkhira. *Journal of Bioscience and Agriculture Research,* **8**(2):726-733. dx.doi.org/10.18801/jbar.080216.86

Hussain, I., Perera, L. (2004) Improving agricultural productivity for poverty alleviation through integrated service provision with public-private sector partnerships: examples and Issues, IWMI.

Kabir, M.S., Salam, M., Islam, A.K.M.S., Sarkar, M.A.R., Mamun, M., Rahman, M., Nessa, B., Kabir, M., Shozib, H., Hossain, M., Chowdhury, A. (2021) Doubling rice productivity in Bangladesh: A way to achieving SDG 2 and moving forward. *Bangladesh Rice Journal,* **24**(2): 1-47. doi.org/10.3329/brj.v24i2.53447

Kamara, A., Kamara, H.S., Kamara, M.S. (2015) Effect of rice straw biochar on soil quality and the early growth and biomass yield of two rice varieties. *Agricultural Sciences,* **6**(8): 798-806. doi.org/10.4236/as.2015.68077

Khoury, C.K., Bjorkman, A.D., Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., Rieseberg, L.H., Struik, P.C. (2014) Increasing homogeneity in global food supplies and the implications for food security. *Proceedings of the Natural Academy Science of the United States of America*, **111**(11): 4001–4006.

Laird, D.A., Brown, R.C., Amonette, J.E., Lehmann, J. (2009) Review of the pyrolysis platform for coproducing bio-oil and biochar. *Biofuels, Bioproducts and Biorefining* **3**: 547-562. doi.org/10.1002/bbb.169

Lakitan, B., Alberto, A., Lindiana, L., Kartika, K., Herlinda, S. and Kurnianingsih, A. (2018). The benefits of biochar on rice growth and yield in tropical riparian wetland, South Sumatra, Indonesia. *Chiang Mai University Journal Natural Sci*ence, **17**(2): 111-126. doi.org/10.12982/CMUJNS.2018.0009

Latif, A., Islam, M., Hasan, A., Salam, M., Rahman, A., Zaman, F. (2020) Effect of source of irrigation water on yield performance of *Boro* rice. *Archives of Agriculture and Environmental Science*, **5**(3). 254-260. doi.org/10.26832/24566632.2020.050304

Leng, L., Huang, H., Li, H., Li, J., Zhou, W. (2019) Biochar stability assessment methods: A review. *Science of the Total Environment*, **647**: 210–222. doi.org/10.1016/j.scitotenv.2018.07.402

Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B, Skjemstad, J.O., Thies, J., Luizão, F.J., Petersen, J., Neves, E.G. (2006) Black carbon increases cation exchange capacity in soils. *Soil Science Society of America Journal*, **70**(5): 1719-1730.

Liu, L., Zhu, Y., Tang, L., Cao, W., Wang, E. (2013) Impacts of climate changes, soil nutrients, variety types and management practices on rice yield in East China: a case study in the Taihu region. *Field Crops Research,* **149**: 40-48. doi.org/10.1016/j.fcr.2013.04.022

Major, J., Lehmann, J., Rondon, M., Goodale, C. (2010) Fate of soil-applied black carbon: downward migration, leaching and soil respiration. *Global Change Biology*, **16:** 1366–1379. doi.org/10.1111/j.1365-2486.2009.02044.x

Nhamo, N., Rodenburg, J., Zenna, N., Makombe, G., Luzi-Kihupi, A. (2014) Narrowing the rice yield gap in East and Southern Africa: using and adapting existing technologies. *Agricultural System*, **131**: 45–55. doi.org/10.1016/j.agsy.2014.08.003

Nin, A., Arndt, C., Preckel, P.V. (2003) Is agricultural productivity in developing countries really shrinking? New evidence using a modified nonparametric approach. *Journal of Development Economics*, **71**(2): 395–415.

O'Donnell C.J. (2010) Measuring and decomposing agricultural productivity and profitability change. *Australian Journal of Agricultural and Resource Economics*, **54**(4): 527–560.

Oni OA, Nkonya EM, Pender JL, Phillip D, Kato E. (2009) Analyzing drivers of food crop productivity in Nigeria. *Journal of Rural Economics and Development*, **18**: 36–45. doi.org/10.22004/ag.econ.147904

Peng S, Tang Q, Zou Y. (2009) Current status and challenges of rice production in China. *Plant Production Science*, **12**(1): 3–8. doi.org/10.1626/pps.12.3

Pingali, P.L. (2012) Green revolution: impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences of the United States of America*, **109**(31):12302–12308. doi.org/10.1073/pnas.0912953109

Qin, X., Wang, H., Liu, C., Li, J., Wan, Y., Gao, Q., Fan, F., Liao, Y. (2016) Long-term effect of biochar application on yield-scaled greenhouse gas emissions in a rice paddy cropping system: A four-year case study in south China. *The Science of the Total Environment,* **569**: 1390-1401. doi.org/ 10.1016/j.scitotenv.2016.06.222

Rahman, M.R., Bulbul, S.H. (2014) Effect of Alternate Wetting and Drying (AWD) Irrigation for *Boro* Rice Cultivation in Bangladesh. *Agriculture Forestry and Fisheries,* **3**(2): 86-92. doi.org/10.11648/j.aff.20140302.16

Semida, W.M., Beheiry, H.R., Sétamou, M., Simpson, C.R., Abd El-Mageed, A., Rady, M.M., Nelson, S.D. (2019) Biochar implications for sustainable agriculture and environment: A review. *South African Journal of Botany,* **127:** 333–347. doi.org/10.1016/j.sajb.2019.11.015

Shah, S. and Shah, T. (2018) Residual Effect of Biochar on Soil Properties and Yield of Maize (*Zea mays L.*) under Different Cropping Systems. *Open Journal of Soil Science*, **8**: 16-35. doi: 10.4236/ojss.2018.81002.

Shahidullah, S.M., Hanafi, M.M., Ashrafuzzaman, M., Ismail, M.R., Salam, M.A. (2009). Tillering dynamics in aromatic rice genotypes. *International Journal of Agriculture and Biology,* **11**(5): 509-514.

Shideed, K.H., El Mourid, M. (2015) Adoption and impact assessment of improved technologies in crop and livestock production systems in the WANA region. The development of integrated crop/livestock production in low rainfall areas of Mashreq and Maghreb Regions (Mashreq/Maghreb Project). ICARDA, Aleppo, Syria.

Shimono, H.(2011) Earlier rice phenology as a result of climate change can increase the risk of cold damage during reproductive growth in northern Japan.AgricultureEcosystems&Environment,**144**(1):201–207. doi.org/10.1016/j.agee.2011.08.006

Thavanesan, S., Seran, T.H. (2018) Effect of rice straw and husk biochar on vegetative growth and yield attributes of *Oryza sativa* L. *International Journal of Crop Science and Technol*, **4**(2): 49-56. doi.org/10.26558/ijcst.427516

Ullah, S.S., Ruhul Amin, A.K.M., Roy, T.S., Mandal, M.H.S., Mehraj, H. (2016) Effect of nitrogen sources for spikelet sterility and yield of Boro rice varieties. *Advances in Plants & Agriculture Research* **5**(5): 00192.

Viger, M., Hancock, R.D., Miglietta, F., Taylor, G. (2015) More plant growth but less plant defence? First global gene expression data for plants grown in soil amended with biochar. *Global Change Biology Bioenergy*, **7**(4): 658-672. doi.org/10.1111/gcbb.12182

Vijay, V., Shreedhar, S., Adlak, K., Payyanad, S., Sreedharan, V., Gopi, G., Sophia van der Voort, T., Malarvizhi, P., Yi, S., Gebert, J., Aravind, P.V. (2021) Review of large-scale biochar field-trials for soil amendment and the observed influences on crop yield variations. *Frontiers in Energy Research,* **9**: 1-21. doi.org/10.3389/fenrg.2021.710766

Wassmann, R., Jagadish, S.V.K., Heuer, S., Ismail, A., Redona, E., Serraj, R., Singh, R.K., Howell, G., Pathak, H., Sumfleth, K. (2009) Climate change affecting rice production: The physiological and agronomic basis for possible adaptation strategies. *Advances in Agron*omy, **101:**59–122.doi.org/10.1016/S0065-2113(08)00802-X

Xiao, G., Zhang, Q., Yao, Y., Zhao, H., Wang, R., Bai, H., Zhang, F. (2008) Impact of recent climatic change on the yield of winter wheat at low and high altitudes in semi-arid northwestern China. *Agriculture, Ecosystem & Environment*, **127**(1–2):37–42. doi.org/10.1016/j.agee.2008.02.007

Zhou, W., Lv, T., Yang, Z., Wang, T., Fu, Y., Chen, Y., Hu, B., Ren, W. (2017).Morphophysiological mechanism of rice yield increase in response to optimized nitrogen management. *Scientific Reports,* **7**(1): 1-10. doi.org/10.1038/s41598-017-17491-y

Zhu, X., Chen, B., Zhu, L., Xing, B. (2017) Effects and mechanisms of biochar-microbe interactions in soil improvement and pollution remediation: A review. *Environmental Pollution,* **227:** 98–115. doi.org/10.1016/j.envpol.2017.04.032

Zhu, Q. , Zeng, D. , Yu, S. , Cui, C. , Li, J. , Li, H. , Chen, J. *et al*. (2018) From golden rice to aSTARice: bioengineering astaxanthin biosynthesis in rice endosperm. *Molicular Plant*, **11**,1440–1448. doi.org/10.1016/j.molp.2018.09.007