Original Research Article

Effect of Micronutrients and Bioinoculants on Seed Yield and Seed Quality of Chilli (*Capsicum annuum* L.) under Kymore Plateau Zone

ABSTRACT

Chilli (*Capsicum annuum* L.) is one of the most extensively cultivated and economically important spice crops cultivated worldwide for its valuable fruits.~~.~~ ~~Chilli is an economically important crop cultivated worldwide for its valuable fruits.~~ The present study aimed to investigate the effect of micronutrients and bioinoculants on seed yield and quality of chilli. The experiment was laid out in Randomized Complete Block Design (RCBD-Factorial) with three replications and twenty treatments, including four micronutrients (M_1-M_5) and three bioinoculants (B_0-B_3). The interaction effect of micronutrients and bioinoculants was found to be significant in enhancing the chilli seed yield and quality. The treatment combination M_5B_3 ($ZnSO_4$ (0.2%) + TV + PF+ AC (2.5 kg/ha +2.5 kg/ha+ 5.0 kg/ha)) showed the highest improvement. Therefore, it can be inferred that a combination of micronutrients and bioinoculants is recommended for increasing the seed yield and quality of chilli.

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Keywords: micronutrients, bioinoculants, sustainable agriculture, seed yield and quality

1. INTRODUCTION

Chilli (*Capsicum annuum* L., 2n=24) is a significant vegetable, spice, and cash crop in India, belonging to the Solanaceae family. It is widely grown in both rainfed and irrigated environments throughout the country, with dried chilli production centered in the southern states. Madhya Pradesh alone produces 574.80 thousand tonnes of green chilli annually, cultivated in an area of 33.64 thousand ha, with major producing districts including Mandsaur, Khargone, Dhar, Shajapur, Ujjain, Chhindwara, Rajgarh, Khandwa, and Betul. Chilli is known for its pungency due to capsaicin present in the fruit's placenta and pericarp, which has diverse medicinal uses, and is rich in ascorbic acid. Capsanthin, a pigment, is responsible for the red colour. Chilli may be grown in various soils, although well-drained loam soil is optimal. Chilli colour extracts are gaining popularity as a natural food colour substitute. The chilli variety 'Arka Lohit' developed as a pure line selection from IIHR 324 (local collection), was released in 1990 at the AICRP (VC) workshop for national-level recognition. This variety exhibits tall plants with straight, smooth fruits that have pointed tip. The fruits undergo a color transformation from dark green to deep red and possess a high level of pungency. Arka Lohit adapts well to both irrigated and rainfed environments. Micronutrients play a crucial role in plant growth and the production of profitable crops, even though they are required in small quantities. Their application

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in various vegetables, including chillies, has been found to have positive effects on growth, seed yield, and quality [1,2].

Micronutrients play a crucial role in plant growth and development, and they can be provided to plants through foliar sprays for immediate nutrient availability. Essential micronutrients like iron, zinc, and boron are required in small quantities but have specialized physiological functions (growth and metabolism~~, etc~~.) in plants. Iron is essential for chlorophyll production and is particularly important for red chilli carotenoid synthesis, indirectly enhancing the quality of red chillies and paprika. Zinc is involved in auxin and protein synthesis and helps maintain membrane integrity. Additionally, zinc acts as a component of several enzymes; including dehydrogenase, aldolase, isomerases, proteinase, peptidase, and phosphohydrolase, further emphasizing its importance in plant metabolism [3]. Plant Growth Promoting Rhizobacteria (PGPR) plays a vital role in promoting healthy growth and increasing the yield of various crops. These beneficial bacteria actively colonize plant roots and enhance plant growth and yield through the production of phytohormones. Moreover, they protect plants from phytopathogenic microorganisms by producing siderophores, antibiotics, enzymes, and fungicidal compounds. Additionally, PGPR is known for its ability to perform asymbiotic N_2 fixation. Utilizing PGPR as biofertilizers and bioenhancers is an eco-friendly alternative to chemical fertilizers for various crop plants. In light of these benefits, this experiment was conducted to investigate the effect of micronutrients and bioinoculants on chilli seed yield and quality.

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2. MATERIALS AND METHODS

The experiment entitled "Effect of Micronutrients and Bioinoculants on Seed Yield and Seed Quality of Chilli (*Capsicum annuum* L.) under Kymore Plateau Zone" was conducted during the Rabi season at the Horticulture Complex, Maharajpur, Department of Horticulture, JNKVV, Jabalpur (MP). A field experiment was conducted using a Randomized Complete Block Design (RCBD-Factorial) with various treatment combinations. The experiment included micronutrient treatments (M_1-M_5), bioinoculant treatments (B_0-B_3), and their interactions (M_1B_0-M_5B_3). Each treatment was replicated thrice to minimize experimental errors. Healthy 30 days old seedlings were transplanted at a spacing of 60 cm × 45 cm in the experimental plots. Foliar sprays of micronutrients were applied at three stages of plant growth: 60, 90, and 120 days after transplanting. In each plot, five randomly selected plants were tagged to collect biometric data on seed yield parameters, germination percentage, Seed vigour index-I, and Seed vigour index-II. The germination percentage of seeds was calculated by the guidelines of ISTA. Paper towels were used to hold the seeds, and 100 seeds from three replications were tested. The first and second germination counts were recorded on the fourth and tenth days, respectively, and the percentage of germination was calculated based on normal seedlings. The seedling index was determined using two methods described by [4]. The Seedling Vigour index was calculated by multiplying the germination percentage with either the seedling length (cm) or the seedling dry weight (g). Overall, the experimental setup and data collection procedures were conducted meticulously to evaluate the effects of micronutrients and bioinoculants on seed yield and seed quality of chilli.

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3. RESULTS AND DISCUSSION

3.1 Seed yield parameters

The application of micronutrients and bioinoculants, both individually and in combination, had a significant impact on the characteristics of chilli seed yield.

3.1.1 100 seed weight (g)

The data in Table 1 shows that there was a highly significant effect on 100 seed weight. The maximum 100 seed weight was recorded in the application of micronutrients M_5 (2.81 g), while the lowest was observed in M_1 (1.63 g). Zinc plays a role in auxin and protein synthesis and contributes to seed formation and maturity. This finding is consistent with previous studies by [5,6]. Similarly, the application of bioinoculants also significantly influenced the 100 seed weight. B_3 (2.92 g) had the highest seed weight, while B_0 (2.00 g) had the lowest. *Trichoderma viride* and PGPR promote the production of growth substances such as auxins and cytokinins in plants, which positively affect processes like cell division and enlargement, resulting in bolder and heavier seeds. These findings are supported by [7,8]. Furthermore, when micronutrients and bioinoculants (*Trichoderma viride* and PGPR) were combined, their interaction had an impact on the 100 seed weight. The treatment combination M_5B_3 exhibited the highest seed weight (3.40 g), while the combination M_1B_0 had the lowest (1.42 g).

3.1.2 Number of seed per fruit

Under the micronutrient treatment, the highest number of seeds per fruit was recorded in M_5 (35.77), while the lowest count was observed in M_1 (25.41). The utilization of bioinoculants also had a significant impact on the number of seeds per fruit, with the maximum count noted as B_3 (36.33) and the minimum count as B_0 (30.07). The interaction effects of micronutrients and bioinoculants, specifically *Trichoderma viride* and PGPR, showed a significant influence on the number of seeds per fruit. The maximum number of seeds per fruit was recorded in the M_5B_3 (38.88), whereas the minimum count was observed in the M_1B_0 (21.04). Zinc plays a vital role in seed development by aiding in auxin and protein synthesis. Additionally, the inoculation of plants with bioinoculants can enhance seed quality by improving nutrient uptake and stimulating the production of growth-promoting chemicals. These findings align with previous studies conducted by [5,6,7,910].

3.1.3 Seed yield per plant (g)

In Table 1, the results indicate that the application of micronutrients had a substantial impact on seed yield per plant. Among the treatments, the highest seed yield per plant was recorded in M_5 (3.99 g), while the lowest yield was observed in M_1 (2.77 g). Similarly, the application of bioinoculants also significantly influenced seed yield per plant, with the maximum yield recorded in B_3 (4.38 g) and the minimum yield in B_0 (3.07 g). The combined effects of micronutrients and bioinoculants, specifically *Trichoderma viride* and PGPR, found a significant influence on seed yield per plant. The maximum seed yield per plant was observed in the M_5B_3 treatment combination (4.85 g), while the minimum yield was found in the M_1B_0 combination (2.48 g).

Table 1: Individual and interaction effect of different micronutrients and bioinoculants on Seed Yield and Seed Quality Parameters

Treatments	Seed Yield Parameters				Seed Quality Parameters		
	100 seed weight (g)	**No. of seed/ fruit**	**Seed yield /plant (g)**	**Seed yield/ hectare (q)**	**Germi nation %**	**Seed vigour index–I**	**Seed vigour index–II**
Micronutrients							
M_1 No micronutrient	1.63	25.41	2.77	0.094	62.53	345.38	179.10
M_2 $FeSO_4$ (0.2%)	2.52	34.04	3.64	0.125	71.95	766.63	252.87
M_3 $(CaNO_3)_2$ (0.2%)	2.58	34.92	3.71	0.128	72.12	809.23	258.01
M_4 Borax (0.1%)	2.65	35.12	3.81	0.132	73.41	875.49	264.05
M_5 $ZnSO_4$ (0.2%)	2.81	35.77	3.99	0.136	74.52	908.77	268.25
S.Em±	0.09	0.13	0.005	0.003	0.16	19.41	1.00
C.D.5% level	0.25	0.38	0.013	0.009	0.48	55.79	2.88
Bioinoculants							
B_0 No bioinoculant	2.00	30.07	3.07	0.103	65.49	577.75	211.71
B_1 TV (2.5 kg/ha)	2.30	32.17	3.20	0.112	70.21	671.57	237.57
B_2 TV + PF (2.5 kg/ha +2.5 kg/ha)	2.54	33.65	3.69	0.13	73.06	786.15	255.87
B_3 TV + PF+AC (2.5 kg/ha +2.5 kg/ha +5.0kg/ha)	2.92	36.33	4.38	0.146	74.87	928.94	272.69
S.Em±	0.08	0.12	0.004	0.003	0.15	17.36	0.89
C.D.5% level	0.22	0.34	0.012	0.008	0.43	49.89	2.87
Interaction							
M_1 B_0	1.42	21.04	2.48	0.083	60.83	284.75	142.40
M_1 B_1	1.57	25.03	2.50	0.083	62.81	326.33	169.01
M_1 B_2	1.72	26.33	2.95	0.103	62.84	360.75	194.45
M_1 B_3	1.82	29.25	3.14	0.105	63.64	409.69	210.55
M_2 B_0	1.98	31.21	3.16	0.106	66.39	558.89	221.07
M_2 B_1	2.38	33.45	3.27	0.115	69.56	725.82	251.60
M_2 B_2	2.63	34.98	3.59	0.127	74.84	802.82	263.04
M_2 B_3	3.07	36.52	4.55	0.152	76.99	979.00	275.78
M_3 B_0	2.10	32.20	3.20	0.107	66.56	602.54	224.73
M_3 B_1	2.42	33.74	3.36	0.119	69.99	752.19	253.25
M_3 B_2	2.67	35.31	3.65	0.133	74.87	833.86	273.07
M_3 B_3	3.12	38.45	4.61	0.154	77.07	1048.32	280.98
M_4 B_0	2.18	32.84	3.24	0.108	66.66	718.55	235.01
M_4 B_1	2.50	33.72	3.37	0.121	74.34	767.28	254.77
M_4 B_2	2.75	35.35	3.87	0.138	75.31	964.60	273.39
M_4 B_3	3.18	38.56	4.77	0.159	77.35	1051.53	293.05
M_5 B_0	2.30	33.07	3.26	0.111	67.01	723.99	235.32
M_5 B_1	2.60	34.89	3.48	0.124	74.34	786.21	259.20
M_5 B_2	2.95	36.25	4.37	0.146	77.45	968.70	275.39
M_5 B_3	3.40	38.88	4.85	0.162	79.29	1156.17	303.10
S.Em±	0.17	0.26	0.009	0.006	0.33	38.82	2.00
C.D.5% level	N.S.	0.77	0.027	N.S	0.97	111.57	5.75

TV=*Trichoderma viride*, PF=*Pseudomonas fluorescence*, AC=*Azotobacterchroococcum*

3.1.4 Seed yield per hectare (q)

The data presented in Table 1 provides clear evidence of the significant impact of micronutrients on seed yield per hectare. Among the treatments, the highest seed yield per hectare was recorded in M_5 (0.136 q), while the lowest yield was observed in M_1 (0.094 q). Similarly, the application of bioinoculants also demonstrated a considerable influence on seed yield per hectare. Treatment B_3

exhibited the highest seed yield per hectare (0.146 q), while the lowest yield was recorded in B_0 (0.103 q). In the combined effects of micronutrients and bioinoculants, the maximum seed yield per hectare was achieved in the M_5B_3 (0.162 q), whereas the minimum yield was observed in the M_1B_0 (0.083 q). Zinc, an essential component of protein synthesis and nitrogen fixation, plays a crucial role in improving seed set and nutrient uptake, thereby contributing to increased seed yield. Bioinoculants, on the other hand, produce growth-promoting chemicals and facilitate enhanced nutrient uptake. These findings are consistent with previous studies conducted by [6,7,10,11,12].

3.2 Seed Quality Parameter

The combined application of micronutrients and bioinoculants resulted in significant improvements in seed quality parameters, including germination percentage, seedling vigour index - I, and seedling vigour index - II.

3.2.1 Seed germination percentage

Seed germination percentage was significantly influenced by the foliar application of micronutrients. Treatment M_5 exhibited the highest seed germination percentage (74.52%), while the lowest percentage was recorded in treatment M_1 (62.53%). Similarly, the application of bioinoculants also had a notable effect on seed germination percentage, with the highest value observed in treatment B_3 (74.87%) and the lowest in treatment B_0 (65.49%). The combined effects of micronutrients and bioinoculants demonstrated a significant impact on seed germination percentage, with the highest percentage recorded in the M_5B_3(79.29%) and the lowest in the M_1B_0 (60.83%). The inclusion of zinc sulphate in the micronutrient treatments increased metabolic activity and germination speed due to a higher concentration of metabolites, promoting the restart of embryonic growth during germination. Zinc, known for its involvement in protein synthesis, facilitated a better source-sink interaction, resulting in improved seed growth and increased germination. The enhanced production of hormones such as gibberellins may have activated specific enzymes that promoted early germination, potentially explaining these results. These findings are consistent with previous studies conducted by [10,13,14,15,17].

3.2.2 Seed vigour index-I

In the foliar application of micronutrients, the treatment M_5 recorded the highest value of seed vigour index-I (908.77), while the lowest seed vigour index-I was recorded in M_1(345.38). Regarding bioinoculants, the maximum seed vigour index-I was observed in B_3 (928.94), whereas the minimum seed vigour index-I was recorded in B_0 (577.75). When considering the combined effects of micronutrients and bioinoculants, the treatment combination M_5B_3 exhibited the highest seed vigour index-I (1156.17), while the lowest value was observed in the treatment combination M_1B_0 (284.75).

3.2.3 Seed vigour index-II

In the foliar application of micronutrients, treatment M_5 (268.25) exhibited the highest value of seed vigour index-II, while treatment M_1 had the lowest value (179.10). Regarding bioinoculants, the maximum seed vigour index-II was recorded in treatment B_3 (272.69), whereas the minimum seed vigour index-II was observed in B_0 (211.71). The interaction effects between micronutrients and bioinoculants were found to be significant. The highest seed vigour index-II was recorded in the treatment combination M_5B_3 (303.10), while the lowest value was observed in the combination M_1B_0 (142.40). Zinc plays a crucial role in protein synthesis and has been associated with a better source-sink interaction, resulting in improved seed development and a higher vigour index. Bioinoculants can significantly enhance seed germination, and the notable increase in seed vigour can be attributed to their increased auxin production. These findings are consistent with previous studies conducted by [6,10,15,16,17,18]. The above results reveal that the interaction effect of micronutrients and bioinoculants was the most effective treatment combination for increasing chilli seed yield and quality.

4. CONCLUSION

The application of micronutrients and bioinoculants in chilli cultivation offers a promising and sustainable approach to enhancing seed yield and quality. The findings highlight that this approach significantly improves microbial population and leads to substantial enhancements in seed yield and quality compared to the control group. The most effective treatment combination involves specific application rates of $ZnSO_4$, *Trichoderma viride, Pseudomonas fluorescens, and Azotobacter chroococcum*. This research provides valuable insights for farmers, researchers, and policymakers, emphasizing the importance of nutrient management and biological interventions in sustainable agriculture. However, further research is needed to optimize the application methods and rates, timing of these treatments for different chilli varieties and environmental conditions. Long-term field trials, scalability, mechanistic studies, and economic analysis are necessary to gain a deeper understanding of the underlying mechanisms, long-term effects, and economic feasibility of implementing these practical strategies for maximizing chilli seed yield and quality in commercial farming.

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