



Improving Productivity and Profitability of Mungbean [*Vigna radiata* (L). Wilczek] Through Agronomic Fortification of Iron and Zinc under Arid Conditions of Western Rajasthan

Preeti Devatwal¹, M.L. Mehriya¹, Roshan Choudhary², M.L. Reager³, B.L. Dudwal⁴, P.R. Raiger⁵, S.K. Yadav⁶, Pinky Yadav⁷, Vimal Pratap Singh⁸, Arun Pratap Singh⁹, Vijendra Kumar Meena¹⁰

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ABSTRACT

Background: Mungbean [*Vigna radiata* (L.) Wilczek] is considered as an extremely nutritious crop possessing a high level of micronutrients. However, the low bioavailability of these micronutrient leads to their deficiency in human. Agronomic fortification is a short-term strategy for increasing micronutrient concentrations, but it is easier and more feasible to achieve as compared to breeding.

Methods: The field experiment was laid out in Split-Split Plot Design (SSPD) with twenty-four treatment combinations and replicated thrice. The main plot treatment was comprised with two varieties namely GM-7 and GM-4 varieties, in sub plots three iron fortification levels and in sub-sub plot treatments assigned with different doses of zinc sulphate and seed inoculation (SI) with zinc solubilizing bacteria (ZSB).

Result: Results revealed that mungbean variety GM 4 significantly outperformed GM 7 in terms of mean seed yield (1076 kg/ha). This higher yield resulted in a maximum net return of ₹66,974/ha and a notable improvement in the benefit-cost (B:C). Agronomic bio-fortification with zinc and iron levels of 20 kg FeSO₄/ha (0.5%) and seed inoculation with ZSB+20 kg ZnSO₄/ha + 0.5% foliar sprays at flower initiation and pod formation stage scientifically improves mungbean productivity and seed yield (1025 kg/ha and 1052 kg/ha, respectively) and also provided higher net returns of ₹62,051/ha and ₹64,202/ha, with improved economic feasibility, yielding B:C ratios of 3.20 and 3.26 on a pooled basis.

Key words: Bio-fortification, Productivity, Variety, Zinc, ZSB.

INTRODUCTION

Legumes play a vital role in global nutrition, serving as a major source of plant-based protein, especially in vegetarian and low-income diets are considered an essential source of protein which is consumed globally. India produces 50 per cent of the world's mungbean production, followed by China and Myanmar. It is grown on an area of 5.31 million ha, with a productivity of 668 kg/ha and production of 3.74 million tonnes. It is primarily grown in the states of Rajasthan, Karnataka, Maharashtra, Bihar, Andhra Pradesh, Madhya Pradesh, Tamil Nadu and Telangana. In Rajasthan, it is mainly grown in dry and semi-arid regions of Nagaur, Jodhpur, Pali, Sikar, Jhunjhunu, Ajmer and Jaipur districts and has occupied 2.33 million hectares area with the production of 1.17 million tonnes having productivity of 505 kg/ha (DES, 2022-23). The available zinc content of the soils appears to be low in Alwar, Jhalawar and Bhilwara. The soils of Alwar and Jhalawar have 0.50 ppm of available zinc while in Bhilwara soils, it was found in traces indicating that the soils of these places may show zinc deficiency (Nagar *et al.*, 2018). At present about 48.1 per cent of Indian soils are deficient in zinc and 11.2 per cent in iron. It is mainly cultivated during the *Kharif* season (July to October), but it is short growth duration also makes it suitable for cultivation in the summer season (March to June) under irrigated conditions (Choudhary *et al.*, 2020). It thrives best under moist climatic conditions; however, it can also be successfully sown in region with limited water availability due to its moderate drought tolerance and low water availability (Malik *et al.*, 2021).

¹Department of Agronomy, Agriculture University, Jodhpur-342 304, Rajasthan, India.

²Department of Agronomy, Sri Karan Narendra Agriculture University, Jobner-303 329, Rajasthan, India.

³Department of Agronomy, Swami Keshwanand Rajasthan Agricultural University, Bikaner-334 006, Rajasthan, India.

⁴Department of Agronomy, Sri Karan Narendra College of Agriculture, Sri Karan Narendra Agriculture University, Jobner-303 329, Rajasthan, India.

⁵Department of Soil Science, Agriculture University, Jodhpur-342 304, Rajasthan, India.

⁶Department of Agriculture Research Station, Agriculture University, Kota-324 001, Rajasthan, India.

⁷Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur-313-001, Rajasthan, India.

⁸Department of Agronomy, Raja Mahendra Pratap Singh University, Aligarh-202 140, Uttar Pradesh, India.

⁹ICAR-Indian Institute of Vegetable Research, Krishi Vigyan Kendra, Kushinagar-274406, Uttar Pradesh, India.

¹⁰ICAR- National Dairy Research Institute, Karnal-132 001, Haryana, India.

Corresponding Author: Roshan Choudhary, Department of Agronomy, Sri Karan Narendra Agriculture University, Jobner-303 329, Rajasthan, India. Email: roshan.agro@sknau.ac.in

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Besides this, mungbean plays a vital role in biological nitrogen fixation, which enhances soil health by improving its chemical, physical and biological properties and by increasing soil nitrogen content. However, while mungbean contributes to soil fertility, the productivity and nutritional quality of crops are still often limited by micronutrient deficiencies particularly zinc (Zn) and iron (Fe). These deficiencies have led to adverse effects such as reduced crop yield and lower micronutrient concentrations, ultimately contributing to malnutrition in both humans and animals (Yadahalli *et al.*, 2022). Zinc deficiencies in human leads to number of symptoms, including pneumonia, diarrhoea, stunted growth, weakened immune systems, dwarfism, delayed mental development, impaired cognitive function, behavioural issues, memory impairment, difficulties with spatial learning and neuronal atrophy (Prasad, 1988). The recommended daily allowance (RDA) of zinc for adult women 8mg/day and adult male 11 mg/day (National Institutes of Health). Zinc is a trace element which is considered crucial as it possesses antioxidant properties and is required for proper growth, immune system development, enzyme activation and neurobehavioral development (Rathika and Ramesh, 2023). Its lack in the diet may result in serious health-related issues, such as stunted growth in children, increased illness susceptibility, poor birth outcomes and harm to the brain and immune system. The critical limit of zinc in soil and plant remains as <0.6 mg/kg and 20-100 ppm, respectively. In addition to this, Fe plays an outstanding role in plant respiration, photosynthesis, sulphur absorption and nitrogen-fixing (Dhaliwal, 2022). It acts as an important protein constituent which helps in transporting oxygen and regulating cell growth along with differentiation. The critical limit of iron in soil and plant is <4.6 mg/kg and 50-150 ppm, respectively. Fe deficit diet leads to limited oxygen delivery to cells resulting in fatigue, lowered immunity and an increased risk of blood anaemia. Further, deficiency of Fe may lead to chlorosis in crops along with the deterioration of produce (Kumar and Dahaliwal, 2021). The recommended daily allowance (RDA) of iron for adult women with low and high iron bioavailability diets is around 60 and 20 mg/day, respectively (Majeed *et al.*, 2020). Agronomic fortification is a short-term strategy for increasing micronutrient concentrations, but it is easier and more feasible to achieve as compared to breeding. It could provide a quick fix for mineral deficits while also serving as a supplement to ongoing breeding programs (Haider *et al.*, 2018). The agronomic fortification of zinc and iron significantly enhanced seed yield in legumes (Farooq *et al.*, 2025). Among different types of fortification techniques, foliar application is considered as the best way of increasing the micronutrient level in crops, as nutrients are directed towards the leaves at suitable growth stages. The quick absorption encourages nutrient translocations in edible grain sections and prevents nutrient loss in the environment (Usman *et al.*, 2014). Furthermore, it encourages plant

development even under less favourable weather circumstances. Several researchers have been probing the effect of enhancing bioavailable Zinc and Fe in various legume crops through foliar application. Biofortification of Zinc has been found to escalate the grain yield along with the concentration of Zinc in mungbean. Another study demonstrated the priming of Zn seed to enhance the growth and yield in mungbean through agronomic biofortification (Ramesh *et al.*, 2014). Additionally, biofortification of mungbean by using FeSO_4 resulted in increased growth as well as yield significantly. Keeping this in view, the present work aimed to assess the effect of bio-fortification of iron and zinc on productivity and profitability on mungbean [*Vigna radiata* (L). Wilczek] in western Rajasthan.

MATERIALS AND METHODS

A field experiment was carried out at Instructional Farm, College of Agriculture, Mandor, Jodhpur (Rajasthan) in the *Kharif* season 2022 and 2023. Geographically, it is located between 26°15'N to 26°45' North latitude and 73°00'E to 73°29' East longitude at an altitude of 231 meter above mean sea level. This region falls under agro-climatic zone IA (Arid Western Plain Zone) of Rajasthan. The average annual rainfall is about 367 mm (CV 52%) and bulk of it (85 to 90%) is received from June to September (*Kharif* season) by the south-west monsoon. To illustrate climate variable and their relation in this context, the periodical mean weekly weather parameters the maximum and minimum temperatures during crop growing season ranged between 29.2 to 38.2°C and 20.5 to 26.4°C during *Kharif* season of 2022 and range between 33.0 to 38.0°C and 21.9 to 27.6°C during *Kharif* season 2023. The maximum and minimum relative humidity ranged between 64.2 to 87.3 and 49.5 to 71.1 per cent during 2022, respectively and the corresponding values in the year of 2023 were between 88.3 to 65.0 and 35.9 to 69.1 per cent. The total rainfall received during experimental period of 2022 was higher (580.5 mm) than that received during 2023 (185.7 mm).

The field experiment was laid out in Split-Split Plot Design (SSPD) with twenty-four treatment combinations and replicated thrice. The main plot treatments consisted of a combination of two factors *viz.* two varieties namely GM 7 and GM 4 and three levels of iron fortification levels namely control (Fe_0), soil application of 20 kg FeSO_4 + 0.5% Fe foliar spray at flower initiation and pod formation stages (Fe_1) and soil application of 25 kg FeSO_4 + 0.5% Fe at flower initiation and pod formation stages (Fe_2) in subplots. In sub-sub plots, seed inoculation with zinc solubilizing bacteria (ZSB) was combined with different doses of zinc sulphate with 0.5% Zn foliar spray at flower initiation and pod formation stages and there were four treatments *viz.* control (Zn_0), ZSB (SI) + 15 kg ZnSO_4 /ha + 0.5% Zn foliar spray at flower initiation and pod formation stages (Zn_1), ZSB (SI) + 15 kg ZnSO_4 /ha + 0.5 % Zn foliar spray at flower initiation and pod formation stages (Zn_2), ZSB (SI) + 25 kg ZnSO_4 /ha + 0.5 % Zn foliar spray at flower initiation and pod

formation stages (Zn_3) cropping have plot size 5x3m. After thorough field preparation initial soil samples were taken to analyze the initial soil properties. The initial soil sample was analyzed for available major nutrients; nitrogen (N), phosphorous (P), potassium (K), zinc (Zn) and iron (Fe), organic carbon (OC), pH and soluble salts. The experimental soil possessed a pH of 8.2 and 8.1, an EC of 0.12 and 0.11 dS/m and low in organic carbon of 0.13% and 0.14% in 2022 and 2023, respectively. The N status of the experimental field was low (175 and 178 kg ha⁻¹), medium in available P (15.4 and 16.5 kg ha⁻¹) and available K status was in higher range (287.4 and 289.6 kg ha⁻¹). Micronutrient levels in soil were initially 0.47 and 0.49 and 3.26 and 3.27, mg/kg in the case of Zn and Fe, respectively during both the years (Table 1). A basal dose of 15 kg N/ha and 40 kg P₂O₅/ha was applied through diammonium phosphate (87 kg/ha DAP). The fertilizers were applied as basal application at the time of sowing in individual plots at the depth of 7 to 8 cm. According to the treatments, foliar spray of iron sulphate (FeSO₄.H₂O) and Zinc (ZnSO₄.7H₂O) was applied at flower initiation and pod formation stages and also applied in soil at the time of sowing as per treatment. Plant samples were collected for chemical analysis of nitrogen, phosphorus, potassium, iron and zinc and in seed and straw samples. The total microbial (bacteria) population was counted at harvest stage only during both the years of investigation. The standard protocols for samples preparations and their laboratory analysis were adopted as per details. Soil sample were taken from each plot randomly by soil sampling auger from 4 to 5 places at harvest stage of crop and same protocols was used for sampling from each plot. Different semi-solid

media were used for different microorganism. These are Thronton s agar media used for estimation of bacteria. The number of Colony Forming Unit (CFU) in the selective media was determined by means of the serial dilution technique developed by Salle (1973). Analysis was performed in three replications. In ground seed and straw samples, N was estimated by micro Kjeldahal method (Piper 1966). Phosphorus content in plant (seed and stover) after harvest was determined by "Vanado molybdophosphate" yellow colour method. Digestion of samples was done by di-acid mixture (HNO₃:HClO₄) by (Jackson, 1973). For analysis of potassium in plant extracts after harvest of crop, a tri acid mixture (400 ml of concentrated HNO₃ + 40 ml of concentrated H₂SO₄ + 120 ml of 70% concentrated HClO₄) was used to digest the samples. Zinc and iron in plant extract determined by wet digestion of plant samples with di-acid (HNO₃ + HClO₄) in the ratio of 3:1. The aliquot of digested material was analysed with the help of AAS (Lindsay and Norvell, 1978). For available N in soil is determined by Alkaline KMnO₄ method (Subbiah and Asija 1956), for estimation of P soil samples were extracted with 0.5 M NaHCO₃ (pH = 8.5) (Olsen *et al.* 1954) and P content in the extracts was determined as described by Jackson (1973). Available zinc and iron was determined in soil by DTPA extract method using Atomic Absorption Spectrophotometer (AAS).

The observations on no. of pods/plant, no. of seeds/pod, 1000 seed weight (g) were recorded manually on five randomly selected representative plants from each plot of each replication separately as well as yield were recorded as per the standard method. Yield attributes were also recorded at physiological maturity stage. The seed and

Table 1: Physico-chemical characteristics of soil of the experimental field.

Particulars	Values	
Mechanical properties		
Coarse sand (%)	7.8	
Fine sand (%)	68.4	
Silt (%)	10.7	
Clay (%)	13.0	
Textural class	Sandy-loam	
Physical properties		
Parameters	2022	2023
Bulk density (Mg/m³)	1.53	1.52
Field capacity (% moisture at 1/10 bars)	13.17	13.20
Permanent wilting point (PWP) % moisture at 15 bars)	3.19	3.21
Chemical properties		
Organic carbon (%)	0.13	0.14
Available N (kg/ha)	175.1	178.5
Available P ₂ O ₅ (kg/ha)	15.4	16.5
Available K ₂ O (kg/ha)	287.4	289.6
Available Zn (mg/kg)	0.47	0.49
Available Fe (mg/kg)	3.26	3.27
EC (dS/m) (1:2 soil water suspension at 25°C)	0.12	0.11
Soil pH (1:2 soil water suspension)	8.2	8.1

stover yield was recorded from net plot area of each treatment. The data obtained from various characters under study were analyzed by the method of analysis of variance as described by (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Yield and yield attributes

Effect of varieties

A result indicates that the variety GM 4 exhibited superior performance, with a significantly higher number of pods/plant (18.3), seeds/pod (10.01) and 1,000-seed weight (40.82 g) compared to GM 7 (Table 2). These variations in yield-contributing traits can be attributed to the varietal potential of GM 4, which demonstrated higher genetic adaptability under arid conditions. This adaptability, coupled with improved dry matter accumulation during successive growth stages, likely contributed to its enhanced yield attributes. Similar findings have been reported by Swathi *et al.* (2021), emphasized on varieties showed highly significant variations in the agronomic traits indicating the varieties responded differently into different environment. These genetically controlled phenomena explain the higher or lower yield attributes observed in different varieties. Similar variations among mungbean varieties have been documented by Rathika and Ramesh (2023), who emphasized the role of genetic variability.

The two-year mean analysis revealed that the mungbean variety GM 4 recorded significantly higher seed yield (1076 kg/ha), stover yield (2010 kg/ha), biological yield (3086 kg/ha) and harvest index (34.38%) compared to GM 7 (Table 3). The superior performance of GM 4 is attributed to its ability to form more yield attributes, resulting in higher stover and biomass yields. The ability of GM 4 to synthesize and convert photosynthates efficiently contributed to its higher dry matter production during the experimental years. GM 4 demonstrated efficient utilization of agronomic inputs and superior energy allocation from source to sink. The higher seed yield of GM 4 can be primarily ascribed to its greater number of pods/plant and superior test weight in the present study. Conversely, the lower seed yield of GM 7 may be due to inefficient assimilate partitioning between vegetative growth and seed formation stages, leading to reduced dry matter accumulation, stover and biomass yields. These findings align with the studies by Choudhary *et al.* (2020). Under the present study, correlation studies also showed (Table 4) the dependence of seed yield on yield attributes such as number of pods/plant (0.97), numbers of seeds/pod (0.96) and test weight (0.97).

Effect of iron fortification

Soil application of 20 kg/ha FeSO_4 superimposed with foliar sprays of FeSO_4 (0.5%) at flower initiation (FI) and pod formation stage (PF) significantly recorded higher yield attributing traits *viz.*, number of pods/plant (17.9), seeds/pod (9.79) and 1000-seed weight (40.23 g) demonstrating significant superiority over the other treatments in Table 2.

These results are consistent with the findings of Bahaduri *et al.* (2020) and Manjhi *et al.* (2020). They observed improvements in yield attributes of mungbean due to the soil application of FeSO_4 and its foliar spray (0.5%) can be attributed to enhanced mineral nutrition. Numerous studies have shown the positive effects of iron fortification on crops, with evidence suggesting that its application promotes growth and yield-forming traits like no of pods/plant, no. of seeds/pod and 1000 seed weight (Pal, 2018). The increase in yield parameters due to enhances photosynthesis and the production of metabolites, which may contribute to improved flowering, fruiting and seed formation iron Zafar *et al.* (2023). The effect of zinc and iron on yield attributes of pigeon pea was assessed and the results showed significant improvement in key yield parameters-number of pods per plant, number of seeds per pod and 100-seed weight-after the application of zinc and iron Farooq *et al.* (2025). Under the present study, correlation studies also showed (Table 4) the dependence of seed yield on yield attributes such as number of pods/plant (0.97), numbers of seeds/pod (0.96) and test weight (0.97). Pooled analysis of the data revealed that the soil application of 20 kg FeSO_4 /ha, combined with its two foliar applications (0.5%) at the flower initiation and pod formation stages significantly increased seed yield (1025 kg/ha), stover yield (1923 kg/ha), biological yield (2948 kg/ha) and harvest index (34.70) over control in mungbean in table 3. The results show that soil and foliar application of Fe significantly enhanced primary branches, plant height, pods/plant, pod length, seeds/pod, test weight, seed yield. However, iron content in seed was enhanced due to its foliage application. These results are consistent with the findings of Yadav *et al.* (2021) and Zafar *et al.* (2023). An increase in grain Fe iron concentration might also be attributed to the availability of Fe at the reproductive stage of mungbean due to foliar application (Sawires, 2001).

Effects of zinc solubilizing bacteria (ZSB) and zinc level

Data reveal that progressive increment in soil application of ZnSO_4 up to 20 kg/ha in combination with seed inoculation (SI) with ZSB and its foliar application (0.5 %) at flower initiation (FI) and pod formation (PF) stages tended to increases seed yield (1052 kg/ha) significantly over ZSB + soil application with 15 kg ZnSO_4 /ha and foliar application (0.5%) at FI and PF stages (966 kg/ha) and control (845 kg/ha) which was found at par with treatment integrated as seed inoculation with ZSB (SI) + 25 kg ZnSO_4 with foliar application 0.5% at FI and PF stages (Zn_3). Significant improvements in growth attributes due to ZSB inoculation and varying levels of zinc fertilization with foliar sprays at different stages these findings align closely with those of Salunke *et al.* (2022) and Prajapati *et al.* (2022). The improvement in yield attributes could be attributed due to the critical role of zinc in crop nutrition long with foliar sprays as it is involved in various enzymatic reactions, metabolic processes and oxidation-reduction reactions (Zafar *et al.*, 2023). Carbohydrate metabolism is positively

Table 2: Effect of zinc and iron levels on yield attributes through agronomic fortification in mungbean.

Treatments	Yield attributes						
	No. of pods/plant			No. of seeds/pod			
Variety	2022	2023	Pooled	2022	2023	Pooled	1000-seed weight
GM 7	17.1	16.6	16.8	9.45	9.30	9.38	38.72
GM 4	18.5	18.1	18.3	10.08	9.95	10.01	40.82
SEm $\pm$	0.23	0.21	0.15	0.07	0.06	0.05	0.22
CD (P=0.05)	1.37	1.27	0.60	0.41	0.38	0.18	0.86
Iron (FeSO₄) fortification							
Control	17.0	16.5	16.8	9.54	9.39	9.47	38.68
20 kg FeSO ₄ /ha (SA) + 0.5% FeSO ₄ (FA) at FI and PF	18.1	17.6	17.9	9.86	9.72	9.79	40.23
25 kg FeSO ₄ /ha (SA) + 0.5% FeSO ₄ (FA) at FI and PF	18.2	17.8	18.0	9.90	9.76	9.83	40.40
SEm $\pm$	0.19	0.20	0.14	0.06	0.06	0.04	0.20
CD (P=0.05)	0.63	0.65	0.42	0.19	0.19	0.12	0.59
Zinc (ZnSO₄) fortification							
Control	16.7	16.2	16.4	9.44	9.28	9.36	38.17
ZSB (SI) + 15 kg ZnSO ₄ /ha (SA) + 0.5% ZnSO ₄ (FA) at FI and PF	17.6	17.2	17.4	9.72	9.58	9.65	39.56
ZSB (SI) + 20 kg ZnSO ₄ /ha (SA) + 0.5% ZnSO ₄ (FA) at FI and PF	18.3	17.8	18.1	9.93	9.78	9.86	40.54
ZSB (SI) + 25 kg ZnSO ₄ /ha (SA) + 0.5% ZnSO ₄ (FA) at FI and PF	18.5	18.1	18.3	9.97	9.86	9.91	40.81
SEm $\pm$	0.19	0.20	0.14	0.06	0.06	0.04	0.20
CD (P=0.05)	0.55	0.58	0.39	0.16	0.17	0.12	0.56

Table 3: Effect of zinc and iron on productivity of mungbean through agronomic fortification on yield.

Treatments	Seed yield (kg/ha)				Stover yield (kg/ha)				Biomass yield (kg/ha)				HI (%)			
	2022	2023	Pooled		2022	2023	Pooled		2022	2023	Pooled		2022	2023	Pooled	
Variety																
GM 7	925	862	893		1753	1646	1700		2677	2508	2592		34.43	34.25	34.34	
GM 4	1103	1050	1076		2054	1965	2010		3157	3015	3086		34.89	34.78	34.83	
SEm $\pm$	28	26	19		47	44	32		75	70	51		0.07	0.06	0.05	
CD (P=0.05)	170	158	75		289	268	127		459	426	202		0.40	0.39	0.18	
Iron (FeSO₄) fortification																
Control	919	860	890		1743	1644	1693		2661	2504	2583		34.35	34.26	34.30	
20 kg FeSO ₄ /ha (SA) + 0.5% FeSO ₄ (FA) at FI and PF	1054	997	1025		1971	1875	1923		3024	2871	2948		34.79	34.60	34.70	
25 kg FeSO ₄ /ha (SA) + 0.5% FeSO ₄ (FA) at FI and PF	1068	1011	1040		1996	1899	1948		3064	2910	2987		34.84	34.69	34.76	
SEm $\pm$	24	25	17		41	42	29		65	67	46		0.07	0.07	0.05	
CD (P=0.05)	78	81	52		133	136	87		211	217	139		0.24	0.23	0.15	
Zinc (ZnSO₄) fortification																
Control	878	813	845		1673	1564	1618		2550	2376	2463		34.26	34.06	34.16	
ZSB (SI) + 15 kg ZnSO ₄ /ha (SA) + 0.5% ZnSO ₄ (FA) at FI and PF	994	938	966		1871	1776	1823		2865	2714	2789		34.62	34.50	34.56	
ZSB (SI) + 20 kg ZnSO ₄ /ha (SA) + 0.5% ZnSO ₄ (FA) at FI and PF	1085	1020	1052		2024	1914	1969		3108	2934	3021		34.87	34.71	34.79	
ZSB (SI) + 25 kg ZnSO ₄ /ha (SA) + 0.5% ZnSO ₄ (FA) at FI and PF	1098	1053	1075		2046	1969	2008		3144	3021	3083		34.89	34.81	34.85	
SEm $\pm$	24	25	17		40	42	29		64	67	47		0.07	0.08	0.05	
CD (P=0.05)	69	72	49		116	121	83		185	193	131		0.21	0.22	0.15	

influenced by zinc nutrition, as it enhances photosynthesis, the formation and transport of sucrose and starch biosynthesis, all of which ultimately affect the formation of yield attributes. Similar findings were reported by Ramesh *et al.* (2014) and Rana *et al.* (2012). Significant improvements in growth attributes due to zinc fertilization were applied through foliar spray which were further enhanced by coupling with zinc solubilizing bacteria (ZSB), had a considerable impact on improving yield attributes and ultimately increasing the yield of mungbean. Zinc plays a significant role in the initiation of primordial and the partitioning of food materials from leaves to reproductive parts, which ultimately results in better fruiting (Zafar *et al.*, 2023), thereby prominently increasing yield attributes. Similar improvements in the number of pods/plant and seeds/pod in mungbean due to zinc application were also observed by Haider *et al.* (2018) and Usman *et al.* (2014) reported that 1000-seed weight of mungbean was enhanced with zinc application at 20 kg/ha. The higher seed yield and biological yield was observed in mungbean crop with the application of 20 kg Zn/ha.

Interaction effect of Iron levels x zinc levels

Seed yield, stover yield and biological yield

Interaction effect of iron and zinc fortification levels significantly increases in seed yield by the combined application of ZSB + 20 kg ZnSO₄ with foliar spray (0.5%) at flower initiation and pod formation stages and 20 kg FeSO₄ + 0.5% superimposed with foliar spray at flower initiation and pod formation stages produced significantly higher seed yield (1092 kg/ha) but it was found at par with variation irrespective to treatment ZSB (SI) + 25 kg ZnSO₄ with foliar spray at flower initiation and pod formation stages

(1150 kg/ha) However, further data recorded that seed yield were decreased considerably under the influence of their higher levels of zinc and iron fortification treatment (1006 kg/ha) on pooled basis (Table 5).

Economics

Effect of varieties

Variety GM 4 produced a net return of ₹66,974/ha, accompanied by a higher benefit-cost (B C) ratio of 3.41, compared to GM 7 in Fig 1 and 2. Both varieties showed notable variation in these parameters, primarily due to differences in seed and stover yield. GM 4 consistently outperformed GM 7 in both seed and stover production, resulting in higher net returns and a more favourable benefit cost ratio. These findings are in line with previous studies that highlighted the correlation between yield productivity and economic profitability (Rathika and Ramesh, 2023), who reported that the better yield attributes and yields produced by Co(Gg) 8 which might be responsible for higher economics of mungbean.

Effect of iron fortification

The data revealed that soil application of 20 kg FeSO₄/ha combined with a 0.5% foliar spray at flower initiation and pod formation stages (Fe₁) in mungbean resulted in the highest net return (₹ 62,051/ha) and the highest B:C ratio (3.20) during the experimentation (Table 2). These findings align with the results of Manjhi *et al.* (2020) and Bahadari *et al.* (2020). This improvement can be attributed to the substantial increase in yield resulting from the enhanced availability of iron through both soil and foliar fortification, which addressed the hidden deficiency of iron and promoted better nutrition for the crop.

Table 4: Correlation coefficients between independent variables and seed yield in mungbean varieties under agronomic fortification of zinc and iron.

Dependent variable (Y)	Independent variable (X)	Correlation coefficient (r)		
		2022	2023	Pooled
Seed yield	No. of pods/plant	0.9675	0.9794	0.9741
	No. of seeds/pod	0.9566	0.9682	0.9633
	Test weight	0.9675	0.9794	0.9741

Table 5: Interaction effect of zinc and iron fortification levels on seed yield (kg/ha) of mungbean.

Iron × zinc fortification levels	2022				2023				Pooled			
	Fe ₀	Fe ₁	Fe ₂	Mean	Fe ₀	Fe ₁	Fe ₂	Mean	Fe ₀	Fe ₁	Fe ₂	Mean
Zn ₀	680	921	1030	877	705	819	914	813	693	870	972	845
Zn ₁	869	1001	1112	994	787	974	1053	938	828	987	1082	966
Zn ₂	999	1133	1121	1084	935	1051	1073	1020	967	1092	1097	1052
Zn ₃	1126	1158	1009	1098	1012	1142	1003	1052	1069	1150	1006	1075
Mean	919	1053	1068		860	996	1011		889	1025	1039	
SEm±			41.42				43.23				29.93	
CD (P=0.05)			118.80				123.98				84.39	

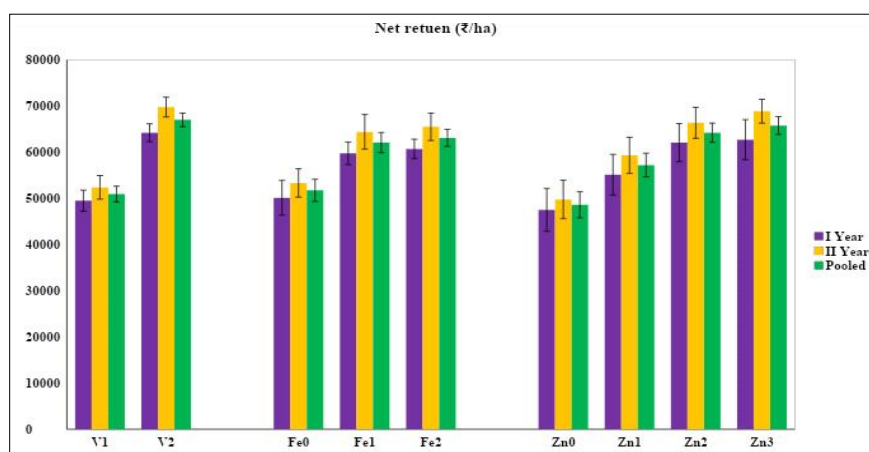


Fig 1: Effect of agronomic fortification of zinc and iron on net returns of mungbean.

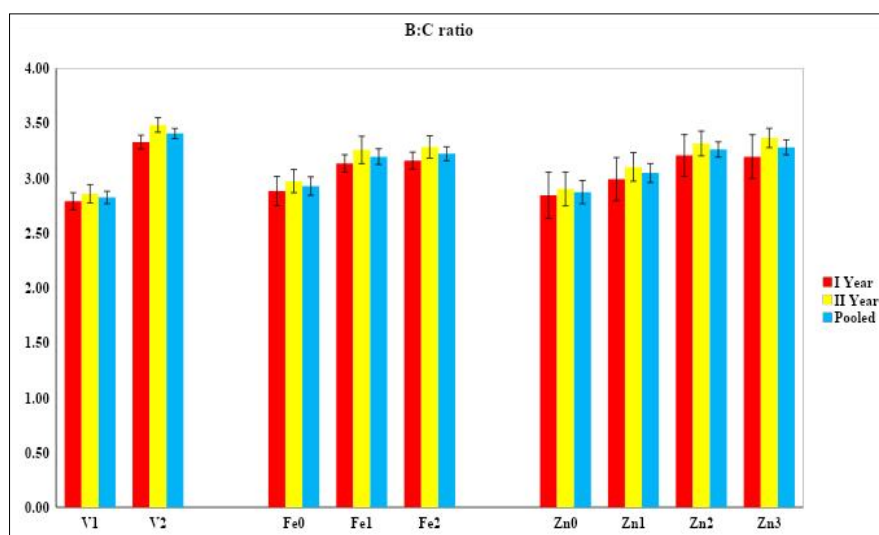


Fig 2: Effect of agronomic fortification of zinc and iron on B:C ratio of mungbean.

Effects of zinc solubilizing bacteria (ZSB) and zinc level

Among the treatments, seed inoculation with ZSB, supplemented with 20 kg ZnSO_4/ha and a 0.5% foliar spray at the flower initiation and pod development stages (Zn_2), achieved the highest net returns (₹64,202/ha) and a B:C ratio of 3.26 on a pooled basis (Fig 1 and 2). This economically optimal treatment outperformed preceding zinc levels while also yielding higher profitability. The results align with findings reported by Prajapati *et al.* (2022). The superior net returns under the Zn_2 treatment were attributed to the higher seed and stover yields, in comparison to the ZSB + 15 kg ZnSO_4/ha (Zn_1) and control treatments. However, the Zn_2 treatment was found to be statistically at par with ZSB + 25 kg ZnSO_4/ha (Zn_3). These findings are consistent with those reported by Gahlot *et al.* (2020) and Khan and Prakash (2014), who observed similar trends in mungbean under soil-applied zinc treatments.

CONCLUSION

The mungbean variety GM 4 demonstrated remarkable performance, surpassing GM 7 with an impressive average seed yield of 1076 kg/ha. This higher yield translated into a maximum net return of ₹66,974/ha, along with a substantial boost in the Benefit-Cost (B:C) ratio to 3.41. Under the conditions of western Rajasthan, the productivity and profitability of mungbean can be significantly enhanced through fortification with zinc (Zn) and iron (Fe), coupled with seed inoculation (ZSB) and the application of 20 kg ZnSO_4/ha along with 0.5% foliar sprays at flower initiation and pod formation stages. This integrated approach holds promising potential for optimizing mungbean cultivation, benefiting both yield and economic returns.

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Disclaimers

Author declares that all works are original and this manuscript has not been published in any other journal.

Informed consent

The database generated and/or analysed during the current study are not publicly available due to privacy, but are available from the corresponding author on reasonable request.

Conflict of interest

The author declare that they have no conflicts of interest to report regarding the present study.

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