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ROLE OF BIOCHAR AND MICROBIAL CONSORTIUM ON PRODUCTIVITY AND PROFITABILITY OF WHEAT

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ABSTRACT
A field experiment was carried out in the Rabi season of 2024-25 at the Research Farm of the Department of Agriculture, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana to assess the effects of biochar and microbial consortium on wheat growth, yield, and economic aspects. The experiment was laid out in split plot design with three replications. In the main plot, 2 levels biochar were applied 0 and 4t ha^{-1} and in sub plots six microbials were applied including Zinc Solubilizing bacteria, Phosphate Solubilizing bacteria, Potassium Solubilizing bacteria, Acetobacter, and their consortium. The variety of wheat used was WH 1124. Biochar significantly increased grains per spike, spike length, effective tillers, grain yield, straw yield and biological yield. In the case of microbial treatments, the consortium showed the significantly highest grains per spike (43.2), spike length (12.1 cm), effective tillers (327.75 m^{-2}), grain yield (4114 kg ha^{-1}) and straw yield (5504 kg ha^{-1}) and biological yield (9619 kg ha^{-1}). The study concludes that the combined use of biochar and microbial consortium is an effective and environmentally sustainable nutrient management strategy for improving wheat productivity, maintaining soil health, and increasing farm income.

KEYWORDS: Acetobacter, Biochar, Consortium, Economics, Wheat, Yield

INTRODUCTION
Wheat (*Triticum aestivum L.*) is one of the most important cereal crops in the world. A significant source of food and nutrition, as well as being a significant *Rabi* crop in India. The enhancement of wheat production is crucial to the growing demand for food. But with continuous chemical fertilizer use, it can lead to soil degradation and decreased nutrient use efficiency. Biochar is an effective soil ameliorator with the potential to enhance soil structure, nutrient retention, soil water holding capacity and soil microbial activity. It has emerged as one of the most promising soil amendments for sustainable agriculture. The beneficial microorganisms can also aid plants by enhancing nutrient assimilation and root development. Zinc-solubilizing bacteria, Phosphate-solubilizing bacteria, Potassium-mobilizing bacteria and Acetobacter can be beneficial to wheat plants in different ways. These useful microorganisms can be used in microbial consortium. They can grow and be active in the presence of biochar. These bacteria convert unavailable nutrients into forms that plant roots can absorb. As a result, crops require less chemical fertilizer and produce better yields. Biochar and microbial consortium are increasingly being studied together because they complement each other in improving soil quality and crop performance (Elad *et al.,* 2010; Van Zwieten *et al.,* 2010). Biochar provides a porous habitat that protects beneficial microorganisms from environmental stress while improving soil moisture retention, aeration, and nutrient availability. This favourable environment enhances microbial colonization and activity in the rhizosphere. The microorganisms, in turn, improve nutrient solubilization and mineralization, making essential nutrients more readily available for plant uptake (Asghar *et al.,* 2023). In this study, the effect of biochar and microbial consortium on wheat yield attributes, yield, and economics were therefore evaluated.

MATERIALS AND METHODS
The present study was carried out in Agricultural Research Farm, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana during *Rabi* 2024–25. The experimental site was at 30°17′ N latitude, 77°3′ E longitude and 264 m above mean sea level. The texture of the soil of the experimental field was sandy loam. It contained 55% sand, 32% silt, and 13% clay. The pH of the soil was 7.98 which indicates a slightly alkaline soil. The electrical conductivity was 0.98 dS m^{-1} and organic carbon was 0.30%. The supply of available nitrogen was 165.43 kg ha^{-1}. Available P_2O_5 was 14.40 kg ha^{-1} and available K_2O was 210.51 kg ha^{-1}. It was experimented in a split-plot design and replicated three times. The main plots were treated with two treatments. They were M_1: control and M_2: biochar @ 4 t ha^{-1}. There were six treatments with microorganisms in the sub-

plots. These were, S_1: control, S_2: Zinc-solubilizing bacteria (ZSB), S_3: Phosphate-solubilizing bacteria (PSB), S_4: Potassium-solubilizing bacteria (KSB), S_5: Acetobacter, and S_6: microbial consortium (ZSB + PSB + KSB + Acetobacter). On 3rd December 2024, WH 1124 variety was sown. The seed rate was 120 kg ha^{-1} and spacing between rows was 20 cm. Biochar was added to the assigned main plots at the rate of 4 t ha^{-1} prior to sowing. The microbial cultures were applied at 1×10^{8}cfu mL^{-1}. The recommended fertilizer rate was 156:60:60 kg ha^{-1} of N, P_2O_5 and K_2O respectively. Half of recommended nitrogen was applied before sowing with the full recommended phosphorus and potassium doses. Remaining nitrogen was applied after the 1st irrigation. All other crop management practices remained the same for all plots. Yield attributes were taken at harvest. The following were included: number of grains per spike, spike length, 1000-grain weight, and number of effective tillers at harvest. Grain yield was measured by weighing the grains from each net plot and then converting this weight to kg ha^{-1}. The total harvested biomass was used to obtain biological yield. Biological yield was used to determine the amount of straw yield by subtracting the grain yield. Grain yield and biological yield were used for calculating harvest index. Economic observations comprised cost of cultivation, gross returns, net returns and benefit-cost ratio. The data collected were statistically analysed in the usual manner of split plot experiments. Analysis of variance was used to test the effect of the treatments. Only treatments which showed a significant difference were compared using the critical difference.

RESULTS AND DISCUSSION

Number of effective tillers: The information on effective tillers at harvest m^{-2} as presented in (Table 1) revealed that significantly highest number of effective tillers m^{-2} were recorded in main plot M_2 (304.3) than control (M_1). In the case of sub plots the significantly highest numbers of tillers were recorded in microbial consortium (S_6) (327.7) followed by Acetobacter (S_5) and Zinc solubilizing bacteria (S_2). The higher number of effective tillers may be due to soil physical conditions and favourable environment provided by biochar. The results were similar to Khan *et al*., (2021) who reported that biochar-based treatments significantly improved number of effective tillers by 7%. While Dawalatzai *et al*., (2017) reported that application of Azotobacter + Phosphate Solubilizing microorganisms + fertilizers increased effective tillers by 15.8% compared with 75% Nitrogen alone.

Number of grains per spike: The data pertaining to number of grains per spike as presented in (Table 1) revealed that among the main plot treatments, biochar (M_2) recorded significantly highest number of grains per spike (40.1) over control (M_1). Similarly, in the sub-plot treatments, the microbial consortium (S_6) produced significantly highest number of grains per spike (43.2) followed by Acetobacter (S_5) and Zinc solubilizing bacteria (S_2) and control (S_1). The improvement in grains per spike may be attributed to better nutrient availability, enhanced photosynthetic activity, and efficient translocation of assimilates under biochar application and microbial inoculation. Similar findings have been reported by Asghar *et al*., (2023), who reported that the integrated application of plant growth-promoting bacteria, farmyard manure, and DAP produced the highest number of grains per spike (87.7). While Haider *et al*., (2020) reported that biochar application increased grains per spike (32.6, 32.3, 30.6), at tillering, flowering and grain filling stage, respectively.

Spike length: The data pertaining spike length as presented in (Table 1) revealed that in main plot treatments Biochar (M_2) recorded highest spike length (11.3) over (M_1). similarly in the sub-plots microbial consortium (S_6) produced the highest spike length (12.1) followed by Acetobacter (S_5) and Zinc solubilizing bacteria (S_2). The increase in spike length may be attributed to improved soil fertility, enhanced nutrient uptake, and better crop growth under biochar application and microbial inoculation, which contributed to improved reproductive development. Similar findings were also reported by Haider *et al*., (2020) that showed application of biochar @ 37.18 g kg^{-1} produced the maximum spike length (12.2cm, 12.1cm, 10.7cm) at tillering, flowering and grain filling stage.

1000 grain weight: The data regarding 1000 grain weight showed in (Table 1) revealed that the main plots and sub plots did not show any significant result in case of 1000 grain weight. The non- significant response might be attributed to the stable genetic control of grain size in the wheat WH1124 and prevailing environmental conditions during grain development. Similar results were reported by authors Ali *et al*., (2019) who observed that the effect of biochar and FYM was non - significant on 1000 grain weight.

Table 1. Effect of biochar and microbial consortium on yield attributes of wheat

Treatments	Effective tillers (m^{-2})	Grains spike^{-1}	Spike length (cm)	1000-grain weight (g)
Main plot				
M_1 – Control	283.1	37.0	10.5	41.5
M_2 – Biochar	304.3	40.1	11.3	41.5
SE(m) ±	3.4	0.4	0.1	0.2
CD	21.1	2.8	0.8	NS
Sub plot				

Treatments	Effective tillers (m^{-2})	Grains spike^{-1}	Spike length (cm)	1000-grain weight (g)
S_1 – Control	259.1	34.3	9.9	41.8
S_2 – ZSB	306.0	39.3	11.3	41.6
S_3 – PSB	284.8	36.8	10.5	41.95
S_4 – KMB	278.5	36.7	10.3	41.90
S_5 – Acetobacter	306.3	40.8	11.4	41.45
S_6 – Consortium	327.7	43.2	12.1	40.74
SE(m) ±	6.8	0.7	0.2	0.30
CD	20.1	2.3	0.6	NS

Grain yield: The data related to grain yield (Table 2) revealed that among the main plot treatments, biochar application (M_2) recorded significantly highest grain yield (3810 kg ha^{-1}). In case of sub plot, significantly highest grain yield (4114 kg ha^{-1}) was recorded in microbial consortium (S_6) which was followed by Acetobacter (S_5), zinc solubilizing bacteria (S_2) and control (S_1) (3241 kg ha^{-1}). This increase in grain yield might be attributed to positive correlation of the yield attributing characters with grain yield. Application of biochar and microbial consortium increased that yield attributes of wheat crop which ultimately enhanced the grain yield of the crop. Similar findings were also reported by Ijaz *et al*., (2019), who reported that biochar application along with half a dose of NPK fertilizer with PGPR consortium increased the grain yield by 39.97% over half dose of NPK fertilizer. While Game *et al*., (2020) reported that a grain yield of 44.22 q ha^{-1} was achieved with a microbial consortium with 100% recommended fertilizer, which is approximately 4.8% higher than 100% recommended fertilizer alone.

Table 2. Effect of biochar and microbial consortium on yield of wheat

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Main plot				
M_1 – Control	3515	4538	8053	43.66
M_2 – Biochar	3810	5109	8920	42.73
SE(m) ±	47	59	102	0.26
CD	286	364	622	NS
Sub plot				
S_1 – Control	3241	4266	7508	43.17
S_2 – ZSB	3772	4980	8753	43.05
S_3 – PSB	3523	4611	8134	43.34
S_4 – KMB	3480	4420	7900	44.06
S_5 – Acetobacter	3846	5160	9006	42.61
S_6 – Consortium	4114	5504	9619	42.92
SE(m) ±	83	115	170	0.57
CD	246	342	504	NS

Straw yield: The data regarding straw yield (Table 2) revealed that among the main plot treatments, biochar (M_2) recorded significantly highest straw yield (5109 kg ha^{-1}) than control (M1). In case of sub plot (S_6) microbial Consortium recorded the highest straw yield (5504 kg ha^{-1}) followed by Acetobacter (S_5), Zinc solubilizing bacteria (S_2) and control (S_1) (4266 kg ha^{-1}). Straw yield increase under biochar application attributed to improved soil physical conditions, vegetative growth which ultimately promoted greater biomass accumulation. Similar results were reported by authors Iqbal *et al*., (2022) who reported that biochar application significantly improved straw yield. Another similar finding was reported by Kewat *et al*., (2022) who reported that the combined application of Azotobacter, Phosphate-solubilizing bacteria, and 7.5% seaweed extract produced highest straw yield of 10.68 t ha^{-1}.

Biological yield: The data related to biological yield (Table 2) revealed that among the main plot biochar (M_2) recorded significantly highest biological yield (8920 kg ha^{-1}) than control M_1. In case of sub plot significantly highest biological yield (9619 kg ha^{-1}) was recorded in (S_6) Microbial Consortium followed by Acetobacter (S_5), Zinc solubilizing bacteria (S_2) and control (S_1) (7508 kg ha^{-1}). The increase in biological yield may be attributed to the combined improvement in grain and straw yields under biochar application and microbial inoculation. Earlier Zafar-ul-Hye *et al*., (2019) also reported similar results that showed the Combined application of *Bacillus amyloliquefaciens* and 30 Mg ha^{-1} Biochar under three irrigations, significantly increased biological yield upto (40%). While Haider *et al*., (2020) reported application of biochar resulted in a 13.92%, 9.43%, 19.50% and a 6.42% increase in grain yield, biological yield, compared with untreated soil.

Harvest Index: The data regarding harvest (Table 2) revealed that the main plots and sub plots did not show any significant result in case of harvest index. The similar results were supported by Ijaz *et al*., (2019) who concluded that combined biochar application with PGPR improved grain and straw production but there was no such effect on harvest index.

Table 3. Relative Economics of Wheat

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	B:C
Main plot				
M_1 – Control	40068	111745	71676	1.7
M_2 – Biochar	88068	122461	34392	0.3
Sub plot				
S_1 – Control	64033	103619	39586	0.8
S_2 – ZSB	64076	120693	56617	1.1
S_3 – PSB	64076	112432	48356	1.0
S_4 – KMB	64076	110113	46037	1.0
S_5 – Acetobacter	64076	123627	59551	1.1
S_6 – Consortium	64076	132133	68057	1.3

Relative Economics: The data related to relative economics of wheat (Table3) revealed that among the main plot biochar (M_2) recorded higher Cost of cultivation (Rs 88068 ha^{-1}), Gross return (Rs 122461 ha^{-1}), Net return (Rs 34392 ha^{-1}) than control M_1 but B:C was higher in control (M_1) (1.7) than (M_2). In case of sub plots higher Cost of cultivation (Rs 64076 ha^{-1}), Gross return (Rs 132133 ha^{-1}), Net return (Rs 68057 ha^{-1}), B:C (1.3) were higher in (S_6) microbial Consortium than Acetobacter (S_5), Zinc solubilizing bacteria (S_2).

CONCLUSION

The study revealed that biochar and microbial consortium could enhance wheat productivity and profitability. Biochar application at 4 t ha^{-1} enhanced the number of grains per spike, spike length, number of effective tillers, grain, straw yield, and biological yield over the control. The consortium of ZSB + PSB + KMB + Acetobacter gave the best result in microbial treatments. It had 43.2 grains per spike, 12.1 cm spike length, 327.75 effective tillers m^{-2}, 4114 kg ha^{-1} grain yield, 5504 kg ha^{-1} straw yield and 9619 kg ha^{-1} biological yield. Considering all these points, biochar application at 4 t ha^{-1} along with seed treatment with consortium of ZSB, PSB, KMB and Acetobacter is recommended for obtaining higher productivity of wheat. However, higher cost of biochar severely reduces profitability of the treatment which can be managed if biochar is produced from on farm residues.

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