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Effect of Rhizobium Inoculation with Zinc and Boron Fertilizers on Growth and Yield of Mungbean (*Vigna radiata* L.)

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Mungbean is considered as an extremely nutritious crop possessing a high level of micronutrients. The field experiment was conducted to evaluate the response of growth and yield of Mungbean to zinc, boron and rhizobium inoculation. The experiment was laid out in split-plot design with tree replications during kharif season of 2021 and 2022 at Instructional farm, Kamla Nehru Institute of Physical and Social Sciences Sultanpur, U.P. India. Four levels of zinc (0, 2.5, 5.0 and 7.5 Kg Zn ha^{-1}), three levels of boron (0, 0.5 and 1.0 Kg B ha^{-1}) and two levels of rhizobium *i.e.* Uninoculated (Control) and inoculated were used in this study. Zinc levels were allocated to the main plots, boron levels in the sub-plot, while Rhizobium inoculation in the sub-sub plot. The results revealed that plant height, number of branches per plant, dry weight, number of nodules and seed and stover

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yield were higher in mungbean inoculated with Rhizobium inoculation with application of zinc 7.5 kg ha^{-1} and Application of boron 1.0 kg ha^{-1}. The findings of the current study would improve the growth and yield of mungbean.

Keywords: Boron; inoculation; rhizobium; synergetic effect; yield; zinc.

1. INTRODUCTION

"Mungbean [*Vigna radiata* L. (Wilczek)] is considered as an extremely nutritious crop possessing a high level of micronutrients" [1].

"It is a diploid, self-pollinated legume crop species with 22 chromosomes (2n=2x=22). It's also known as green gram or moong bean, and belongs to the Fabaceae botanical family and the genus Vigna. Mungbean is a warm-season crop that's fast-growing, with a short life cycle of 60–75 days, relative tolerance to drought, and ability to improve soil fertility through atmospheric nitrogen (N_2) fixation in symbiosis with *Rhizobium* and *Bradyrhizobium* bacteria in the soil" [2]. "Hence, it plays an important role in crop diversification and sustainable agricultural intensification in Asia. It's mainly cultivated in South, East, and Southeast Asia for its edible seeds and sprouts, and is an inexpensive source of protein, carbohydrates, iron, and folic acid. Mungbean is also a low-input crop that can be used as livestock feed and green manure" [3,4]. "The yield and yield components of mungbean can be improved by using high yielding varieties and balanced fertilization" [5].

"The Zn essentially is being employed in functional and structural component of several enzymes, such as carbonic anhydrase, alcohol dehydrase, alkaline phosphatase, phospholipase, carboxypeptidase [6] and RNA polymerase" [7]. "Further, plants emerging from seeds with lower Zn could be highly sensitive to biotic and abiotic stresses" [8]. "Zn enriched seeds performs better with respect to seed germination, seedling growth and yield of crops" [9]. "Zinc also converts ammonia into nitrates in crops which contribute to yield" [10].

"In addition, boron (B) supply is a critical role in growing tissues and any imbalance may inhibit the vegetative and reproductive growth in plants. Its deficiency might lead to inappropriate adsorption of NPK and S in different field crops including mungbean" [11].

Therefore, the study was undertaken with the objectives to investigate the response of Zn, B and *rhizobium* inoculation on the yield and yield contributing characteristics of mungbean and to select the suitable dose of Zn and B fertilizer.

2. MATERIALS AND METHODS

A field experiment was conducted during two consecutive seasons of *kharif* 2021 and 2022 at Instructional farm, Kamla Nehru Institute of Physical and Social Sciences Sultanpur, U.P. (India). The experimental site falls under sub-tropical conditions with remarkable humidity and lies between 26.2927^0 North latitude and 82.1278^0 East longitude with an altitude of about 95 m from mean sea level. The experimental field was well levelled having good irrigation and drainage facilities. Four levels of zinc (0, 2.5, 5.0 and 7.5 Kg Zn ha^{-1}), three levels of boron (0, 0.5 and 1.0 Kg B ha^{-1}) and two levels of rhizobium *i.e.* Uninoculated (Control) and inoculated. A split-split plot design with three replications was used. Zinc levels were allocated to the main plots, boron levels in the sub-plot, while Rhizobium inoculation in the sub-sub plot. Soil sample was taken before sowing and after harvest of the crop to know the fertility status of the experiment field. The growth and yield analysis were done as per standard procedures.

3. RESULTS AND DISCUSSION

3.1 Growth Parameters

3.1.1 Plant height

Data analysis revealed that zinc levels had significant effect on plant height at all growth stages except 30 DAS (Table 1). Plant height increased successively with increasing the zinc levels up to 7.5 kg ha^{-1}. Maximum plant height was recorded under 7.5 kg Zn ha^{-1}, which was at par with 5 kg Zn ha^{-1} and significantly superior over control and 2.5 kg Zn ha^{-1} at all the crop growth stages. The increased plant height was attributed to proper establishment of crop as it gives the strength to the plant tissues besides activation of numerous enzymes in the plant system. Similar results were also reported by Farhad et al. [12].

Plant height influenced greatly due to application of boron, it increased with the advancement of the crop growth upto harvest stage in all the levels of boron. Significant impact of boron levels was also noted at all the stages of growth except at 30 days after sowing. Application of 1 kg B ha^{-1} registered significantly more plant height which was at par with application 0.5 Kg B ha^{-1}. Similar results were also reported by Hossain et al. [13] and Mathew and George [14]. The increase in number of branches might be due to the role of B in cell division, tissue differentiation, carbohydrate metabolism and maintenance of conducting tissue with regulatory effect on another element.

Rhizobium inoculation had also pronounced effect on plant height at all the stages of plant growth excluding at 30 days after sowing. Rhizobium inoculated treatment exhibited significantly more plant height than that of un inoculated ones.

The interaction effect of different treatments on plant height was found non-significant at all the stages of crop growth.

3.1.2 Number of branches $plant^{-1}$

Data analysis on number of branches at successive stages of growth as affected by different treatments are summarized in Table 2. The number of branches $plant^{-1}$ increased progressively till the harvest stage, irrespective of treatments.

Application of different levels of zinc significantly enhanced the number of branches $plant^{-1}$. The magnitude of increase in number of branches $plant^{-1}$ due to zinc fertilization at 7.5 kg ha^{-1} was higher by 11.65 and 11.91 per cent over control during first and second years of study at harvest stage. However, application of zinc at 5 kg ha^{-1} being on par with 7.5 kg Zn ha^{-1} at harvest, recorded 9.52 and 9.49 per cent increase in number of branches $plant^{-1}$ over control during both respective years of investigation.

Significant influence of boron application was also noticed maximum number of branches $plant^{-1}$ was noted 11.96 and 12.35 during both the years of study, when 1.0 Kg ha^{-1} boron was applied, which was on par with application of 0.5 kg B ka^{-1} and significantly superior to control.

Rhizobium inoculation also registered significant impact of production of branches $plant^{-1}$. Percent increase in number of branches $plant^{-1}$ due to inoculation over uninoculated plants was 12.66% and 12.62 % during first and second years of study.

Interactions of different treatments were not significant during both the years of investigation.

Table 1. Effect of Zn, Bo and rhizobium inoculation on plant height of *kharif* mungbean at different stages of growth

Treatments	Plant height (cm)							
	30 DAS		45 DAS		60 DAS		At harvest	
	2021	2022	2021	2022	2021	2022	2021	2022
Zinc levels (kg ha^{-1})								
Z_0: 0	27.17	28.28	34.40	35.43	39.86	41.10	43.24	44.57
Z_1: 2.5	28.02	28.86	35.87	36.97	41.60	42.80	45.08	46.46
Z_2: 5.0	28.88	29.46	37.70	38.80	43.67	45.03	47.38	49.36
Z_3: 7.5	29.17	30.04	38.43	39.64	44.52	45.87	48.33	49.73
SEm$\pm$	0.532	0.547	0.624	0.707	0.796	0.793	0.788	0.911
CD (P=0.05)	NS	NS	1.78	2.01	2.27	2.26	2.24	2.59
Boron levels (kg ha^{-1})								
B_0: 0	27.59	28.43	34.77	35.84	40.30	41.50	43.70	45.39
B_1: 0.5	28.60	29.45	36.97	38.08	42.82	44.15	46.46	47.92
B_2: 1.0	28.74	29.59	38.06	39.22	44.11	45.45	47.86	49.28
SEm$\pm$	0.461	0.474	0.541	0.612	0.690	0.687	0.682	0.789
CD (P=0.05)	NS	NS	1.54	1.74	1.96	1.96	1.94	2.25
Rhizobium inoculation								
I_1: Un-inoculated	28.02	28.86	34.40	35.44	39.88	41.08	43.25	44.83
I_2: Inoculated	28.60	29.46	38.80	39.98	44.94	46.32	48.76	50.23
SEm$\pm$	0.376	0.387	0.442	0.500	0.563	0.561	0.557	0.644
CD (P=0.05)	NS	NS	1.26	1.42	1.60	1.60	1.59	1.83

Table 2. Effect of Zn, Bo and rhizobium inoculation on number of branches plant^{-1} at different stages of growth of Mungbean

Treatments	Number of branches plant^{-1}							
	30 DAS		45 DAS		60 DAS		At harvest	
	2021	2022	2021	2022	2021	2022	2021	2022
Zinc levels (kg ha^{-1})								
Z_0: 0	5.83	6.00	7.99	8.20	9.78	10.08	10.82	11.17
Z_1: 2.5	6.08	6.33	8.33	8.63	10.19	10.53	11.28	11.60
Z_2: 5.0	6.39	6.55	8.76	9.07	10.71	11.07	11.85	12.23
Z_3: 7.5	6.51	6.73	8.93	9.23	10.92	11.29	12.08	12.50
SEm±	0.110	0.068	0.160	0.126	0.155	0.202	0.213	0.194
CD (P=0.05)	0.31	0.19	0.46	0.36	0.44	0.58	0.60	0.55
Boron levels (kg ha^{-1})								
B_0: 0	5.89	6.06	8.08	8.38	9.88	10.20	10.93	11.30
B_1: 0.5	6.26	6.48	8.59	8.88	10.50	10.87	11.62	11.98
B_2: 1.0	6.45	6.68	8.84	9.10	10.82	11.16	11.96	12.35
SEm±	0.095	0.059	0.139	0.109	0.134	0.175	0.184	0.168
CD (P=0.05)	0.27	0.17	0.40	0.31	0.38	0.50	0.52	0.48
Rhizobium inoculation								
I_1: Un-inoculated	5.83	6.03	7.99	8.25	9.78	10.11	10.82	11.17
I_2: Inoculated	6.57	6.78	9.01	9.32	11.02	11.38	12.19	12.58
SEm±	0.077	0.048	0.113	0.089	0.109	0.143	0.150	0.137
CD (P=0.05)	0.22	0.14	0.32	0.25	0.31	0.40	0.43	0.39

Table 3. Effect of Zn, Bo and rhizobium inoculation on dry weight plant^{-1} of mung- bean at different stages of growth

Treatments	Dry weight (g plant^{-1})							
	30 DAS		45 DAS		60 DAS		At harvest	
	2021	2022	2021	2022	2021	2022	2021	2022
Zinc levels (kg ha^{-1})								
Z_0: 0	3.20	3.29	7.61	7.85	10.90	11.23	11.66	12.00
Z_1: 2.5	3.33	3.45	7.94	8.18	11.37	11.72	12.15	12.54
Z_2: 5.0	3.50	3.62	8.34	8.60	11.95	12.32	12.77	13.17
Z_3: 7.5	3.57	3.68	8.51	8.77	12.18	12.57	13.02	13.43
SEm±	0.064	0.066	0.147	0.128	0.221	0.177	0.179	0.227
CD (P=0.05)	0.182	0.188	0.418	0.364	0.629	0.503	0.508	0.647
Boron levels (kg ha^{-1})								
B_0: 0	3.23	3.33	7.70	7.93	11.02	11.35	11.78	12.15
B_1: 0.5	3.43	3.55	8.18	8.43	11.72	12.08	12.52	12.93
B_2: 1.0	3.54	3.65	8.42	8.69	12.06	12.44	12.90	13.28
SEm±	0.055	0.057	0.127	0.111	0.191	0.153	0.155	0.197
CD (P=0.05)	0.157	0.163	0.362	0.316	0.545	0.435	0.440	0.560
Rhizobium inoculation								
I_1: Un-inoculated	3.33	3.30	7.61	7.85	10.91	11.25	11.66	12.04
I_2: Inoculated	3.50	3.72	8.59	8.85	12.30	12.66	13.14	13.53
SEm±	3.57	0.047	0.104	0.091	0.156	0.125	0.126	0.161
CD (P=0.05)	0.064	0.133	0.296	0.258	0.445	0.355	0.359	0.457

3.1.3 Dry weight (g) plant^{-1}

Data pertaining to dry weight of plant as influenced by different levels of zinc, boron and rhizobium inoculation have been presented in Table 3.

A perusal of data clearly indicated that marked variations in dry matter of mungbean was recorded due to varying levels of zinc. Application of zinc at 7.5 kg/ha being on par with 5 kg/ha recorded significantly higher dry matter accumulation (3.57 and 3.68), (8.51 and 8.77), (12.18 and 12.57) and (13.02 and 13.43) g plant^{-1} at 30, 45, 60 days after sowing and harvest stage during first and second years of study, respectively. Percentage increase in dry matter production due to application of zinc at the rate of 2.5, 5, 7.5 kg/ha was 4.20, 9.52 and 11.66% during first year and 4.50, 9.75 and 11.92% during second year at harvest stage.

Dry matter accumulation was recorded highest under application of 1 kg B ha^{-1} which was non-significantly followed by 5 kg B ha^{-1} and significantly superior to control at all stages of growth. The trend of data was similar during both the years of investigation. Rhizobium inoculation showed marked impact on dry matter accumulation of mungbean at all stages of growth. Significantly more dry matter was noted under rhizobium inoculated plants as compared to uninoculated ones during both respective years of experimentation.

Interactions of different treatments were not significant during both the years of investigation.

3.1.4 Number of nodule plant^{-1}

Data on account of number of nodules plant^{-1} as influenced by various doses of zinc, boron and rhizobium inoculation have been presented in Table 4. Increasing trend in number of nodules was noted with each increment of zinc dose. Maximum number of nodules were noted when 7.5 kg Z ha^{-1} was applied and it was significantly more than that of 0.5 kg Z ha^{-1} and control. However, the differences among values of nodules plant^{-1} under 7.5 kg Z ha^{-1} and 5 kg Z ha^{-1} were not significant. It is observed that data was similar during both the years of study.

Data revealed that application of 1 kg B ha^{-1} significantly affected number of nodules plant^{-1} in mungbean. A significant increase of 6.36 and 9.45 per cent during first year and 6.44 and 9.59 per cent during second year, respectively, over control was noted at application of 0.5 kg B ha^{-1} and 1 kg B ha^{-1} respectively.

Rhizobium inoculation exhibited marked impact on number of nodules plant^{-1} in mungbean. Significantly more number of nodules plant^{-1} was noted under rhizobium inoculated plants as compared to uninoculated ones during both the years of experimentation.

Interactions of different treatments were not significant during both the years of investigation.

Table 4. Effect of Zn, Bo and rhizobium inoculation on number and weight of nodule plant^{-1} of mung- bean at different stages of growth

Treatments	No. of nodule plant^{-1}		Fresh wt. of nodule plant^{-1}		Dry wt. of nodule plant^{-1}	
	2021	2022	2021	2022	2021	2022
Zinc levels (kg ha^{-1})						
Z_0: 0	45.14	46.43	158.82	163.08	84.83	88.22
Z_1: 2.5	47.04	48.43	165.58	170.10	88.44	92.02
Z_2: 5.0	49.44	50.93	174.03	178.78	92.95	96.77
Z_3: 7.5	50.40	51.93	177.41	182.29	94.81	98.67
SEm±	0.795	0.701	2.713	3.255	1.536	1.591
CD (P=0.05)	2.26	1.99	7.72	9.27	4.37	4.53
Boron levels (kg ha^{-1})						
B_0: 0	45.60	46.93	160.51	164.71	85.73	89.16
B_1: 0.5	48.50	49.95	170.65	175.40	91.18	94.91
B_2: 1.0	49.92	51.43	175.72	180.58	93.85	97.71
SEm±	0.688	0.607	2.349	2.819	1.330	1.378
CD (P=0.05)	1.96	1.73	6.69	8.03	3.79	3.92
Rhizobium inoculation						
I_1: Un-inoculated	45.13	46.47	158.82	163.10	84.83	88.29
I_2: Inoculated	50.88	52.40	179.10	184.02	95.68	99.56
SEm±	0.562	0.496	1.918	2.302	1.086	1.125
CD (P=0.05)	1.60	1.41	5.46	6.55	3.09	3.20

Table 5. Effect of Zn, Bo and rhizobium inoculation on Seed and stover yield q ha^{-1} of mungbean

Treatments	Seed yield (q ha^{-1})		Stover yield (q ha^{-1})	
	2021	2022	2021	2022
Zinc levels (kg ha^{-1})				
Z_0: 0	7.71	7.94	31.04	31.91
Z_1: 2.5	8.12	8.37	32.56	33.46
Z_2: 5.0	8.45	8.54	33.75	34.02
Z_3: 7.5	8.53	8.79	33.98	34.89
SEm$\pm$	0.140	0.160	0.527	0.564
CD (P=0.05)	0.40	0.46	1.50	1.60
Boron levels (kg ha^{-1})				
B_0: 0	7.79	8.03	31.22	32.11
B_1: 0.5	8.37	8.49	33.48	33.90
B_2: 1.0	8.45	8.70	33.80	34.70
SEm$\pm$	0.121	0.139	0.457	0.489
CD (P=0.05)	0.35	0.40	1.30	1.39
Rhizobium inoculation				
I_1: Un-inoculated	7.87	8.11	31.56	32.44
I_2: Inoculated	8.53	8.71	34.10	34.70
SEm$\pm$	0.099	0.113	0.373	0.399
CD (P=0.05)	0.28	0.32	1.06	1.14

3.1.5 Seed yield (q ha^{-1})

Seed yield is an important parameter which decides the efficiency and superiority of a particular treatment over other treatments. Data pertaining to seed yield plant^{-1} as influenced by zinc, boron and rhizobium inoculation are presented in Table 5.

It is clear from data, yield of mungbean was improved significantly with every increasing level of zinc upto 7.5 kg ha^{-1}. It attained the yield of (8.53 and 8.79) q ha^{-1} with a remarkable increase of 10.64 and 10.71 per cent over control during 2021 and 2022 respectively. Whereas, (9.60 and 9.70) and (5.32 and 5.42) per cent increments in yield were obtained under 5 and 2.5 kg zinc/ha over control, respectively. Likewise, application of zinc to mungbean at 7.5 kg/ha enhanced grain yield by 0.82, 0.41, 0.08 at which date of sowing and 0.85, 0.42, 0.08 q/ha over control, at both years respectively.

A further to data revealed that increasing levels of boron significantly increased the seed yield of mungbean. Application of 1kg B ha^{-1} recorded an increase of 8.47 per cent over control during both years of study.

Rhizobium inoculation also registered significant impact on yield q ha^{-1} of mungbean. Percent increase in seed yield due to inoculation over uninoculated plants was 8.39% and 8.25 % during first and second years of study.

3.1.6 Stover yield (q ha^{-1})

Data pertaining to seed yield plant^{-1} as influenced by zinc, boron and rhizobium inoculation are presented in Table 5.

It is clear from data, stover yield of mungbean was improved significantly with every increasing level of zinc upto 7.5 kg ha^{-1}. It attained the stover yield of (33.98 and 34.89) q ha^{-1} with a remarkable increase of 9.34 and 9.57 per cent over control during both the years respectively. It was non significantly followed by 5 kg Zn ha^{-1} and significantly followed by rest levels of zinc. Minimum stover yield of 31.04 and 31.91 q ha^{-1} was noted under control plots during both years of investigation respectively. Application of boron significantly increased the stover yield of mungbean. Application of 1 kg B ha^{-1} recorded highest stover yield of 33.80 and 34.70 q ha^{-1} during 2021 and 2022 respectively and it was statistically superior to control. Minimum stover yield of 31.22 and 32.11 q ha^{-1} was recorded from control plots. Rhizobium inoculation also registered significant impact on stover yield of mungbean. Significantly more stover yield was noted under inoculated plots than that in uninoculated ones during both respective years of study.

3.2 Discussion

"The favourable influence of zinc on photosynthetic and enzymatic activities would in turn increase vegetative growth of plants" [15]. Thus increased availability of zinc in rhizosphere might be resulted in greater uptake by the plant, consequently leading to a favourable stimulatory effect on physiological and metabolic processes of plant. The importance of zinc for nodulation was reported that zinc nutrition is essential and paramount for *Rhizobium* activity to fix nitrogen and increase weight of nodules. Upadhyay et al. [16] also reported increased nodule weight with the application of zinc. More nodules formation is associated with zinc application. Increase in nodulation by zinc could be due to increase in root weight or size, which provided sufficient site for nodulation.

The maximum values for almost all parameters were recorded with zinc application at 7.5 kg/ha. The effect of zinc nutrition on physiological and metabolic processes of plants, role in more absorption of essential elements due to increased cation exchange capacity of roots and thereby bearing more yield contributing characters are possible basis of more yield. Zinc application for soil at 7.5 kg/ha enhanced grain yield and stover yield significantly, compared with no zinc application. This indicated that mungbean responded better to zinc application for soil even at higher rates without showing the symptoms of zinc toxicity. In an earlier study Jamal et al. [17] reported that "mungbean responded upto application of zinc at 10 kg/ha". "Zinc also has significant role in primordia initiation, indole-acetic acid synthesis and partitioning of food material from leaves to reproductive parts which ultimately results in good fruiting" [18,19].

4. CONCLUSIONS AND RECOMMENDATION

Accurate micronutrients application is essential to prevent both deficiencies and toxicities in plants. Ensuring the correct amounts used promotes optimal plant health and sustainable agricultural practices. Therefore, to enhance the production, Rhizobium inoculation with application of Zinc 7.5 kg ha^{-1} and Boron 1.0 kg ha^{-1} for soil has proved its superiority for better plant growth, dry matter, yield and productivity of mungbean.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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