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Effect of Biochar and Bio-inoculants on Yield, Nutrient Content and Uptake of Mungbean

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Abstract*— *A field experiment was conducted to study the effect of biochar and bio-inoculants on yield attributes and yield of mungbean, and to assess the impact of biochar and bio-inoculants on nutrient content and uptake by mungbean during Kharif 2024, at the Instructional Farm, SKNAU. Variety RMG-492 was used for the experiment at seed rate of 15 Kg ha^{-1}. The experiment consisted of treatments having 4 levels of biochar (control, 2, 4 and 6-ton ha^{-1} biochar) and four treatments of bio-inoculants (Control, Rhizobium, PSB and Rhizobium + PSB) total of 16 treatment combinations were laid out in factorial randomized block design and replicated thrice. Mungbean variety RMG-492 was taken as a test crop. The experimental results indicated that the application of 6-ton ha^{-1} biochar significantly increased test weight (36.97 g), seed yield (1266 Kg ha^{-1}), stover yield (2652 Kg ha^{-1}) and biological yield (3918 Kg ha^{-1}) of mungbean over the control. The content of N, P and K in seed and stover and their uptake by mungbean were observed to be significantly increased with the application of 6-ton ha^{-1} biochar over that under control. Results further indicated that dual inoculation of Rhizobium+ PSB significantly increased the seed yield (1247Kg ha^{-1}), stover yield (2570 Kg ha^{-1}), biological yield (3795 Kg ha^{-1}) and test weight (35.63 g) over control. Maximum N, P and K content and their uptake in seed and stover of mungbean were recorded under the co-inoculation of Rhizobium+PSB. The interactive effect of different levels of biochar and bioinoculants on seed and stover yield of mungbean was statistically significant. A consistent increase in yield was observed with the combined application of biochar and bioinoculants. The interactive effects of biochar and bioinoculants on nutrient content and uptake in mungbean seed and stover were also statistically significant.*

***Keywords*— Factorial, Biochar, Bioinoculants, Mungbean, Yield attributes, Nutrient content and uptake**

I. INTRODUCTION

Mungbean is an important pulse crop having high nutritive value. Its seed contains 24.2% protein, 1.3% fat and 60.4% carbohydrate. It is a short duration crop. The average yield is quite low which requires attention of the crop experts. Among various factors, judicious use of fertilizer is of prime importance. It is evident from the literature that application of major nutrients *i.e.* NPK improved mungbean yield (Ali *et al*., 2010) vis-a-vis micronutrients also play a vital role in plant growth and sustainability of the crop. Mungbean, being a leguminous crop fixes 31-85 kg N/ha. Rhizobium which supplies about 20-40 kg N/ha, can be considered as a complementary or supplementary source of plant nutrient. Roy and Hore (2012) demonstrated highest soil fertility build up with organic manure microbial inoculants combination compared to inorganic nutrient. Inoculation of Rhizobium to mungbean enhances nodulation, nitrogen fixation and grain yield. In India the area of mungbean is 5.18 million ha with production of 3.10 million tones (Anonymous 2023-2024) In Rajasthan the area of mungbean is 2.27 million ha with production of 0.82 million tones and productivity of 344 kg/ha (Anonymous 2023-24).

Biochar is a porous, carbon-rich material produced by heating organic matter to temperatures of between 300 °C and 600 °C in an environment with limited or no oxygen (Verheijen *et al*., 2010) . Meta-analysis of the effects of biochar suggests that it is most effective in acidic, degraded and coarse-textured soils (Crane-Droesch *et al*.,2013). The physical and chemical characteristics of any amendment determine its effectiveness as liming agent (Barber 1984). The ameliorating ability of biochar can be varied due to differences in their physical and chemical properties. Bioinoculants, also known as microbial inoculants or biofertilizers, are formulations containing beneficial microorganisms like bacteria, fungi, or algae that are applied to seeds, soil, or plants to promote growth by increasing the supply or availability of essential nutrients (Vessey, 2003). These microbes enhance plant health through various mechanisms, including nitrogen fixation, phosphate solubilization, production of growth-promoting substances and protection against plant pathogens. Keeping this in view the above facts, present field experiment was planned to study the effect of biochar and bio-inoculants on yield attributes and yield of mungbean as well as to assess the effect of biochar and bio-inoculants on nutrient content and uptake by mungbean.

II. MATERIALS AND METHODS

The field experiment was conducted at Instructional farm, S.K.N. College of Agriculture, Jobner (Rajasthan) during *kharif* season of year 2024. The experiment was laid out in FRBD with three replications. The treatments were randomly allotted to different plots using random number table of Fisher and Yates (1963) [8]. The details of treatment and their symbols are given as under:

A	Biochar Levels		
1	Control	:	BC_0
2	Biochar @ 2.0 t ha^{-1}	:	BC_1
3	Biochar@ 4.0 t ha^{-1}	:	BC_2
4	Biochar @ 6.0 t ha^{-1}	:	BC_3
B.	**Bioinoculant Levels**		
1	Control	:	B_0
2	Rhizobium	:	B_1
3	PSB	:	B_2
4	Rhizobium + PSB	:	B_3

Observation recorded-

Test weight- From the seed samples of each plot, 1000-seed were counted and weighed the weight was expressed as test weight in gram (g). Biological yield - After complete drying, the produce of individual plot was weighed before threshing and the weight was recorded as biological yield Seed yield- After recording the biological yield, the material was threshed manually and winnowed. The clean seed obtained from individual plots were weighed and the weight was recorded as grain yield in kilogram per hectare (kg ha^{-1}). Stover yield- was obtained by subtracting the grain yield from biological yield. The seed and stover yield recorded under each plot were converted into kilogram per hectare (kg ha^{-1}).

Nutrient content and uptake

The plant samples at harvest were collected from each plot separately and dried in oven at constant temperature of 70 °C until they attained constant weight. The dried samples were separated part wise and powdered in a grinder having stainless steel blades. An acid extract of grain and stover samples was used for the determination of N, P, K content as per the standard method.

Nutrient uptake

The nutrient content was expressed as per cent and uptake was calculated in terms of kg ha^{-1} by using the following formula:

$$\text{Nutrient uptake of N, P and K by grain/stover (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content grain/stover (\%)} \times \text{Grain/stover yield (kg ha}^{-1}\text{)}}{100}$$

Statistical analysis

The experimental data recorded, were subjected to statistical analysis in accordance with the "Analysis of Variance" technique suggested by (Fisher, 1950) [9]. Appropriate standard error for each of the factor was worked out. Significance of differences among treatment effects was tested by "F" test. Critical difference (CD) was worked out, wherever the difference was found significant at 5.0 per cent level of significance. The "Analysis of Variance" of different components for all the parameters are given in the annexures at the end.

III. RESULT AND DISCUSSION

Effect of biochar and bioinoculant on the yield and yield attributes of mungbean

Effect of biochar

The data presented in Table 1 revealed that the application of biochar at different levels brought significant improvement in test weight of mungbean as compared to control. The highest (36.97 g) test weight of mungbean was recorded with the application of Biochar @ 6 ton ha^{-1} (BC_3) which was followed by the application of Biochar @ 4 ton ha^{-1} (BC_2) (34.92 g). It is apparent from the data presented in Table 1 and depicted in figure 1 that the seed yield of mungbean increased significantly due to application of increasing levels of biochar. Among the different levels of biochar, the highest seed yield of mungbean was recorded with the application Biochar @ 6 ton ha^{-1} (BC_3) (1266 kg ha^{-1}) which was significantly higher in comparison to control (BC_0) (1000 kg ha^{-1}) and Biochar @ 4 ton ha^{-1} (BC_2) (1195 kg ha^{-1}). It is apparent from the data presented in Table 1 and depicted in figure 1 that the stover yield of mungbean increased significantly due to application of increasing levels of biochar. Among the different levels of biochar, the highest stover yield of mungbean was recorded with the application Biochar @ 6 ton ha^{-1} (BC_3) (2652 kg ha^{-1}) which was significantly higher in comparison to control (1936 kg ha^{-1}). It is apparent from the data presented in Table 1 that the biological yield of mungbean increased significantly due to application of increasing levels of biochar. Among the different levels of biochar, the highest biological yield of mungbean was recorded with the application Biochar @ 6 ton ha^{-1} (BC_3) (3918 kg ha^{-1}) which was significantly higher in comparison to control (2936 kg ha^{-1}). It is apparent from the data presented in Table 1 that the harvesting index of mungbean influenced significantly due to application of levels of biochar. Among the different levels of biochar, the highest biological yield of mungbean was recorded with the control (BC_0) (20.62) followed by, Biochar @ 2 ton ha^{-1} (BC_1) (19.70) and Biochar @ 4 ton ha^{-1} (BC_2) (19.47). Choudhary *et al*. (2023) and Verma and Mathur (2009) similarly documented significant yield and biomass improvements with biochar via better soil health and nutrient supply. Sihag *et al*.(2020) reported that biochar amendment soils improved seed filling and seed weight in pulses due to enriched soil nutrient status and microbial activity

Effect of bio-inoculants

It is apparent from the data Table 1 that the test weight of mungbean was influenced by the inoculation of bio-inoculants. Among the bio-inoculants, the maximum test weight was recorded with the dual inoculation of Rhizobium + PSB (B_3) (35.63 g) which was found superior over control (B_0) (31.91 g). Data reveals that the seed yield of mungbean was significantly influenced by the inoculation of bio-inoculants. Maximum seed yield of mungbean was recorded with the dual inoculation of Rhizobium + PSB (B_3) (1247 kg ha^{-1}). Data reveals that the stover yield of mungbean was significantly influenced by the inoculation of bio-inoculants. Maximum stover yield of mungbean was recorded with the dual inoculation of Rhizobium + PSB (B_3) (2570 kg ha^{-1}) which was superior in comparison to control (B_0) (2120 kg ha^{-1}). Data reveals that the biological yield of mungbean was significantly influenced by the inoculation of bio-inoculants. Maximum biological yield of mungbean was recorded with the dual inoculation of Rhizobium + PSB (B_3) (3795 kg ha^{-1}). Data reveals that the biological yield of mungbean was significantly influenced by the inoculation of bio-inoculants. Maximum biological yield of mungbean was recorded with the dual inoculation of Rhizobium + PSB (B_3) (3795 kg ha^{-1}). The application of bio-inoculants (Rhizobium + PSB) significantly improved mungbean yield attributes and yield by boosting nitrogen through biological fixation and phosphorus via solubilization, leading to better seed filling, yield and biomass consistent with Choudhary *et al*. (2010), Tagore *et al*. (2013) and Yadav *et al*. (2014).

Table 1: Effect of biochar and bio-inoculants on test weight(g), seed yield, stover yield and biological yield of mungbean

Treatment	Test weight (g)	Seed yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Harvesting index (%)
Biochar					
Control	31.26	1000	1936	2936	20.62
Biochar @ 2 ton ha^{-1}	33.90	1154	2314	3468	19.70
Biochar @ 4 ton ha^{-1}	34.92	1195	2457	3622	19.47
Biochar @ 6 ton ha^{-1}	36.97	1266	2652	3918	19.22
SEm±	0.88	9	18	31	0.14
CD (P=0.05)	2.56	25	53	86	0.41
Bio-inoculants					
Control	31.91	1044	2120	3164	20.04
Rhizobium	34.60	1150	2310	3460	19.58
PSB	34.92	1173	2359	3532	19.86
Rhizobium+PSB	35.63	1247	2570	3795	19.52
SEm±	0.88	9	18	31	0.14
CD (P=0.05)	2.56	25	53	86	0.41

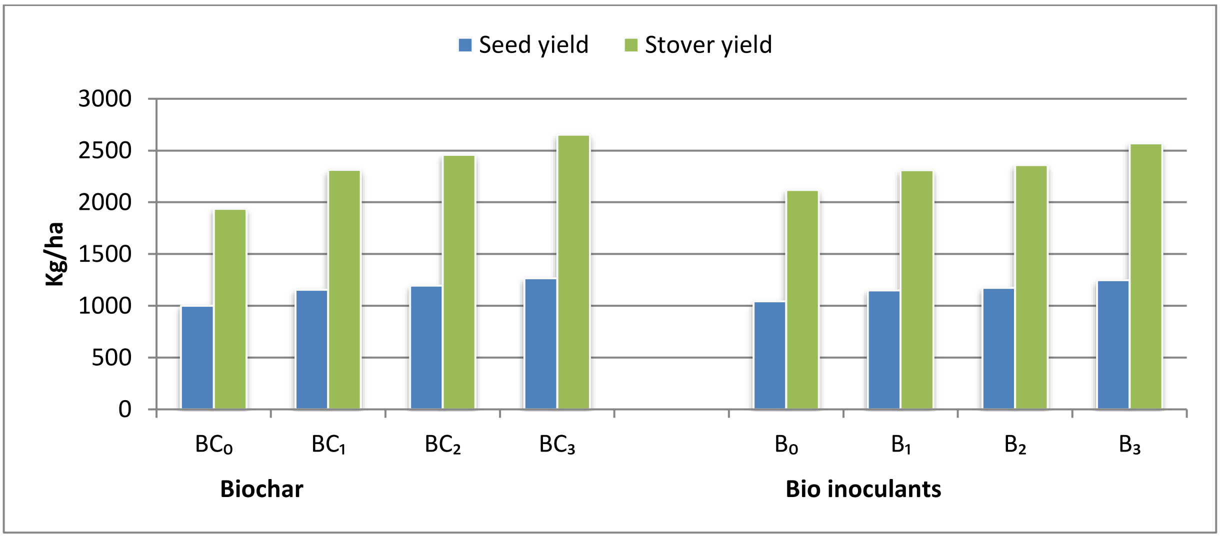

Fig 1: Effect of biochar and bio-inoculants on seed yield and stover yield of mungbean

Effect of biochar and bio-inoculants on nutrient content and uptake: -

N content and uptake by seed and stover

Effect of biochar

A critical examination of data Table 2 and depicted in figure 2 reveal that application of different levels of biochar had significant effect on N content in seed and stover of mungbean. The maximum N content was recorded with the application of Biochar @ 6 ton ha^{-1} (BC_3) (3.54 % in seed and 1.63 % in stover) and lowest under control (3.10 % in seed and 1.42 % in stover.A close pursual of data Table 2 and depicted in figure 2.2 reveal that biochar exerted positive influence on N uptake by seed and stover of mungbean. Among all the treatments, the highest N uptake was recorded with the application of Biochar @ 6 ton ha^{-1} (BC3) (47.00 kg ha^{-1} by seed and 43.16 kg ha^{-1} by stover) and lowest under control (31.23 kg ha^{-1} by seed and 27.67

kg ha⁻¹ by stover). Its moderately high cation exchange capacity and porous structure enhanced nitrogen retention and mineralization, supported by increased soil organic carbon and aeration, reducing NH_4^+ leaching and nitrogen volatilization (Changjiang *et al*. 2022; Bhatt *et al*. 2021).

Effect of bio-inoculant

The data presented in Table 2 reveal that the nitrogen content in seed and stover of mungbean was affected significantly by the inoculation of bio-inoculants. The maximum nitrogen content in seed and stover of mungbean was recorded with the dual inoculation of Rhizobium + PSB (B3) (3.53 % in seed and 1.58 % in stover) and lowest under control (B0) (3.08% in seed and 1.47 % in stover). The findings presented in Table 2 reveal that N uptake by seed and stover of mungbean was significantly influenced by the inoculation of bio-inoculants. The maximum N uptake in seed and stover of mungbean was recorded with the dual inoculation of Rhizobium + PSB (B3) (46.35 kg ha^{-1}) in seed and 40.69 kg ha^{-1} in stover) and minimum under control (32.15 kg ha^{-1} in seed and 31.41 kg ha^{-1} in stover). Nitrogen improvement was mainly due to Rhizobium's biological nitrogen fixation, increasing protein synthesis and biomass, with residual soil nitrogen also benefiting from root decay (Meena *et al*., 2015)

Interactive effect of biochar and bioinoculants on nitrogen content and uptake by seed and stover

The interactive effect of biochar and bioinoculants on nitrogen content and uptake in seed and stover of mungbean was found to be statistically significant (Table 2.1). The data indicated that nitrogen content in seed and stover subsequently increased with increasing levels of biochar and bioinoculants application. The maximum nitrogen content was recorded under the treatment combination BC_3B_3 (6 t ha^{-1} biochar and Rhizobium + PSB). Nitrogen content and uptake were highest under combined treatments, driven by biochar's improvement of root and microbial environments and its cation exchange capacity reducing nitrogen losses, supported by increased biological nitrogen fixation. This was corroborated by Jabborova *et al.* (2025), who found that combination of biochar and Biofertilizer treatment significantly enhanced plant nitrogen (N) content. Ali *et al.* (2022), who concluded that the effect of biochar and biofertilizer agents on increment in N uptake by 15% and nitrogen uptake efficiency by 17%.

Table 2: Effect of biochar and bio-inoculants on nitrogen content and uptake by mungbean

Treatment	N content (%)		N uptake(kg/ha)		Total
	Seed	Stover	Seed	stover	
Biochar					
Control	3.10	1.42	31.23	27.67	57.36
Biochar @ 2 ton ha⁻¹	3.23	1.49	36.41	33.65	69.54
Biochar @ 4 ton ha⁻¹	3.40	1.56	41.03	38.30	78.79
Biochar @ 6 ton ha⁻¹	3.54	1.63	47.00	43.16	87.94
SEm±	0.01	0.01	0.26	0.38	0.53
CD (P=0.05)	0.04	0.03	0.76	1.11	1.54
Bio-inoculants					
Control	3.08	1.47	32.15	31.41	63.04
Rhizobium	3.41	1.54	36.12	35.43	73.19
PSB	3.25	1.50	41.04	35.25	73.01
Rhizobium+PSB	3.53	1.58	46.35	40.69	84.38
SEm±	0.01	0.01	0.26	0.38	0.53
CD (P=0.05)	0.04	0.03	0.76	1.11	1.54

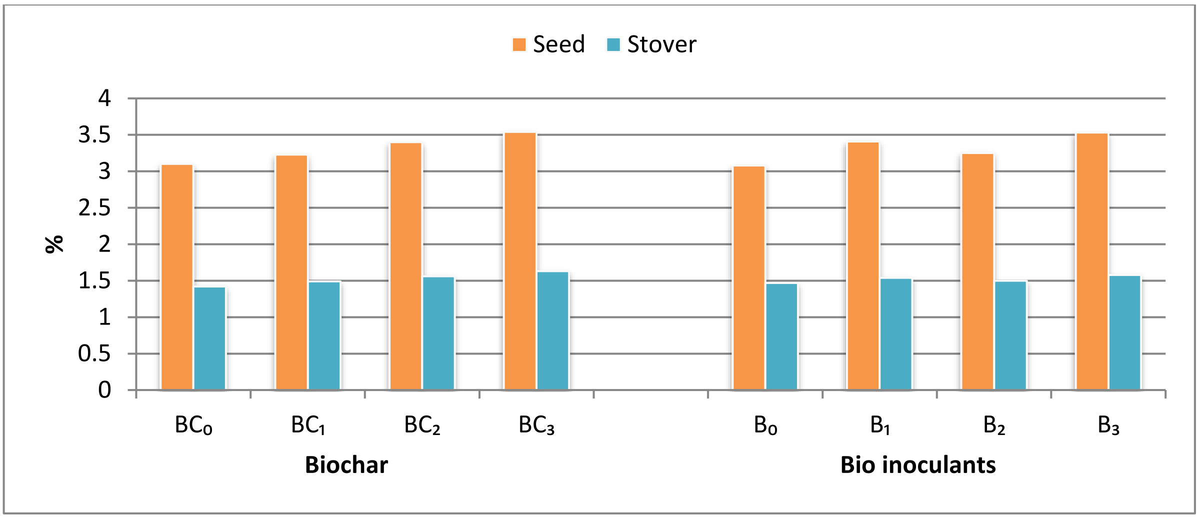

Fig 2: Effect of biochar and bio-inoculants on nitrogen content in mungbean

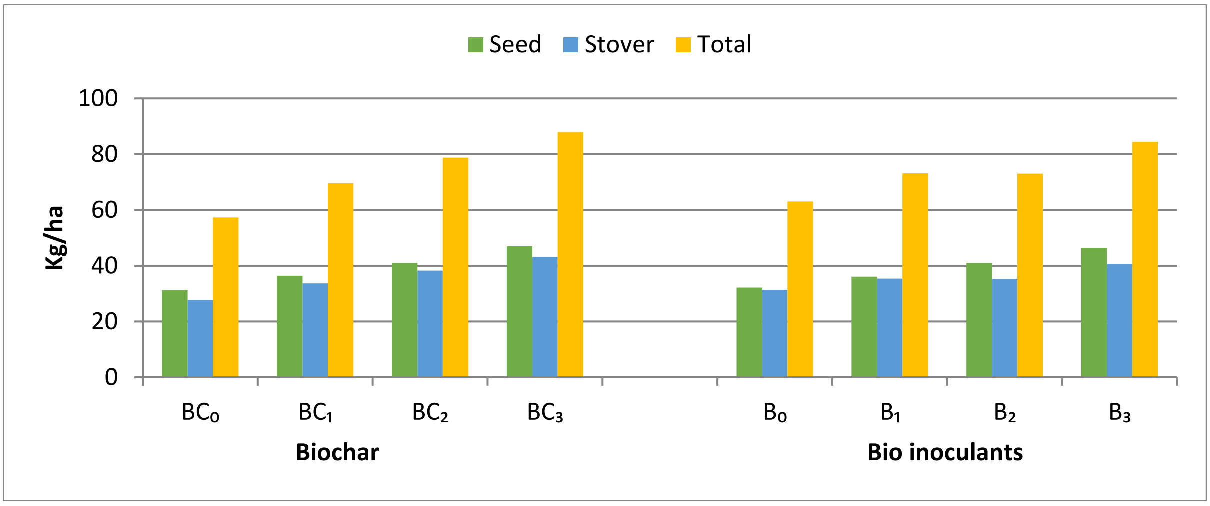

Fig 3: Effect of biochar and bio-inoculants on nitrogen uptake by mungbean

Table 2.1: Interactive effect of biochar and bioinoculants on N uptake in seed

Interaction table (Mean)

	B0	B1	B2	B3
BC0	18.77	22.42	41.67	42.05
BC1	33.39	35.55	36.06	40.63
BC2	35.86	40.56	40.57	47.10
BC3	40.56	45.94	45.86	55.63
		SEm±	**CD**	
		0.53	1.53	

Table 2.2: Interactive effect of biochar and bioinoculants on N uptake in stover

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	19.65	29.22	29.86	31.93
BC1	30.27	32.65	33.57	38.11
BC2	36.49	38.16	36.69	41.85
BC3	39.22	41.67	40.85	50.88
		SEm±	**CD**	
		0.77	2.22	

Table 2.3: Interactive effect of biochar and bioinoculants on N content in stover

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	1.31	1.44	1.41	1.51
BC1	1.44	1.48	1.46	1.54
BC2	1.54	1.58	1.51	1.59
BC3	1.58	1.65	1.59	1.67
			SEm±	**CD**
			0.02	0.06

Table 2.4 Interactive effect of biochar and bioinoculants on N content in seed

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	2.87	3.20	3.01	3.30
BC1	3.06	3.28	3.18	3.37
BC2	3.14	3.50	3.37	3.57
BC3	3.23	3.62	3.42	3.88
			SEm±	**CD**
			0.03	0.07

P content and uptake by seed and stover: -

Effect of biochar

A critical examination of data Table 3 and depicted in figure 4 reveal that the phosphorus content in seed and stover of mungbean increased significantly due to application of biochar at different levels. The maximum phosphorus content was recorded with the application of Biochar @ 6 ton ha^{-1} (BC3) (0.46 % in seed and 0.19 % in stover) and lowest under control (0.36 % in seed and 0.149 % in stover). An examination of data Table 3 and depicted in figure 5 reveals that phosphorus uptake by seed and stover of mungbean influenced significantly due to the application of subsequently increasing levels of biochar. Among all the treatments, the highest phosphorus uptake was recorded with the application of Biochar @ 6 ton ha^{-1} (BC3) (5.91 kg ha^{-1} by seed and 5.08 kg ha^{-1}by stover). In addition, babool biochar directly contributed phosphorus via its ash and reduced soil phosphorus fixation, while enhanced organic matter and microbial activity boosted phosphatase enzyme production for better phosphorus mineralization and uptake (Bhatt *et al*. 2021)

Effect of bio-inoculants

The data presented in Table 3 reveal that the phosphorus content in seed and stover of mungbean was affected significantly by the inoculation of bio-inoculants. The maximum P content in seed and stover of mungbean was recorded with the dual inoculation of Rhizobium + PSB (B3) (0.47 % in seed and 0.186 % in stover) and lowest under control (0.36 % in seed and 0.152 % in stover). Data presented in Table 3 reveals that the inoculation of different bio-inoculants significantly increased the phosphorus uptake by seed and stover of mungbean. The maximum phosphorus uptake in seed and stover of mungbean was recorded with the dual inoculation of Rhizobium + PSB (B3) (5.89 kg ha^{-1} in seed and 4.82 kg ha^{-1} in stover) and minimum under control (3.73 kg ha^{-1} in seed and 3.26 kg ha^{-1} in stover). PSB improved phosphorus availability by solubilizing insoluble phosphates and promoting root growth, enhancing phosphorus uptake (Tomar *et al*., 2001)

Interactive effect of biochar and bioinoculants on phosphorus content and uptake by seed and stover

The interactive effect of biochar and bioinoculants on phosphorus content in seed and stover of mungbean was found to be statistically significant . The results indicated that the combined use of biochar and bioinoculants effectively improved the phosphorus content in mungbean seed and stover . The data indicated a progressive increase in phosphorus content with the application of biochar and bioinoculants. The maximum phosphorus content and uptake was recorded in the treatment combination BC_3B_3 (6 t ha^{-1} biochar and Rhizobium + PSB) . These findings corroborate with those of Yang *et al*. (2023 Egamberdieva *et al*. (2021) observed that the interactive application improves soil microbial biomass and enzyme activities such as acid and alkaline phosphatase, which directly facilitate the mineralization of organic phosphorus and increase its availability in the rhizosphere

Table 3: Effect of biochar and bio-inoculants on phosphorus content and uptake by mungbean

Treatment	P_2O_5 content (%)		P_2O_5 uptake(kg/ha)		Total
	Seed	Stover	Seed	Stover	
Biochar					
Control	0.364	0.149	3.63	2.91	6.54
Biochar @ 2 ton ha^{-1}	0.405	0.162	4.53	3.67	8.20
Biochar @ 4 ton ha^{-1}	0.433	0.174	5.19	4.29	9.48
Biochar @ 6 ton ha^{-1}	0.466	0.191	5.91	5.08	10.99
SEm±	0.004	0.001	0.07	0.04	0.09
CD (P=0.05)	0.011	0.004	0.19	0.13	0.25
Bio-inoculants					
Control	0.357	0.152	3.73	3.26	6.99
Rhizobium	0.392	0.162	4.40	3.73	8.12
PSB	0.447	0.176	5.24	4.15	9.39
Rhizobium+PSB	0.472	0.186	5.89	4.82	10.71
SEm±	0.004	0.001	0.07	0.04	0.09
CD (P=0.05)	0.011	0.004	0.19	0.13	0.25

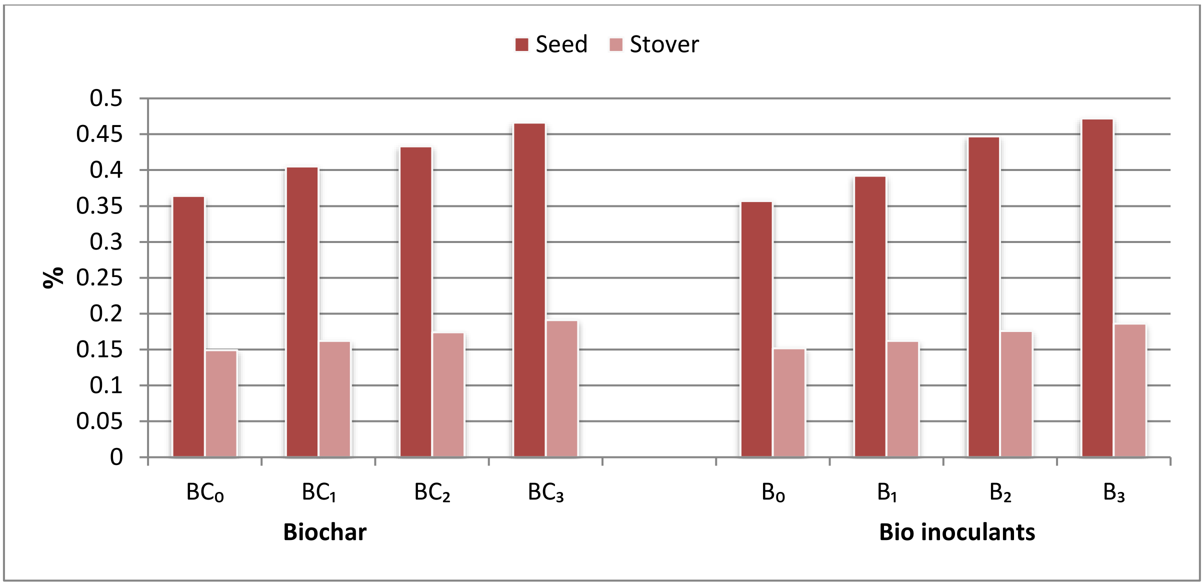

Fig 4: Effect of biochar and bio-inoculants on phosphorus content in mungbean

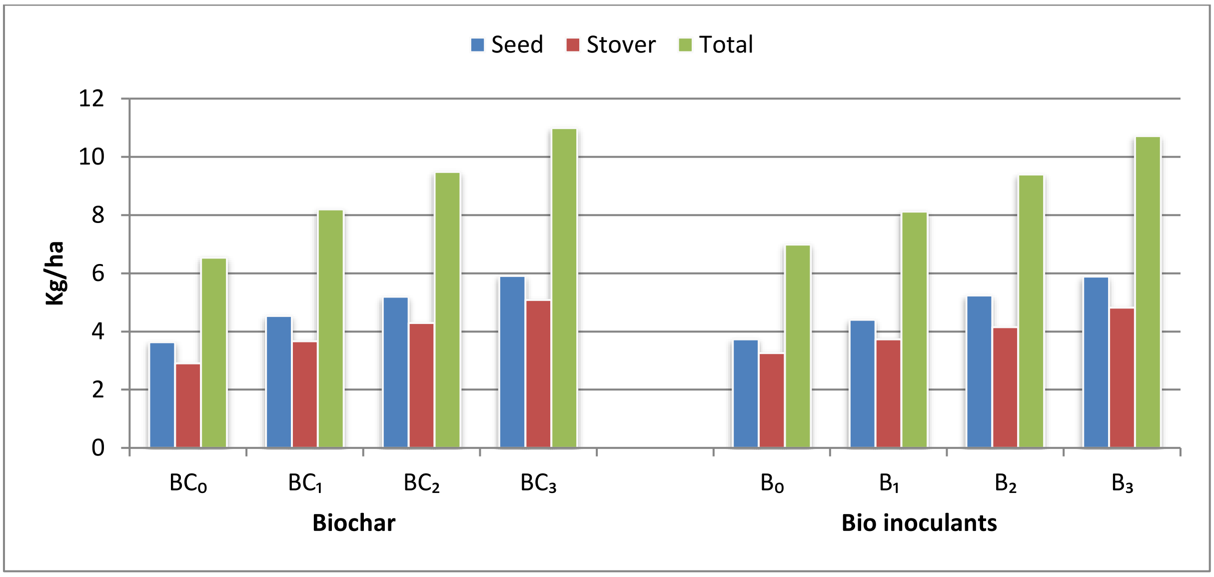

Fig 5: Effect of biochar and bio-inoculants on phosphorus uptake by mungbean

Table 3.1 Interactive effect of biochar and bioinoculants on P content in seed

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	0.31	0.33	0.39	0.41
BC1	0.32	0.39	0.43	0.46
BC2	0.36	0.40	0.46	0.49
BC3	0.42	0.44	0.48	0.51
			SEm±	**CD**
			0.01	0.022

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Table 3.2 Interactive effect of biochar and bioinoculants on P content in stover

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	0.131	0.143	0.158	0.164
BC1	0.145	0.157	0.170	0.175
BC2	0.160	0.169	0.182	0.187
BC3	0.172	0.179	0.194	0.217
			SEm±	**CD**
			0.003	0.009

Table 3.3 Interactive effect of biochar and bioinoculants on P uptake in seed

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	2.81	3.30	4.05	4.34
BC1	3.32	4.27	4.94	5.57
BC2	3.96	4.62	5.64	6.51
BC3	4.80	5.37	6.31	7.13
			SEm±	**CD**
			0.13	0.38

Table 3.4 Interactive effect of biochar and bioinoculants on P uptake in stover

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	1.96	2.88	3.31	3.47
BC1	3.02	3.45	3.91	4.31
BC2	3.78	4.05	4.41	4.91
BC3	4.27	4.51	4.96	6.59
			SEm±	**CD**
			0.09	0.26

K content and uptake by seed and stover

Effect of biochar

An examination of data presented in Table 4 reveal that the application of biochar exerted significant effect on potassium content in seed and stover of mungbean. The maximum potassium content was recorded with the application of Biochar @ 6 ton ha^{-1} (BC3) (1.24 % in seed and 1.24 % in stover) and lowest under control (0.90 % in seed and 1.09 % in stover). A close perusal of data Table 4 reveals that potassium uptake by seed and stover of mungbean increased significantly due to the increasing levels of biochar. Among all the levels of biochar, the highest potassium uptake was recorded with the application of Biochar @ 6 ton ha^{-1} (BC3) (15.64 kg ha^{-1} by seed and 32.89 kg ha^{-1} by stover) over control. For potassium, the biochar's high exchangeable K content and improved soil properties led to greater K availability and uptake, as shown in fenugreek (Bhatt *et al*. 2021) and rice (Priyanka Rani *et al*., 2015)

Effect of bio-inoculant

The data pertaining to potassium content in seed and stover of mungbean are presented in Table 4. Results indicate that the potassium content in seed and stover of mungbean was influenced by the inoculation of bio-inoculants. The maximum potassium content was found with the dual inoculation of Rhizobium+PSB (1.20% in seed and 1.21 % in stover) and minimum under control (0.99 % in seed and 1.12 % in stover). It is apparent from the data presented in Table 4 that the potassium uptake by seed and stover of mungbean was found to be significantly increased due to inoculation of different bio-inoculants. The maximum potassium uptake was recorded with the dual inoculation of Rhizobium + PSB (15.02 kg ha^{-1} in seed and 31.06 kg ha^{-1} in stover) and minimum under control (10.32 kg ha^{-1} in seed and 23.83 kg ha^{-1} in stover). Potassium uptake increased through microbial activity and better root exploration, as noted by Mohammad *et al*. (2017)

Interactive effect of biochar and bioinoculants on potassium content and uptake in seed and stover

The interaction effect of different levels of biochar and bioinoculants on potassium content in mungbean seed and stover was found to be statistically significant (Table 4.1). A progressive increase in potassium content and uptake was observed with the increase in biochar levels from 0 to 6 t ha^{-1} and with the application of bioinoculants. The maximum potassium content and uptake in seed and stover was recorded under the treatment combination BC_3B_3 (6 t ha^{-1} biochar and Rhizobium + PSB)), which was found to be significantly superior over all other treatment combinations. Jabborova *et al.* (2025), who found that combination of biochar and Biofertilizer treatment significantly enhanced plant potassium (K) content by 51.8%. Additionally, biochar's porous structure acts as a favourable habitat for soil microbial colonization, enhancing microbial activity and nutrient cycling.

Table 4: Effect of biochar and bio-inoculants on potassium content and uptake by mungbean

Treatment	K_2O content (%)		K_2O uptake (kg/ha)	
	Seed	Stover	Seed	Stover
Biochar				
Control	0.90	1.09	8.97	21.08
Biochar @ 2 ton ha^{-1}	1.08	1.14	12.00	25.73
Biochar @ 4 ton ha^{-1}	1.18	1.18	14.03	28.89
Biochar @ 6 ton ha^{-1}	1.24	1.24	15.64	32.89
SEm±	0.01	0.01	0.17	0.24
CD (P=0.05)	0.03	0.02	0.49	0.70
Bio-inoculants				
Control	0.99	1.12	10.32	23.89
Rhizobium	1.05	1.15	11.79	26.30
PSB	1.15	1.16	13.51	27.40
Rhizobium+PSB	1.20	1.21	15.02	31.06
SEm±	0.01	0.01	0.17	0.24
CD (P=0.05)	0.03	0.02	0.49	0.70

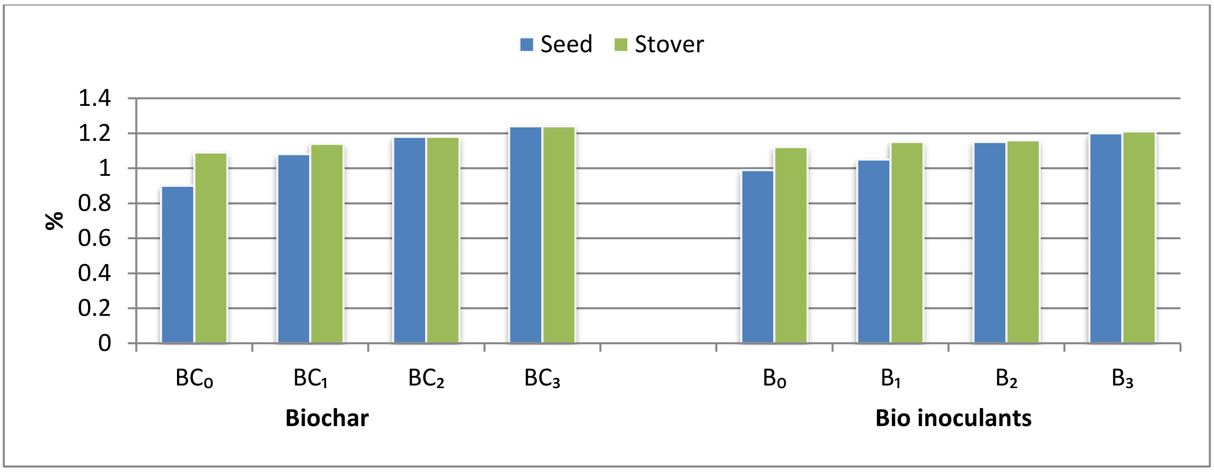

Fig 6: Effect of biochar and bio-inoculants on potassium content by mungbean

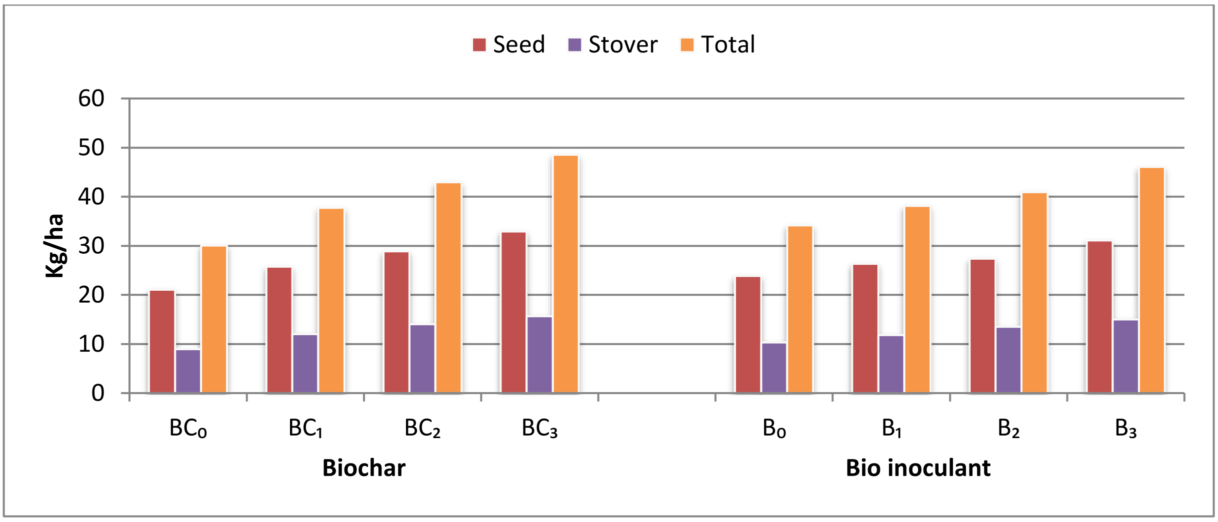

Fig 7: Effect of biochar and bio-inoculants on potassium uptake by mungbean

Table 4.1 Interactive effect of biochar and bioinoculants on K content in seed

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	0.74	0.87	0.94	1.02
BC1	0.97	1.05	1.11	1.16
BC2	1.10	1.12	1.21	1.27
BC3	1.12	1.15	1.31	1.35
			SEm±	**CD**
			0.02	0.05

Table 4.2 Interactive effect of biochar and bioinoculants on K content in stover

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	1.08	1.08	1.08	1.10
BC1	1.09	1.11	1.13	1.18
BC2	1.13	1.15	1.17	1.23
BC3	1.18	1.23	1.25	1.29
			SEm±	**CD**
			0.011	0.032

Table 4.3 Interactive effect of biochar and bioinoculants on K uptake in seed

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	6.78	8.69	9.80	10.58
BC1	9.91	11.38	12.67	14.03
BC2	11.82	12.99	14.61	16.69
BC3	12.75	14.09	16.93	18.78
			SEm±	**CD**
			0.34	0.98

Table 4.4 Interactive effect of biochar and bioinoculants on K uptake in stover

Interaction table (Mean)				
	B0	**B1**	**B2**	**B3**
BC0	16.21	21.83	22.89	23.37
BC1	22.94	24.55	26.14	29.27
BC2	26.87	27.79	28.50	32.39
BC3	29.30	31.01	32.06	39.19
			SEm±	**CD**
			0.49	1.40

IV. CONCLUSION

On the basis of findings obtained from the present field experiment, it can be concluded that the integrated application of biochar @ 6 t ha^{-1} along with combined inoculation of Rhizobium + PSB proved to be the most effective treatment combination for enhancing mungbean productivity under loamy sand soil conditions. This treatment combination significantly maximized crop yield attributes, yield, nutrient content and nutrient uptake of mungbean. Hence, this combination can be recommended for sustaining soil fertility and securing higher crop productivity in mungbean-based cropping systems, particularly under the loamy sand soils of semi-arid regions.

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