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

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Abstract. Soil applied micronutrient, especially boron (B) and zinc (Zn) can trigger growth, yield attributes, yield and nutritional value of crops including grass pea, however determination of their optimal dose under changing pedo-climatic conditions needs fresh studies. A trial was conducted to study the effect of B (B_1 = 0 kg ha^{-1}, B_2 = 4 kg ha^{-1}, B_3 = 8 kg ha) and Zn (Zn_1 = 0 kg ha^{-1}, Zn_2 = 1.5 kg ha^{-1}, Zn_3 =3.0 kg ha^{-1}) on growth and yield of grass pea (cv. BARI Khesari-5). The response variables included plant height, fresh shoot and root weight, dry shoot and root weight, number of grains and pods plant^{-1}, 100 grain weight, grain yield, biological yield and harvest index. Additionally, B and Zn contents of grass pea were also determined. The B_2 treatment recorded the tallest plants (109.70 cm) and 100 grain weight (5.79 gm) which led to maximum grain yield (1.72 t ha^{-1}), biological yield (4.54 t ha^{-1}) and harvest index (37.86 %). The same treatment remained superior by recording the maximum B and Zn contents of 31.55 ppm) and 56.47 ppm, respectively, whereas B_1 had the lowest corresponding values. Among Zn doses under investigation, Zn_2 remained unmatched by producing the maximum yield attributes, whereas Zn_1 could not perform at par to the rest of the treatments. Overall, the interactive effect of B_2 and Zn_2 surpassed other treatment combinations by exhibiting superior yield attributes which led to the highest grain yield (1.94 t ha^{-1}), straw yield (2.92 t ha^{-1}), biological yield (4.86 t ha^{-1}), harvest index (39.96 %). The same treatment combination gave the maximum B (33.29 ppm) and Zn content (58.70 ppm), whereas B_1 andZn_1 treatment combination remained inferior to rest of treatment combinations. Based on recorded findings, it could be inferred that co-application of B (4 kg ha^{-1}) and Zn (1.5 kg ha^{-1}) with recommended doses of other fertilizers hold potential to increase the seed yield and minerals bio-fortification of grass pea.
Keywords: *dose optimization, growth, micro-nutrients, yield traits, minerals bio-fortification*

Introduction

Pulses are important in human nutrition among the food crops grown in Bangladesh, and are considered as meat of the poor as well as cheapest source of protein for underprivileged group of people who cannot afford to buy animal proteins (Hariyappa, 2006; Asif et al., 2013). Food legumes are integral component of daily diets in South Asian states especially Bangladesh (Rahman et al., 2000). These are extensively cultivated as a source of dietary protein, and to ensure the diversification in predominating cereal-based cropping systems. On an average, Bangladeshi diet only of 8-10% of the protein intake originate from animal sources, while the rest comes from the consumption of pulses (Kabir, 1987). Due to rich in fiber and phenols, pulses also have therapeutic values (preventive against cancer, diabetes, and heart disease, digestibility) as well as rich source of vitamins (Vitamin B including foliate, thiamine and niacin) and minerals (iron, zinc, potassium, and magnesium). According to FAO's estimates for 2014-16, there are nearly 795 million undernourished people in the world, and 267 million are from Southern Asia most of which are concentrated in India (71%), Pakistan (14%), and Bangladesh (9%). In case of Bangladesh, domestic production can supply about 13 g/head/day in Bangladesh, whereas annual demand is 2.50 million metric tons, but domestic production is only 1.0386 million metric tons/year, which is only 41.54% of the total demand (AIS, 2019; Pandey et al., 2019). Consequently, every year Bangladesh spends a huge foreign exchange (US$1659 million) for importing pulses where 411, 590 and 658 million US$ were spent in 2018-19, 2019-20 and 2020-21 financial year, respectively (Bangladesh Bank, 2021).

Grass pea (*Lathyrus sativus* L.), belonging to the family Fabaceae, constitutes as a vital grain pulse crop in Bangladesh (Hanbury et al., 2000). In addition, the potential of grass pea for animal feed is also high owing to huge biomass production that makes it a competitive forage crop (Hasan et al., 2015). It ranked as one of the most cultivated pulse crop during 2017-18 in terms of area (0.2783 million hectares), production (0.3529 million metric tons) and average yield (1.268 t ha^{-1}), cultivated as a pulse crop in Bangladesh (Pandey et al., 2019). As per data of the FAO (2006), grass pea yield in Bangladesh has remained persistently low compared to China (5,900 kg ha^{-1}), Kazakhstan (3,127 kg ha^{-1}), Russian Federation (2,425 kg ha^{-1}), Israel (1,634 kg ha^{-1}), and Mexico (1,534 kg ha^{-1}). Several underlying limiting factors exist, including suboptimal use of fertilizers concerning timing, quantity, application method, and dosage (Mansoor, 2007). Micronutrients deficiency, a notable factor particularly in nutrient scarcity, significantly crop yield potential. However, there is considerable potential to increase production by cultivating high-yielding varieties and implementing balanced fertilization practices, including the application of micronutrients.

Micronutrients deficiencies especially zinc (Zn) and boron (B) has been reported as leading cause of suboptimal yield of crops including grass pea (Fageria and Baligar, 2005; Duffy et al., 2007; Khatun et al., 2018; Das and Parida, 2020; Islam et al., 2021; Ghosh et al., 2021; Sridhar et al., 2021). These micronutrients improve crops yield by triggering biological nitrogen fixation (BNF) process. The Zn in optimum concentration is required by crop plants for balanced metabolism and activation of numerous physiological functions such as sustaining rate of photosynthesis, biosynthesis of sugar, avoid sterility, promote seed production, and imparts disease resistance (Solanki et al., 2016). Its deficiency has been associated with decreased crop yield and resulted in delayed maturity of crops (Islam et al., 2017a). Additionally, Zn deficiency caused significant decline in water use efficiency (Khan et al., 2004; Kasim, 2007; Disante et al., 2010) along with hampering the nodulation and BNF process (Ahlawat et al., 2007; Fageria, 2008). However, its application on optimal concentration is highly mandatory because its toxicity restricts photosynthesis by preventing the biosynthesis of chlorophyll (Doncheva et al., 2001). It enables crop plants to sustain the deleterious

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effects of heat stress (Peck and McDonald, 2010) and salinity (Tavallali et al., 2010). More importantly, Zn triggers the biosynthesis of IAA precursor called tryptophan (Alloway, 2004), thus its deficiency reduced the biosynthesis of growth hormones especially auxin (Brennan, 2005; Valenciano et al., 2010; Rehman et al., 2012).

Besides Zn, another vital micronutrient is B which, tends to increase crop plants height and other vegetative growth-related traits including the leaf area index (Qamar et al., 2016; Choudhary et al., 2022; Bari et al., 2023a,b). In addition, numerous physiological process including cell division, maturation and elongation are affected by B concentration, along with reproductive growth traits such as pod formation and grain filling. Moreover, several metabolic process are suppressed by B deficiency such as growth hormones, proteins and carbohydrates biosynthesis which compromise the stability of phenol metabolism and membranes integrity (Bhatt et al., 2004; Singh et al., 2004; Vitosh et al., 2006; Tanaka and Fujiwar, 2008; Sathya et al., 2009; Islam et al., 2017b). The B deficiency caused the necrosis of terminal buds, internodes shortening, chlorosis, and flower buds shedding. Ahmad et al. (2012) inferred that restricted nodulation caused huge yield losses in legumes owing to B stress.

Although irregular research works on grass pea response to primary fertilizers have been done but the effect of B and Zn on growth, yield, and micronutrients bio-fortification of grass pea are still scanty. Therefore, there is a prime need to study the effects of B and Zn on the yield of grass pea in Old Himalayan Piedmont Plain (AEZ-1) preferably under field trials. Moreover, farmers are unaware about the use of micronutrient like Zn and B in grass pea cultivation that have capability to increase the yield of grass pea. So, fresh research was needed to bridge the research gaps for increasing grass pea yield through optimized application of B and Zn. Thus, an experiment entailing variable rates of B and Zn application was conducted to assess their individual and interaction effects on grass pea yield attributes, yield, and micronutrients bio-fortification in grains.

Materials and Methods

Location and duration

The trial was conducted at the Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh (25.6980º N; 88.6550º E and 40 m above sea level) during the period from November 2021 to February 2022 in the Agro Ecological Zone (AEZ) of Old Himalayan Piedmont Plain (AEZ-1) (BARC, 2018).

Climatic conditions

The climate was subtropical with low temperature and minimum rainfall during November to February that is the main feature of the Rabi season. Temperature during the cropping period ranged from 8.95 to 31.91 °C, whereas humidity varied from 60.45 to 73.52%. The total sunshine hour during the crop growing season was 3.43-6.64 hrs, whereas the minimum precipitation (2.61 mm average) was received during the entire duration of the trial (*Table 1*).

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***Table 1.** Monthly recorded of air temperature, rainfall, relative humidity and sunshine at the experimental site*

Months	Temperature (^{0}C)		Relative humidity (%)	Rainfall (mm) Total	Sunshine (hr) (Total)
	Minimum	Maximum			
November 2021	10.51	20.81	60.45	2.12	5.23
December 2021	8.95	22.40	62.14	0.00	3.43
January 2022	13.98	28.19	66.69	0.00	5.73
February 2022	18.81	31.91	73.52	8.30	6.64

Source: Bangladesh Meteorological Department (Weather Research Station) Rajbati, Dinajpur

Characteristics of experimental field soil

The soil of the experimental field belongs to Ranisankil series of Non-calcareous brown floodplain under the AEZ-1. As per USDA soil classification system, the experimental soil falls under Inceptisol order (UNDP and FAO, 1988). Soil of the experimental plot was analyzed before seed sowing. The experimental plot was medium high land with good drainage capacity and sandy loam soil with the pH range from 5.5 to 7.5. The morpho-physico-chemical properties of the experiment soil are presented in the *Table 2*.

Experimental treatments and design

The experiment entailed three levels of boron viz., $B_1 = 0$ kg ha^{-1}, $B_2 = 4$ kg ha^{-1}, $B_3 = 8$ kg ha^{-1}, and three Zn levels viz., $Zn_1 = 0$ kg ha^{-1}, $Zn_2 = 1.5$ kg ha^{-1}, $Zn_3 = 3.0$ kg ha^{-1}. Randomized Complete Block Design (RCBD) having three replications were used to execute the trial. The layout of the experiment was prepared for distributing the combination of doses of B and Zn. The net plot size was 2.5 m × 2.0 m.

Planting material

The variety BARI Khesari-5 was used as the test crop. The seeds were collected from the Agricultural Research Station, Rajbari, Dinajpur. Bangladesh Agriculture Research Institute (BARI), Gazipur developed BARI Khesari-5 in 2010, in collaboration with the International Agricultural Research Institute ICARDA (International Center for Agricultural Research in the Dry Areas). Therefore, this variety was approved for commercial cultivation by the National Seed Board in 2018. The variety can be grown in *Rabi* season (mid October to mid March). Life cycle of this variety ranges from 120-125 days, with a maximum grain yield of 1.6-1.9 t ha^{-1}.

Growing of crops

Before ploughing, the experimental block was irrigated, and subsequently power tiller was employed. Thereafter, four ploughing were performed to pulverize the soil. Urea, triple super phosphate (TSP), muriate of potash (MOP), and gypsum were added for nitrogen (N), phosphorous (P), potassium (K), and gypsum (S) sources, respectively. Their dose was40, 80, 30, 50 kg ha^{-1} of N, P, K and S, respectively following the recommendation BARI (2019). All of the fertilizers along with Zn and B were applied from $ZnSO_4$ and boric acid, respectively as per treatment during final land preparation. The seeds of grass pea (variety BARI Khesari-5) were treated with Provax 200FF @ 0.3% (for preventing soil borne diseases) and sown on 25 November 2021.

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Table 2. *Morpho-physioco-chemical properties of soil (experimental field)*

A. *Morphological characteristics of the soil*

Constituents	Characteristics
Location	Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh
Agro-ecological zone	Old Himalayan Piedmont Plain (AEZ-1)
Geographical position	$25^0$38N latitude and $88^0$41E longitude
General Soil type	Non-calcareous dark grey floodplain
Parent materials	Old Brahmaputra River borne deposit
Land type	Medium high land
Elevation	37 meter above the mean sea level
Drainage	Well drained
Topography	Fairly level
Soil texture	Sandy loam
Soil Color	Dark grey
Flood level	Above flood level

B. *Physical properties of experimental field soil*

Constituents	Results
Particle size analysis	
Sand (%)	58
Silt (%)	28
Clay (%)	14
Soil texture	Sandy loam

C. *Chemical properties of experimental field soil*

Characteristics	Analytical value	Critical value	Interpretation	Analytical methods
pH (Soil: water = 1: 1.25	5.41	-	VL	Glass-electrode pH meter method (Page et al., 1982)
Organic carbon	0.72	-	L	Wet oxidation method (Black, 1965).
Organic matter	1.25	-	L	Calculated by Van Bemmelen factor 1.73 (Piper, 1966).
Total N	0.08	0.12	VL	Micro-Kjeldahl method (Bremner and Mulvaney, 1982).
Available P (ppm)	11.20	12.00	L	Molybdate blue ascorbic acid method (Bray and Kurtz, 1945)
Exchangeable K (meq)	0.10	0.12	L	Determined by Flame photometer
Exchangeable Ca (meq)	2.48	2.00	L	Atomic Absorption Spectrophotometer (AAS) (Knudsen et al., 1982)
Exchangeable Mg (meq)	2.29	0.50	M	Extractable method (Hunter, 1972)
Available S (ppm)	17.29	10.00	M	Turbidity method using $BaCl_2$ (Fox et al., 1964)
Available B (ppm)	0.14	0.20	L	Mono-calcium bi-phosphate method, determined by Spectro-photometer following Azomethine H method (Page et al.,1982)
Available Zn (ppm)	0.92	0.60	M	AAS (Lindsay and Norvell, 1978)
Available Fe (ppm)	44.22	4.00	M	AAS (Lindsay and Norvell, 1978)
Available Mn (ppm)	12.13	1.00	H	AAS (Lindsay and Norvell, 1978)
CEC (meq/100 g soil)	5.7	-	-	Sodium acetate saturation method (Rhoades, 1982)

Source: Results obtained from the chemical analysis of the initial soil sample (SRDI, Dinajpur)

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Furrow (having depth of 2-3 cm) sowing method was adopted, whereas 25 cm was the row to row distance. Thinning was done twice (15 and 30 DAS) in order to eradicate extra plant population. At early stage of growth, few worms (*Agrotis ipsilon*) and virus vectors (jassid) infested the young plants, and at later stage of growth, the pod borer (*Maruca testulalis*) attacked the plant. Dimacron 50 EC was sprayed at the rate of 1 liter ha^{-1} to control the insects. Harvesting was done when 90% of the pods became brown in color. The matured pods were collected from a pre-demarked area of three linear meters at the center of each plot.

Data collection

Randomly, five plants were selected for recording data of response variables. The height of grass pea plant was measured using a Tailor's measuring tape. In addition, grain yield and stover yield were estimated by harvesting whole plots, and their weight was measured using a spring balance. Moreover, harvest index was determined using below equation:

$$\text{HI (\%)} = \frac{\text{Economic yield (seed weight)}}{\text{Biological yield (Total dry weight)}} \times 100 \qquad \text{(Eq.1)}$$

Chemical analysis

The content of boron in samples was determined by spectrophotometric method using Azomethine-H reagent. Exactly 5 ml of exact was taken in a 25 ml volumetric flask, followed by the addition of 4 ml buffer masking solution and 4 ml Azomethine-H. Then the volume was made up to the mark. After one hour, the absorbance was measured at a wavelength of 420 nm using a spectrophotometer following the analytical technique outline by Tandon (1995). Zinc was determined by atomic absorption spectrometry by direct aspiration of the sample into an air-acetylene flame. The blank (acidified water) was aspirated to set the automatic zero control. The automatic concentration control was used to set the concentrations of standards. Five standard zinc solutions were used, and the instrument was calibrated each time a set of samples was analyzed and checked calibration at reasonable interval.

Estimation of optimum level of B and Zn through simple polynomial regression equation

The most advantageous level of B and Zn was calculated from simple polynomial regression equation i.e., $Y = a + bx – cx^2$ (Gomez and Gomez, 1984). Here, Y = dependent variable (yield attributes), a = Intercept (constant), b and c are the regression coefficients and x = Independent variable (nutrient element). The optimum levels of B and Zn for maximum yield was NO = -b/2c. Calculation of grain yield was also measured against optimum B and Zn levels through developed functional relationship.

Statistical analysis

The collected data of all response variables were statistically analyzed to determine the significant difference using the MSTAT-C statistical package by employing the

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analysis of variance (ANOVA). Thereafter, Duncan's Multiple Range Test (DMRT) at 5% level of probability was employed to determine the significance among treatment means (Gomez and Gomez, 1984).

Results and Discussion

Crop growth characteristics of grass pea

Plant height (cm)

The plant height of grass pea showed statistically significant variation at 30, 45, 60 DAS and at final harvest due to the application of different dose of B and Zn (*Table 3*). Result showed that the B_2 treatment showed the tallest plant (23.82 and 109.70 cm) at 30 DAS and final harvest, respectively. While, the shortest plant (19.01, 30.55, 41.73 and 100.5 cm) was recorded from B_1 treatment at 30, 45 and 60 DAS and FH, respectively. Previously, it has been reported that B promoted the growth of crop plants by triggering the cell division process, and resulted in robust vegetative growth. Our findings revealed that increasing rate of B fertilizer resulted in taller plants of grass pea. Chatterjee and Bandyopadhyay (2017), Islam et al. (2019), Hoque et al. (2021), Karthik et al. (2021a), Roshid (2021), Deep et al. (2022), Bari et al. (2023a,b) and many other researchers recorded similar results in different crops from their earlier experiment. Islam et al. (2017a) found a positive effect of boron on the plant height of mungbean. In case of Zn effect, the Zn_3 treatment showed the tallest plant (111.90 cm) at FH which was statistically similar with Zn_2, whereas the shortest plant (19.89, 33.27, 46.96, and 96.81 cm) was recorded with Zn_1 at 30, 45, 60 DAS and at FH, respectively. Among the different treatments, Zn_3 was found very effective in producing tallest plants. These results are in agreement to the findings obtained by Yashona et al. (2018), Saakshi et al. (2020), Ghosh et al. (2021), Sümer and Yaraşir (2022). Combined application of B and Zn showed statistically significant variation on the plant height at all sampling dates (*Table 3*). At 60 DAS, B_2 x Zn_2 treatment gave the tallest plant (57.08 cm) which was statistically similar with B_3 x Zn_2 (56.98 cm), B_3 x Zn_3 (56.63 cm), B_2 x Zn_3 (56.32 cm), and at harvest, the tallest plant (117.50 cm) was observed from B_2 x Zn_3 treatment. Contrarily, the most dwarf plants (17.32, 27.13, 38.65 and 97.67 cm at 30, 45, 60 and FH, respectively) were observed from B_1 x Zn_1 treatment. Similar results were found by Karan and Singh (2014), Islam et al. (2017a), Saha et al. (2018), Doddamani et al. (2020), Fatima et al. (2021), and Roy et al. (2022).

Shoot fresh weight

The shoot fresh weight of grass pea exhibited statistically significant difference at 30, 45, 60 DAS and at FH due to the application of B and Zn (*Table 4*). Results indicated that B_2 showed the highest shoot fresh weight, with values of 4.74, 10.23, 14.00 and 14.61 g plant^{-1} was observed from at 30, 45 & 60 DAS and FH, respectively. However, these values were statistically similar with B_3 treatment at 45 and 60 DAS. On the contrary, the lowest shoot fresh weight (2.21, 5.89, 9.12 and 9.67 g plant^{-1} at 30, 45, 60 DAS and FH, respectively) was recorded with B_1 treatment. Moghazy et al. (2014) discovered that foliar spraying with boron (boric acid 17% B) at 50 ppm improved the vegetative development features of green pea, i.e., shoot fresh weight per plant.

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Table 3. *Effect of boron and zinc on the plant height of grass pea at different DAS*

Treatments	Plant height (cm)			
	30 DAS	**45 DAS**	**60 DAS**	**FH**
		Levels of B		
B_1	19.01 c	30.55 b	41.73 b	100.50 c
B_2	23.82 a	42.38 a	54.71 a	109.70 a
B_3	22.96 b	42.17 a	55.03 a	107.00 b
LSD	0.286	0.392	0.516	0.914
		Levels of Zn		
Zn_1	19.89 c	33.27 b	46.96 b	96.81 c
Zn_2	23.10 a	40.94 a	52.42 a	108.40 b
Zn_3	22.79 b	40.89 a	52.10 a	111.90 a
$LSD_{0.05\%}$	0.286	0.392	0.516	0.914
		Interaction of B and Zn		
B_1 x Zn_1	17.32 g	27.13 d	38.65 d	97.67 f
B_1 x Zn_2	19.82 f	32.33 c	43.18 c	100.60 e
B_1 x Zn_3	19.89 f	32.28 c	43.35 c	103.10 d
B_2 x Zn_1	21.62 d	36.37 b	50.73 b	100.70 e
B_2 x Zn_2	25.20 a	45.45 a	57.08 a	115.00 b
B_2 x Zn_3	24.65 b	45.32 a	56.32 a	117.50 a
B_3 x Zn_1	20.75 e	36.30 b	51.48 b	96.07 f
B_3 x Zn_2	24.18 bc	45.15 a	56.98 a	109.70 c
B_3 x Zn_3	23.93 c	45.07 a	56.63 a	115.20 b
CV (%)	1.30	1.02	1.02	0.86
$LSD_{0.05\%}$	0.49	0.679	0.894	1.583

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV: Co-efficient of variation, LSD: Least significant difference

Table 4. *Effect of B and Zn on the shoot fresh weight of grass pea at different DAS*

Treatments	Shoot fresh weight (g $plant^{-1}$)			
	30 DAS	**45 DAS**	**60 DAS**	**FH**
		Levels of B		
B_1	2.21 c	5.89 b	9.12 b	9.67 c
B_2	4.74 a	10.23 a	14.00 a	14.61 a
B_3	4.64 b	10.22 a	13.87 a	14.17 b
LSD	0.077	0.158	0.383	0.426
		Levels of Zn		
Zn_1	2.90 b	7.22 b	10.56 b	10.42 b
Zn_2	4.38 a	9.60 a	13.26 a	13.48 a
Zn_3	4.31 a	9.51 a	13.17 a	13.35 a
$LSD_{0.05\%}$	0.077	0.158	0.383	0.426
		Interaction of B and Zn		
B_1 x Zn_1	1.71 e	4.74 d	7.74 d	9.57 e
B_1 x Zn_2	2.49 d	6.47 c	9.73 c	11.27 d
B_1 x Zn_3	2.44 d	6.47 c	9.91 c	11.17 d
B_2 x Zn_1	3.60 b	8.49 b	12.03 b	12.34 c
B_2 x Zn_2	5.33 a	11.11 a	14.86 a	15.94 a
B_2 x Zn_3	5.29 a	11.07 a	15.00 a	15.84 a
B_3 x Zn_1	3.40 c	8.44 b	11.82 b	12.94 c
B_3 x Zn_2	5.31 a	11.22 a	14.92 a	15.83 a
B_3 x Zn_3	5.20 a	10.99 a	14.87 a	16.04 a
CV (%)	1.92	1.79	3.11	3.53
LSD0.05%	0.134	0.274	0.664	0.738

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, FH: Final harvest, LSD: Least significant difference

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It was noted that at 30, 45 and 60 DAS and FH, the highest shoot fresh weight (4.38, 9.60, 13.26, 13.48 g plant^{-1}) was observed from Zn_2 treatment which was statistically similar (4.31, 9.51, 13.17 and 13.35 g plant^{-1} at 30, 45 and 60 DAS, and FH) with Zn_3 treatment, whereas the lowest shoot fresh weight (2.90, 7.22, 10.56, and 10.42 g plant^{-1}, respectively) was recorded from Zn_1. El-Afifi et al. (2016) had also inferred similar results. At harvest, the shoot fresh weight of 16.04 g plant^{-1} was observed from B_3 x Zn_3 treatment which was statistically similar with B_2 x Zn_2 (15.94 g plant^{-1}), B_2 x Zn_3 (15.84 g plant^{-1}), B_3 x Zn_2 (15.83 g plant^{-1}) treatments, while the lowest shoot fresh weight (1.71, 4.74, 7.74 and 9.57 g plant^{-1}) was recorded with B_1 x Zn_1 at 30, 45, 60 and FH, respectively. Similar results were found by Moghazy et al. (2014), among others. El-Afifi et al. (2016) discovered that spraying cowpea plants with a mixture of 6% Fe, 5% Zn, and 1% B significantly increased root fresh weight in all experiments compared to controls.

Root fresh weight

The root fresh weight of grass pea was significantly influenced by the application of B, Zn, and their interaction at 30, 45, 60 DAS and at FH (*Table 5*). However, the results indicated that B_2 showed the highest root fresh weight 0.58, 0.59, 0.63 and 0.67 g plant^{-1} at 30, 45, 60 DAS and FH, respectively which was statistically similar with B_3 (0.56, 0.58, 0.62 and 0.65 g plant^{-1} at 30, 45, 60 DAS and FH, respectively). On the contrary, the lowest root fresh weight (0.39, 0.41, 0.52 and 0.55 g plant^{-1}, respectively) was recorded with B_1 treatment. Moghazy et al. (2014) found that the vegetative growth traits of green pea, i.e., root fresh weight per plant had high significant values by foliar spraying with boron (boric acid 17% B) at 50 ppm. The highest root fresh weight (0.54, 0.56, 0.59, and 0.62 g plant^{-1}) was observed from Zn_2 treatment at 30, 45, 60 DAS, and at FH, respectively, which was statistically similar (0.53, 0.55, 0.58, and 0.60 g plant^{-1}, respectively) with Zn_3. On the contrary, the lowest root fresh weight (0.46, 0.48, 0.51 and 0.52 g plant^{-1} at 30, 45, 60 DAS, and FH, respectively) was recorded with Zn_1. Among the different treatments, Zn_2 was found very effective to had maximum root fresh weight. El-Afifi et al. (2016) and many other researchers recorded similar results in different crops from their earlier experiment. Combined application of B and Zn revealed that the highest root fresh weight (0.67 g plant^{-1}) was observed from B_2 x Zn_2 treatment which was statistically similar with B_3 x Zn_3 (0.65 g), B_2 x Zn_3 (0.65 g), B_3 x Zn_2 (0.64 g plant^{-1}) treatments, while the lowest root fresh weight (0.37, 0.39, 0.41, and 0.42 g plant^{-1} at 30, 45, 60 and FH, respectively) was recorded with B_1 x Zn_1. Among the different treatments, B_2 x Zn_2 was found very effective to had maximum root fresh weight. El-Afifi et al. (2016), who found significant increase in root fresh weight in cowpea plants sprayed with a mixture of 6% Fe, 5% Zn, and 1% B compared to controls.

Shoot dry weight

The shoot dry weight of grass pea showed statistically significant variation at 30, 45, 60 DAS and FH due to the application of B, Zn, and their combined effect (*Table 6*). Results indicated that at 30, 45, 60 DAS and at FH, the highest shoot dry weight (0.12, 0.60, 1.86 and 1.96 g plant^{-1}, respectively) was observed from B_2 which was statistically similar with B_3 (0.12, 0.57, 1.84 and 1.95 g plant^{-1} at 30, 45, 60 DAS and FH, respectively). On the contrary, the lowest shoot dry weight (0.07, 0.34, 1.21 and 1.30 g plant^{-1} at 30, 45, 60 DAS and during FH, respectively) was recorded with B_1. Among the different treatments, B_2 was found very effective in achieving maximum shoot dry weight.

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Table 5. *Effect of B and Zn on the root fresh weight of grass pea at different DAS*

Treatments	Root fresh weight (g plant^{-1})			
	30 DAS	**45 DAS**	**60 DAS**	**FH**
	Levels of B			
B_1	0.39 b	0.41 b	0.52 b	0.55 b
B_2	0.58 a	0.59 a	0.63 a	0.67 a
B_3	0.56 a	0.58 a	0.62 a	0.65 a
LSD	0.032	0.032	0.032	0.077
	Levels of Zn			
Zn_1	0.46 b	0.48 b	0.51 b	0.52 b
Zn_2	0.54 a	0.56 a	0.59 a	0.62 a
Zn_3	0.53 a	0.55 a	0.58 a	0.60 a
$LSD_{0.05\%}$	0.032	0.032	0.032	0.077
	Interaction of B and Zn			
B_1 x Zn_1	0.37 c	0.39 d	0.41 d	0.42 d
B_1 x Zn_2	0.39 c	0.41 c	0.43 c	0.45 c
B_1 x Zn_3	0.40 c	0.41 c	0.44 c	0.46 c
B_2 x Zn_1	0.51 b	0.50 b	0.54 b	0.55 b
B_2 x Zn_2	0.64 a	0.62 a	0.65 a	0.67 a
B_2 x Zn_3	0.60 a	0.61 a	0.64 a	0.65 a
B_3 x Zn_1	0.51 b	0.52 b	0.54 b	0.56 b
B_3 x Zn_2	0.59 a	0.60 a	0.63 a	0.64 a
B_3 x Zn_3	0.59 a	0.61 a	0.63 a	0.65 a
CV (%)	7.49	1.87	1.63	1.51
LSD0.05%	0.055	0.055	0.055	0.039

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, FH: Final harvest, LSD: Least significant difference

Table 6. *Effect of B and Zn on the shoot dry weight of grass pea at different DAS*

Treatments	Shoot dry weight (g plant^{-1})			
	30 DAS	**45 DAS**	**60 DAS**	**FH**
	Levels of B			
B_1	0.07 b	0.34 b	1.21 b	1.30 b
B_2	0.12 a	0.60 a	1.86 a	1.96 a
B_3	0.12 a	0.57 a	1.84 a	1.95 a
LSD	0.032	0.032	0.045	0.077
	Levels of Zn			
Zn_1	0.08 a	0.41 b	1.39 b	1.51 b
Zn_2	0.11 a	0.56 a	1.77 a	1.90 a
Zn_3	0.11 a	0.55 a	1.76 a	1.83 a
$LSD_{0.05\%}$	0.032	0.032	0.045	0.077
	Interaction of B and Zn			
B_1 x Zn_1	0.05 d	0.28 d	0.99 d	1.10 e
B_1 x Zn_2	0.08 c	0.37 c	1.33 c	1.42 d
B_1 x Zn_3	0.08 c	0.37 c	1.34 c	1.38 d
B_2 x Zn_1	0.10 b	0.48 b	1.62 b	1.75 c
B_2 x Zn_2	0.12 a	0.64 a	1.99 a	2.20 a
B_2 x Zn_3	0.13 a	0.67 a	2.01 a	2.06 b
B_3 x Zn_1	0.10 b	0.47 b	1.57 b	1.69 c
B_3 x Zn_2	0.13 a	0.62 a	1.96 a	2.05 b
B_3 x Zn_3	0.13 a	0.63 a	1.98 a	2.07 b
CV (%)	2.55	4.30	2.92	4.39
LSD0.05%	0.055	0.055	0.077	0.134

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, FH: Final harvest, LSD: Least significant difference

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Padbhushan and Kumar (2014), Islam et al. (2019), Devi et al. (2021) and Halder et al. (2022) noticed that B has a more positive influence on dry matter yield. Similarly, Karthik et al. (2021b) reported the highest dry weight with the application of N at 25 kg ha^{-1} + B 0.2% foliar application at 35 DAS. The highest shoot dry weight (0.11, 0.56, 1.77 and 1.90 g plant^{-1}) was observed from Zn_2 treatment, which was statistically similar (0.11, 0.55, 1.76 and 1.83 g plant^{-1}) at 30, 45, 60 DAS, and FH, respectively, with Zn_3. Conversely, the lowest shoot dry weight (0.08, 0.41, 1.39, and 1.51 g plant^{-1} at 30, 45, 60 DAS, and FH, respectively) was recorded with Zn_1. Among the different treatments, Zn_2 was found very effective to have maximum shoot dry weight. Valenciano et al. (2011) reported that plants fertilized with Zn and with Mo had a greater total dry matter production. Ghosh et al. (2021) also noticed that effect of Zn and iron (Fe) on dry matter accumulation of relay grass pea. At FH, the highest shoot dry weight (2.20 g plant^{-1}) was observed from B_2 x Zn_2 treatment, while B_1 x Zn_1 jointly showed the lowest shoot dry weight (0.05, 0.28, 0.99 and 1.10 g plant^{-1}) at 30, 45, 60 and FH, respectively. Krishna et al. (2022) reported that the maximum plant dry weight noted with the application of Zn at 15 kg ha^{-1} + B foliar spray of 0.3%. A similar trend was found by Mecarty et al. (2022), where the maximum dry weight was found with the application of treatment RDF + Co at 1g/kg (seed treatment) as compared to other treatments.

Root dry weight

The root dry weight of grass pea depicted statistically significant atypical values at 30, 45, 60 DAS and at FH due to the application of B, Zn, and combined effect (*Table 7*). However, the highest root dry weight (0.07 and 0.086 g) was observed from B_3 at 30 and 60 DAS, respectively. But at 45 DAS, the highest shoot dry weight (0.076 g) was observed from both B_2 and B_3. At harvest, the highest root dry weight (0.104 g) was observed from B_2, while the lowest root dry weight (0.052, 0.061, 0.072 and 0.086 g plant^{-1}) was recorded with B_1 treatment at 30, 45, 60 DAS and at FH, respectively. Sharmila et al. (2020) also found that soil application of boron @ 1.5 kg ha^{-1} and foliar application of borax @ 0.25 per cent at critical growth stages of the crop registered the highest root dry weight. These results were collaborated to findings of Islam et al. (2019). The highest root dry weight (0.068 and 0.084 g plant^{-1}) was observed from Zn_2 treatment at 30, and 60 DAS, respectively which was statistically similar (0.068 and 0.084 g plant^{-1} at 30, 60 DAS, respectively) with Zn_3. At FH, the highest root dry weight (.104 g plant^{-1}) was observed from Zn_2 treatment, while the lowest root dry weight (0.053, 0.063, 0.073, and 0.086 g plant^{-1}) was recorded with Zn_1 at 30, 45, 60 DAS and FH, respectively. Among the different treatments, Zn_2 was found very effective to had highest root dry weight. Valenciano et al. (2011) recorded co-application of Zn and Mo effective in boosting the accumulation of total dry matter. The results are also in agreement with the findings of Ghosh et al. (2021) who noticed that application of Zn significantly increased the dry matter accumulation of grass pea. Combined application of B and Zn exhibited the highest root dry weight (0.077, 0.083, 0.093 and 0.130 g plant^{-1}) observed from B_2 x Zn_2 treatment at 30, 45, 60 DAS and FH, respectively, while the lowest root dry weight (0.04, 0.053, 0.063, and 0.077 g plant^{-1}, respectively) was recorded with B_1 x Zn_1 (*Table 7*). Montenegro et al. (2010) inferred that co-application of Zn and B with Mo resulted in a higher accumulation of dry matter. Similar results were also reported by Saha et al. (2018).

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Table 7. *Effect of B and Zn on the root dry weight of grass pea at different DAS*

Treatments	Root dry weight (g plant^{-1})			
	30 DAS	**45 DAS**	**60 DAS**	**FH**
		Levels of B		
B_1	0.052 c	0.061 b	0.072 c	0.086 c
B_2	0.067 b	0.076 a	0.084 b	0.104 a
B_3	0.070 a	0.076 a	0.086 a	0.097 b
$LSD_{0.05\%}$	0.032	0.032	0.032	0.01
		Levels of Zn		
Zn_1	0.053 b	0.063 c	0.073 b	0.086 c
Zn_2	0.068 a	0.073 b	0.084 a	0.104 a
Zn_3	0.068 a	0.076 a	0.084 a	0.097 b
$LSD_{0.05\%}$	0.032	0.032	0.032	0.01
		Interaction of B and Zn		
B_1 x Zn_1	0.040 g	0.053 g	0.063 h	0.077 f
B_1 x Zn_2	0.053 f	0.060 f	0.073 g	0.087 e
B_1 x Zn_3	0.063 e	0.070 d	0.080 e	0.093 d
B_2 x Zn_1	0.053 f	0.067 e	0.077 f	0.097 e
B_2 x Zn_2	0.077 a	0.083 a	0.093 a	0.130 a
B_2 x Zn_3	0.070 c	0.077 c	0.083 d	0.097 c
B_3 x Zn_1	0.67 d	0.070 d	0.080 e	0.093 d
B_3 x Zn_2	0.073 b	0.077 c	0.086 c	0.097 c
B_3 x Zn_3	0.070 c	0.080 b	0.090 b	0.100 b
CV (%)	7.64	4.90	5.40	8.98
LSD (0.05)	0.055	0.055	0.017	0.017

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, FH: Final harvest, LSD: Least significant difference

Yield contributing traits

Number of branches plant^{-1}

Due to application of different levels of B and Zn, the number of branches plant^{-1} of grass pea showed statistically significant variation (*Table 8*). However, the highest number of branches plant^{-1} (5.89) was observed from B_3 which was statistically dissimilar with B_2 (5.33), while the lowest number of branches plant^{-1} (3.77) was recorded from B_1 treatment. Among the different treatments, B_3 remained effective in maximizing the number of branches plant^{-1}. The results are in accordance with the findings of Islam et al. (2017a,b) in mungbean and Islam et al. (2019) in sesame who concluded that B and Zn fertilization had significant effect for increasing the number of branches plant^{-1}. The results also showed that Zn_2 treatment remained superior by recording the greatest number of branches plant^{-1} (5.56) which was statistically similar with Zn_3 (5.33), while the lowest number of branches plant^{-1} (4.11) was recorded from Zn_1 treatment. Similar results found by Khatun et al. (2018), Doddamani et al. (2020), Islam et al. (2021). Combined application of B and Zn exhibited the highest number of branches plant^{-1} (6.67) from the treatment combination of B_2 x Zn_2, which was statistically similar with B_3 x Zn_2 (6.33) and B_3 x Zn_3 (6.33), whereas the lowest number of branches plant^{-1} (3.33) was recorded with the treatment combination of B_1 x Zn_1. The results are in line with the findings of Islam et al. (2017a) who noticed that the different levels of B and Zn significantly influenced the yield and yield contributing characteristics of mungbean plant. Another, Katiyar et al. (2017) conducted a study and concluded that the values of yield attributes viz., number of branches plant^{-1} was varied at different levels of B and Zn.

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Table 8. *Effect of boron and zinc on yield contributing traits of grass pea at different DAS*

Treatments	Yield contributing traits					
	No. of branches plant^{-1}	**No. of pods plant^{-1}**	**No. of grains pod^{-1}**	**Pod length (cm)**	**No. of grains plant^{-1}**	**100 grain wt. (g)**
Levels of B						
B_1	3.77 c	13.56 c	2.42 b	2.69 b	34.52 c	5.06 b
B_2	5.33 b	15.85 a	3.33 a	2.89 a	40.95 a	5.79 a
B_3	5.89 a	15.41 b	3.29 a	2.92 a	39.99 b	5.77 a
$LSD_{0.05\%}$	0.499	0.286	0.253	0.095	0.249	0.032
Levels of Zn						
Zn_1	4.11 b	14.15 b	2.59 b	2.76 b	35.00 b	5.19 b
Zn_2	5.56 a	15.37 a	3.30 a	2.92 a	40.25 a	5.73 a
Zn_3	5.33 a	15.33 a	3.16 a	2.83 ab	40.22 a	5.70 a
$LSD_{0.05\%}$	0.499	0.286	0.253	0.095	0.249	0.032
Interaction of B and Zn						
B_1 x Zn_1	3.33 e	12.78 e	2.17 e	2.67 d	28.19 g	4.77 g
B_1 x Zn_2	3.67 de	13.33 d	2.43 de	2.70 d	37.05 f	5.03 f
B_1 x Zn_3	4.33 cd	14.56 c	2.67 cd	2.72 cd	38.32 e	5.36 d
B_2 x Zn_1	4.33 cd	14.44 c	2.60 cde	2.74 cd	36.67 f	5.24 e
B_2 x Zn_2	6.67 a	16.44 a	4.07 a	3.12 a	42.33 a	6.17 a
B_2 x Zn_3	5.33 b	15.33 b	3.33 b	2.83 bcd	40.97 c	5.90 b
B_3 x Zn_1	4.67 bc	15.22 b	3.00 bc	2.88 bc	40.15 d	5.54 c
B_3 x Zn_2	6.33 a	16.11 a	3.40 b	2.93 b	41.27 bc	5.92 b
B_3 x Zn_3	6.33 a	16.22 a	3.47 b	2.96 b	41.45 b	5.91 b
CV (%)	10.00	1.92	8.41	3.40	0.65	0.48
LSD0.05%	0.865	0.496	0.44	0.165	0.431	0.055

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, LSD: Least significant difference

Number of pods plant^{-1}

The number of pods plant^{-1} of grass pea significantly influenced due to the application of different levels of B and Zn (*Table 8*). It was noted that the highest number of pods plant^{-1} (15.85) was observed from B_2, while the lowest number of pods plant^{-1} (13.56) was recorded with B_1 treatment. Among the different treatments, B_2 was found very effective to had maximum number of pod plant^{-1}. Ravi et al. (2022) conducted a field experiment and the results showed that application of IAA 600 ppm + boron 0.5% (T_1) was recorded the highest number of pods plant^{-1} (63.89) as compared to other treatments, and many other researchers recorded similar results in different crops from their earlier experiment (Islam et al., 2017a,b; Halder et al., 2022). In contrary, the highest number of pods plant^{-1} (15.37) was observed from Zn_2 which was statistically similar with Zn_3 (15.33), while the lowest number of pods plant^{-1} (14.15) was recorded from Zn_1 treatment. Among the different treatments, Zn_2 was found very effective in achieving the maximum number of pods plant^{-1}. The results are in accordance with the findings of Islam et al. (2017 a, b) who concluded that B and Zn fertilization had significant effect for increasing the number of pods plant^{-1} of mungbean. It was also noted that the B_2 x Zn_2 treatment combination showed the highest number of pods plant^{-1} (16.44) which was statistically similar with B_3 x Zn_2 (16.11) and B_3 x Zn_3 (16.22), while the lowest number of pods plant^{-1} (12.78) was recorded from B_1 x Zn_1 treatment. Among the different treatments, the treatment combination B_2 x Zn_2 was found very effective to had highest number of pods plant^{-1}.

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These results are in agreement to the findings obtained by Ravi et al. (2022) who reported that B and Zn significantly increased the number of pods plant^{-1} of blackgram.

Pod length

The pod length of grass pea showed statistically significant variation due to the application of different levels of B and Zn (*Table 8*). The results revealed that the highest pod length (2.92 cm) was observed from B_3, which was statistically similar with B_2 (2.89 cm), while the lowest pod length (2.69 cm) was recorded with B_1 treatment. Application of B triggered the vegetative growth along with yield attributes such as pod length of mungbean (Pervin, 2016; Islam et al., 2017a, b) and black gram (Afroj, 2016). It was noted that the highest pod length (2.92 cm) was observed from Zn_2 which was statistically similar with Zn_3 (2.83 cm), while the lowest pod length (2.76 cm) was recorded with Zn_1 treatment. Similar results were found by Mubeen et al. (2020), Fatima et al. (2021). Various quantities of B and Zn jointly revealed significant effect and the combination of B_2 x Zn_2 showed the highest pod length (3.12 cm), whereas the lowest pod length (2.67 cm) was recorded with the treatment combination of B_1 x Zn_1 (*Table 8*). This finding is paralleled with the findings of Islam et al. (2017b) who revealed that yield attributes of mungbean were remarkable influenced by B and Zn doses. Similar results were also noted by Habib and Ahsan (2013), Habib et al. (2018), Mubeen et al. (2020), and Fatima et al. (2021).

Number of grains pod^{-1}

The number of grains pod^{-1} of grass pea showed statistically significant variation due to the application of different levels of B and Zn as well as dual effect (*Table 8*). The results showed that the highest number of grains pod^{-1} (3.33) was observed from B_2 which was statistically similar with B_3 (3.29), while the lowest grains pod^{-1} (2.42) was recorded with B_1 treatment. Pervin (2016) concluded that foliar application of B had a significant effect on most of the growth and yield contributing parameters such as the number grains pod^{-1} of mungbean varieties. Many other researchers including Islam et al. (2017a,b, 2019), Naznin et al. (2020) and Bari et al. (2023a,b) recorded the similar results in different crops in their experiments. Similarly, the highest number of grains pod^{-1} (3.30) was observed from Zn_2 treatment which was statistically similar (3.16) with Zn_3. Zn_1 treatment showed the lowest number of grains pod^{-1} (2.59). Among the different treatments, Zn_2 was found very effective to have highest number of grains pod^{-1}. The results are also in agreement with the findings of Katiyar et al. (2017) and Islam et al. (2017a) who noticed that application of Zn significantly increased the grains pod^{-1} of different crops. Yashona et al. (2018) found that the number of grains pod^{-1} varied significantly due to application of Zn. Pooled action of B and Zn showed statistically significant variation for grains pod^{-1} of grass pea (*Table 8*). However, the highest number of grains pod^{-1} (4.07) was observed from the B_2 x Zn_2, whereas the lowest number of grains pod^{-1} (2.17) was recorded with B_1 x Zn_1 treatment combination. Mecarty et al. (2022) found significantly higher numbers of grains pod^{-1} with the application of Zn and B, and similar results were found by Karimunnisa et al. (2021) who observed significant variation in grain yield and obtained higher grain yield with higher doses of B and Zn application.

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Number of grains plant^{-1}

Application of different levels of B, Zn and their joint action showed statistically significant variation for the number of grains plant^{-1} of grass pea (*Table 8*). It was noted that the highest number of grains plant^{-1} (40.95) was observed from the B_2 treatment, while the lowest number of grains plant^{-1} (34.52) was recorded with B_1 treatment. The result of this study was in conformity with the findings of Islam et al. (2017b), Ravi et al. (2022) who noticed that the number of grains plant^{-1} increased at different B levels as compared to without B. Similarly, Zn increased the number of grains plant^{-1} of grass pea (*Table 8*). Nonetheless, the highest number of grains plant^{-1} (40.25) was observed from Zn_2, which was statistically similar with Zn_3 (40.22), while the lowest number of grains plant^{-1} (35.00) was recorded with Zn_1 treatment. The results are certified by the many other researchers like Islam et al. (2017a), Saakshi et al. (2020) who reported that Zn application considerably increased the number of grains plant^{-1} in different crops. Combined application of B and Zn with B_2 x Zn_2 doses exhibited the highest number of grains plant^{-1} (42.33), whereas the lowest number of grains plant^{-1} (28.19) was recorded with the treatment combination of B_1 x Zn_1. The results are in line with the findings of Islam et al. (2017a) who noticed that the yield and yield contributing characteristics of mungbean plant was significantly influenced by the different levels of B and Zn. Additionally, Katiyar et al. (2017) conducted a study and concluded that the values of yield attributes viz., number of grains pod^{-1} was varied at different levels of B and Zn.

100-grain weight

The recorded data on the 100-grain weight of grass pea was significant for the sole application of different B and Zn doses, and their combined action (*Table 8*). It was noted that the highest 100-grain weight (5.79 g) was observed from the B_2 treatment, which was statistically similar with B_3 (5.77 g), whereas the lowest 100-grain weight (5.06 g) was recorded with B_1 treatment. Roshid (2021) reported that B application remained effective in improving the 100-grain weight. Similar results found by Habib and Ahsan (2013) in blackgram, Sultana (2018) in grass pea, Fardus (2016) in BARI Jhar sheem-1, Islam et al. (2017b) and Quddus et al. (2022) in mungbean, Khatun et al. (2018) and Bari et al. (2023a,b) in rice. However, the Zn_2 treatment showed the highest 100-grain weight (5.73 g) which was statistically similar with Zn_3 (5.70 g). On the other hand, the lowest 100-grain weight (5.19 g) was recorded with the Zn_1 treatment. These outcomes are also in-line with Islam et al. (2017a, 2021), Sümer and Yaraşir (2022) who concluded that the highest 100-grain weight were obtained from application of zinc. The results of the combined B and Zn indicated that the highest 100-grain weight (6.17 g) was observed from B_2 x Zn_2, whereas the lowest 100-grain weight (4.77 g) was recorded with B_1 x Zn_1 treatment combination. Katiyar et al. (2017) reported that the highest yields of grain was observed at the above same levels of Zn and B, and grain yield was increased by 14.5, 7.2 and 4.8% due to the use of Zn@ 5.0 kg ha^{-1}, B@ 2.0 kg ha^{-1} and Mo@ 400 g ha^{-1}, respectively, over their respective control. Fatima et al. (2021) concluded that application of Zn at early stages, while the application of B at lateral stages, is equally important in grain yield in mash bean. Islam et al. (2017a) and Sultana (2018) have also inferred similar conclusions.

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Yields and harvest index

Grain yield

The grass pea grain yield was significantly influenced by B and Zn doses (*Table 9*). The results exhibited that the highest grain yield (1.72 t ha^{-1}) was observed from the B_2 treatment, while the lowest grain yield (1.31 t ha^{-1}) was recorded with B_1 treatment. The present study also revealed that the treatment B_2 gave the maximum grain yield (1.72 t ha^{-1}) which might be attributed to superior yield attributes recorded by this treatment. Higher B doses remained effective in recording greater yield of grass pea. These results corroborate with the findings of Shil et al. (2007), Islam et al. (2017a), Quddus et al. (2018), Naznin et al. (2020), Nooli et al. (2020), Ramya et al. (2021), Roshid (2021) and Deep et al. (2022), who concluded that application of B with other fertilizers significantly produced the highest values of yield attributes and yields over control. Due to different levels of Zn, the results of the findings exhibited that the highest grain yield (1.72 t ha^{-1}) was observed from the Zn_2, while the lowest grain yield (1.36 t ha^{-1}) was recorded with Zn_1 treatment. Similar results were found by Yashona et al. (2018) conducted a field experiment where foliar Zn significantly influenced the yield, total biomass, and test weight of pigeon pea. Other studies conducted by Islam et al. (2017b), Muindi et al. (2019), Alam et al. (2020), Borah et al. (2021), Ghosh et al. (2021), Sümer and Yaraşir (2022) consistently reported that the application of zinc resulted in the highest grain yield. The results of the combined application of B and Zn showed that the highest grain yield (1.94 t ha^{-1}) was observed from the B_2 x Zn_2, whereas the lowest grain yield (1.00 t ha^{-1}) was recorded with B_1 x Zn_1 treatment combination. The addition of zinc alongside boron resulted in an increased grain yield of mungbean (Quddus et al., 2011; Praveena et al., 2018), BARI Motorshuti-1 (Hossain, 2014), lentil (Quddus et al., 2014), French bean (Islam et al., 2018) and chickpea (Hussain et al., 2022). Roy et al. (2022) also reported that increasing doses B had corresponding response from crop plants.

Stover yield

The B and Zn application in different doses had significant effect on the stover yield of grass pea (BARI Khesari-5). Data presented in *Table 9* indicated that increasing B levels had corresponding response in terms of stover yield. However, the highest stover yield (2.85 t ha^{-1}) was observed from B_3, while the lowest stover yield (2.43 t ha^{-1}) was recorded with B_1 treatment. This increase in stover yield might be attributed that B tend to increase the growth of grass pea plants and untimely greater stover yield production. Previously, the role of B in the biosynthesis of cell walls and ribonucleic acid (RNA) along with cell differentiation have been reported by Roy et al. (2022). The results are in agreement with the findings of Shil et al. (2007), Meem (2017) and Menaka et al. (2018) in chickpea, Ramya et al. (2021) in green gram. The effects of Zn noted that the highest stover yield (2.82 t ha^{-1}) was observed from Zn_3 which was statistically similar with Zn_2 (2.80 t ha^{-1}), while the lowest stover yield (2.50 t ha^{-1}) was recorded with Zn_1 treatment. The result obtained from the present study on stover yield is in agreement with the findings of Karan and Singh (2014), Alam (2016), Islam et al. (2017a), Ghosh et al. (2021) and Verma et al. (2021). Interaction effect of B and Zn showed statistically significant on the stover yield of grass pea (*Table 9*). The highest stover yield (2.92 t ha^{-1}) was observed from the treatment combination of B_2 x Zn_2 which was statistically similar with B_2 x Zn_3 (2.88 t ha^{-1}), B_3 x Zn_2 (2.88 t ha^{-1}), B_3 x Zn_3 (2.90 t ha^{-1}), whereas

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the lowest stover yield (2.07 t ha^{-1}) was recorded with B_1 x Zn_1 treatment. Karan and Singh (2014) reported that stover yield of lentil was significantly increased with the application of B and Zn than control. Similar results found by Verma et al. (2021) in pigeon pea.

Table 9. *Effect of boron and zinc on yield of grass pea at different DAS*

Treatments	Crop harvest			
	Grain yield (t ha^{-1})	**Stover yield (t ha^{-1})**	**Biological yield (t ha^{-1})**	**Harvest index (%)**
Levels of B				
B_1	1.31 c	2.43 c	3.74 c	35.02 c
B_2	1.72 a	2.82 b	4.54 a	37.86 a
B_3	1.65 b	2.85 a	4.50 b	36.66 b
$LSD_{0.05\%}$	0.316	0.316	0.011	0.071
Levels of Zn				
Zn_1	1.36 b	2.50 b	3.86 b	34.97 c
Zn_2	1.72 a	2.80 a	4.52 a	37.90 a
Zn_3	1.63 b	2.82 a	4.45 a	36.60 b
$LSD_{0.05\%}$	0.032	0.32	0.032	0.071
Interaction of B and Zn				
B_1 x Zn_1	1.00 f	2.07 d	3.07 g	32.53 h
B_1 x Zn_2	1.39 e	2.59 c	3.98 f	34.87 g
B_1 x Zn_3	1.53 d	2.63 c	4.16 d	36.74 e
B_2 x Zn_1	1.43 e	2.64 c	4.07 e	35.16 f
B_2 x Zn_2	1.94 a	2.92 a	4.86 a	39.96 a
B_2 x Zn_3	1.80 b	2.88 a	4.68 b	38.42 c
B_3 x Zn_1	1.65 c	2.79 b	4.44 c	37.24 d
B_3 x Zn_2	1.82 b	2.88 a	4.70 b	38.60 b
B_3 x Zn_3	1.82 b	2.90 a	4.72 b	38.60 b
CV (%)	0.49	0.45	0.42	0.19
LSD0.05%	0.055	0.055	0.055	0.122

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, LSD: Least significant difference

Biological yield

Statistically significant variation was recorded for the biological yield of grass pea due to the application of B and Zn (*Table 9*). Results exhibited that the highest biological yield (4.54 t ha^{-1}) was observed from the B_2 treatment, while the lowest biological yield (3.74 t ha^{-1}) was recorded with B_1 treatment. The result obtained from the present study on grain yield ha^{-1} was in agreement with the findings of Menaka et al. (2018) in chickpea, Roshid (2021) in field pea, El-Waraky et al. (2013) in pea and Deep et al. (2022) in green gram. It was also noted that the highest biological yield (4.52 t ha^{-1}) was observed from Zn_2 which was statistically similar with Zn_3 (4.45 t ha^{-1}). On the other hand, the lowest biological yield (3.86 t ha^{-1}) was recorded with Zn_1 treatment. A study was conducted by Usman et al. (2014) and results showed that significantly the maximum biological yield (5738.0 kg ha^{-1}) was obtained where 20 kg ha^{-1} zinc sulphate was applied as soil application. Results of the combined application of B_2 x Zn_2 exhibited that the highest biological yield (4.86 t ha^{-1}), while the lowest biological yield (3.07 t ha^{-1}) was recorded with B_1 x Zn_1 treatment. Karan and Singh (2014) reported that biological yield of pulse crop was improved with B and Zn application in different doses. Similar results have been reported by Tekale et al. (2009)

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in pigeon pea, Alam and Islam (2016) in mungbean, Sultana (2018) in lentil whereby they observed the maximum biological yield for co-application of Zn and B.

Harvest index

The grass pea's harvest index (HI) exhibited pronounced variation due to the application of different levels of B and Zn (*Table 9*). However, the highest HI of 37.86% was observed from B_2, while the lowest HI of 35.02% was recorded with B_1 treatment. The result pertaining to grain yield are in agreement with the findings of Islam et al. (2017b), Roshid (2021), Deep et al. (2022). Furthermore, the results showed that the highest HI (37.90%) was observed from Zn_2, while the lowest value (34.97%) was recorded with Zn_1 treatment. The result obtained from Ghosh et al. (2021) was in agreement with the findings of the present study on the harvest index. Statistically significant variation was recorded for the HI of grass pea due to the combined application of B and Zn (*Table 9*). The highest harvest index (39.96%) was observed from the treatment combination of B_2 x Zn_2, while B_1 x Zn_1 treatment could not perform at par to rest of treatment combinations. These results corroborate the findings of Islam et al. (2017a) in mungbean.

Nutrients content in grains

Boron content (ppm)

The B content in grass pea grains varied significantly due to different doses of B and Zn application (*Table 10*). The results indicated that the treatment B_2 exposed the maximum B content (31.55 ppm) in grains of grass pea. On the other hand, the minimum B content (27.47 ppm) was recorded from the B_1 that was significantly different from other treatments. Increasing B levels improved B uptake along with other macro- and micro-nutrients. Movalia et al. (2020), Mishra et al. (2018), Devi et al. (2021) and Rehman et al. (2022) reported that application of B increased the nutrient contents. Moreover, the highest B content (31.57 ppm) was recorded from Zn_3, while the lowest B content (27.51 ppm) was in Zn_1 treatment. Increasing levels of Zn application in lentil significantly increased B uptake, and improved available nutrients. Hossain et al. (2020), Mishra et al. (2018) reported that application of Zn increased the nutrient contents. The highest B content (33.29 ppm) was obtained from the treatment combination of B_2 x Zn_2, while the lowest B content (26.07 ppm) was obtained from the treatment combination of B_1 x Zn_1. Mishra et al. (2018) and Shamsuddoha et al. (2011) reported that combined application of B and Zn increased the nutrient contents. Rathod et al. (2020) suggested significantly higher uptake of Zn, B was recorded in B and Zn treatment, and the lowest uptake of nutrient recorded in control (without B and Zn).

Zinc content (ppm)

The Zn content in grass pea grains were remarkable influenced due to different doses of by B and Zn application in atypical doses (*Table 10*). The results indicated that the treatment B_2 exposed the maximum Zn content (56.47 ppm) in grains of grass pea. On the other hand, the minimum Zn content (51.66 ppm) was recorded from the B_1 that was significantly different from other treatments. These findings are similar to those reported by different researchers that B application increased the nutrient contents like Zn in blackgram (Mishra et al., 2018) and in chickpea (Rehman et al., 2022). Furthermore, the highest Zn content (56.30 ppm) was recorded from Zn_3, while the

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lowest Zn content (52.02 ppm) was in Zn_1 treatment. These findings are alike to those reported by Hossain et al. (2020), Mishra et al. (2018) whereby Zn application increased the nutrient contents. Interaction effect of different levels of B and Zn showed significant variation on the Zn content in the grains of grass pea (*Table 10*). Results showed that the highest Zn content (58.70 ppm) was obtained from the B_2 x Zn_2 treatment combination, while the lowest Zn content (50.24 ppm) was obtained from the B_1 x Zn_1 treatment combination. Shamsuddoha et al. (2011), Salih (2013), and Mishra et al. (2018) reported that combined application of B and Zn increased the nutrient contents in grains.

Table 10. *Effect of B and Zn on boron and zinc content in grains of grass pea*

Treatments	Boron content (ppm)	Zinc content (ppm)
Levels of Boron		
B_1	27.47 c	51.66 c
B_2	31.55 a	56.47 a
B_3	31.36 b	55.71 b
$LSD_{0.05\%}$	0.077	0.045
Levels of Zinc		
Zn_1	27.51 c	52.02 c
Zn_2	31.30 b	55.53 b
Zn_3	31.57 a	56.30 a
$LSD_{0.05\%}$	0.077	0.045
Interaction of B and Zn		
B_1 x Zn_1	26.07 g	50.24 g
B_1 x Zn_2	27.60 f	51.39 f
B_1 x Zn_3	28.75 c	53.36 d
B_2 x Zn_1	28.39 d	52.92 e
B_2 x Zn_2	33.29 a	58.70 a
B_2 x Zn_3	32.97 b	57.79 b
B_3 x Zn_1	28.08 e	52.89 e
B_3 x Zn_2	33.01 b	56.49 c
B_3 x Zn_3	32.97 b	57.76 b
CV (%)	0.25	0.09
LSD0.05%	0.185	0.255

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, LSD: Least significant difference

Correlation analysis

In the study, most of the yield components and growth traits were found to have a significant positive strong ($p = 0.001$), moderate ($p = 0.01$) and low ($p = 0.05$) correlation from each other's (*Figure 1*). However, the traits RDWFH alone perform negative non-significant association with all of the studies traits, and PL showed positive non-significant association with PHFH. Our results were correlated with findings of Afrin (2012) in mungbean and Uddin et al. (2020) in lentil, who demonstrated that the GY is highly correlated with the improvement of growth and yield related parameters which received B fertilizer. A similar conclusion was suggested from recent studies in mungbean (Islam et al., 2017b, 2021, 2023).

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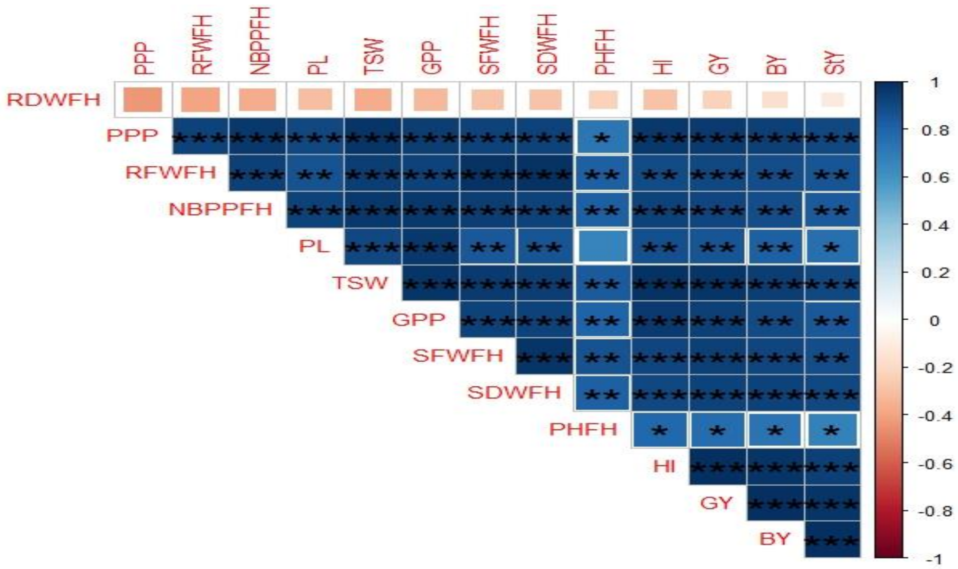

Figure 1. *Relationship of yield components and growth traits with grain yield of grass pea (PHFH= Plant height at harvest; NBPPFH = Number of branch plant^{-1} at final harvest; PPP= Pods plant^{-1}; PL= Pod length; GPP= Grains pod^{-1}; TSW= Thousand seed weight; StY= Straw yield; BY= Biological Yield; HI= Harvest Index; SFWFH= Shoot fresh weight at final harvest; SDWFH= Stem dry weight at final harvest; RFWFH= Root fresh weight at final harvest; RDWFH= Root dry weight at final harvest; GY= Grain yield; *=significant at p=0.05; **=significant at p=0.01; ***= significant at p=0.001)*

Functional association between grain yield and driven B and Zn level

The polynomial (one factor quadratic) functional equation was well fitted to the grain yield data as subjected to various levels of B and Zn. From the regression equation, predicted optimum doses of B and Zn for highest yield and their corresponding yields were found (*Figure 1*). The coefficient of determination representing as R^2 = 100 and 100 expressed the yield response of grass pea about 100% due to B and Zn incorporation, respectively. Grain yield increased 0.162 and 0.390 kg ha^{-1} due to inclusion of 1 kg ha^{-1} of B and Zn, respectively.

Optimum level of B and Zn

By developed function, the predicted optimum dose of B was 5.06 kg ha^{-1} and expected maximum grain yield was 1.72 t ha^{-1} (*Figure 2*).

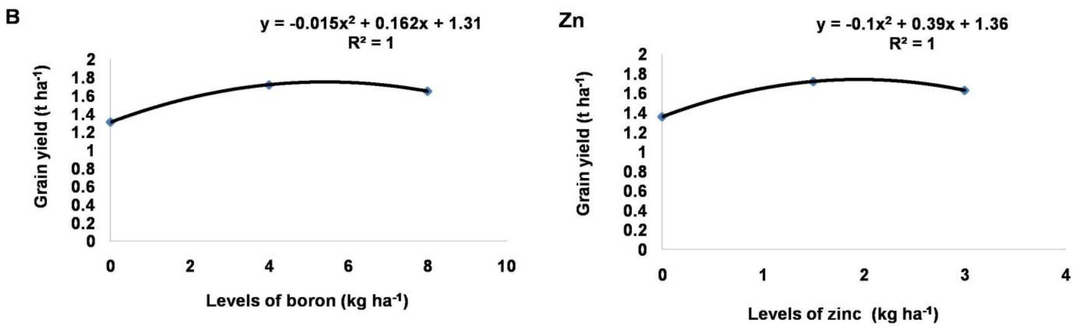

Figure 2. *Response function of grass pea to B and Zn for grain yield*

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For Zn, optimum dose of 1.95 kg ha^{-1} could produce the expected maximum grain yield of 1.74 t ha^{-1}. It means that grain yield increased with increasing rates of B and Zn up to 5.06 and 1.95 kg ha^{-1}, respectively and further application over the optimum level would reduce the grain yield.

Conclusion

Considering the above results, it may be summarized that growth, nutrient content, yield contributing parameters and grain yield of grass pea are positively correlated with B and Zn application. The optimum doses of B and Zn fertilizer were predicted to be 5.06 and 1.95 kg ha^{-1}, respectively. Application of B above 5.06 kg and Zn 1.95 kg ha^{-1} caused a reduction in all parameters of yield attributes and grain yield of grass pea. Therefore, the results suggest that grass pea can be grown with application of 5.06 kg B ha^{-1} and 1.95 kg Zn ha^{-1} along with a blanket dose of 40, 80, 30 and 50 kg ha^{-1} of urea, triple super phosphate, muriate of potash and gypsum, respectively for increasing the grain yield of grass pea variety BARI Khesari-5 under in Old Himalayan Piedmont Plain (AEZ-1).

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Conflicts of Interest. The authors declare no conflict of interest.

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