Research Article

Enhancing Spring Maize Performance Through Strategic Soil Potassium and Foliar Boron Application

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Abstract | Application of potassium (K) and boron (B) plays a vital role in enhancing maize growth and yield by supporting key physiological processes. Optimizing the application rates of these nutrients is essential to achieve maximum productivity. To investigate this, a field experiment was conducted during the spring season of 2020 to evaluate the effects of soil-applied potassium (0 and 60 kg ha^{-1}) and foliar-applied boron (0, 1, 2, and 3 kg ha^{-1}) on the growth and yield performance of spring maize. The study followed a randomized complete block design (RCBD) with three replications. Potassium was applied as a basal dose before sowing in the form of potassium chloride (KCl), while boron was administered as a foliar spray one month after crop emergence using boric acid (H_3BO_3). The results indicated that potassium application at 60 kg ha^{-1} significantly delayed phenological stages (tasselling, silking, and physiological maturity) and improved several growth and yield parameters, including plant height (201 cm), number of grains per ear (349), thousand-grain weight (284.4 g), biological yield (11,136.3 kg ha^{-1}), grain yield (4,413 kg ha^{-1}), and harvest index (39.4%). Foliar application of boron at 3 kg ha^{-1} resulted in a noticeable delay in phenology and led to increased plant height (208 cm) and biological yield (11,601.3 kg ha^{-1}). Conversely, the 2 kg ha^{-1} B treatment significantly enhanced reproductive traits, yielding a higher number of grains per ear (344), greater thousand-grain weight (294.8 g), increased grain yield (4,424.7 kg ha^{-1}), and improved harvest index (40.2%). These findings suggest that the independent application of 60 kg ha^{-1} K at sowing and a 2 kg ha^{-1} foliar application of B one month after emergence significantly improves the growth and yield of spring maize under the agro-climatic conditions of the Peshawar region. This dual-nutrient management strategy is therefore recommended to optimize maize productivity in similar agro-ecological zones.

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Introduction

Maize yield and quality are significantly influenced by the availability of essential plant nutrients. However, the imbalanced application of these nutrients, particularly K) has been identified as a major factor contributing to reduced crop productivity. In Pakistan, the decreasing soil K levels present a significant challenge, with the net K depletion rate estimated at around 0.3 kg ha^{-1} per year (Saleem *et al*., 2011). This depletion is exacerbated by the notably low K application rate in the country, which stands at 0.8 kg ha^{-1} $year^{-1}$, a stark contrast to the global average of 15.1 kg ha^{-1} $year^{-1}$ (Khalil *et al*., 2010). Alarmingly, the current K usage is less than half of what it was in the mid-1990s and represents only 25% of the target set by the government at the conclusion of the Eighth Five-Year Plan.

Potassium deficiency in soils leads to a significant decline in photosynthetic efficiency and adversely impacts gene expression in crops (Jasar *et al*., 2019). Numerous studies have demonstrated that applying K during water stress conditions boosts crop resilience to drought while also promoting plant growth, efficient dry matter distribution, and increased yield. Potassium is essential for regulating plant water balance and maintaining ionic stability within cells. It is also vital for the stimulation of over 60 enzymes involved in various metabolic processes, including the uptake and translocation of nitrates from roots to aerial parts of the plant (Orats, 2018). Given the critical role of K in plant physiology and its impact on crop productivity, it is imperative to address the declining K levels in Pakistani soils. Strategic interventions, such as balanced fertilizer application and the adoption of K-efficient crop varieties, could significantly enhance maize productivity under both normal and stress conditions. Furthermore, research into innovative fertilization techniques and soil management practices is essential to ensure sustainable maize production and food security in the region.

Potassium plays a crucial role in regulating the water requirements of crops during drought conditions due to its dominant influence on stomatal function. Stomata, the microscopic pores on the leaf surface, regulate both transpiration and the intake of CO_2, which is essential for photosynthesis. Adequate K availability ensures optimal stomatal activity, thereby minimizing water loss through transpiration and maximizing carbon dioxide uptake. Conversely, K deficiency leads to reduced stomatal function, increasing transpiration losses and negatively impacting crop performance (Jiang *et al*., 2018).

Traditional methods of applying K fertilizers directly to the soil often result in the nutrient becoming fixed with clay minerals, rendering it unavailable to plants (Rehim *et al*., 2018). While most soils possess a significant capacity to supply K under normal conditions, several factors have led to substantial depletion of soil K reserves. These factors include increased cropping intensity, extensive removal of crop residues, excessive use of tube well irrigation, and the adoption of high-yielding hybrid varieties. Enhancing maize productivity necessitates the optimal provision of essential nutrients, including nitrogen (N), phosphorus (P), K, and micronutrients, which are critical determinants of corn yield (Gomaa *et al*., 2017).

Micronutrients, although required in minute quantities, are vital for plant growth and development. Boron is an essential micronutrient, especially vital for corn, as it contributes to various physiological processes in plants. It is crucial for maintaining the structural and functional integrity of cell walls and membranes, facilitating ion transport, supporting cell division and elongation, and regulating nitrogen and carbohydrate metabolism, as well as sugar transport (Wasaya *et al*., 2017). B deficiency is a significant nutritional disorder in maize, leading to non-viable pollen, disrupted fertilization, and incomplete seed filling, ultimately reducing crop yield. The B requirement varies significantly among plant species, with maize having a low but sensitive demand for this micronutrient. The optimal range of B concentration in corn cob leaves is between 4 to 25 ppm (Saleem *et al*., 2016). Adequate B availability enhances meristematic growth, facilitates the cross-linking of cellulose molecules in the cell wall, and activates various enzymes. B deficiency can result in impaired assimilate partitioning, reduced biosynthesis of hormones such as indole acetic acid and cytokinins, and arrested growth of root and shoot apex cells. This deficiency severely impacts plant metabolism, leading to decreased maize yield (Anjum *et al*., 2017).

Foliar application of B is particularly beneficial when soil conditions inhibit B uptake by plant roots.

According to Rafiullah *et al.* (2020), in sandy loam soil, foliar application is up to 20% more efficient in comparison to soil applied fertilizer. Similarly, Soomro *et al.* (2011) reported that soil and applied boron at 2 kg ha^{-1} did not remain effective for growth and yield of maize crop as compared to foliarly applied boron. Factors such as soil pH, texture, temperature, moisture content, microbial activity, organic matter content, and the presence of calcium carbonate can all affect B availability (Chahal *et al.*, 2025). Foliar nutrition not only supplies essential nutrients but also provides supplementary water, which is crucial in addressing water scarcity and nutrient unavailability in crops (Amanullah *et al.*, 2016).

This study addresses a critical knowledge gap in precision nutrient management by systematically evaluating the combined effects of soil-applied potassium and foliar boron in maize production systems. The investigation holds particular significance for semi-arid agricultural regions where optimal micronutrient management remains challenging. By elucidating the timing-method interactions between these essential nutrients, this work provides a scientific basis for developing more efficient fertilization strategies. The findings contribute to sustainable intensification efforts by potentially reducing input costs while maintaining crop productivity, offering practical solutions for resource-constrained farming systems in similar agro-ecologies. Given the importance of K and B in enhancing the yield of spring maize, the present study was designed to examine the optimal arrangement of these nutrients to improve its grain yield. By determining the most effective K and B supplementation strategy, it would be possible to improve crop resilience to drought and nutrient deficiencies, thereby maximizing yield potential.

Materials and Methods

Experimental site

The experiment was performed at the Agronomy Research Farm, The University of Agriculture, Peshawar (34.0206° N, 71.4814° E), located in northwestern Pakistan. The soil at the site was classified as silt loam (up to 30 cm depth), consisting of 20.16% sand, 70.21% silt, and 9.63% clay. It was slightly alkaline (pH 8.65) with an electrical conductivity (EC) of 1.92 dS m^{-1} and a bulk density of 1.48 g cm^{-3}. The soil was also characterized by low organic carbon content (0.35%), total nitrogen (0.04 g kg^{-1}), and AB-DTPA extractable P (3.78 mg kg^{-1}) and K (1.08 mg kg^{-1}) (Khan *et al.*, 2023).

Experimental setup and treatment applications

The experiment followed a randomized complete block design (RCBD) with three replications. Each plot had dimensions of 3.5 m × 4.5 m, consisting of six rows with an inter-row spacing of 75 cm and plant to plant distance of 20 cm. The study incorporated two experimental factors: (a) Potassium (K) levels (0 and 60 kg ha^{-1}) and (b) Boron (B) levels (0, 1, 2, and 3 kg ha^{-1}). Potassium was applied to the soil as K chloride (KCl, fertilizer grade), whereas B was administered as a foliar spray using boric acid (H_3BO_3, analytical grade).

Crop husbandry

The maize hybrid CS-200 (Petal Seed Company Pvt. Ltd) was planted at a seeding rate of 30 kg per hectare. Nitrogen (N) was applied in the form of urea at the recommended rate of 120 kg per hectare, divided into two applications: Half at sowing and the other half at the knee-high growth stage. Boron treatments were applied one month after sowing. Foliar spray was applied to the respective plots after determining the volume of water required to ensure uniform distribution across the entire plot.

The sowing was performed using a seed drill on March 8th, 2020, and the crop was harvested on July 21st, 2020. Thinning was carried out at the four-leaf stage to ensure optimal plant density. The field was irrigated uniformly at critical growth stages, including sowing, emergence, four-leaf stage, six-leaf stage, tasseling, and maturity. Weed management was conducted manually, with two rounds of hoeing to maintain a weed-free environment, thereby minimizing competition for nutrients, water, and light.

Observations and traits measurement

Field-data on the following key agronomic parameters were documented to assess the impact of the experimental treatments on plant performance and yield outcomes i.e., days to phenological observations (tasseling, silking and physiological maturity) was determined as the days difference between sowing to 75% occurrence of each growth stage in their respective treatments. The appearance of yellow color and formation of black scar at the point of attachment of grains to the cobs determined the physiological maturity of maize. Plant height in each plot was measured as the distance from the base of the plant near the soil surface to the base of the tassel (excluding the tassel) for five representative plants. The average of these measurements was then calculated. The number of grain rows ear^{-1} was determined by counting the rows on five randomly selected ears from each plot, and then averaged. The number of grains per ear was determined according to Khan *et al.* (2024) by counting the total grains on five randomly selected ears from each plot. The average grain count per ear was then calculated for each plot. To determine the 1000-grain weight, a random sample of grains was collected from each plot, and exactly 1000 grains were counted and weighed using a digital balance. Biological yield was assessed by harvesting the three central rows in each plot. The harvested plants were sun-dried, and their weight was measured (Khan *et al.*, 2024). The yield was then converted to kg ha^{-1} using the following formula:

$$Biological\ yield\ (kg\ ha^{-1}) = \frac{Weight\ of\ biomass\ harvested}{R-R\ distance\ \times\ no.of\ rows\ \times row\ length} \times 10{,}000\ m^2$$

For determining grain yield the biomass harvested and dried for biological yield was threshed and weight was recorded in three central rows with the help of electronic balance (Khan *et al.*, 2024). The wight was then converted to kg ha^{-1} using the following formula:

$$Grain\ yield\ (kg\ ha^{-1}) = \frac{Grain\ weight\ of\ central\ rows}{R-R\ distance\ \times\ no.\ of\ rows\ \times row\ length} \times 10{,}000\ m^2$$

After determining biological yield and grain yield the harvest index was worked out according to Khan *et al.* (2024) using the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Biological yield (kg ha}^{-1})} \times 100$$

Statistical analysis

The data were subjected to statistical analysis using Analysis of Variance (ANOVA) appropriate for Randomized Complete Block (RCB) design, following the methodology recommended by Steel and Torrie (1984). Computer software Statistix 8.1 was sused for all analyses (Statistix 8.1, 2008). After a significant F-test result, pairwise comparisons of treatment means were performed using the Least Significant Difference (LSD) test at a 95% confidence level to identify specific differences between treatments. This approach ensures robust identification of significant variations among treatment groups, thereby enhancing the reliability of the experimental conclusions.

Results and Discussion

Phenological observations

The days to phenological observation (tasseling, silking, and physiological maturity) of maize showed pronounced variation in response to soil applied K and foliar applied B application (Table 2 and Figure 1). The main effect of soil K and foliar B was found significant for phenological observations while the interaction (K × B) was found non-significant. The application of 60 kg K ha^{-1} had delayed the tasseling and silking by 2 days while the physiological maturity delayed by 4 days compared with control (0 kg K ha^{-1}). Likewise, the ranking and different foliar B application rates were similar for days to tasseling (Figure 1). The application of 3 kg B ha^{-1} had delayed the tasseling and silking by 4 days compared with control. However, the days observed with 1 and 2 kg B ha^{-1} was similar in case of tasseling (54) and silking (59) higher than control. Similarly, the increasing levels of B from 0 to 3 kg ha^{-1} had delayed the physiological maturity from 90 to 96 days indicating the superiority of higher level in term of increasing the days to physiological maturity (Figure 1).

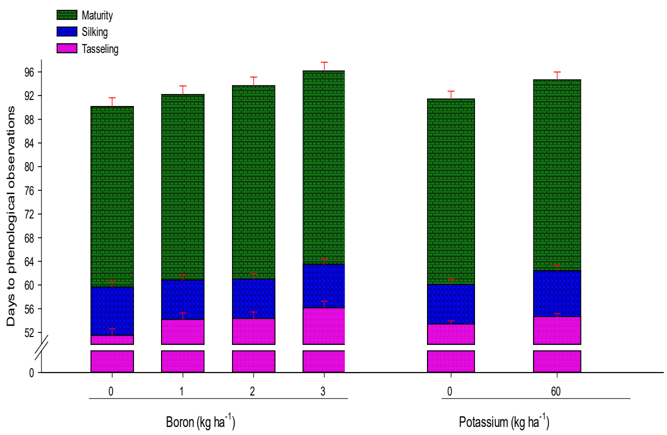

Figure 1: *Dyas to phenological observations (tasseling, silking and physiological maturity) as affected by Boron and Potassium application.*

Plant height

Statistical analysis indicates that application of potassium (K) and boron (B) significantly (P≤0.05) influenced the plant height, although their interaction did not exhibit a statistically significant effect (Table 1). The tallest plants, with an average height of 200 cm, were observed with the application 60 kg K ha^{-1} as depicted in Table 3. Conversely, the control treatment (0 kg K ha^{-1}), produced shorter plants with an average

Table 1: *Mean squares for seven quantitative traits in spring maize under varying potassium and boron regimes during 2020 at Peshawar.*

SOV	DF	DTT	DTS	DTM	PH	Rows ear^{-1}	Grains ear^{-1}	TGW	BY	GY	HI
Rep	2	0.04	15.61	1.29	52.0	0.17	90.5	561.4	107308	120521	10.2
B	3	22.15**	32.67**	38.38**	503.3**	4.17NS	650.8**	3498.3**	2562663**	904815.1**	15.2*
K	1	9.38**	1.22**	63.38**	280.2*	0.17NS	2090.7*	2134.2**	1241240*	1051013**	18.4*
B × K	3	0.15NS	0.52NS	0.15NS	12.6NS	0.61 NS	66.1NS	239.7NS	596191NS	89468.6NS	1.2NS
Error	14	0.47	15.61	0.39	42.5	1.50	133.5	269.4	202882	32675.4	3.2
Total	23										

*PH= plant height; TGW=thousand-grain weight; BY=biological yield; GY=grain yield; HI=harvest index. *, significant at P≤0.05, ** Significant at P ≤0.01, NS, Non significant.*

height of 193 cm. Regarding B foliar application, the tallest maize plants (208 cm) were recorded with 3 kg B ha^{-1} application (Table 1). However, the shorter plants (187 cm) were observed with 0 kg B ha^{-1} application.

Table 2: *Days to tasseling, silking and physiological maturity of spring maize as affected by boron and potassium fertilization.*

Bron (kg ha^{-1})	DTT	DTS	DTPM
0	52 c	58 c	90 d
1	54 b	59 b	92 c
2	54 b	59 b	94 b
3	56 a	62 a	96 a
$LSD_{0.05}$	0.8	0.9	0.8
Potassium (kg ha^{-1})			
0	53 b	58 b	91 b
60	55 a	60 a	95 a
$LSD_{0.05}$	0.6	0.6	0.6
Interaction (B×K)	NS	NS	NS

Boron was applied as foliar spray while, potassium was applied to soil. DTT, Days to tasseling; DTS, Days to silking; DTPM, Days to physiological maturity.

Yield components

Statistical analysis of field-data revealed that soil application of K and foliar B at varying levels did not significantly affect the rows ear^{-1} in the maize crop (Table 3). The application of 60 kg K ha^{-1} led to a significant increase (5.6%) in grains ear^{-1} compared to 0 kg K ha^{-1}, representing the significant influence of K fertilization (Table 3). While, in case of foliar B application, a significant increase (6.7%) in grains ear^{-1} over control 0 kg B ha^{-1} was noticed with application of 3 kg B ha^{-1}. Furthermore, the interaction of soil applied K and foliar B was found non-significant for number of grains ear^{-1}. Both soil applied K and foliar B at different levels brought about significant variation in 1000 grains weight of maize while, the interaction (K × B) was found non-significant (Table 1). Application of 60 kg K ha^{-1} to soil had increased the 1000 grains weight by 7.1% compared with untreated control (0 kg K ha^{-1}). Similarly, the 1000-grain weight did not differ between 2 and 3 kg B ha^{-1} but was significantly higher compared to 0 and 1 kg B ha^{-1}. The higher B level (3 kg ha^{-1}) increased the 1000-grain weight by 18.7% and 14.5% compared to 0 and 1 kg B ha^{-1}, respectively. The findings indicate that biological yield was significantly affected by the main effects of soil-applied K and foliar B at different levels, whereas their interaction (K × B) remained non-significant (Table 1).

Table 3: *Plant height, rows ear^{-1}, grains ear^{-1}, and 1000 grains weight of spring maize as affected by boron and potassium fertilization.*

Bron (kg ha^{-1})	Plant height (cm)	Rows ear^{-1}	Grains ear^{-1}	1000 grain weight
0	187.8c	11.7	331.5b	249.8b
1	191.8bc	12.3	332.8b	258.9b
2	198.2b	12.7	344.0ab	294.8a
3	208.8a	13.7	353.7a	296.5a
$LSD_{0.05}$	8.1	NS	14.3	14.2
Potassium (kg ha^{-1})				
0	193.3b	12.5	331.2b	265.6b
60	200.1a	12.7	349.8a	284.4a
$LSD_{0.05}$	5.7	NS	10.1	10.3
Interaction (B×K)	NS	NS	NS	NS

Boron was applied as foliar spray while, potassium was applied to soil.

The application of 60 kg ha^{-1} of K produced the highest biological yield, averaging 11,136.3 kg ha^{-1}, while the lowest yield (10,681.5 kg ha^{-1}) was recorded in the untreated control plots (Table 4). Similarly, the application of 2 and 3 kg B ha^{-1} resulted in statistically similar but significantly higher biological yields (11,323 and 11,601 kg ha^{-1}, respectively) compared to 0 kg B ha^{-1} (10,262 kg ha^{-1}). Additionally, the biological yield observed with 1 kg B ha^{-1} was statistically comparable to that of the 0 kg B ha^{-1} treatment.

Table 4: *Biological yield, grain yield, and harvest index of spring maize as affected by B and K fertilization.*

Boron (kg ha^{-1})	Biological yield (kgha^{-1})	Grain yield (kg ha^{-1})	Harvest index (%)
0	10262 b	3796 b	36.5b
1	10449 b	3967 b	38.2ab
2	11323 a	4425 a	40.2a
3	11601 a	4630 a	39.3a
$LSD_{0.05}$	558	223.8	2.2
Potassium (kg ha^{-1})			
0	10682 b	3995 b	37.7b
60	11136 a	4413 a	39.4a
$LSD_{0.05}$	394	158.2	1.6
Interaction (B×K)	NS	NS	NS

Boron was applied as foliar spray while, potassium was applied to soil.

The application of 60 kg K ha^{-1} resulted 10.5% increase in grain yield compared to the untreated control, highlighting the significant impact of K fertilization (Table 4). Likewise, foliar application of B significantly influenced grain yield, with the highest yield (4,630 kg ha^{-1}) recorded at 3 kg B ha^{-1}, while the lowest (3,796 kg ha^{-1}) was observed in the absence of B application. However, grain yield did not differ significantly between 2 and 3 kg B ha^{-1}, as well as between 0 and 1 kg B ha^{-1} treatments. However, the interaction between K and B (K × B) had no significant effect on grain yield. The results further demonstrated that both K and foliar B applications significantly influenced the harvest index, while their interaction remained non-significant (Table 4). The application of 60 kg K ha^{-1} resulted in the highest harvest index (39.4%), compared to 37.7% in the control. Similarly, applying B at rates above 1 kg ha^{-1} significantly improved the harvest index over 0 kg B ha^{-1}. The most notable increase was observed with 2 kg B ha^{-1}, which enhanced the harvest index by 9.01%, whereas 3 kg B ha^{-1} led to a 8% increase. Additionally, the application of 1 kg B ha^{-1}, though statistically similar to the control, improved the harvest index by 4.7% compared to 0 kg B ha^{-1}.

Delayed tasseling, silking, and physiological maturity were observed with the application 60 kg K ha^{-1} and 3 kg B ha^{-1} application compared with the control. The pronounced effects on phenological stages can be attributed to improved nutrient availability, particularly K and B, which are vital for physiological and biochemical processes (Samet *et al*., 2015). Potassium plays a critical role in enzymatic activation, water regulation, and energy transfer, which may promote extended vegetative growth, thereby delaying phenological events (Pandey and Mahiwal, 2020; Damalas and Koutroubas, 2024). Similarly, Boron, as a key micronutrient, contributes to cell wall formation, sugar transport, and reproductive organ development (Kohli *et al*., 2023). Enhanced nutrient availability, particularly under 60 kg K ha^{-1} and 3 kg B ha^{-1}, likely contributed to vigorous growth and delayed phenology (Khan *et al*., 2023). Conversely, the control treatments, characterized by limited nutrient supply, accelerated phenological events, potentially due to stress-induced early reproductive transitions (Khan *et al*., 2023, 2024). These findings indicate the importance of balanced nutrient management in optimizing maize growth and development while delaying phenological stages to achieve better productivity.

Soil application of K and foliar applied B significantly influenced the growth and yield attributes of maize (*Zea mays* L.), though their interaction was non-significant. An increase in K levels up to 60 kg ha^{-1} led to a notable enhancement in plant height. This increase can be attributed to the crucial role of K in promoting growth, and physiological attributes of plants (Biswas *et al*., 2023). These findings are coherent with previous research by Raza *et al*. (2021) and Iqbal *et al*. (2025) who observed a positive correlation between increased K application and enhanced plant height. Potassium is particularly noted for its role in increasing plant height and improving nutrient uptake, which directly contribute to better crop productivity (Rawat *et al*., 2022). Similarly, B foliar spray positively impacted maize plant height, with the potential mechanism being Boron's role in cell wall formation, nucleic acid synthesis, and membrane function, which collectively contribute to plant height increment. This observation aligns with the results of Bayar *et al*. (2024), who reported that B application significantly increased plant height. Despite their individual benefits, the combined effect of K and B has not shown statistically significant interaction in most cases. For example, research by and Wasaya *et al.* (2021) showed that foliar-applied K positively impacts maize by enhancing photosynthesis and strengthening plant structure. Imtiaz *et al.* (2023) further reported that K facilitates water uptake and nutrient transport, which are key to improving plant growth and yield under stress conditions. However, these studies also confirm that the interaction between K and B, while beneficial independently, does not result in significant synergistic effects on growth parameters like plant height or biomass.

The grains ear^{-1} was also positively influenced by K and B application. Potassium is essential for a plant's physiological processes, including water uptake, enzyme activation, photosynthesis, and the translocation of nutrients to developing parts like grains (Mostofa *et al*., 2022). Abido *et al.* (2023) observed that K application in maize resulted in higher grains ear^{-1} due to its critical role in osmotic regulation, enabling better water and nutrient movement, especially to reproductive organs like grains. Alqudah *et al.* (2025) further confirmed this by showing that K application enhanced grain number in wheat and maize by improving assimilate transport to grain sites. Higher K levels promoted better pollen viability and grain setting, extending the grain filling period and leading to increased grain yield. Boron is crucial for reproductive development, affecting flowering, pollen germination, and seed formation. Boron deficiency can lead to incomplete fertilization, causing poor grain setting. In other studies, B foliar sprays at critical stages of crop growth significantly boosted grain setting and yield. In wheat, for instance, B application enhanced the formation of pollen tubes, thereby increasing the number of grains ear^{-1} (Khan *et al*., 2019). Boron also improves the structural integrity of cell walls, promoting better nutrient flow within the plant (Gulut, 2024). This mechanism is further supported by findings of Rerkasem *et al.* (2020) who documented enhanced maize grain yield through B foliar sprays due to improved grain set and a longer grain filling period. The combined application of micronutrients like K and zinc, as noted by researchers such as Dezfouli *et al.* (2024), also showed synergistic effects on grain yield by optimizing both vegetative growth and reproductive development.

Thousand-grain weight, a critical determinant of final yield, was significantly improved by the application of both K and B. The highest grain weight was achieved with increasing K doses, consistent with Ribeiro *et al.* (2022), Bayar *et al.* (2024) who observed that K application up to 60 kg ha^{-1} improved thousand-grain weight in maize by 8%, while foliar application of B (1%) further enhanced thousand-grain weight, likely by reducing infertility and improving vegetative growth, leaf area, photosynthesis, and nutrient translocation. These findings are supported by Izhar-Ullah *et al.* (2024), who reported significant improvements in seed weight with B application. Similarly, Bayar *et al.* (2024) reported that B application significantly enhanced thousand-grain weight in maize by addressing B deficiencies that lead to incomplete grain development, such as partly grain-free ears. In calcareous soils, B deficiency limits nutrient uptake and grain set, but applying B improves grain formation, nutrient translocation, and yield. This effect was even more pronounced when B was combined with Zn, as both nutrients synergistically boost grain yield and maize growth Safdar *et al.* (2023).

The application of K and B had a significant impact on biological yield, however, their interaction did not show a significant effect. The increase in biological yield could be attributed to the enhanced CO_2 assimilation rate, osmotic regulation, stomatal conductance, and enzyme activity facilitated by K, leading to greater carbohydrate formation. Similar findings were also reproduced by Raza *et al.* (2021) who concluded that higher K levels led to increased biomass production in spring maize. Boron application also increased biological yield, likely due to its role in enhancing vegetative growth and leaf area. These findings align with the results of Wasaya *et al.* (2017), who reported that foliar application of B enhanced biomass production in maize.

The impact of K and B on grain yield revealed critical insights for maize cultivation. Potassium is known to activate over 60 enzymes involved in essential metabolic processes, contributing to better nutrient uptake, photosynthesis, and improved water-use efficiency (Sardans and Penuelas, 2021; Johnson *et al*., 2022). For instance, Hussain (2018) demonstrated significant increases in maize yield with K application under different moisture conditions, while other studies highlighted K's crucial role in nutrient translocation and enzymatic regulation, leading to yield improvements (Asante-Badu *et al*., 2020).

Boron, on the other hand, plays a crucial role in cell wall formation and reproductive development in maize. When applied at optimal levels, it can mitigate grain sterility and enhance nutrient transport, particularly phloem mobility. Studies, including those by Shahgholi *et al.* (2023) and others, have reported improved grain yield with B application, especially in zinc-deficient soils.

Although the interaction between K and B in our study was non-significant as both nutrients individually contributed to higher grain yields. These findings align with contemporary research, which underscores the complementary yet independent roles of K in enzyme activation and B in reproductive health of crops. The absence of significant interaction may indicate that these nutrients influence different physiological pathways, leading to additive rather than synergistic effects on yield. This is supported by the findings of Jasar *et al.* (2019) and Amanullah *et al.* (2016), who reported increased grain yield with higher K application. Similarly, grain yield increased with B application up to 60 kg ha^{-1}, likely due to enhanced phloem translocation. This is consistent with the results of Bayar *et al.* (2024), who noted that B spray improved grain yield in maize.

The statistical analysis of K and B application on the harvest index revealed significant effects, underscoring their role in crop productivity, particularly in maize. Potassium is vital for enhancing assimilate partitioning and translocation, which directly contributes to an improved harvest index (Hasanuzzaman *et al.*, 2018). Research has shown that increased K levels lead to better nutrient mobilization and accumulation in various plant parts, which positively impacts the overall grain yield and harvest index (Ray *et al.*, 2020). Boron also plays a crucial role, particularly at foliar application rates of 2 kg ha^{-1}. It enhances leaf area, which increases the plant's capacity for photosynthesis, and thereby improves assimilate translocation to reproductive organs. Studies in the Himalayan regions confirm that B application improves nutrient partitioning and grain production, supporting the notion that B deficiency can negatively impact yield and harvest index (Thakur *et al.*, 2023). These findings are consistent with earlier research, such as Raza *et al.* (2021), which reported similar improvements in maize yield with increased K fertilization, and Anjum *et al.* (2017), who noted that B significantly boosts the HI by supporting better growth and nutrient distribution in maize. This interplay between K and B ensured optimal growth and yield, making these nutrients vital for effective maize cultivation strategies.

Conclusions and Recommendations

The study revealed that foliar supplementation of K and B significantly improved maize (*Zea mays* L.) growth and yield parameters, though their interaction did not show statistical significance. The application of K at 60 kg ha^{-1} extended phenological stages and led to increased plant height, grain count per ear, 1000-grain weight, biological yield, and grain yield. Likewise, B applied at 2 kg ha^{-1} positively influenced phenology and yield attributes. Therefore, for optimizing maize growth and productivity under the agro-climatic conditions of Peshawar, a soil application of 60 kg K ha^{-1} combined with a foliar application of 3 kg B ha^{-1} is recommended. Future studies could explore the long-term effects of potassium and boron application on soil health and maize productivity. Investigating maize genotypic responses to different nutrient levels may help identify optimal cultivars. Additionally, nano-fertilizers and integrated nutrient management strategies could improve efficiency. Experiments on split potassium application and drought stress mitigation would provide valuable insights into sustainable fertilization practices.

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Novelty Statement

This study uniquely combines soil-applied potassium and foliar boron to enhance nutrient synergy and boost spring maize productivity—an approach rarely explored in this cropping season.

Author's Contribution

Amir Rahman and Shazma Anwar: Conceived and executed the research.
Said Badshah and Muhammad Ibrar: Conducted the statistical analysis.
Sheraz Ahmed, Haris Khan and Sajid Khan: Critically reviewed the first draft of the manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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