Environment and Ecology 41 (4D) : 2965—2974, October—December 2023
Article DOI: https://doi.org/10.60151/envec/PZST7163
ISSN 0970-0420

Performance of Mungbean in Response to Zinc and Iron through Agronomic Mechanism of Biofortification

B. C. Dhayal, U. N. Shukla, Sita Ram Kumhar, Ummed Singh, M. M. Kumawat, H. P. Prewa, R. C. Meena

Received 23 June 2023, Accepted 1 November 2023, Published on 29 December 2023

ABSTRACT

A field experiment was conducted at College of Agriculture, Agriculture University, Jodhpur in *kharif* season during 2020 and 2021 to study the effect of agronomic biofortification of zinc and iron on growth, yield and quality of mungbean (*Vigna radiata* (L.) Wilczek) varieties. The experiment was laid out in a split plot design, comprised with two varieties namely GM-7 and MH-421 and three treatments of foliar spray of iron (Fe) and urea in main-plots and four treatments included seed inoculation by zinc solubilizing bacteria with soil application of zinc (Zn) in a combinations were assigned to sub-plots. In this way, the experiment had twenty four treatment combinations were replicated thrice. Mung bean variety 'MH-421' had performed prominently with respect to all growth and yield parameters, while taller height was recorded under variety 'GM-7' during both the years as well as pooled basis of experimentations. Biofortified treatment of iron with urea spray and zinc significantly higher growth and yield attributes were recorded under treatment foliar spray of 0.5% Fe + 2% urea at flower initiation and pod formation stages and seed inoculation with ZSB + soil application of higher dose of zinc sulphate i.e. ZSB (SI) + 25 kg $ZnSO_4$/ha, which remained at par with foliar spray of 0.5% Fe + 2% urea at flower initiation stage and ZSB (SI) + 20 kg $ZnSO_4$/ha at 25, 50 DAS and at harvest stage of mungbean, respectively.

Keywords Foliar spray, Iron sulphate, Zinc sulphate, Zinc solubilizing bacteria, Yield.

INTRODUCTION

In the dry and semi-arid regions of India, mungbean (*Vigna radiata* (L.) Wilczek) is a significant short durant pulse crop. After chickpea and pigeon pea, mungbean is the third most important grain legume grown and consumed in India (Samant and Mohanty 2017). Mungbean is grown on 3.69 million hectares in India, with a total production of 3.16 million tonnes and an average productivity of 567 kg/ha (Anonymous 2022). Rajasthan held the top position in India, producing 1.32 million tonnes of mung beans on 2.16 million hectares with an average yield of 610 kg/ha (Anonymous 2022).

B. C. Dhayal[1]*, U. N. Shukla[2], Sita Ram Kumhar[3], Ummed Singh[4], M. M. Kumawat[5], H. P. Prewa[6], R. C. Meena[7]

[1]PhD Scholar, [2]Associate Professor, [3]Professor, Department of GPB, [4]Professor, Department of Agronomy, [5]Professor, Department of Entomology, [6]Assistant Professor, Department of Agri. Chem. and Soil Science, [7]Assistant Professor, Department of Plant Physiology

[1,2,3,4,5,6,7]Agriculture University, Jodhpur, Rajasthan 342304, India

Email : dhayalbhagchand45@gmail.com
*Corresponding author

More than half of the world's population is affected due to micronutrients deficiency particularly in the developing countries. In particular, zinc (Zn) and iron (Fe) deficiency in human nutrition are wide spread in Asian developing countries including India (Alloway 2008). Singh and Behera (2011) were analyzed three lakh soil samples across from India and observed that nearly 49% soils were deficient in zinc, 12% in iron, 3% in copper, 5% in manganese, 33% in boron and 13% in molybdenum.

Factually, zinc is one of the eight essential micro-nutrient require for acceleration of growth and reproduction of the plants. Zinc enriched finger proteins are required in signal transduction, regulation and transcription of deoxyribonucleic acid (DNA)/ ribonucleic acid (RNA) or other proteins in the plant (Graham 2008). Zinc involved in the root nodulation of plant and enables to the pulse crops to fix inert nitrogen in the root nodule. Zinc deficiency is not only causing low productivity of the crops, but it also affects the human health. The major six categories of enzymes which play vital role in the human nutrition have contained zinc (Barak and Helmke 1993).The solubility of zinc in the soil is very less leading to poor uptake resulted into low bioavailability in the plant and has become the major problems across the world (Alloway 2009). Therefore, seed inoculation and/or soil application of zinc solubilizing bacteria (ZSB) is need of the day to enhance crop production and nutritional quality by improving zinc availability. The zinc solubilizer mainly ZSB produces so many organic acids and dissolved the non-labial forms of zinc cations and acidifying the rhizosphere that alter the soil pH (Glick 2012 and Alexander 1997). Other mechanisms possibly involved in zinc solubilization include oxido-reductive system, production of siderophores and proton that make insoluble form of zinc sulphide to the soluble form of zinc sulphate (Saravanan *et al.* 2011).

According to Arnon and Stout (1939), iron (Fe) is an essential micronutrient without which life cycle of plants won't be completed. It is actively participated in the chlorophyll synthesis and act as structural component of hemes, hematin and leghaemoglobin involved in the nitrogen fixation in pulses catalyzed by an enzyme called 'nitrogenase'. Although, ubiquitous presence of iron in earth's crust, but low solubility makes it lesser availability and finally poor uptake by crops. It play important role in formation of hemoglobin, transport of oxygen, activation and inactivation of various enzymes which performed main function in the human body (Underwood and Suttle 1999). It leads to poor pregnancy, high risk of morbidity in children, reduced working capacity in adults, retard mental growth, anemia and disability in human particularly in children (Sheftela *et al.* 2011).

The foliar spray of urea and their effect on improvement of zinc and iron concentration in mungbean grains are not well established and has doubt whether it increases concentration of zinc and iron in grain or not. Some of the studies revealed that cost of application can be lowered by tank mix application of nitrogen along with zinc and iron (micronutrients). Furthermore, compatibility of micronutrients along with nitrogen applies through urea need to be studied in depth whether it could be out yielded additive or antagonistic (Petroff 2003).

Biofortification word derived from Greek language *"bios"* means *"life"* and Latin word *"fortificare"* means "*making strong"*. It can be defined as the process of increasing the concentrations of certain micronutrients in edible portions of plants naturally by application of mineral fertilizers i.e. agronomic approaches or through conventional breeding approaches. It is the idea to increase nutritional value of micronutrients particularly zinc and iron through agronomic approaches (fertilizer application), which helps to ensure nutrition security by improving the quality of grains in addition to enhancing productivity of crops (Marquez-Quiroz *et al.* 2015 and Pathak *et al.* 2012, Meena *et al.* 2023). Agronomic related approaches have provided compatible and easy solutions to overcome the deficiency of zinc and iron in human body. Soil and foliar application of zinc and iron are major tools of agronomic approaches to provide nourishment to the crops and also increases the accumulation of zinc and iron in the edible part of plants (Cakmak 2008). However, remobilization and translocation of zinc and iron in the plants are governed by genetic factors. Also, the chemical compatibility of zinc and iron in the tank mixed are a major concerned for their mobility through xylem and phloem tissues of the plant cell (Cakmak *et al.* 2004). Therefore, the present experiment was conducted to study the effect of agronomic biofortification of zinc and iron on growth and yield of mungbean (*Vigna radiata* (L.) Wilczek) varieties.

MATERIALS AND METHODS

A field experiment was conducted on mungbean (*Vigna radiata* (L.) at College of Agriculture, Jodhpur (Rajasthan) during *kharif* season of 2020 and 2021. The soil of experimental site was sandy-loam, slightly alkaline in soil reaction (pH 8.0 to 8.2), non-saline in conductivity (EC 0.12 to 0.13d/Sm), low in organic carbon (0.13 to 0.14%) and available nitrogen (174 to 175.8 kg/ha), whereas medium in phosphorus (20.1 to 21.3 kg/ha), and high in available potassium (325 to 329.4 kg/ha). Similarly, the micronutrient analysis of the experimental soil was low in available zinc (0.46 to 0.48 mg/kg) and available iron (3.20 to 3.21 mg/kg). The average bulk density of soil of the experimental field was 1.74 to 1.77 Mg/m^3. It is evident from data that the maximum and minimum temperature during crop growing season ranged between (31.6 to 39.7°C and 20.3 to 32.0^{o}C)and (29.1 to 38.6°C and 23.0 to 31.3°C) during *kharif* 2020 and 2021, respectively. The maximum and minimum relative humidity ranged between (46.7 to 91.0 and 17.3 to 78.5) and (35.6 to 89.8 and 11.6 to 31.3) per cent during *kharif* 2020 and 2021, respectively. The total rainfall received during the crop season 2020 and 2021 were 197.26 and 181.74 mm, respectively. A field experiment was comprised with two varieties namely GM-7 and MH-421 and three treatments of foliar spray of Fe with urea in main-plots (control, 0.5% Fe + 2% urea at flowering initiation and 0.5% Fe + 2% urea at flowering initiation and pod formation stage) and four treatments of seed inoculation with zinc solubilizing bacteria and along with soil application of zinc (Zn) in a combinations (control, ZSB (SI) + 15 kg $ZnSO_4$/ha, ZSB (SI) + 20 kg $ZnSO_4$/ha and ZSB (SI) + 25 Kg $ZnSO_4$/ha) were assigned to sub-plots. In this way, the experiment had twenty four treatment combinations and replicated thrice in Split Plot Design. The seed were sown in furrow opened at the depth of about 4-5 cm using seed rate of 15 kg/ha with inter row spacing of 30 cm. The data recorded for growth parameters, yield and other characters were put to statistical analysis in accordance with the analysis of variance for split plot design by Fisher (1925).

RESULTS AND DISCUSSION

Effect of varieties

Growth attributes

Data presented (Tables 1-2) on growth attributes significantly influenced plant height and dry matter accumulation at 25, 50 DAS and at harvest stage of mungbean, while there was no significant variation found on initial and final plant population of mungbean (Figs. 1-2) during both the years of experimentation as well as pooled mean basis. Mungbean variety

Table 1. Effect of agronomic biofortification of zinc and iron on plant height (cm) of mungbean varieties.

Treatments	Plant height (cm)								
	25 DAS			50 DAS			At harvest		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Varieties (V)									
V_1: GM-7	12.9	13.4	13.2	44.4	46.2	45.3	54.7	56.3	55.5
V_2: MH-421	12.3	12.6	12.5	42.4	44.0	43.2	52.5	53.7	53.1
SEm±	0.17	0.20	0.13	0.59	0.65	0.44	0.70	0.80	0.53
CD (p= 0.05)	0.53	0.63	0.38	1.87	2.06	1.30	2.20	2.53	1.57
Iron and Urea spray (Fe+U)									
FeU_0: Control	12.4	12.7	12.5	41.7	43.2	42.4	51.0	52.5	51.8
FeU_1: 0.5% Fe + 2% Urea at FI	12.6	13.0	12.8	43.9	45.8	44.8	54.0	55.6	54.8
FeU_2: 0.5% Fe + 2% Urea at FI and PF	12.8	13.4	13.1	44.7	46.2	45.5	55.7	56.8	56.3
SEm±	0.21	0.24	0.16	0.72	0.80	0.54	0.86	0.98	0.65
CD (p= 0.05)	NS	NS	NS	2.28	2.52	1.59	2.70	3.10	1.92

Table 1. Continued.

Treatments	Plant height (cm)								
	25 DAS			50 DAS			At harvest		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Zinc levels (Zn)									
Z_0: Control	10.2	10.9	10.5	36.7	38.1	37.4	44.5	45.1	44.8
Z_1: ZSB (SI) + 15 kg $ZnSO_4$/ha	12.5	12.8	12.6	43.0	44.8	43.9	52.7	54.2	53.4
Z_2: ZSB (SI) + 20 kg $ZnSO_4$/ha	13.7	14.1	13.9	46.7	48.4	47.6	57.9	59.9	58.9
Z_3: ZSB (SI) + 25 kg $ZnSO_4$/ha	13.9	14.3	14.1	47.3	49.1	48.2	59.3	60.7	60.0
SEm±	0.14	0.14	0.10	0.49	0.51	0.35	0.60	0.63	0.44
CD (p= 0.05)	0.40	0.41	0.28	1.40	1.46	0.99	1.73	1.81	1.23
Interaction (V × Fe)									
SEm±	0.29	0.34	0.23	1.03	1.13	0.76	1.21	1.39	0.92
CD (p= 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (V × Zn)									
SEm±	0.20	0.20	0.14	0.69	0.72	0.50	0.85	0.89	0.62
CD (p= 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (Fe × Zn)									
SEm±	0.24	0.25	0.09	0.84	0.88	0.31	1.05	1.09	0.38
CD (p= 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2. Effect of agronomic biofortification of zinc and iron on dry matter accumulation (g/plant) of mungbean varieties.

Treatments	Dry matter accumulation (g/plant)								
	25 DAS			50 DAS			At harvest		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Varieties (V)									
V_1: GM-7	2.92	2.97	2.94	11.68	12.58	12.13	18.85	19.68	19.26
V_2: MH-421	3.07	3.14	3.11	13.54	14.61	14.06	21.13	22.04	21.58
SEm±	0.04	0.04	0.03	0.16	0.17	0.12	0.24	0.26	0.18
CD (p= 0.05)	0.12	0.14	0.08	0.49	0.55	0.34	0.76	0.81	0.52
Iron and Urea spray (Fe+U)									
FeU_0: Control	2.96	3.03	2.99	10.70	11.75	11.22	18.07	18.92	18.50
FeU_1: 0.5% Fe + 2% Urea at FI	2.99	3.06	3.03	13.44	14.51	13.96	20.78	21.68	21.23
FeU_2: 0.5% Fe + 2% Urea at FI and PF	3.03	3.08	3.05	13.67	14.53	14.10	21.12	21.97	21.55
SEm±	0.05	0.05	0.03	0.19	0.21	0.14	0.30	0.31	0.22
CD (p= 0.05)	NS	NS	NS	0.60	0.67	0.42	0.94	0.99	0.64
Zinc levels (Zn)									
Zn_0: Control	2.66	2.70	2.68	9.46	10.72	10.09	16.60	17.49	17.05
Zn_1: ZSB (SI) + 15 kg $ZnSO_4$/ha	3.04	3.09	3.06	12.72	13.63	13.16	20.00	20.85	20.42
Zn_2: ZSB (SI) + 20 kg $ZnSO_4$/ha	3.14	3.21	3.17	13.98	14.86	14.42	21.55	22.38	21.96
Zn_3: ZSB (SI) + 25 kg $ZnSO_4$ /ha	3.15	3.22	3.18	14.26	15.18	14.70	21.81	22.71	22.26
SEm±	0.03	0.03	0.02	0.14	0.16	0.10	0.21	0.23	0.16
CD (p= 0.05)	0.09	0.10	0.07	0.40	0.45	0.29	0.61	0.65	0.44
Interaction (V × FeU)									
SEm±	0.06	0.07	0.05	0.27	0.30	0.20	0.42	0.44	0.31
CD (p= 0.05)	NS	NS	NS	NS	NS	NS	1.32	1.40	0.90
Interaction (V × Zn)									
SEm±	0.05	0.05	0.03	0.20	0.22	0.15	0.30	0.32	0.22
CD (p= 0.05)	NS	NS	NS	NS	NS	NS	0.86	0.92	0.62
Interaction (FeU× Zn)									
SEm±	0.06	0.06	0.02	0.24	0.27	0.09	0.37	0.39	0.13
CD (p= 0.05)	NS	NS	NS	NS	NS	NS	1.05	1.12	0.38

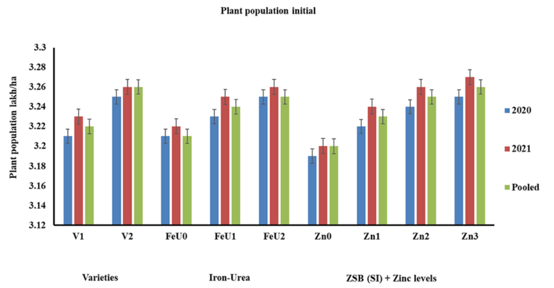

Fig. 1. Effect of agronomic biofortification of zinc and iron on plant population initial (lakh/ha) of mungbean varieties.

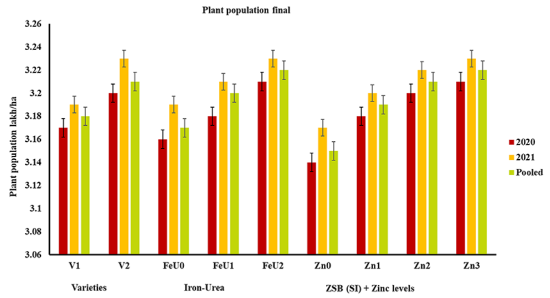

Fig. 2. Effect of agronomic biofortification of zinc and iron on plant population final (lakh/ha) of mungbean varieties.

'GM-7' (V_1) significantly improved plant height at 25, 50 DAS and at harvest to the tune of 5.60, 4.86 and 4.52%, respectively over variety 'MH-421' (V_2). In contrast to variety 'GM 7' (V_1), variety 'MH-421' (V_2) had performed prominently with respect to significantly increases in dry matter accumulation by magnificent level of (5.78, 11.76 and 12.04) per cent at 25, 50 DAS and at harvest over variety 'GM-7' (V_1), respectively. The significant variations in plant height and dry matter accumulation among the varieties may be due to their genetic variability for this trait. The similar results have also been reported by Choudhary *et al.* (2018), Rahim *et al.* (2010) and Goswami *et al.* (2010).

Table 3. Effect of agronomic biofortification of zinc and iron on yield parameters of mungbean varieties.

Treatments	Seed yield (kg/ha)			B: C ratio		
	2020	2021	Pooled	2020	2021	Pooled
Varieties (V)						
V_1: GM-7	894	952	923	3.06	3.16	3.11
V_2: MH-421	1078	1142	1110	3.68	3.79	3.73
SEm±	11.80	12.77	8.69	-	-	-
CD (p= 0.05)	37.18	40.25	25.65	-	-	-
Iron and Urea spray (Fe +U)						
F_0: Control	806	852	829	2.86	2.93	2.89
F_1: 0.5% Fe + 2% Urea at FI	1035	1099	1067	3.54	3.65	3.59
F_2: 0.5% Fe + 2% Urea at FI and PF	1117	1192	1154	3.71	3.84	3.77
SEm±	14.45	15.64	10.65	-	-	-
CD (p= 0.05)	45.53	49.29	31.41	-	-	-
Zinc levels (Zn)						
Z_0: Control	785	841	813	2.82	2.93	2.87
Z_1: ZSB (SI) + 15 kg $ZnSO_4$/ha	957	1008	983	3.25	3.33	3.29
Z_2: ZSB (SI) + 20 kg $ZnSO_4$/ha	1092	1159	1126	3.68	3.80	3.74
Z_3: ZSB (SI) + 25 kg $ZnSO_4$/ha	1109	1181	1145	3.72	3.85	3.78
SEm±	11.25	12.68	8.48	-	-	-
CD (p= 0.05)	32.28	36.37	23.90	-	-	-
Interaction (V × Fe)						
SEm±	20.43	22.12	15.06	-	-	-
CD (p= 0.05)	64.39	69.71	44.42	-	-	-
Interaction (V × Zn)						
SEm±	15.92	17.93	11.99	-	-	-
CD (p= 0.05)	45.65	51.43	33.80	-	-	-
Interaction (Fe × Zn)						
SEm±	19.49	21.96	7.34	-	-	-
CD (p= 0.05)	55.91	62.99	20.70	-	-	-

Yield

The results indicated that seed yield significantly influenced by mungbean varieties (Table 3) during both the years as well as pooled data. On pooled basis, variety 'MH-421' (V_2) magnitude of improvement pertained to seed yield was 20.26% over 'GM-7' (V_1) variety. Attainments of particularly higher or lower yield attributing character among the different varieties are the genetically controlled phenomenon. Such variations in yield attributes among the mungbean varieties have also been observed by several research workers (Goswami *et al*. 2010, Verma *et al.* 2011, Choudhary *et al*. 2018 and Singh *et al.* 2023).

B:C ratio

Perusal of data exhibited (Table 3) that marked improvement in B: C ratio was obtained due to different varieties. On basis variety 'MH-421' (V_2) had achieved higher profitability level in respect of B: C ratio (3.73) and showed its economic feasibility over variety 'GM-7' (V_1) (3.11) during investigation. Moreover, variety 'MH-421' (V_2) recorded 19.33% higher economic profitability in terms of B: C ratio over 'GM-7' (V_1) during investigation. The higher grain yield was responsible for the corresponding higher B:C ratio of these treatments as compared to control. Similar findings of higher net returns were also reported by Praveena *et al.* (2018) and Haider *et al.* (2020).

Effect of iron and urea spray

Growth attributes

A perusal of data (Tables 1-2) reveals that foliar spray of iron and urea significantly influenced plant height and dry matter accumulation at 50 DAS and at harvest stage of mungbean, while there was no significant variation found at 25 DAS as well as initial and final plant population of mungbean (Figs. 1-2) during both the years of experimentation as well as pooled mean basis. On pooled basis, significantly increased plant height by 5.66, 5.79 and 7.31, 8.68 and dry matter accumulation 24.42 and 14.75 and 25.67 and 16.48% due to foliar spray of 0.5 % Fe + 2 % urea at flower initiation stage (FeU_1) and 0.5 % Fe + 2% urea at flower initiation and pod formation stages (FeU_2) at 50 DAS and at harvest stage of mungbean over control (FeU_0), respectively. The higher growth in term of height and dry matter accumulation with the application of iron might be attributed to the favorable influence of iron on metabolism and biological activity and stimulatory effect on photosynthetic pigments and enzymatic activity which in turn increase vegetative growth of plants. The results of present investigation are in conformity with those of Mondal *et al.* (2011), Meena and Meena (2013), Solanki *et al.* (2017). Higher nitrogen levels might have resulted in increased cell division, cell elongation and meristematic activities that finally expressed morphologically on the increased height of the plant,resulting in higher dry matter accumulation of plant. The increase in plant height due to foliar spray of urea was also reported by Venkatesh and Basu (2011) and Pal *et al.* (2019).

Yield

Foliar spray of iron and urea had marked effect on seed yield of mungbean during both the years of investigation as well as in pooled analysis (Table 3). It was noticed foliar sprayed with 0.5% Fe+ 2% urea at flower initiation and pod formation stage (FeU_2) and 0.5% Fe + 2% urea at flower initiation stages (FeU_1) magnificent increments in seed yield by 28.70 and 39.20 % over control (FeU_0), respectively. However, both the treatments (FeU_2 and FeU_1) showed significant relationship with each others during both the years of experimentation. Foliar spray of 0.5% $FeSO_4$ increase in grain and straw yield may be attributed to the fact that favorable nutritional environment in rhizosphere and absorption of iron by plant leaves led to increased photosynthetic efficiency and production of assimilates as stated above, might have also favored efficient partitioning of photosynthates in different vegetative and reproductive structures particularly the seed which is ultimate sink (Guruprasad *et al.* 2009, Mondal *et al.* 2011). Urea application as foliar applied at later stages of crop growth might have helped in increasing the efficiency of older nodules (Da Silva *et al.*1993), thus improving the symbiotic efficiency of plant and ultimately increasing the grain yield. Better photosynthetic efficiency with urea application might have helped in easy translocation of carbohydrates to grain, which could also have ultimately resulted in higher grain yield. The similar results have also been reported by Pal *et al.* (2019) and Meena *et al.* (2020).

B:C ratio

Results presented in Table 3 revealed that foliar sprayed with 0.5% Fe+ 2% urea at flower initiation and pod formation stage (FeU_2) of fetched higher profitability level in respect of B: C ratio (3.77) and showed its economic feasibility over rest of the treatments during both the year of experimentation as well as on pooled basis. Moreover, foliar sprayed with fetched B: C ratio to the tune of 5.01 and 30.44% over 0.5% Fe + 2% urea at flower initiation stages (FeU_1) and control (FeU_0) during experimentation. The higher grain yield was responsible for the corresponding higher B C ratio of these treatments as compared to control. Similar findings of higher net returns were also reported by Dhaliwal *et al* (2021) and Pal *et al.* (2019).

Effect of ZSB and zinc levels

Growth attributes

Data revealed that all the growth attributes viz. plant height and dry matter accumulation were significantly affected by seed inoculation with zinc solubilizing bacteria and along with zinc application at all the growth stages of mungbean (Tables 1-2), while there was no significant variation found on initial and final plant population of mungbean (Figs. 1-2). On pooled basis data, seed inoculation of mungbean with ZSB + 20 kg $ZnSO_4$/ha (Zn_2) and ZSB (SI) + 25 kg $ZnSO_4$/ha (Zn_3) significantly improved plant height to the tune of 32.38, 28.27, 31.47 and 34.28, 27.87, 33.92 and dry matter accumulation 18.28, 42.91, 28.79 and 20.14, 45.88, 30.55% at 25, 50 DAS and at harvest stages over control (Zn_0), respectively. However, both (Zn_2 and Zn_3) these treatments were remained statistically at par to each other. Vigorous growth of plants is attributed due to cellular growth, differentiation and metabolism in which zinc plays a pivotal role leading to increased growth parameters. Similar results of significant effect of soil application of zinc sulphate on plant growth parameters were also reported by Kharol *et al*. (2014) and Solanki *et al.* (2017). In the present study, application of zinc and co-inoculation with Zn solubilizing *Bacillus* strains promoted mungbean growth and yield, however, co-inoculation treatments showed better increase in mungbean growth and yield that might be due to better competency of the strains in plant growth-promoting attributes e.g., solubilization of Zn and P minerals, production of phytohormones, siderophore, urease, catalase activity, and ammonia and exopolysaccharides production ability (Mumtaz *et al.* 2017, Dinesha *et al.* 2018). Moreover, several studies related to Zn solubilizing bacterial strains were reported to promote plant growth parameters (Shakeel *et al.* 2015, Khande *et al.* 2017, Mumtaz *et al.* 2020).

Yield

The results indicated that seed yield of mungbean was significantly affected by seed inoculation with zinc solubilization bacteria and zinc application during 2020 and 2021 of field trial as well as on pooled analysis basis (Table 3). On pooled basis, the magnitudes of increment subjected to grain yield under seed inoculation with ZSB + 25 kg $ZnSO_4$/ha (Zn_3) and ZSB (SI) + application of 20 kg $ZnSO_4$/ha (Zn_2) by 16.48, 40.84 and 14.55, 38.50% over ZSB (SI) + 15 kg $ZnSO_4$/ha (Zn_1) and control (Zn_0), respectively. Positive effect of zinc solubilizing bacteria and zinc application on grain yield may be due to higher carbonic anhydrase activity, which is localized in cytoplasm and chloroplast facilitating the transfer of CO_2 or HCO_3- during CO_2 assimilation phase of photosynthesis through increasing the rate of equilibrium between CO_2 and HCO_3- in solution. On the other hand, SOD helps to scavenge free radicles and protects the photosynthetic apparatus from oxidative damage (Potarzycki and Grzebisz 2009). Enhancement in major yield attributes, resulted in higher grain yield. This result is also in line with findings of Phattarakul *et al.* (2012), Rehman *et al.* (2012), Meena *et al.* (2021), Ash *et al.* (2020), Gahlot *et al.* (2020) and Singh *et al.* (2023).

B:C ratio

Results presented in Table 3 revealed that on pooled basis seed inoculation with ZSB + 25 kg $ZnSO_4$/ha (Zn_3) fetched higher profitability level in respect of B: C ratio (3.78) and showed its economic feasibility

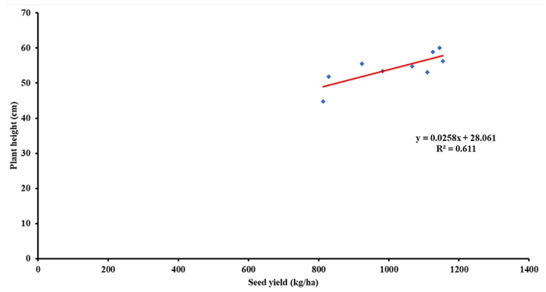

Fig. 3. Regression between plant height (cm) and seed yield (kg/ha) of mungbean.

over rest of the treatments during the year of investigation. Moreover, seed inoculation with ZSB + 25 kg $ZnSO_4$/ha (Zn_3) fetched B: C ratio to the tune of 1.06, 14.89 and 35.97% over ZSB (SI) + application of 20 kg $ZnSO_4$/ha (Zn_2),ZSB (SI) + 15 kg $ZnSO_4$/ha (Zn_1) and control (Zn_0), respectively on pooled basis.The higher grain yield was responsible for the corresponding higher B:C ratio of these treatments as compared to control. Similar findings of higher net returns were also reported by Khan and Prakash (2014), Soni and Kushwaha, (2020) and Gahlot *et al.* (2020) in mungbean due to soil application of zinc along with RDF.

Regression

The mungbean seed yield positively correlated with plant height (cm) and dry matter accumulation (g/plant) with correlation coefficient of 0.611 and 0.9417. This was further supported by the regression analysis. Thus, unit increased in plant height (cm) and dry matter accumulation (g/plant) caused increase in seed yield by 28.061 kg/ha and 7.3656 kg/ha (Figs. 3-4).

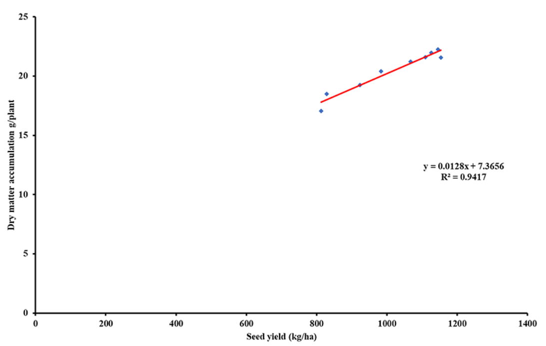

Fig. 4. Regression between dry matter accumulation (g/plant) and seed yield (kg/ha) of mungbean. .

CONCLUSION

Based on pooled analysis of two years experimental results, it may concluded that growing of mungbean variety 'MH-421' significantly higher growth attributes and seed yield resulted in prominent improvement in B:C ratio as compare to variety 'GM-7'. While, significantly taller height was recorded under variety 'GM 7' as compared with 'MH-421'. Among agronomic biofortification treatments, two times foliar spray of 0.5% Fe + 2% urea at flower initiation and pod formation stages and seed inoculation with ZSB and soil application of higher dose of zinc sulphate i.e. ZSB (SI) + 25 kg $ZnSO_4$/ha in mungbean gave significantly higher growth attributes and seed yield resulted in improved economic viability and feasibility as B:C ratio.

REFERENCES

Alexander M (1997) Introduction to Soil Microbiology. New York, NY: JohnWiley and Sons.

Alloway BJ (2008) Zinc in soils and crop nutrition 2nd edn. IZA Publications, International Zinc Association Brussels, Belgium and International Fertilizer Association Paris, France, pp 139.

Alloway BJ (2009) Soil factors associate with zinc deficiency in crops and humans. *Environm Geochem Hlth* 31(5): 537-548.

Anonymous (2022) Agricultural Statistics at a Glance 2018. Department of Agriculture, Cooperation and Farmers Welfare, Directorate of Economics and Statistics, pp 125-126.

Arnon DI, Stout PP (1939) The essentiality of certain elements in minute quantity for plants with special reference to copper. *Pl Physiol* 14: 1460–1470.

Ash M, Yadav J, Yadav JS (2020) Yield attributes of rice (*Oryza sativa*) as affected by integrated use of zinc oxide and zinc solubilizers. *Ind J Agricult Sci* 90 (11): 2180-2184.

Barak P, Helmke PA (1993) The chemistry of zinc. Proceedings of International Symposium on Zinc in Soil and Plants, pp 1-13.

Cakmak I (2008) Enrichment of cereal grains with zinc: Agronomic or genetic biofortification. *Pl Soil* 302: 1-17.

Cakmak I, Torun A, Ozkan H, Millet E, Feldman M, Fahima T, Korol AB, Nevo E, Braun H (2004) *Triticum dicoccoides:* An important genetic resource for increasing zinc and iron concentration in modern cultivation wheat. *J Soil Sci Pl*

Nutrition 50: 1047-1054.

Choudhary H, Yadav LR, Yadav MR, Kantwa R, Kumawat R (2018) Growth and productivity of mungbean verities under foliar application of iron in semi-arid eastern plain zone of Rajasthan. *Int J Chem Studies* 6(5): 2269-2274.

Da Silva PM, Tsai SM, Bonetti R (1993) Response to inoculation and N fertilization for increased yield and biological nitrogen fixation of common bean (*Phaseolus vulgaris* L.). *Pl Soil* 152:123–130. doi:10.1007/ BF00016341.

Dhaliwal SS, Sharma V, Shukla AK, Verma V, Behera SK, Singh P, Alotaibi SS, Gaber A, Hossain A (2021) Comparative efficiency of mineral, chelated and nano forms of zinc and iron for improvement of zinc and iron in chickpea (*Cicer arietinum* L.) through biofortification. *Agronomy* 11(12): 2436.

Dinesha R, V Srinivasana S, Hamza C, Sarathambal SJ, Anke gowda AN, Ganeshamurthy SB, Gupta VA, Nair KP, Subila A, Lijina VC, Divya (2018) Isolation and characterization of potential Zn solubilizing bacteria from soil and its effects on soil Zn release rates, soil available Zn and plant Zn content. *Geoderma* 321:173–186.

Fisher RA (1925) Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd.

Gahlot N, Ram M, Parewa HP, Meena R, Sarita (2020) Enhancing mungbean productivity and profitability through zinc and iron application in western Rajasthan. *Int J Bio-resource Stress Manag* 11(2): 178-182.

Glick BK (2012) Plant growth-promoting bacteria: Mechanisms and applications. *Hindawri Publishing Corporation Scientific*a 5: 15.

Goswami KR, Choudhary H, Sharma MK, Sharma D, Bhuyan J (2010) Evaluation of greengram genotypes for morphological, physiological traits and seed yield. *Annals Pl Physiol* 24(2): 115-120.

Graham RD (2008) Micronutrient deficiencies in crops and their global significance. Micronutrient Deficiencies in Global Crop Production, pp 41-61.

Guruprasad BP, Kurigod V, Hundekar ST (2009) Influence of methods of iron sulphate application on yield and nutrient uptake by groundnut (*Arachis hypogaea* L.) genotypes on calcareous soils. *Karnataka J Agricult Sci* 22(5): 1104-1106.

Haider MU, Hussain M, Farooq M, Nawaz A (2020) Optimizing zinc seed priming for improving the growth, yield and grain biofortification of mungbean (*Vigna radiata* (L.) Wilczek). *J Pl Nutrition* 43(10):1438-1446.

Khan K, Prakash V (2014) Effect of rhizobial inoculation on growth, yield, nutrient and economics of summer urdbean (*Vigna mungo* L.) in relation to zinc and molybdenum. *Int J Adv Res Chem Engg* 1(1): 1-10.

Khande R, Sharma SK, Ramesh A, Sharma MP (2017) Zinc solubilizing *Bacillus* strains that modulate growth, yield and zinc biofortification of soybean and wheat. *Rhizosphere* 4:126–138.

Kharol S, Sharma M, Purohit HS, Jain HK, Lal M, Sumeriya HK (2014) Effect of sulfur and zinc nutrition on yield, quality and nutrient content and uptake by chickpea. *Environ Ecol* 32(4): 1470-1474.

Marquez-Quiroz C, De-la-Cruz-Lázaro E, Osorio-Osorio R, Sánchez-Chávez E (2015) Biofortification of cowpea beans with iron: Influence on mineral content and yield. *J Soil Sci Pl Nutrition* 15(4): 839-847.

Meena KK, Meena RS (2013) Effect of sulfur and iron fertilization on growth parameters, yield attributes, yields and nutrient uptake of mungbean (*Vigna radiata* L.) in arid western Rajasthan. *Environ Ecol* 31(1A): 227-231.

Meena SN, Jadon C, Meena LK, Meena BS, Yadav RK, Singh P (2021) Impact of gibberellic acid on growth, yield and economics of pigeonpea (*Cajanus cajan* (L.). *Ind J Agric Allied Sci* 7(2): 65-69.

Meena SN, Patidar BK, Jadon C, Meena HP, Meena BS, Yadav RK, Yadav SL, Meena NL, Singh P, Jat ML (2020) Response of pigeonpea (*Cajanus cajan* (L.) to foliar application of nutrient and pest management at flowering stage. *Int J Bio-res Stress Manag* 11(5) : 432-436. DOI: HTTPS://DOI.ORG/10.23910/1.2020.2126b

Meena SN, Singh P, Meena LK, Yadav SL, Dhakad U, Regar SN, Meena BS (2023) Effect of plant growth regulators in conjunction with insecticides on the productivity of pigeonpea (*Cajanus cajan* (L.) Millsp.). *Environ Ecol* 41(1B): 480-485.

Mondal MMA, Rahman MA, Akhter MB, Fakivz MSA (2011) Effect of foliar application of nitrogen and micronutrient on growth and yield in mungbean. *Leg Res* 34 (3):166-171.

Mumtaz MZ, Ahmad M, Jamil M, Hussain T (2017) Zinc solubilizing *Bacillus* spp. potential candidates for biofortification in maize. *Microbiol Res* 202: 51–60.

Mumtaz M Z, Malik A, Nazli F, Latif M, Zaheer A, Ali O, Jamil M, Ahmad M (2020) Potential of zinc solubilizing *Bacillus* strains to improve growth, yield, and quality of maize (*Zea mays*). *Int J Agricult Biol* 24(4): 691–698.

Pal V, Singh G, Dhaliwal SS (2019) Agronomic biofortification of chickpea with zinc and iron through application of zinc and urea. *J Commun Soil Sci Pl Anal* 50(15): 1864-1877.

Pathak GC, Gupta B, Pandey N (2012) Improving reproductive efficiency of chickpea by foliar application of zinc. *Brazilian J Pl Physiol* 24(3): 173-180.

Petroff R (2003) Pesticide adjuvents and surfactants. Montana State University Extension, Bozeman, MT,USA.

Phattarakul N, Rerkasem B, Li LJ, Wu LH, Zou CQ, Ram H, Yazici A (2012) Biofortification of rice grain with zinc through zinc fertilization in different countries. *Pl Soil* 361(1-2): 131-141.

Potarzycki J, Grzebisz W (2009) Effect of zinc foliar application on grain yield of maize and its yielding component. *Pl Soil Environ* 55(12): 519-527.

Praveena R, Ghosh G, Singh V (2018) Effect of foliar spray of boron and different zinc levels on growth and yield of *kharif* greengram (*Vigna radiata*). *Int J Curr Microbiol Appl Sci* 7(8): 1422-1428.

Rahim M, Mia A, Mahmud F, Zeba N, Afrin KS (2010) Genetic variability, character association and genetic divergence in mungbean (*Vigna radiata* L. Wilczek). *Pl Omics* 3(1): 1-6. (https://doi.org/10. 18805/ijare.a-4929).

Rehman HU, Aziz T, Farooq M (2012) Zinc nutrition in rice production systems: A review. *Pl Soil* 361(1-2): 203–226. doi: 10.1007/s11104-012-1346-9.

Samant TK, Mohanty TR (2017) Effect of sowing date and weed management on productivity and economics of rainfed mungbean (*Vigna radiata*). *Ind J Agron* 62(3): 332-337.

Saravanan VS, Kumar MR, Sa T (2011) Microbial zinc solubilization and their role on plants. Bacteria in agrobiology: Plant nutrient management edition 1 : 47-63.

Shakeel M, Rais A, Hassan MN, Hafeez FY (2015) Root associated *Bacillus* spp. improves growth, yield and zinc translocation for basmati rice (*Oryza sativa*) varieties. *Front Microbiol* l6:1–12.

Sheftela AD, Mason AB, Ponka P (2011) The long history of iron in the universe and in health and disease. *Biochimica et Biophysica Acta-General Subjects* 3: 161-187.

Singh MV, Behera SK (2011) AIRCP on micro and secondary nutrients and pollutant elements in soil and plants- A profile. *Res Bull* 10: 1-57.

Singh U, Dey P, Singh LN, Ram M, Choudhary R (2023) Improved varietal selection and optimum soil application of Zn enhance mungbean (*Vigna radiata* L. Wilczek) productivity and profitability. Annals of Agricult Res New Series 44(1): 83-87.

Solanki DR, Swata, Solanki MS (2017) Growth, yield and yield attributes of summer green gram (*Vigna radiata* L.Wilczeck) under medium black 69 calcareus soils as influenced by application of sulfur and zinc levels. *Int J Agric Sci Res* 7(4): 663-668.

Solanki RB, Yadav LR, Gupta A, Yadav SS (2017) Correlation studies in clusterbean as influence by varieties and foliar application. *J Pharmacog Phytochem* 6 (5): 289-291.

Soni J, Kushwaha HS (2020) Effect of foliar spray of zinc and iron on productivity of mungbean (*Vigna radiata* (L.) Wilczek. *J Pharmacog Phytochem* 9 (1): 108-111.

Underwood EJ, Suttle NF (1999) The mineral nutrition of Live stock 3rd edn. CABI International Publishing, Wallingford Oxon, pp 614.

Venkatesh MS, Basu PS (2011) Effect of foliar application of urea on growth, yield and quality of chickpea under rainfed conditions. *J Food Leg* 24(2): 110-112.

Verma CK, Yadav D, Singh V (2011) Effect of yield and quality of green gram varieties by foliar spray of urea and seed rate. *Pl Arch* 11(1): 289-291.