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Maximizing Growth and Yield Of Black Seed (Nigella Sativa L) through Optimized Phosphorus and Boron Levels

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Cover Page Footnote

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MAXIMIZING GROWTH AND YIELD OF BLACK SEED (*Nigella Sativa* L) THROUGH OPTIMIZED PHOSPHORUS AND BORON LEVELS

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ABSTRACT

Improper nutrient management cause yield reduction in black seed yield and quality. Therefore, a field trial was executed in the growing season 2022-23 at The University of Agriculture Peshawar to inspect the effects of different phosphorus (P) and boron (B) levels on black seed (*Nigella sativa* L.). The experiment used a randomized complete block design with a split-plot arrangement, replicated thrice. The study examined four P levels (0, 15, 30, and 45 kg/ha) and four B levels (0, 1, 2, and 3 mg/L) on various growth and yield parameters of black seed. Plots treated with 45 kg/ha of P exhibited the taller plants (37.00 cm), more branches (16.60), larger leaf area (128.30 cm²), longest roots (10.00 cm), highest levels of chlorophyll a, b and carotenoids (1.80, 1.30 and 1.10 mg/g) compared to control. 45 kg/ha P also produced maximum flowers/plant (23.10), capsules/plant (22.80), seeds/plant (1325.50), thousand-seed weight (2.80 g), and the maximum seed yield (255.30 kg/ha). Similarly, plants treated with 3 mg/L of B had the tallest plants (33.60 cm), more branches (15.90), leaf area (128.20 cm²), longest roots (8.70 cm), chlorophyll a, b and carotenoids (1.40, 1.20 and 1.00 mg/g), more flowers/plant (21.30), capsules/plant (20.70), seeds/capsule (58.70), seeds/plant (1193.60), the heaviest thousand-seed weight (2.70 g) and the maximum seed yield (255.30 kg/ha). Moreover, significant association was prominent between growth and yield components with seed yield of black seed under different treatments. Therefore, it was concluded that the best growth and yield for black seed were observed with fertilization of 45 kg/ha of P and 3 mg/L of B.

Keywords: Crop productivity, growth indices, nutrient optimization, Ranunculaceae , black seed.

INTRODUCTION

The annual herb black seed (*Nigella sativa* L.), fit in the Ranunculaceae family, originates from the Mediterranean region but also grows in various parts of the world, including Pakistan, India, Turkey, Saudi Arabia, the Middle East, and North America (Ara et al., 2020). In Roman times, it was primarily grown for culinary and therapeutic means (Rifat-ul-Zuman and Khan, 2004). As per Islamic teachings, black seed holds significant healing properties. Prophet Muhammad (PBUH) indicated that it can heal all diseases except death (Hajra, 2011). Iqbal et al., (2010) asserted that Pakistan possesses significant potential for the cultivation, expansion, and harvesting of black cumin seeds. The exceptional diversity of medicinal plants in Pakistan distinguishes it among emerging countries, attributed to its distinctive soil composition and climate conditions. Pakistan is home to more than 6,000 diverse species of medicinal plants, primarily concentrated in parts of the nation.

The black seed is a source of various nutrients such as carbohydrates, protein, fiber, volatile and fixed oils, with the water content ranging from 33.9 % to 6 % fixed oils (Rajsekhar and Kuldeep, 2011). These seeds are abundant in bioactive compounds renowned for their health-promoting effects (Hussain et al., 2006), which are essential for the enzymatic and amino acid functions in cells and provide vital macro- and micronutrients (Ansari et al., 2004). *Nigella sativa* has attracted considerable attention in the medical and pharmacological spheres due to its therapeutic attributes in the treatment of diverse diseases. Research has emphasized its potential in controlling blood sugar levels, exhibiting antibacterial properties, and managing hypertension (Ahmad et al., 2021).

It is widely renowned that the proper application of chemical fertilizers enhances the yield and quality of aromatic plants. Black seed, in particular, requires a healthy balance of soil nutrients to achieve high yields and quality. One reason for lower productivity could be inadequate nutrient management. Although micronutrients are present in much smaller amount, plants cultivated in micronutrient-deficient soils also exhibit reduced production (Yang et al., 2009). Pi s integral to various physiological processes in plants, impacting root development and serving as a fundamental constituent of amino acids, the foundational elements of proteins, DNA, and RNA. A multitude of plant enzymes are reliant on proteins, underscoring the significance of Pin facilitating diverse metabolic functions (Yang et al., 2009). Moreover, P is a key component of the chlorophyll molecule. Inadequate P levels can lead to chlorosis in plants, diminishing the fruit quality. Furthermore, P contributes to the enhancement of digestible fiber in crops due to its presence in cell walls. Application of P-based fertilizers has been found to bolster plant growth in terms of height, leaf dimensions, stem thickness, dry matter content, and crude protein yield in crops like legumes and cereals. The augmentation of protein levels in grains through P supplementation raises their nutritional value. Moreover, the provision of P results in an increase in root surface area, thus improving nutrient absorption and productivity in plants (Yan et al., 2019). The optimal growth and progression of higher plants hinge on the presence of the macronutrient P (Hawkesford et al., 2012). Nonetheless, the fixation and sluggish diffusion of P in soils often limit crop productivity (Bieleski, 2015; Syers et al., 2008). Consequently, the global agricultural community commonly employs P fertilizers to augment crop output (Withers et al., 2014).

B acts as a biostimulant with an organic charge that significantly affects plant growth, development, and productivity. Its application is widely recognized for improving nutrient absorption in plants, particularly in crops where it helps maintain flower and fruit set. B plays a crucial role in regulating carbohydrate metabolism, aiding seed formation, and supporting processes like cell division and pod and seed development (BARC, 2005). It also influences the uptake of nitrogen, phosphorus, and potassium, and its deficiency can disrupt the balance of these essential nutrients. Understanding the availability of B for specific crops and the potential environmental factors that impact its availability during seed germination is crucial when utilizing B fertilizer in agricultural practices. B plays a crucial role in enhancing the various properties of acidic, calcareous, and low-fertility soils, thereby improving soil fertility and agricultural productivity. Recognized as a vital plant nutrient, B is utilized on crops and fruit trees to stimulate pollen production and development, which are critical for seed germination and the production of fruits, nuts, and grains as noted by Imran and Al-Tawaha, (2020). The main aim of this research was to determine the most effective combinations of P and B for achieving increased yields while also assessing the effects of varying levels of these nutrients on the growth and yield of black seed. The hypothesis posits that optimal combinations of P and boron (B) will enhance the growth, yield, and quality of black seed by improving nutrient absorption, root development, and metabolic functions, addressing nutrient management challenges and leveraging the significant potential for black seed cultivation in diverse regions, including Pakistan.

MATERIALS AND METHODS

Experimental Design and Field preparation

An open field trial was executed at Research Farm of The University of Agriculture Peshawar. The trial was laid out in a randomized complete block design that was replicated twice. P levels were applied with four different levels: 0, 15, 30, and 45 kg/ha while B, applied via foliar, also had four levels: 0, 1, 2, and 3 mg/L. This setup involved applying Pas the main plot factor and B as the subplot factor in the experimental design. Soil samples were examined for their physicochemical properties at the laboratory of soil science to analyze the soil of the experimental field. Results of the analyzed data are given in the (Table 1). Two weeks before ploughing, the field was prepared using a cultivator to remove unwanted plants and other debris. Each experimental unit consisted of four rows, each containing ten plants spaced five centimeters apart within rows and thirty centimeters apart between rows. Sowing was done with the help of seed planter and Line KS-313 of black cumin obtained from National Agriculture Research Council was planted.

Table 1: Pre sowing soil properties of the site

Properties of soil	Units	Values
Soil texture	-	Silt loam
PH	-	7.2
Electric conductivity	dSm^{-1}	0.31
Organic matter	%	0.94
Nitrogen	%	0.19
Phosphorus	%	0.06
Potassium	%	0.21
Boron	%	0.24

Description of treatments and their application

P applied in the form of DAP (46 % P), was administered at the time of sowing on a plot size of 0.6 m², with 1.95 g of DAP used per 15 kg/ha of P applied. To balance the nitrogen effect (since DAP also contains 18 % nitrogen), urea (46 % N) was added during the second irrigation. For instance, 0.76 g of urea was added for the 30 kg/ha P treatment, 1.52 g for the 15 kg/ha treatment, and 2.28 g for the control, to compensate for the nitrogen present in the DAP. Moreover, B was applied as a spray using borax (which contains 10.5 % B). To prepare the spray, 4.76 mg of borax was mixed with one liter of water to achieve the required concentration of 0.50 mg of B per liter. This mixture was applied twice: the first spray was administered one month after planting, and the second, twenty days later. Application continued until the leaves began to drip with the spray mixture.

Growth Indices

Plant height was assessed by randomly selecting five plants per treatment and replication, measuring the distance from the base to the top of each plant using a measuring tape, and then calculating the average height. Similarly, branches per plant were counted by randomly selecting five plants per treatment and replication, tallying the number of branches on each, and computing the average for that specific treatment and replication. Leaf area was determined using a petiole app from the Android Play Store, where five plants per treatment and replication were randomly chosen, and their leaf areas were measured and averaged. Lastly, root length measurement was conducted on five randomly chosen plants in each plot by measuring tape and then averaged.

Chlorophyll Pigments

To assess chlorophyll pigments (a, b and carotenoids), fresh leaf samples weighing 0.2 grams were immersed in 20 milliliters of 80 % acetone and stored in darkness at room temperature for 48 hours. Absorbance measurements at wavelengths 663 nm, 645 nm, and 470 nm were conducted using a spectrophotometer.

Chlorophyll a was determined using the equation (12.7 x A663) – (2.69 x A645), while Chlorophyll b was determined with (22.9 x A645) – (4.68 x A663). For carotenoid content (Cx+c), the equation (1000A470 – 1.82Ca – 85.02Cb) / 198 was applied. To quantify these values in terms of mg/g fresh weight (FW), the equation Q = (CV/W) x 100 was used. Here, C denotes concentration measured in milligrams per liter, V signifies the volume of the solvent, and W represents the fresh weight of the sample.

Yield and Related Indices

To quantify yield related indices, flowers/plant was noted by counting them on five randomly selected plants from every subplot, calculating the average per plant. Capsules per plant were determined by summing the total fruits across each treatment, followed by calculating the average per plant. For seed collection, five randomly chosen plants per treatment and replication had their capsules harvested, and seeds were manually counted from each capsule. Seeds/capsule was then found by averaging across five plants in each treated plot. Additionally, thousand-seed samples were collected from five randomly selected plants per treatment and their weight was measured using a balance. The average seed weight per replication was obtained and the seed yield (kg/ha) was computed using the below given equation based on the mean seed weight obtained.

$$\text{Seed yield} = \frac{\text{yield per plot} \times 10000\ \text{m}^2}{Area\ of\ plot\ (m^2)}$$

Statistical Analysis

The collected data for all indices go through analysis of variance (ANOVA) using SAS following Steel and Torrie, (1997) guidelines. Means of different treatments were determined and different according to least significant difference at 0.05. Moreover, correlation analysis was performed using OriginPro 2023.

RESULTS

Growth Indices

The data concerning growth indices indicated that P and B had significant impact however the interactive between them was non-significant as determined in ANOVA (Table 3). Taller plants (37.00 cm) were noted in plots that were commenced with 45 kg/ha of P, compared plots fertilized with 30 kg/ha (34.10 cm) over control (27.00 cm) (Table 2). Regarding B, plants treated with 3 mg/L produced tall plants (33.60 cm), compared to plants fertilized with 2 mg/L (32.80 cm) and control (31.90 cm). It was found that plants supplied with 45 kg/ha of P exhibited the more branches (16.60) while in comparison, the control group showed the lowest number of branches (6.70). In terms of B treatments, plants treated with 3 mg/L displayed the highest branches (15.90) compared to those treated with 2 mg/L, (13.80) and untreated (8.60). Based on mean values, plants treated with 45 kg/ha of P exhibited the largest leaf area (128.33 cm²) trailed by those treated with 30 kg/ha (116.67 cm²). Conversely, the control group showed the smallest leaf area at 101.17 cm². Plants treated with 3 mg/L displayed the largest leaf area at 128.17 cm², compared to those treated with 2 mg/L, (120.00 cm²) and control group exhibited the smallest leaf area (100.83 cm²). The longest roots (9.95 cm) were observed in plants treated with 45 kg/ha of P compared to untreated control plants that exhibited shortest roots (5.50 cm). For B treatments, plants treated with 3 mg/L showed the greatest root length (8.67 cm) over control group that recorded the shortest roots (6.35 cm).

Table 2: Influence of phosphorus and foliar boron on growth indices of black seeds.

	Plant height (cm)	Branches/plant	Leaf area (cm^2)	Root length (cm)
Phosphorus levels (P)				
Control	27.50 D	6.70 D	101.17 C	5.50 D
15 kg/ha	31.00 C	12.30 C	112.00 B	6.97 C
30 kg/ha	34.10 B	14.10 B	116.67 B	7.68 B
45 kg/ha	37.00 A	16.60 A	128.33 A	9.95 A
Foliar boron (B)				
Control	31.00 C	8.60 D	100.83 D	6.35 C
1mg/L	32.10 B	11.40 C	109.17 C	7.21 B
2 mg/L	32.80 AB	13.80 B	120.00 B	7.86 B
3 mg/L	33.60 A	15.90 A	128.17 A	8.67 A
$LSD_{(0.01)}$ for P	0.94	2.31	3.53	0.36
$LSD_{(0.01)}$ for B	0.64	3.51	5.91	0.56

Means values that follow variable latters are different from each other based on LSD value at a significance level of 0.01.

Table 3: F statistical for growth related indices under the influence of phosphorus and boron.

Treatments	Plant height (cm)	Branches/plant	Leaf area (cm^2)	Root length (cm)
		F values		
Phosphorus (P)	225.86^{**}	283.78^{**}	122.09^{**}	309.75^{***}
Foliar boron (B)	26.10^{***}	57.07^{**}	35.11099^{***}	26.52^{**}
P x B	1.45^{ns}	2.23^{ns}	0.93^{ns}	1.26^{ns}
CV % (main)	2.38	6.97	3.08	4.85
CV % (sub))	2.36.	11.62	6.12	8.79

*CV represents the critical values of main and subplots. Ns stand for non-significant results whereas * = significant result, ** = moderately significant results and *** = highly significant results at (P ≤ 0.01).*

Chlorophyll pigments

The mean table results suggest that P and B application had a significant effect on chlorophyll pigments (Table 4). However, their interactive was found to be not significant (Table 5). It was observed that plots commenced with 45 kg/ha of P had the highest chlorophyll a content (1.82 mg/g), followed by plants receiving 30 kg/ha of P(1.09 mg/g). The control group had the lowest chlorophyll a content (0.94 mg/g). For B treatment, plants exposed to 3 mg/L of B had a chlorophyll a content (1.35 mg/g), followed by those treated with 2 mg/L of B (1.20 mg/g). Mean data revealed that plants receiving 45 kg/ha of P had maximum chlorophyll b (1.32 mg/g) that was succeeded by plants treated with 30 kg/ha of P (0.95 mg/g). However, untreated plots minimum chlorophyll b (0.72 mg/g). Regarding B treatment, plants given 3 mg/L of B had a highest chlorophyll b concentration (1.16 mg/g) trail by those treated with 2 mg/L of B, which had 1.02 mg/g and control group had the lowest chlorophyll b content (0.74 mg/g). Lastly, plants treated with 45 kg/ha of P had the highest carotenoid content (1.06 mg/g) trail by plants receiving 30 kg/ha of P (0.92 mg/g) and control group had the lowest carotenoid content (0.51 mg/g).

Regarding B treatment, plants exposed to 3 mg/L of B had a carotenoid content of 1.00 mg/g, while those treated with 2 mg/L of B had 0.87 mg/g over control (0.66 mg/g).

Table 4: Influence of phosphorus and foliar boron on chlorophyll pigments of black seeds.

	Chlorophyll a (mg/g)	**Chlorophyll b (mg/g)**	**Carotenoids (mg/g)**
Phosphorus levels (P)			
Control	0.73 C	0.72 C	0.51 C
15 kg/ha	0.93 BC	0.83 BC	0.81 BC
30 kg/ha	1.09 B	0.95 B	0.92 B
45 kg/ha	1.82 A	1.32 A	1.06 A
Foliar boron (B)			
Control	0.94 C	0.74 C	0.66 C
1mg/L	1.08 BC	0.90 B	0.76 B
2 mg/L	1.20 B	1.02 AB	0.87 B
3 mg/L	1.35 A	1.16 A	1.00 A
$LSD_{(0.01)}$ for P	0.18	0.11	0.07
$LSD_{(0.01)}$ for B	0.10	0.11	0.08

Means values that follow variable latters are different from each other based on LSD value at a significance level of 0.01.

Table 5: F statistical for chlorophyll pigments under the influence of phosphorus and boron.

Treatments	**Chlorophyll a (mg/g)**	**Chlorophyll b (mg/g)**	**Carotenoids (mg/g)**
	F values		
Phosphorus (P)	85.41^{***}	67.31^{**}	129.94^{**}
Boron (B)	23.64^{**}	20.67^{**}	24.72^{***}
P x B	0.96^{ns}	1.94^{ns}	0.611^{ns}
CV % (main)	15.61	11.45	8.58
CV % (sub))	10.95	14.28	12.33

*CV represents the critical values of main and subplots. Ns stand for non-significant results whereas * = significant result, ** = moderately significant results and *** = highly significant results at ($P \leq 0.01$).*

Table 6: Influence of phosphorus and foliar boron on yield indices of black seeds.

	Flowers/plant	Capsules/plant	Seeds/capsule
Phosphorus levels (P)			
Control	13.40 D	12.30 D	51.17 C
15 kg/ha	15.60 C	15.20 C	53.50 BC
30 kg/ha	20.30 B	19.10 B	57.08 AB
45 kg/ha	23.10 A	22.80 A	59.42 A
Foliar boron (B)			
Control	13.60 D	13.00 D	51.25 C
1mg/L	17.70 C	16.80 C	55.00 B
2 mg/L	19.80 B	18.90 B	56.25 AB
3 mg/L	21.30	20.70 A	58.67 A
$LSD_{(0.01)}$ for P	1.90	2.21	2.6179
$LSD_{(0.01)}$ for B	1.31	1.18	2.21

Means values that follow variable latters are different from each other based on LSD value at a significance level of 0.01.

Table 7: Influence of phosphorus and foliar boron on yield indices of black seeds.

	Seeds/plant	Thousand grain weight (g)	Seed yield (kg/ha)
Phosphorus levels (P)			
Control	655.10 D	2.02 C	269.17 D
15 kg/ha	788.40 C	2.35 B	314.42 C
30 kg/ha	1092.50 B	2.45 B	363.42 B
45 kg/ha	1325.50 A	2.77 A	438.58 A
Foliar boron (B)			
Control	664.00 D	2.13 C	313.75 C
1mg/L	931.40 C	2.32 BC	335.08 BC
2 mg/L	1072.50 B	2.49 AB	355.08 B
3 mg/L	1193.60 A	2.65 A	381.67 A
$LSD_{(0.01)}$ for P	98.258	0.17	20.16
$LSD_{(0.01)}$ for B	61.59	0.27	18.74

Means values that follow variable latters are different from each other based on LSD value at a significance level of 0.01.

Yield and Yield Related Indices

The statistical analysis results indicated a significant improvement in yield and indices when plants were subjected to varying levels of P and B (Table 6 and 7). However, the combine effect of P and B levels was not statistically significant (Table 8). Data showed that the highest flowers/plant (23.10) was observed in plants supplied with 45 kg/ha of phosphorus, compared to control (13.40). For B, plants treated with 3 mg/L produced the most flowers (21.30), trailed by 19.80 flowers at 2 mg/L, while the control group had the lowest count (13.60). Plants receiving 45 kg/ha of P had the highest number of capsules per plant (22.80), while those given 30 kg/ha had the second highest (19.10) over control (12.30). For B, plants treated with 3 mg/L produced the most capsules (20.70), succeeded by those treated with 2 mg/L (18.90).

The control group recorded 13.00 capsules. Regarding seeds per capsule, plants supplied with 45 kg/ha of P had the highest count (59.42), compared to 30 kg/ha (57.08) and control (51.17). For B, more seeds/capsule (58.67) was observed in plants treated with 3 mg/L, trailed by 2 mg/L (56.25) over control (51.25). Plants treated with 45 kg/ha of P produced the most seeds per plant (1325.50), followed by those given 30 kg/ha (1092.50). The control group had the fewest seeds per plant (655.1). For B, more seeds/plant (1193.60) was observed in plants treated with 3 mg/L, trailed by those treated with 2 mg/L (1072.50). The control group recorded 664.00 seeds per plant. Finally, more thousand-seed weight (2.77 g) was seen in plots commenced with 45 kg/ha of phosphorus, followed by those given 30 kg/ha (2.45 g). The control group had the lowest thousand-seed weight (2.02 g). For B, plants treated with 3 mg/L had a thousand-seed weight of 2.65 g, followed by those treated with 2 mg/L (2.49 g). The control group recorded a thousand-seed weight of 2.13 g.

Table 8: F statistical for chlorophyll pigments under the influence of phosphorus and boron

Treatments	Flowers/ plant	Capsules/p lant	Seeds/ capsule	Seeds/ plant	Thousand grain weight (g)	Seed yield (kg/ha)
			F values			
Phosphorus (P)	146.47^{***}	116.13^{**}	23.56^{*}	259.53^{**}	36.57^{*}	146.89^{**}
Boron (B)	103.45^{***}	121.65^{**}	16.75^{**}	213.79^{**}	10.66^{*}	20.31^{**}
P x B	2.09^{ns}	1.58^{ns}	1.12^{ns}	2.06^{ns}	1.162^{ns}	2.18^{ns}
CV % (main)	6.94	8.44	4.75	6.72	7.31	5.98
CV % (sub)	6.32	5.99	4.73	5.59	9.94	6.42

*CV represents the critical values of main and subplots. ns stand for non-significant results whereas * = significant result, ** = moderately significant results and *** = highly significant results at ($P \leq 0.01$).*

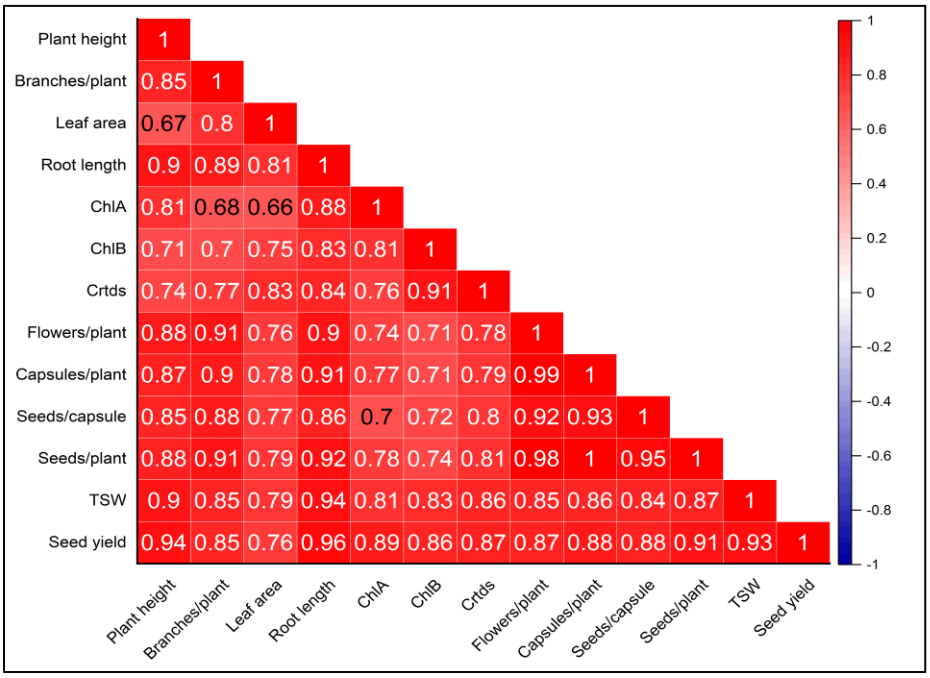

Figure 1. Pearson correlation analysis of different indices of black seeds under the influence of phosphorus and boron application

Statistical analysis revealed that the highest seed yield (438.58 kg/ha) was achieved in plants commenced with 45 kg/ha of phosphorus, followed by a yield of 363.42 kg/ha in plants given 30 kg/ha. The control group had the lowest seed yield, measuring 249.17 kg/ha. Regarding B, plants treated with 3 mg/L produced the maximum seed yield (381.67 kg/ha), followed by those treated with 2 mg/L (355.08 kg/ha). The control group recorded the lowest yield at 313.75 kg/ha.

Correlation Analysis

Pearson's correlation analysis was conducted in order to study the association between different growth and yield related indices under the influence of soil applied P and foliar B application. Upon analysis significant association was revealed between all the indices of black seed when treated with P and B. Growth indices (Plant height, branches/plant, leaf area and root length) had a strong association with yield related indices (Flowers/plant, capsules/plant, seeds/capsules, seeds/plants and thousand grain weight) as mentioned in Figure 1 from correlation coefficients. Moreover, all the indices i.e. growth, chlorophyll pigments and yield related indices were also significantly associated with seed yield of black seed.

Discussion

Phosphorus (P) is a crucial macronutrient required for the optimal functioning of the shoot and root tips of plants due to their heightened metabolic activity and rapid cell division, as observed by Ndakidemi and Dakora (2007). Our research findings are consistent with the observation of Yan et al., (2019), who demonstrated that greater levels of P enhance plant height in leguminous plants, suggesting a direct relationship between P concentrations and plant growth, particularly in legumes. B, functioning as an organic biostimulant, exerts influence on crop productivity, plant development, and nutrient absorption, as highlighted by Thapa, (2006). The observed increase in plant height in our study is likely attributed to the abundant supply of P and B. However, our results diverge from those of Soni and Kushwaha (2020), who observed that both P and B contribute to growth and yield enhancement in mungbean, possibly due to discrepancies in experimental conditions or factors influencing plant responses. Augmented levels of P have been shown to enhance the storage of carbohydrates and proteins, facilitating their translocation to different plant parts, thereby stimulating an increase in branches, as documented by Shekara et al., (2010). Consequently, our results are supported by the evidence that P supplementation leads to a rise in the number of branches, a phenomenon also acknowledged by Pareek et al., (2002). The application of the highest dose of foliar B similarly resulted in increased branch formation as micronutrients, functioning as cofactors, likely due to the activation of numerous enzymes, including those involved in photosynthesis by B. The process of activation described could potentially lead to an increased accumulation of carbohydrates within cells, ultimately resulting in improved branch development, which aligns with the findings of Bhutia et al., (2015). According to a study by Mahmoudi et al., (2015), the addition of Pleads was linked to enhancements in leaf area and chlorophyll content in maize. This study also discovered a positive correlation between P supplementation and leaf area. Another research study by Shukla et al., (2011) found that applying P led to an increase leaf surface and produced tall plants. Similarly, a study by Cakmak et al., (2010) focusing on B fertilization demonstrated an increase in leaf area in peas. Specifically, the research demonstrated that commencing B at 1 mg/L resulted in a 25 % increase in leaf area. Correspondingly, Abbasi et al., (2016) discovered that the use of B leads to enhancements in the dry weight, yield, and leaf area of sunflower plants. P plays a crucial role in affecting cell elongation in roots by triggering the synthesis of auxins, which are plant hormones responsible for stimulating cell elongation. An ample availability of P supports optimum auxin production, facilitating the elongation of roots as described by Tabassum et al., (2021). In contrast, B enhances the enzymatic activity within plant roots, which is essential for the absorption of nutrients. This enzymatic mechanism establishes a gradient across the membranes of root cells, promoting the active uptake and transport of important minerals, particularly potassium (K). Inadequate levels of Boron can result in physiological and morphological changes in plants, as a significant portion of Boron is found in cell walls, playing a pivotal role in plant growth. Boron is essential for proper plant development, affecting nitrogen uptake, sugar translocation, cell wall formation, root growth, and nucleic acid synthesis.

P is crucial for strengthening plant stems and promoting the improvement of flower buds and is key nutrient of developmental stages as highlighted by Razaq et al., (2017). Additionally, B significantly contributes to various plant processes, including cell division, cell wall expansion, differentiation, pollen tube growth, pollination, fertilization, and flower bud development, which can lead to increased flower production, as noted by Narayanamma et al., (2009). Our research supports the findings of Patil, (2010), who observed that applying 40 ppm of boron resulted in more flowers and higher plant and fruit yields compared to the control group. Furthermore, increase in the seed/capsules was prominent with elevated P levels, aligning with the findings of Xie et al., (2013). Ojikpong et al.,(2009) observed that higher P levels significantly increased the number of plant capsules, while the control treatments produced the fewest. Jassem and Obaid (2014) demonstrated that applying 25 mg/Lof boron to broad bean plants markedly boosted the number of pods. In contrast to the control treatment, which had 38.90 pods, the boron application resulted in a substantial increase, with the highest count being 53.23 pods at the 0.75 % level. These results are in line Shafeek et al., (2014) and Jana and Paria (1996) who found that higher B doses positively correlated with increased pods in pea plants. Singh et al., (1992) confirmed that boron application enhanced yield parameters, such as the number of pods per plant and seeds per pod.

B plays a vital role in stimulating the manufacturing of cytokinin, which accelerates the fertilization, resulting in increased plant production (Tariq and Mott, 2007). B also involves improving photosynthesis and aiding the movement of photosynthetic products from leaves to pods, which results in a higher number and weight of pods, thus enhancing overall yield (Moore, 2004). Studies by Singh et al., (2004) and Jana and Paria (1996) have demonstrated that boron application increases pod yield in pea plants. Vinutha, **(**2016) observed that foliar application of borax (B) significantly increased pea yield.

P is essential for pollination and seed development, leading to increased seed production per plant. P also supports healthy flower formation and the transfer of energy-rich compounds critical for seed maturation. Research shows that B application promotes pea pod production and increases seed yield in peas and black gram. Studies have also demonstrated improvements in seed quality and yield in peas and cowpeas with B application. The thousand seed weight was profoundly affected by varying levels of P, attributed to P that plays a pivotal role in manufacturing photo assimilates, thereby significantly enhancing dry matter production and seed growth, culminating in an increased thousand seed weight (Manske et al., 2001). Elevating boron levels has been correlated with an augmentation in the thousand seed weight of chickpea crops, as demonstrated by Hoque et al., (2021). Moreover, Bellaloui et al., (2013) corroborated that boron application enhances the thousand seed weight.

As per Kavanová et al., (2006), the application of P stimulates cell division within the meristematic regions of plants, which are essential for improved dry matter and achieving high seed yields. Indices such as the branches and capsules have a direct impact on seed production, as noted by Ozguven and Sekeroglu, (2007). These results align with earlier studies on fenugreek (Dayanand, 2004) and sesame (Mian et al., 2011), which show that optimal P application leads to the highest seed yield per hectare compared to control groups. Ali et al., (2015) found that applying 1.5 ppm of boron produced the maximum fruit yield in tomatoes. Additionally, Jena et al., (2009) reported increased cabbage production with the application of 2 kg of B per acre.

CONCLUSION

The study concluded that applying phosphorus at a rate of 45 kg/ha produced the best results across all parameters compared to untreated and other application levels. Moreover, boron at a concentration of 3 mg/L was found to be most effective for the growth and yield of black seed, outperforming untreated samples and other levels of application. It was also noted that the interaction between phosphorus and boron was non-significant for all the parameters studied.

RECOMMENDATIONS

The application of phosphorus at a rate of 45 kg/ha is optimal for the growth and yield of black seed. Similarly, applying boron at a concentration of 3 mg/L also promotes better growth and yield of black seed. It is recommended that further researches should be conducted to explore the effects of higher levels of phosphorus and boron on black seed and other crops, to fully understand their potential benefits and limitations.

AUTHOR'S CONTRIBUTION

All authors participated in this research study and manuscript writing equally.

CONFLICT OF INTEREST

Authors declare no competing interest in the present research.

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