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Influence of Foliar Application of Boron and Zinc on Growth, Reproductive Traits and Yield Performance of Green Gram (*Vigna radiata* L.)

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ABSTRACT

The experiment was conducted during the pre-*kharif* seasons (March–May) of 2022 and 2023 at the District Seed Farm, AB Block, Kalyani Simanta, under Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India to evaluate the response of two green gram genotypes (TMB-37 and TMB-153). The experimental was designed in Factorial Randomized Block Design (FRBD) with nine different genotypes as treatments replicated thrice. The treatments were water spray as control, zinc at 30 µmol, zinc at 60 µmol, boron at 40 µmol, boron at 40 µmol+zinc at 30 µmol, boron at 40 µmol+zinc at 60 µmol, boron at 80 µmol, boron at 80 µmol+zinc at 30 µmol and boron at 80 µmol+zinc at 60 µmol. Although the genotypes differed significantly in several yield-attributing traits, their final grain yield was statistically similar, indicating yield stability of genotypes. Boron application significantly enhanced floral frequency, flower-to-pod transition, pods plant^{-1}, seeds pod^{-1}, pod weight, seed weight plant^{-1} and grain yield, with the lower dose (40 µmol) proving sufficient and economical. Zinc application also improved most yield components and yield, with optimal response at 30 µmol, while floral frequency and 100-seed weight showed limited sensitivity. Interaction effects were largely non-significant, except for pod weight and yield, where the combined application of boron (40 µmol) and zinc (30 µmol) produced superior performance.

KEYWORDS: Green gram, boron, zinc, pod, seed, yield

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1. INTRODUCTION

Green gram (*Vigna radiata* L. Wilczek) is an important short-duration grain legume which is aboriginal to India and Central Asia (Venkidasamya et al., 2019). It is valued for its high protein content (20–25%), digestibility, and ability to enrich soil fertility through biological nitrogen fixation as the rhizobium-legume symbiosis is a ramification of the evolutionary dynamics of legumes associated root nodule symbionts, making it a key component of sustainable cropping systems (Lambrides and Godwin, 2007; Nair et al., 2019; Bekuzarova et al., 2020; Joshi et al., 2024). Due to its bountiful nutrient profile, it is regarded as green pearl or verdant gem of food legumes (Nair et al., 2013) and colloquially known as chicka-sono-pea, moong, Oregon-pea, and golden gram (Lambrides and Godwin, 2007). Despite its agronomic and nutritional importance, green gram productivity remains relatively low, due to poor flower retention, and inadequate nutrient conditions (Ali and Gupta, 2012). Micronutrients play a crucial role in regulating physiological and biochemical processes that directly influence reproductive development and yield. Boron (B) is essential for cell wall formation, pollen viability, carbohydrate transport, and flower-to-pod transition, while zinc (Zn) is involved in enzyme activation, protein synthesis, auxin metabolism, and photosynthetic efficiency (Marschner, 2012; Cakmak, 2008). Boron plays a key role in root nodule formation, in its deficiency leads to the reduced cell division and enlargement of growing region of root tips which inhibits elongation (Movalia et al., 2020). Boron dearth causes various physio-biochemical and anatomical disorders includes inhibition and disruption of apical growth (Matthes et al., 2020), reduction in leaf expansion, tissue breaking due to brittleness and fragility, necrosis of terminal buds, floral abortion, and fruits dropping (Rerkasem et al., 2020; Goldbach, 1997; Brown et al., 2002). In India, zinc (Zn) stood as fourth utmost imperative yield limiting nutrient in agricultural crops and prospective to upsurge from 49 to 63% by the year 2025 (Ganeshamurthy et al., 2019) Zinc is essential elements for the growth, development, and reproduction in plants and also tryptophan synthesis, as the precursor of Indole acetic acid (IAA) (Mondal and Bose, 2019). Zinc, prominent in function, regulation as co-factor of various enzymes and their activation as they are involved in several metabolic reactions. Zinc is crucial for production of chlorophyll and starch formation supports in seed formation that in turn enhancing photosynthesis and crop yield (Kavya et al., 2021; Naz et al., 2022). Zinc deficiency persuades fluctuations in the antioxidant defence mechanism distressing the ultrastructure of chloroplast due to greater lipid peroxidation (Devi et al., 2023). Deficiencies of B and Zn are widespread in many green gram–growing soils, particularly under intensive cultivation, leading to impaired reproductive growth and reduced yield potential (Alloway, 2008). Therefore, the present study was undertaken to evaluate the effect of foliar application of boron on yield components, grain yield and their correlations of two mung bean genotypes.

2. MATERIALS AND METHODS

The experiment was conducted during the *pre-kharif* season (March–May), 2022 and 2023 at the District Seed Farm, AB Block, Kalyani Simanta, under Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India (22º58' N, 88º32' E), situated in the new alluvial zone at an altitude of 9.75 m above mean sea level. The region had a tropical sub-humid climate characterized by high summer temperatures, erratic rainfall, high humidity, and a short winter. The experiment was executed to study the performance of two green gram genotypes physiologically under foliar nutrition of micronutrients boron and zinc. Two Green gram Genotypes, namely TMB-37 and TMB-153 were collected from the esteemed Bhabha Atomic Research Centre (BARC) Trombay, Mumbai, Maharashtra. The field was prepared using a tractor-drawn cultivator and power tiller to achieve a fine tilth, followed by levelling and providing gentle slope for drainage. Seeds were sown manually at 30 cm row spacing and 3–4 cm depth. The first irrigation was applied immediately after sowing to ensure uniform germination, followed by 3–4 irrigations as required during crop growth. Harvesting was done when over 75% of pods had matured. Five plants were randomly selected from each plot for data collection.

The experimental design employed was a Factorial Randomized Block Design (FRBD), with nine different genotypes as treatments (in 2.1), the experiment consisted of three replications, resulting in a total of 27 plots. Each individual plot spanned an area of 3 m by 3 m, with a spacing of 30 cm by 10 cm between plants and all standard agronomic practices followed strictly.

2.1. *Treatment details*

The treatment details include: Concentrations of boron and zinc as solo and their combinations. T_1: B_0Z_0 (Control) (Water Spray), T_2: B_0Z_L (Zinc at 30 μmol), T_3: B_0Z_H (Zinc at 60 μmol), T_4: B_LZ_0 (Boron at 40 μmol), T_5: B_LZ_L (Boron at 40 μmol+Zinc at 30 μmol), T_6: B_LZ_H (Boron at 40 μmol+Zinc at 60 μmol), T_7: B_HZ_0 (Boron at 80 μmol), T_8: B_HZ_L (Boron at 80 μmol+Zinc at 30 μmol) and T_9: B_HZ_H (Boron at 80 μmol+Zinc at 60 μmol).

2.2. *Statistical analysis*

The data collected were pooled and statistically analyzed in Factorial Randomized Block Design (FRBD), with critical difference (C.D.) at p=0.05 level of significance. All the data was statistically analyzed by using all formulas in

Microsoft Excel and then the results were cross checked by using OPSTAT software.

3. RESULTS AND DISCUSSION

3.1. *Floral frequency*

The average floral frequency of genotypes TMB 37 and TMB 153 was 67.55 and 68.42 flowers plant^{-1}, respectively, with no significant genotypic difference (Table 1). Boron application significantly increased floral frequency, with B_1 (69.16) and B_2 (69.19 flowers plant^{-1}) recording higher values than the control (B_0: 65.61). As B_1 and B_2 were statistically at par, foliar application of boron at 40 mM was sufficient to enhance flowering. Zinc treatments (Z_0–Z_2) did not significantly affect floral frequency. All interaction effects (A×B, A×Z, B×Z, and A×B×Z) were non-significant, and floral frequency among treatment combinations remained statistically similar. Thus, floral frequency was primarily influenced by boron application, while zinc and interaction effects had no substantial impact. Kakon et al., 2015; Selim et al., 2023 reported that foliar application of boron significantly enhanced flower production in French bean and mung bean. All the reports were in agreement with the present investigation.

Table 1: Effect of boron and zinc on floral frequency of mung bean genotypes (TMB-37 AND TMB-153)

A×B	B_0	B_1	B_2	Mean A
A_1	63.98	69.24	69.41	67.55
A_2	67.23	69.09	68.96	68.42
Mean B	65.61	69.16	69.19	
A×Z	Z_0	Z_1	Z_2	Mean A
A_1	66.30	68.04	68.30	67.55
A_2	67.73	68.72	68.82	68.42
Mean Z	67.01	68.38	68.56	
B×Z	Z_0	Z_1	Z_2	Mean B
B_0	64.21	65.84	66.77	65.61
B_1	68.31	69.90	69.29	69.16
B_2	68.53	69.42	69.61	69.19
Mean Z	67.01	68.38	68.56	

A×B×Z	A_1			A_2		
	B_0	B_1	B_2	B_0	B_1	B_2
Z_0	62.58^a	67.85^a	68.46^a	65.84^a	68.76^a	68.6^a
Z_1	64.11^a	70.24^a	69.78^a	67.56^a	69.56^a	69.05^a
Z_2	65.26^a	69.63^a	70^a	68.28^a	68.94^a	69.22^a

Factors	CD (p=0.05)	SEm±
Factor (A)	NS	0.892
Factor (B)	3.142	1.093
Interaction A×B	NS	1.546
Factor (Z)	NS	1.093
Interaction A×Z	NS	1.546
Interaction B×Z	NS	1.893
Interaction A×B×Z	NS	2.677

CD at p=0.05 Level of significance; NS: Non significant, A: Genotypes; A_1: TMB-37; A_2: TMB-153; B: Boron; B_0: No Boron; B_1: Boron low (Bat 40 µmol); B_2: Boron high (Bat 80 µmol.); Z: Zinc; Z_0: No Zinc; Z_1: Zinc low (Zat 30 µmol.); Z_2: Zinc high (Zat 60 µmol)

3.2. *Flower to pod transition percentage* (%)

The flower-to-pod transition was significantly higher in TMB-37 (50.63%) than in TMB-153 (48.42%), indicating superior performance of TMB-37 (Table 2). Boron application significantly improved transition percentage,

Table 2: Effect of boron and zinc on flower to pod transition (%) of mung bean genotypes (TMB-37 AND TMB-153)

A×B	B_0	B_1	B_2	Mean A
A_1	47.11	52.24	52.54	50.63
A_2	46.42	49.47	49.37	48.42
Mean B	46.76	50.85	50.96	
A×Z	Z_0	Z_1	Z_2	Mean A
A_1	48.19	51.98	51.72	50.63
A_2	47.41	48.75	49.10	48.42
Mean Z	47.80	50.36	50.41	
B×Z	Z_0	Z_1	Z_2	Mean B
B_0	46.22	46.77	47.30	46.76
B_1	48.41	53.08	51.06	50.85
B_2	48.76	51.25	52.87	50.96
Mean Z	47.80	50.36	50.41	

A×B×Z	A_1			A_2		
	B_0	B_1	B_2	B_0	B_1	B_2
Z_0	46.31^c	48.15^{bc}	50.11^{abc}	46.14^c	48.68^{bc}	47.41^c
Z_1	47.23^c	55.81^a	52.89^{abc}	46.3^c	50.35^{abc}	49.6^{abc}
Z_2	47.78^c	52.75^{abc}	54.63^{ab}	46.81^c	49.38^{abc}	51.11^{abc}

Factors	CD (p=0.05)	SEm±
Factor (A)	1.942	1.942
Factor (B)	2.379	2.379
Interaction A×B	NS	N/A
Factor (Z)	NS	N/A
Interaction A×Z	NS	N/A
Interaction B×Z	NS	N/A
Interaction A×B ×Z	NS	N/A

with B_1 (50.85%) and B_2 (50.96%) outperforming the control (46.76%). As B_1 and B_2 were statistically at par, foliar boron at 40 mM was sufficient to enhance flower-to-pod transition. Zinc treatments (Z_0–Z_2) showed no significant effect. All interaction effects (A×B, A×Z, B×Z and A×B×Z) were non-significant. Higher transition values were recorded under combinations involving boron, particularly A1B1Z1 and A1B2Z2. Overall, TMB-37 responded better than TMB-153, and boron application was the key factor improving flower-to-pod transition, corroborating earlier findings in legumes.

3.3. *Number of pods plant* $^{-1}$

The number of pods plant^{-1} did not differ significantly between TMB-37 (34.28) and TMB-153 (33.15) (Table 3). Boron application significantly increased pod number, with B_1 (35.19) and B_2 (35.27) producing more pods than the control (30.68); both doses were statistically at par, indicating that foliar boron at 40 mM was adequate. Zinc treatments also significantly enhanced pod number, with Z_1 (34.49) and Z_2 (34.59) outperforming Z_0 (32.06), and the lower zinc dose (30 mM) being sufficient. All interaction effects were non-significant. The positive effects of boron and zinc on pod number corroborate earlier reports in mung bean and other legumes. The positive effect of boron on number of pods plant^{-1} was previously reported by Tania et al. (2019), Alam and Islam (2016), Quddus et al. (2011) in mung bean. The positive effect of zinc on number of pods plant^{-1} was previously reported by Haider et al. (2018), Alam and Islam (2016), Quddus et al. (2011) in mung bean. The positive effect of boron and zinc on number of pods per plant was also reported by Sayed et al. (2024) in grass pea, Kumar et al. (2023) in chick pea, Tribhuwan et al. (2024), Selim et al. (2023), Zafar et al. (2023), Boradkar et al. (2023), Krishna et al. (2022), Mecarty et al. (2022) and Kavya et al. (2021) in green gram, Karimunnisa et al. (2021) in cowpea.

Table 3: Effect of boron and zinc on number of pods plant^{-1} of mung bean genotypes (TMB-37 AND TMB-153)

A×B	B_0	B_1	B_2	Mean A
A_1	30.15	36.20	36.49	34.28
A_2	31.21	34.18	34.05	33.15
Mean B	30.68	35.19	35.27	
A×Z	Z_0	Z_1	Z_2	Mean A
A_1	31.99	35.46	35.38	34.28
A_2	32.13	33.52	33.79	33.15
Mean Z	32.06	34.49	34.59	
B×Z	Z_0	Z_1	Z_2	Mean B
B_0	29.68	30.78	31.57	30.68
B_1	33.07	37.11	35.39	35.19
B_2	33.42	35.58	36.81	35.27
Mean Z	32.06	34.49	34.59	

A×B×Z	A_1			A_2		
	B_0	B_1	B_2	B_0	B_1	B_2
Z_0	28.98^{f}	32.67^{cdef}	34.31^{bcde}	30.38^{ef}	33.47^{cdef}	32.53^{cdef}
Z_1	30.28^{ef}	39.2^{a}	36.91^{abc}	31.28^{def}	35.02^{abcd}	34.25^{bcde}
Z_2	31.18^{def}	36.73^{abc}	38.24^{ab}	31.96^{def}	34.04^{bcde}	35.38^{abcd}

Factors	CD (p=0.05)	SEm±
Factor (A)	NS	0.443
Factor (B)	1.558	0.542
Interaction A×B	NS	0.767
Factor (Z)	1.558	0.542
Interaction A×Z	NS	0.767
Interaction B×Z	NS	0.939
Interaction A×B×Z	NS	1.328

3.4. Number of seeds pod^{-1}

The number of seeds pod^{-1} differed significantly between genotypes, with TMB-37 (10.37) outperforming TMB-153 (9.87) (Table 4). Boron application significantly increased seeds pod^{-1}, as B_1 (10.56) and B_2 (10.49) were superior to the control (9.30) and statistically at par, indicating adequacy of foliar boron at 40 mM. Zinc treatments also showed a significant effect, with Z_1 (10.43) and Z_2 (10.49) producing more seeds pod^{-1} than Z_0 (9.43); both doses were comparable, suggesting 30 mM zinc was sufficient. All interaction effects were non-significant. The positive influence of boron and zinc on seeds pod^{-1} agrees with earlier findings in mung bean and other legumes. The positive effect of boron on number of seeds per pod was previously observed by Zafar et al. (2023), Mubeen et al. (2020), Islam et al. (2017), Alam and Islam (2016), Quddus et al. (2011) in mung bean. The positive effect of zinc on number of seeds pod^{-1} was previously observed by Zafar et al. (2023), Boradkar et al. (2023), Mubeen et al. (2020), Haider et al. (2018), Alam and Islam (2016), in mung bean. The positive effect of boron and zinc on number of seeds pod^{-1} was previously observed by Mubeen et al., (2020) in mung bean, Tripath et al., (2020) in chickpea. All the reports were in agreement with the present investigation.

3.5. Pod weight plant^{-1}(g)

The pod weight pod^{-1} differed significantly between genotypes, with TMB-37 (16.94 g) recording higher values than TMB-153 (15.51 g) (Table 5). Boron application significantly increased pod weight, as B_1 (17.08 g) and B_2 (16.90 g) were superior to the control (14.70 g) and statistically at par, indicating that foliar boron at 40 mM was sufficient. Zinc treatments also showed a significant effect, with Z_1 (16.58 g) and Z_2 (16.77 g) producing higher

Table 4: Effect of boron and zinc on number of seeds pod-1 of mung bean genotypes (TMB-37 AND TMB-153)

A×B	B_0	B_1	B_2	Mean A
A_1	9.67	10.74	10.70	10.37
A_2	8.94	10.38	10.28	9.87
Mean B	9.30	10.56	10.49	
A×Z	Z_0	Z_1	Z_2	Mean A
A_1	9.81	10.59	10.71	10.37
A_2	9.06	10.27	10.27	9.87
Mean Z	9.43	10.43	10.49	
B×Z	Z_0	Z_1	Z_2	Mean B
B_0	8.79	9.56	9.57	9.30
B_1	9.71	11.10	10.87	10.56
B_2	9.81	10.64	11.02	10.49
Mean Z	9.43	10.43	10.49	

A×B×Z	A_1			A_2		
	B_0	B_1	B_2	B_0	B_1	B_2
Z_0	9.02^{cd}	10.16^{abc}	10.26^{abc}	8.55^{d}	9.25^{bcd}	9.37^{bcd}
Z_1	9.96^{abc}	11.1^{a}	10.72^{a}	9.16^{cd}	11.1^{a}	10.56^{ab}
Z_2	10.02^{abc}	10.96^{a}	11.14^{a}	9.11^{cd}	10.78^{a}	10.91^{a}

Factors	CD (p=0.05)	SEm±
Factor (A)	0.388	0.135
Factor (B)	0.475	0.165
Interaction A×B	NS	0.234
Factor (Z)	0.475	0.165
Interaction A×Z	NS	0.234
Interaction B×Z	NS	0.286
Interaction A×B×Z	NS	0.405

Table 5: Effect of boron and zinc on pod weight plant^{-1} of mung bean genotypes (TMB-37 AND TMB-153)

A×B	B_0	B_1	B_2	Mean A
A_1	15.22	17.83	17.78	16.94
A_2	14.17	16.32	16.03	15.51
Mean B	14.70	17.08	16.90	
A×Z	Z_0	Z_1	Z_2	Mean A
A_1	15.79	17.35	17.69	16.94
A_2	14.86	15.80	15.85	15.51
Mean Z	15.33	16.58	16.77	
B×Z	Z_0	Z_1	Z_2	Mean B
B_0	14.30	14.73	15.07	14.70
B_1	15.79	18.42	17.02	17.08
B_2	15.90	16.59	18.22	16.90
Mean Z	15.33	16.58	16.77	

A×B×Z	A_1			A_2		
	B_0	B_1	B_2	B_0	B_1	B_2
Z_0	14.65^{e}	15.97^{cde}	16.76^{bcd}	13.94^{e}	15.61^{cde}	15.05^{de}
Z_1	15.24^{de}	19.46^{a}	17.35^{bc}	14.21^{e}	17.38^{bc}	15.82^{cde}
Z_2	15.78^{cde}	18.06^{ab}	19.22^{a}	14.35^{e}	15.98^{cde}	17.22^{bc}

Factors	CD (p=0.05)	SEm±
Factor (A)	0.566	0.197
Factor (B)	0.693	0.241
Interaction A × B	NS	0.341
Factor (Z)	0.693	0.241
Interaction A×Z	NS	0.341
Interaction B×Z	1.201	0.418
Interaction A×B×Z	NS	0.591

pod weight than Z_0 (15.33 g); both doses were comparable, suggesting adequacy of 30 mM zinc. Among interaction effects, only boron×zinc (B×Z) was significant, while genotype-based interactions were non-significant. The highest pod weight was observed under B_1Z_1 (18.42 g), closely followed by B_2Z_2 (18.22 g), both being statistically similar, indicating that lower combined doses of boron and zinc were sufficient. These findings agreed with earlier reports on the positive role of boron and zinc in improving pod weight in legumes and in ground nut (Aboyeji et al., 2019). All the reports were in agreement with the present investigation.

3.6. Seed weight plant^{-1} (g)

The seed weight plant^{-1} differed significantly between genotypes, with TMB-37 (11.18 g) outperforming TMB-153 (9.40 g) (Table 6). Boron application significantly increased seed weight, as B_1 (10.95 g) and B_2 (11.15 g) were superior to the control (8.77 g) and statistically at par, indicating that B at 40 mM was sufficient. Zinc treatments also showed a significant positive effect, with Z_1 (10.75 g) and Z_2 (10.86 g) producing higher seed weight than Z_0 (9.26 g), and both doses being comparable, suggesting adequacy of Z at 30 mM. The boron × zinc interaction was significant, while genotype-based interactions were non-significant. The highest seed weight was recorded under B_2Z_2 (12.83 g), followed closely by B_1Z_1 (12.62 g), both being statistically similar, indicating that lower combined doses were sufficient. These findings corroborated earlier reports on the beneficial effects of boron and zinc on seed weight in legumes (Mubeen et al., 2020).

Table 6: Effect of boron and zinc on seed weight plant^{-1} of mung bean genotypes (TMB-37 AND TMB-153)

A×B	B_0	B_1	B_2	Mean A
A_1	9.52	11.81	12.20	11.18
A_2	8.02	10.08	10.10	9.40
Mean B	8.77	10.95	11.15	
A×Z	Z_0	Z_1	Z_2	Mean A
A_1	9.98	11.74	11.81	11.18
A_2	8.55	9.75	9.90	9.40
Mean Z	9.26	10.75	10.86	
B×Z	Z_0	Z_1	Z_2	Mean B
B_0	8.26	8.97	9.09	8.77
B_1	9.57	12.62	10.65	10.95
B_2	9.96	10.66	12.83	11.15
Mean Z	9.26	10.75	10.86	

A×B×Z	A_1			A_2		
	B_0	B_1	B_2	B_0	B_1	B_2
Z_0	8.88^{efg}	10.2^{cd}	10.85^{bc}	7.64^{g}	8.94^{defg}	9.06^{def}
Z_1	9.69^{cde}	13.81^{a}	11.74^{b}	8.25^{fg}	11.43^{d}	9.58^{de}
Z_2	10^{cde}	11.42^{b}	14.01^{a}	8.18^{fg}	9.88^{cde}	11.65^{b}

Factors	CD (p=0.05)	SEm±
Factor (A)	0.371	0.129
Factor (B)	0.455	0.158
Interaction A×B	NS	0.224
Factor (Z)	0.455	0.158
Interaction A×Z	NS	0.224
Interaction B×Z	0.787	0.274
Interaction A×B×Z	NS	0.387

3.7. 100 seeds weight (g)

The 100-seed weight differed significantly between genotypes, with TMB-153 (4.64 g) recording higher values than TMB-37 (4.38 g) (Table 7). Boron treatments (B_0–B_2)

Table 7: Effect of boron and zinc on 100 seed weight plant^{-1} of mung bean genotypes (TMB-37 AND TMB-153)

A×B	B_0	B_1	B_2	Mean A
A_1	4.32	4.39	4.44	4.38
A_2	4.46	4.74	4.71	4.64
Mean B	4.39	4.57	4.57	
A×Z	Z_0	Z_1	Z_2	Mean A
A_1	4.37	4.36	4.42	4.38
A_2	4.53	4.81	4.57	4.64
Mean Z	4.45	4.59	4.50	
B×Z	Z_0	Z_1	Z_2	Mean B
B_0	4.37	4.41	4.39	4.39
B_1	4.42	4.72	4.56	4.57
B_2	4.55	4.64	4.53	4.57
Mean Z	4.45	4.59	4.50	

A×B×Z	A_1			A_2		
	B_0	B_1	B_2	B_0	B_1	B_2
Z_0	4.28^{c}	4.38^{bc}	4.44^{abc}	4.46^{abc}	4.46^{abc}	4.66^{abc}
Z_1	4.3^{c}	4.42^{bc}	4.36^{bc}	4.51^{abc}	5.01^{a}	4.91^{ab}
Z_2	4.38^{bc}	4.38^{bc}	4.51^{abc}	4.4^{bc}	4.75^{abc}	4.55^{abc}

Factors	CD (p=0.05)	SEm±
Factor (A)	0.167	0.058
Factor (B)	NS	0.071
Interaction A×B	NS	0.101
Factor (Z)	NS	0.071
Interaction A×Z	NS	0.101
Interaction B×Z	NS	0.123
Interaction A×B×Z	NS	0.175

showed a slight increase in 100-seed weight (4.39–4.57 g), but the differences were statistically non-significant. Similarly, zinc treatments (Z_0–Z_2) resulted in marginal variation (4.45–4.59 g) with no significant effect. All interaction effects (A×B, A×Z, B×Z, and A×B×Z) were non-significant. The observed trends were consistent with earlier reports highlighting the positive influence of boron and zinc on 100-seed weight in legumes (Sayed et al., 2024; Ramya et al., 2021; Quddus et al., 2020; Haider et al., 2018; Mubeen et al., 2020), thereby supporting the present findings.

3.8. Yield (kg ha^{-1})

Grain yield of TMB-37 (936.16 kg ha^{-1}) and TMB-153 (947.18 kg ha^{-1}) did not differ significantly, indicating comparable yield potential between the two genotypes (Table 8). Boron application significantly influenced yield, with B_1 (980.78 kg ha^{-1}) and B_2 (952.66 kg ha^{-1}) producing higher yields than the control (891.57 kg ha^{-1}); the lower dose B_1 (40 mM) was the most effective. Similarly, zinc treatments significantly increased yield, with Z_1 (978.75 kg ha^{-1}) and Z_2 (947.97 kg ha^{-1}) outperforming the control (898.30 kg ha^{-1}), and Z_1 (30 mM) being optimum. The B×Z interaction was significant, and the highest yield was recorded under B_1Z_1 (1057.66 kg ha^{-1}), followed by B_2Z_1 (967.63 kg ha^{-1}), whereas genotype-based interactions were non-significant. The positive effect of boron and zinc on yield was agreed for mung bean and other legumes (Alam and Islam, 2016; Mubeen et al., 2020; Mecarty et al.,2022; Krishna et al., 2022; Boradkar et al., 2023; Zafar et al., 2023; Dhaliwal et al., 2023; Kumar et al., 2023; Jejal et al., 2024; Sayed et al., 2024).

Table 8: Effect of boron and zinc on yield (kg ha^{-1}) of mung bean genotypes (TMB-37 AND TMB-153)

A×B	B_0	B_1	B_2	Mean A
A_1	892.77	962.62	953.09	936.16
A_2	890.37	998.93	952.23	947.18
Mean B	891.57	980.78	952.66	
A×Z	Z_0	Z_1	Z_2	Mean A
A_1	898.33	960.48	949.67	936.16
A_2	898.26	997.01	946.26	947.18
Mean Z	898.30	978.75	947.97	
B×Z	Z_0	Z_1	Z_2	Mean B
B_0	853.72	910.94	910.05	891.57
B_1	917.50	1057.66	967.17	980.78
B_2	923.67	967.63	966.69	952.66
Mean Z	898.30	978.75	947.97	

A×B×Z	A_1			A_2		
	B_0	B_1	B_2	B_0	B_1	B_2
Z_0	856.67^{d}	913.33^{cd}	925^{cd}	850.77^{d}	921.67^{cd}	922.33^{cd}
Z_1	908.85^{cd}	1008.66^{d}	963.92^{bc}	913.04^{cd}	1106.67^{a}	971.33^{bc}
Z_2	912.8^{cd}	965.87^{bc}	970.35^{bc}	907.29^{cd}	968.46^{bc}	963.03^{bc}

Factors	CD (p=0.05)	SEm±
Factor (A)	NS	7.821
Factor (B)	27.537	9.579
Interaction A×B	NS	13.546
Factor (Z)	27.537	9.579
Interaction A×Z	NS	13.546
Interaction B×Z	47.696	16.591
Interaction A×B×Z	NS	23.463

4. CONCLUSION

Although two genotypes, TMB-37 and TMB-153, differed significantly, individually Boron and Zinc as lower doses and in combination also exerted a benevolent effect on crop yield. Ultimately, boron at 40 mM and zinc at 30 mM, either sole or in combination are the best.

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7. REFERENCES

Aboyeji, C., Dunsin, O., Adekiya, A. O., Chinedum, C., Suleiman, K.O., Okunlola, F.O., Olofintoye, T.A., 2019. Zinc sulphate and boron-based foliar fertilizer effect on growth, yield, minerals, and heavy metal composition of groundnut (*Arachis hypogaea* L.) grown on an Alfisol. International Journal of Agronomy 2019(3), 1–7. DOI: 10.1155/2019/5347870.

Alam, M.S., Islam, M.F., 2016. Effect of zinc and boron on seed yield and yield contributing traits of mung bean in acidic soil. Journal of Biosciece and Agriculture Research 11(02), 941–946. DOI: 10.18801/jbar.110216.115.

Ali, M., Gupta, S., 2012. Carrying capacity of Indian agriculture: Pulse crops. Current Science, 102(6), 874–881. Available from: https://www.jstor.org/stable/24084502.

Alloway, B.J., 2008. Micronutrient deficiencies in global crop production. Springer, Dordrecht. https://link.springer.com/book/10.1007/978-1-4020-6860-7.

Bekuzarova, S.A., Kozyrev, A.K., Shabanova, I.A., Lushenko, G.V., Weissfeld, L.I., 2020. Enhancing of nitrogen fixation by legumes. BIO Web of Conferences 23, 02006. DOI: 10.1051/bioconf/20202302006.

Boradkar, S.G., Adsul, P.B., Shelke, M.S., Khule, Y.R., 2023. Effect of iron and zinc application on soil properties, nutrient uptake and yield of green gram (*Vigna radiata* L.) in inceptisol. The Pharma Innovation 12(3), 1663–1669. Available from: https://www.thepharmajournal.com/archives/?year=2023&vol=12&issue=3&ArticleId=19082.

Brown, P.H., Bellaloui, N., Wimmer, M.A., Bassil, E.S., Ruiz, J., Hu, H., Römheld, V., 2002. Boron in plant biology. Plant Biology 4(2), 205–223. DOI:10.1055/s-2002-25740.

Cakmak, I., 2008. Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? Plant and Soil 302, 1–17. Available from: https://link.springer.com/article/10.1007/s11104-007-9466-3.

Devi, K.M., Devi, O.R., Laishram, B., Luikham, E., Priyank, E., Singh, L.R., Babasaheb, D.B., 2023. Effect of planting geometry and nutrient management on yield, economics and quality of dwarf rice bean (*Vigna umbellata*) under rainfed condition. International Journal of Plant and Soil Science 35(9), 1–9. DOI: 10.9734/IJPSS/2023/v35i92897.

Dhaliwal, S.S., Sharma, V., Shukla, A.K., Kaur, M., Kaur, J., Verma, V., Singh, P., Barek, V., Gaber, A., Hossain, A., 2023. Biofortification of mung bean (*Vigna radiata* L. Wilczek) with boron, zinc and iron alters its grain yield and nutrition. Scientific Reports 13(1), 3506. DOI: org/10.1038/s41598-023-30539-6.

Ganeshamurthy, A.N., Rajendiran, S., Kalaivanan, D., Rupa, T.R., 2019. Zinc status in the soils of Karnataka and response of horticultural crops to zinc application: a meta-analysis. Journal of Horticultural Sciences 14(2), 98–108. Available from: https://jhs.iihr.res.in/index.php/jhs/article/download/791/525.

Goldbach, H.E., 1997. A critical review on current hypotheses concerning the role of boron in higher plants: suggestions for further research and methodological requirements. Journal of Trace Microprobe Techniques 15(1), 51–91. Available from: https://www.scienceopen.com/document?vid=7748385e-8922-4701-b6fe-d4f4de62c4a5.

Haider, M.U., Farooq, M., Nawaz, A., Hussain, M., 2018. Foliage applied zinc ensures better growth, yield and grain biofortification of mung bean. International Journal of Agriculture and Biology 20(12), 2817–2822. DOI: 10.17957/IJAB/15.0840.

Islam, M.S., Hasan, K., Sabagh, A.E., Rashwan, E., Barutçular, C., 2017. Yield and yield contributing characters of mung bean as influenced by zinc and boron. Agricultural Advances 6(1), 391–397. DOI: 10.14196/aa.v6i1.2362.

Jejal, A.D., Giri, M.D., Nagoshe, S.G., Shaniware, Y.A. Bachhav, S.S., 2024. Enhancing nutritional value of urd bean (*Vigna mungo* L. hepper) through agronomic biofortification with zinc and iron. International Journal of Plant and Soil Science 36(6), 562–569. DOI:org/10.9734/ijpss/2024/v36i64659.

Joshi, A., Rauta, S.K., Maharaa, B., Dahala, A., Upadhyayab, K.R., 2024. Effect of boron and zinc on yield and yield attributing traits of spring mung bean (*Vigna radiata* L.) in Kailali condition. Sustainability in Food and Agriculture 5(2), 70–77. DOI: http://doi.org/10.26480/sfna.02.2024.70.77.

Kakon, S.S., Bhuiya, M.S.U., Hossain, S.M.A., Sultana, N., 2015. Flowering behaviour and seed yield of french bean as affected by variety. International Journal of Applied Sciences and Biotechnology 3(3), 483–489.

DOI: 10.3126/ijasbt.v3i3.12566.

Karimunnisa, S., Umesha, C., Khan, S.A., 2021. Effect of foliar application of boron and soil application of zinc levels on growth and yield of cowpea (*Vigna unguiculata*). The Pharma Innovation International Journal 10(8), 1341–1344. DOI:org/10.22271/tpi.2021.v10.i8s.7434.

Kavya, P., Singh, S., Hinduja, N., Tiwari, D., Sruthi, S., 2021. Effect of foliar application of micronutrients on growth and yield of green gram (*Vigna radiata* L.). Legume Research 44(12), 1460–1464. DOI: 10.18805/LR-4445.

Krishna, B.M., Kumar, H.S., Priyanka, G., Nail, M., Umesha, C., 2022. Influence of boron and zinc on growth and yield of green gram (*Vigna radiata* L.). The Pharma Innovation 11(3), 1674. Available from: https://arccjournals.com/journal/indian-journal-of-agricultural-research/A-6412.

Kumar, R., Saren, B.K., Patel, S.K., 2023. Effect of foliar application of zinc and boron on growth attributes and yield of chickpea (*Cicer arietinum* L.) varieties. International Journal of Plant and Soil Science 35(21), 958–965. DOI: 10.9734/IJPSS/2023/v35i214066.

Lambrides, C.J., Godwin, I.D., 2007. Mungbean. In: Chittarajan, K. (Ed.), Genome mapping and molecular breeding in plants–pulses, sugar and tuber crops. Springer, 69–90. DOI:org/10.1007/978-3-540-34516-9.

Matthes, M.S., Robil, J.M., McSteen, P., 2020. From element to development: the power of the essential micronutrient boron to shape morphological processes in plants. Journal of Experimental Botany 71(5), 1681–1693. https://DOI.org/10.1093/jxb/eraa042.

Marschner, H., 2012. Marschner's mineral nutrition of higher plants (3rd Edn.). Academic Press, Elsevier. Academy press, DOI: 10.1016/C2009-0-63043-9. ISBN:978-0-12-384905-2.

Mecarty, J.S., Dawson, J., Lalrammawii, C., 2022. Effect of micro-nutreints on growth and yield of green gram (*Vigna radiata* L.*)*. The Pharma Innovation 11(7), 2967–2969. Available from: https://www.thepharmajournal.com/archives/? year=2022&vol=11&issue=7&ArticleId=14457.

Mondal, S., Bose, B., 2019. Impact of micronutrient seed priming on germination, growth, development, nutritional status and yield aspects of plants. Journal of Plant Nutrition 42(19), 2577–2599. DOI:10.1080/01904167.2019.1655032

Movalia, D.J., Donga, S., Parmar, K.B., 2020. Effect of boron and molybdenum on summer green gram (*Vigna radiata* L.) (GM-4) under medium black calcareous soils: A review. In: Proceedings of the National Conference on Innovations in Biological Sciences (NCIBS) 10, 599–625. DOI: 10.2139/ssrn.3585103 https://ssrn.com/abstract=3585103.

Mubeen, A., Saeed, M.T., Saleem, M.F., Wahid, M.A., 2020. Zinc and boron application improves yield, yield components and gross returns of mung bean (*Vigna radiata* L.). Journal of Arable Crops and Marketing 2(2), 79–87. DOI: 10.33687/jacm.002.02.3521.

Nair, R.M., Pandey, A.K., War, A.R., Hanumantharao, B., Shwe, T., Alam, A.K.M.M., Pratap, A., Malik, S.R., Karimi, R., Mbeyagala, E.K., Douglas, C.A., Rane, J., Schafleitner, R., 2019. Biotic and abiotic constraints in mungbean production-progress in genetic improvement. Frontiers in Plant Science 10, 1340. https://doi.org/10.3389/fpls.2019.01340.

Nair, R.M., Yang, R.Y., Easdown, W.J., Thavarajah, D., Thavarajah, P., Hughes, J.D.A., Keatinge, J.D.H., 2013. Biofortification of mung bean (*Vigna radiate* L.) as a whole food to enhance human health. Journal of the Science of the Food and Agriculture 93(8), 1805–1813. DOI: 10.1002/jsfa.6110.

Naz, R., Khan, M.K., Hafeez, A., Fazil, M., Khan, M.N., Ali, B., Javed, M.A., Imran, M., Shati, A.A., Alfaifi, M.Y., Elbehairi, S.E.I., Ahmed, A.E., 2022. Assessment of phytoremediation potential of native plant species naturally growing in a heavy metal-polluted industrial soils. Brazilian Journal of Biology 84. DOI: 10.1590/1519-6984.264473.

Quddus, M.A., Rashid, M.H., Hossain, M.A., Naser, H.M., 2011. Effect of zinc and boron on yield and yield contributing characters of mung bean in low ganges river floodplain soil at Madaripur, Bangladesh. Bangladesh Journal of Agricultural Research 36(1), 75–85. DOI: 10.3329/bjar.v36i1.9231.

Ramya, N., Mamatha, B., Reddy, K. M., Subbarayappa, C. T., Sukanya, T. S., 2021. Effect of soil and foliar application of boron on yield and economics of green gram (*Vigna radiata* L.). International Journal of Plant & Soil Science 33(22), 314–322. DOI: 10.9734/ijpss/2021/v33i2230783.

Rerkasem, B., Jamjod, S., Pusadee, T., 2020. Productivity limiting impacts of boron deficiency, a review. Plant and Soil 455, 23–40. Available from: https://link.springer.com/article/10.1007/s11104-020-04676-0.

Sayed, M., Hosen, M., Rahman, M.H., Morium, M., Islam, M.R., Kubra, M.K., Hossain, M.A., Khatun, M.S., Shaddam, M.O., Islam, M.R., Iqbal, M.A., Soufan, W., El sabagh, A., Islam, M.S., 2024. Effect of boron and zinc on growth, yield attributes, yield and nutrient bio-fortification of grass pea (*Lathyrus sativus* L.) in old himalayan piedmont plain. Applied Ecology and Environmental Research 22(3), 2277–2305. DOI: 10.15666/aeer/2203_22772305.

Selim, M.S., Adhikary, S., Mondal, M.A., Nadim, K.A., Akter, B., 2023. Foliar application of different levels of zinc and boron on the growth and yield of mungbean (*Vigna radiata* L.). Turkish Journal of Agriculture – Food Science and Technology 11(8), 1415–1421. DOI: https://doi.org/10.24925/turjaf.v11i8.1415-1421.6107.

Tania, S.A., Uddin, F.J., Sarkar, M.A.R., 2019. Responses of selected mung bean (*Vigna radiata* L.) varieties to boron fertilization. Fundamental and Applied Agriculture 4(1), 655–660. DOI: https://doi.org/10.5455/faa.815.

Tribhuwan, A.R., Puri, A.N. Chavan, B.R. 2024. Effect of micronutrient application on growth, yield and quality of green gram growing iron and zinc deficient soils of Renapur Tahsil, Latur. International Journal of Plant and Soil Science 36(5), 771–779. DOI: https://doi.org/10.9734/ijpss/2024/v36i54575.

Tripath, D.K., Kumar, S., Zaidi, S.F.A., 2020. Effect of phosphorus, sulphur and micronutrients (Zinc and Boron) levels on performance of chickpea (*Cicer arietinum* L.). National Academy Science Letters 43, 9–11. DOI: https://doi.org/10.1007/s40009-019-00802-4.

Venkidasamy, B., Selvaraj, D., Nile, A. S., Ramalingam, S., Kai, G., Nile, S.H., 2019. Indian pulses: A review on nutritional, functional and biochemical properties with future perspectives. Trends in Food Science and Technology 88, 228–242. https://DOI.org/10.1016/j.tifs.2019.03.012.

Zafar, M., Ahmed, S., Munir, M.K., Zafar, N., Saqib, M., Sarwar, M.A., Gulnaz, A., 2023. Application of zinc, iron and boron enhances productivity and grain biofortification of mung bean. Phyton-International Journal of Experimental Botany 92(4), 983–999. DOI: https://doi.org/10.32604/phyton.2023.025813.