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Original Research

Boron Foliar Application Improves Growth, Yield and Grain Quality of Maize

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Abstract

Balanced nutrition is the key to higher quality crop production. Micronutrients, especially boron (B) have an important role in various physiological processes and stress tolerance while its deficiency could affect the yield and quality of crop plants. In this context, this study investigated the significance of foliar B application at various growth stages on maize yield components, yield, and grain B content. The treatments consisted of boron foliar application levels (0, 0.5, 1, 1.5 and 2%) at different growth stages (V4 = fourth leaf stage, V8 = eighth leaf stage and VT = tasseling stage) during summer 2021 and 2022. The results revealed that plant height, leaf area plant^{-1}, leaf area index, plants at harvest, ear length, grains ear^{-1}, thousand grains weight, shelling percentage, biological yield, grain yield and harvest index were increased with 1 % B foliar spray compared to other levels. In addition, ear length, grains ear^{-1}, thousand grains weight, shelling percentage, biological yield, grain yield and harvest index were increased with B foliar application at VT (tasseling stage) compared to other stages. It was concluded that the application of 1% foliar boron (1.28 kg B ha^{-1}) i.e. 7.32 kg H_3BO_3 at tasseling stage improved growth, yield and yield components of maize.

Keywords: yield components, foliar application, growth stages, maize yield, boron

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Introduction

Maize (*Zea mays* L.) belongs to the Poaceae family, a cross-pollinated and short-day crop that grows well in tropical and subtropical climatic conditions. Maize is known as the "golden food" due to its high production and nutritional value, a rich source of starches, proteins, fats, fiber, and essential minerals [1]. Maize is commonly cultivated as feed for animals, food for humans, and for bioenergy production [2-4].

Boron (B) is an important microelement and due to its importance as a structural element of the cell wall, it is regularly required for plants throughout their life [5]. Boron during flower pollination is required for the pollen tube growth and is therefore essential for better fruit development [6]. Boron application activated enzymes and subsequently enhanced carbon fixation. Thus, increasing photosynthesis and improving the accumulation of dry matter in vegetative parts [7]. It is important for cell wall and cytokinin formation, cell division, sugar metabolism and transportation, indole acetic acid (IAA) and ribose nucleic acid metabolism, seed germination and formation [8]. B helps to maintain the integrity of plant cell membranes, which increases the ability of membranes to transport essential nutrients, different B treatments had a substantial impact on micronutrient uptake [9].

Moreover, the appropriate method of application is necessary for better uptake of boron. Foliar application of micronutrients is the most effective strategy for the improvement of crop productivity when applied at suitable growth stages of crops [10, 11]. The foliar application of micronutrients at the peak demand period preserved the leaf's nutritional balance, enhanced photosynthesis and eventually increased biomass production [12]. This method can ensure that nutrients are transferred immediately from leaf tissues to various plant organs in the case of various nutrient deficits [13, 14]. The foliar spray technique has crucially adapted for the elimination of nutrient scarcity due to its readily absorbance by plant leaves and cost-effectiveness. Foliar application of B at various growth stages of maize crops with a recommended dose of fertilizers enhanced the growth performance and yield of maize [15].

Less availability of B results in weak translocation of assimilates [16]. Decreases in B availability in soil affect enzyme activation and reproductive structure hence decreasing crop productivity [17]. The imbalanced use of boron is one of the primary limiting factors in obtaining the potential yield [18]. Therefore, this experiment was performed to evaluate the optimum level of foliar boron, the best application stage, and its interactive effect on the growth and yield of maize under agro-climatic conditions of Peshawar.

Materials and Methods

An experiment with maize was conducted during the Kharif season 2021 and 2022, using a conventional tillage approach at Agronomy Research Farm (ARF), The University of Agriculture Peshawar. The experimental farm is situated 350 meters above sea level in the Peshawar valley at 34.01°N latitude and 71.35°E longitude. According to the Koppen classification, Peshawar has a semi-arid subtropical continental type of climate and is situated around 1600 km north of the Indian Ocean. The average annual rainfall ranges from 300 to 500 mm, or 60 to 70%. According to the digital weather station of the Agronomy Research Farm at the University of Agriculture Peshawar, the mean annual rainfall is very low (300 to 500 mm), with 60 to 70% of the precipitation falling during the summer and the remaining 30 to 40% falling during the winter. The soil of the site was classified as Alfisol, based on the Soil Survey Staff [19].

Experimental Design and Treatments

The experiment was designed in a randomized complete block design (RCBD) in a 5 × 3 factorial scheme with four replications. The treatments consisted of five foliar boron levels i.e., B1 = control (water spray), B2 = 0.5%, B3 = 1.0%, B4 = 1.5%, B5 = 2.0% boron solution; from the source of boric acid (H_3BO_3), and three growth stages i.e., V4 = fourth leaf stage, V8 = eighth leaf stage and VT = tasseling stage.

Preparation and Application of Boron Solution

Boron solution was prepared with an estimated water volume to cover the crop canopy of each subplot. The amount of boron was calculated for each treatment; 0.5% (28.60 g), 1.0% (57.20 g), 1.5% (85.81 g), and 2.0% (114.41 g) from H_3BO_3 (17.48% B). Each calculated amount of H_3BO_3 was dissolved in 1.0 L of water, as 1.0 L water was sprayed prior to the treatment application and found sufficient for our plot area (22.5 m^2). All the treatments were uniformly sprayed on plants in the late afternoon. Boron was foliar sprayed at V4, V8 and VT growth stages of maize with the help of a knapsack sprayer.

Crop Husbandry

The maize variety "Azam" was sown with a seed rate of 30 kg ha^{-1}. The seedbed was prepared with the help of a tractor, twice plowing followed by a rotavator as required for maize cultivation. The subplot has a width of 4.5 m and a length of 5 m, which accommodates 6 rows. Plant and row distances were kept at 20 and 75 cm, respectively. The nitrogen, phosphorous and potassium were applied at recommended rates i.e. 120, 90 and 60 kg ha^{-1} from the sources of urea (46% N),

Table 1. Physiochemical properties of pre-harvest soil.

Characteristics	Units	Values
Sand	g kg^{-1}	261
Silt	g kg^{-1}	472
Clay	g kg^{-1}	269
$CaCO_3$	g kg^{-1}	111
pH	g kg^{-1}	7.5
Organic Matter	g kg^{-1}	99
EC	Msm^{-1}	143
N content	%	0.1
P content	mg kg^{-1}	34.92
K content	mg kg^{-1}	71.23
Fe content	mg kg^{-1}	0.67
Zn content	mg kg^{-1}	1.20
Hot water soluble B	mg kg^{-1}	0.8

EC: Electrical conductivity.

diammonium phosphate (DAP; 46% P_2O_5) and Muriate of Potash (MOP; 60% K), respectively. The fertilizers were applied in two splits, half at the time of sowing and another half after a month of sowing.

The experimental field was irrigated with surface irrigation from the Warsak canal according to the requirements of crop and weather conditions. A total of four irrigations were applied along natural seasonal precipitation. Weeds were manually eradicated during the crop cycle; the first weeding was conducted after twenty-five days and the second after forty-five days of maize emergence. All other cultural practices i.e. thinning, herbicide and insecticide application were kept uniform for all experimental units.

Soil Analysis

Twenty random samples were collected from the field site prior to the experiment initiation and mixed homogeneously to make a composite soil sample. The composite sample was air-dried, powdered, and sieved through a 2 mm sieve and determined for the physical and chemical characterizations, as summarized in Table 1. The soil pH and electrical conductivity were determined following the protocol of McLean [20]. The soil texture was determined by following the hydrometer method [21]. The available P, K, Zn, and Fe were estimated with the methodology of Soltanpour and Schwab [22]. Nitrogen content was determined by using the Kjeldahl method, following the protocol of Bremner and Mulvaney [23]. The soil and plant B content was determined by hot water extraction technique with the development of color in a curcumin oxalic acid solution, using a spectrophotometer at 420 nm absorbance [24].

Measurements

Leaf area was calculated from the measurement of the length and width of ten random leaves in each plot at the tasseling stage, and the average was multiplied with the correction factor (CF; 0.75) for leaf area $plant^{-1}$ [25]. Plant height was measured with a meter rod from the soil surface to the tassel by selecting ten random plants from each plot. Ear length was measured by measuring tap by selecting ten ears randomly in each experimental unit. The harvested central four rows ears were shelled through maize sheller and grains were weighed for each sub-unit and were converted to grain yield (kg ha^{-1}). The harvested central four rows in each experimental unit were weighed through electronic balance and were converted to biological yield (kg ha^{-1}). For each subplot shelling percentage was calculated by using the weight ratio of grains and ears. The number of plants in the four middle rows of each experimental unit was counted and transferred into plants at harvest ha^{-1} via formula.

$$Plants\ at\ harvest = \frac{Total\ plants\ in\ four\ central\ row}{Number\ of\ rows\ \times\ Row\ length\ (m) \times R - R\ distance\ (m)}$$

Grain Boron Contents (mg kg^{-1})

Grain boron content was quantified by adding 1 mL aliquot of the extract (10 g air-dried soil and 0.2 g charcoal in 20 ml distilled water), 2 mL buffer solution (62.5 g ammonium acetate, 3.75 g ETDA disodium and 31.25 mL glacial acetic acid in 100 mL water) and 2 mL azomethine-H solution into a 10 mL polypropylene tube. The standard curves of standard solution, blank and samples were prepared and measured at 420 nm on a spectrophotometer. The calibration curve for absorbance was prepared and plotted against the respective boron concentrations for each sample.

Statistical Analysis

All the data were run through computer-based software to check for variance in accordance with the protocol. Means were subjected to the least significant difference test (LSD) at the 5% probability were determined to be significant [26]. The data was analyzed using Statistical software (Statistix 8.1). The possible interactions were represented graphically using Sigma Plot 12.

Results and Discussion

Foliar boron concentrations had significant effects while different growth stages had non-significant effects on plant height (Table 2). The interaction of boron and growth stages in both the growing seasons of 2021 and 2022 was found significant (Fig. 1(A, B)). Data

Table 2. Plant height (cm), leaf area plant^{-1} (cm^2), leaf area index and ear length (cm) as influenced by different concentrations of boron and their foliar applications on maize at various growth stages.

Foliar Boron (%)	Plant height (cm)		Leaf area plant^{-1} (cm^2)		Leaf area index		Ear Length (cm)	
	2021	2022	2021	2022	2021	2022	2021	2022
0.0	183 bc	179 b	3632 b	3503 b	3.5 c	3.2 c	11.7 b	10.8 c
0.5	183 bc	182 ab	3778 ab	3524 b	3.3 d	3.1 d	12.5 ab	11.7 b
1.0	189 a	186 a	4013 a	3884 a	3.8 a	3.6 a	12.7 a	11.9 a
1.5	184 b	183 a	3984 a	3855 a	3.7 b	3.4 b	12.6 a	11.7 b
2.0	179 c	178 c	3400 b	3271 b	3.3 d	3.2 c	11.0 b	10.1 c
LSD for B	5	4	319	298	0.3	0.3	0.9	0.8
Fourth leaf stage	185 a	183 a	3927 a	3798 a	3.6 a	3.5 a	12 b	11.1 b
Eight leaf stage	183 a	180 a	3596 b	3417 b	3.4 b	3.1 b	12.2 b	11.4 b
Tasseling stage	184 a	182 a	3456 b	3367 b	3.3 c	3.1 b	12.9 a	12 a
LSD for GS	ns	ns	247	231	0.3	0.2	0.7	0.6
B x GS	*	*	*	*	ns	ns	*	*

Means in the column followed by different letters are significantly different (p-value≤0.05); ***, ** and *-significant at $p < 0.01$, $p<0.05$ and $p<0.10$, respectively; and Ns-non-significant, by F-test.

regarding plant height as a result of various foliar boron concentrations revealed that the plots treated with boron solution in both the 2021 and 2022 growing seasons were seen to have taller plants (3.27% and 3.91%, respectively) as compared to those not treated with boron. In 2021 application of foliar boron at the fourth leaf stage led to taller plants (1.09%), while boron foliar application in 2022 showed that 2.23% taller plants were produced as compared to control. The increase in plant height might be due to boron application because it increases the plant inter-nodal length by increasing cell number, and boron is linked to cell differentiation and the production of cell wall, which promotes plant growth and root and shoot elongation [27]. These results are in line with Humtose et al. [28], who observed that increasing boron foliar spray concentrations increased the height of maize plants.

The effects of various boron foliar concentrations at different growth stages on leaf area plant^{-1} of maize are presented in Table 2. Results noted revealed that in both 2021 and 2022 study years leaf area plant^{-1} as affected by different foliar boron applications at different growth stages showed significant. Also, the interaction of boron and growth stages revealed significant results (Fig. 1(C, D)). Data regards leaf area plant^{-1} as a result of various foliar boron concentrations showed that leaf area plant^{-1} was increased by 10.49% and 10.87% in the presence of boron application in 2021 and 2022, respectively, compared to the control. Similarly, the application of foliar boron at the fourth leaf stage produced 8.1% and 8.42% taller plants in 2021 and 2022 respectively, compared to the control plots. A decrease in mean values noted for leaf parameters at a higher rate of boron application might be due to the burning effect of boron on maize leaves [29]. Under boron nutrition leaf area was increased and therefore maximum photosynthates were available for enhancing attributes related to crop growth [30]. These results are in agreement with that of Shabbir et al. [31], who reported that increased concentrations of boron foliar spray increase the leaf area of maize.

Leaf area index (LAI) was significantly affected by various levels of boron foliar application at different growth stages (Table 2). The interactions of boron levels and various growth stages were found insignificant for the leaf area index in both 2021 and 2022. Regarding foliar spray of boron, the plots treated with 1% boron solution produced 8.57% and 12.50% LAI in 2021 and 2022 respectively compared to their being no B applied plots. In the case of different growth stages, LAI was increased by 2.85% and 9.37% in 2021 and 2022 respectively by foliar application of boron at the fourth leaf stage as compared to the control. It has previously been reported that boron foliar application produced maximum LAI which might be due to an increase in IAA hormone through fertilization of boron [32, 33]. These results are in line with Adarsha et al. [34] observed that boron foliar spray improves leaf parameters of the maize plant.

Ear length was significantly affected by different concentrations of foliar boron at various growth stages (Table 2). The interaction of boron and growth stages for ear length was found significant for both the 2021 and 2022 study years (Fig. 1(E, F)). Data concerning various foliar boron concentrations revealed that 8.54% and 10.18% lengthy ear was obtained in plots treated with 1% boron solution in both 2021 and 2022 study years as compared to no applied boron solution. Similarly,

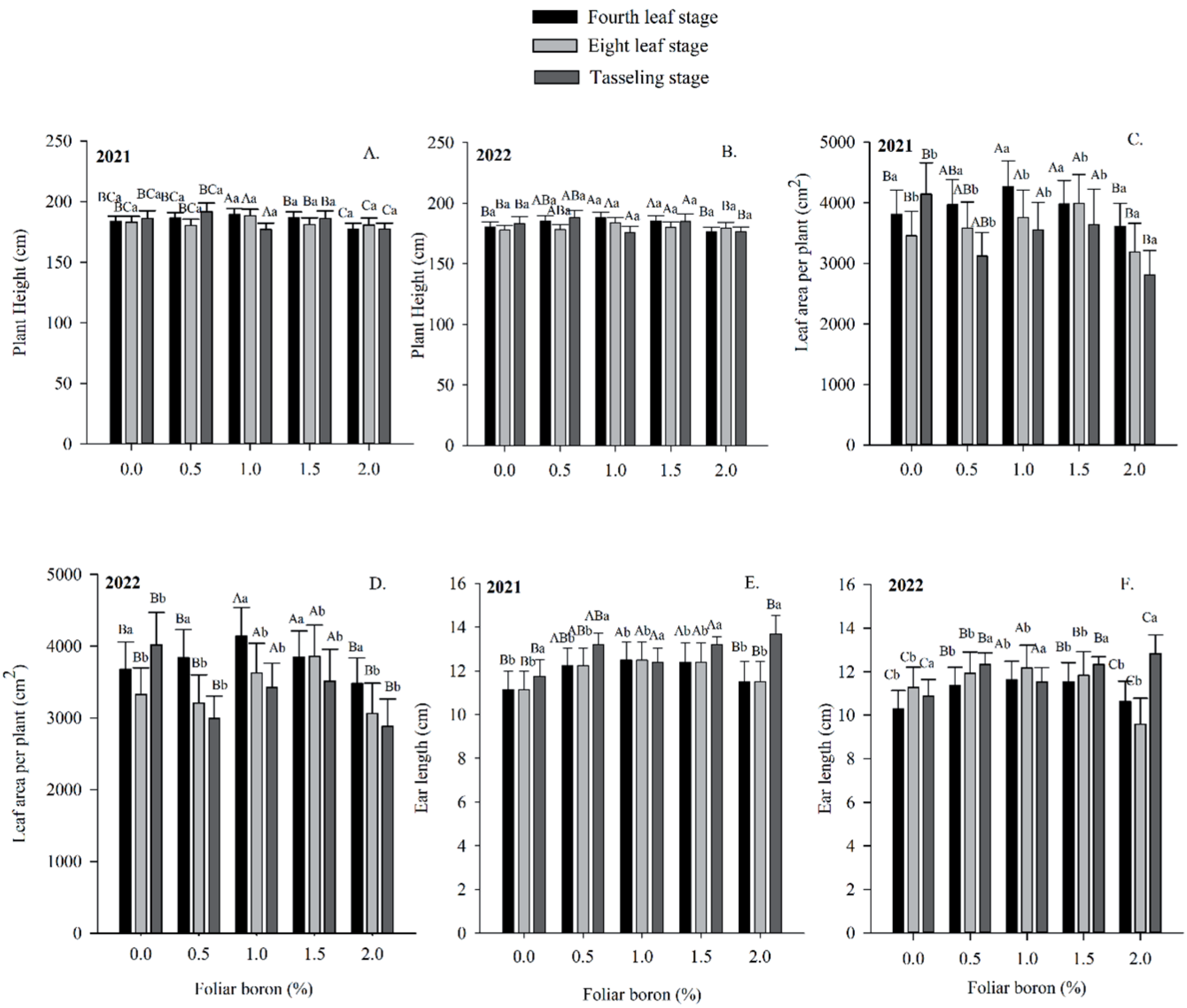

Fig. 1. The influence of different boron levels at different growth stages on maize growth parameters: (A, B) Plant height (cm) in 2021 and 2022 respectively, (C, D) leaf area plant-1 (cm2) in 2021 and 2022 respectively, and (E, F) ear length (cm) in 2021 and 2022 respectively. The uppercase letters are used for foliar boron interactions within each growth stage of application, whereas lowercase letters are used for the growth stages within each boron application. The identical alphabetic letters do not differ from each other, as analyzed by LSD (Foliar boron application; p<0.05) and (growth stages; p<0.05) test for both years. Error bars indicate the standard error of the mean (n = 4 replications.

in the case of foliar boron application at various stages, application at tasseling stage in 2021 and 2022 produced 10.25% and 11.11% lengthy ear respectively when compared with the control. The increase in ear length by the application of boron was due to its importance in cell division and expansion and also other physiological processes such as the conversion of sugar into starches which is necessary for ear length [35]. These results are in accordance with Almosawy et al. [36], who stated that foliar boron application improved ear length. These results are in accordance with Anjum et al. [7], who observed that the plots treated with boron foliar spray have maximum ear length as compared to control.

The number of grains ear^{-1} was significantly influenced by various foliar boron applications at different growth stages of maize plants (Table 3). Statistical analysis revealed that various boron foliar concentrations and their application at different growth stages had significant effects while their interactions had non-significant effects on grain ear^{-1} (Fig. 2(A, B)). Outcomes of the research exhibit that foliar application of boron at 1% resulted in 7.92% and 10.06% maximum grains ear^{-1} in both the 2021 and 2022 study years respectively, as compared to no applied boron solution. In the case of different growth stages, it was noted that 4.29% and 5.55% maximum grains ear^{-1} were produced in 2021 and 2022 respectively when boron was applied at tasseling stage as compared to no treated plot. The increase in grains ear^{-1} is due to the reason that applications of boron improve the process of grain filling by improving the grain setting and thus reduce the male sterility which is often observed in deficient conditions of boron [35]. These results are reassuring with the findings of Sultana et al. [37], who stated that boron

Table 3. Grains ear^{-1}, Shelling percentage (%), thousand grains weight (g) and biological yield (kg ha^{-1}) as influenced by different concentrations of boron and their foliar applications on maize at various growth stages.

Foliar Boron (%)	Grains ear^{-1}		Shelling percentage (%)		Thousand grain weight (g)		Biological yield (Kg ha^{-1})	
	2021	2022	2021	2022	2021	2022	2021	2022
0.0	303 b	288 b	70.5 c	68.5	209.1 b	200.1 b	9699 cd	9456 d
0.5	322 a	312 a	71.9 bc	70.0	211.4 b	202.5 b	10130 c	10006 c
1.0	327 a	317 a	76.3 a	74.0	223.8 a	216.4 a	12140 a	11897 a
1.5	303 b	291 b	72.7 b	71.6	221.1 ab	212.9 a	11413 b	11170 b
2.0	301 b	287 b	67.8 d	66.4	197.0 c	190.3 c	9241 d	8998 e
LSD for B	10	9	1.5	1.5	8.7	7.81	567	540
Fourth leaf stage	307 b	293 b	70.7 b	71.2 b	211.1 a	203 b	10194 b	9951 b
Eight leaf stage	315 a	304 a	73 a	69 b	213.9 b	205.9 b	10855 a	10660 a
Tasseling stage	316 a	304 a	73.7 a	72 a	228.6 a	219.6 a	10986 a	10692 a
LSD for GS	7	7	1.2	1.1	6.7	6.0	439	418
B x GS	*	*	**	**	*	*	**	***

Means in the column followed by different letters are significantly different (p-value≤0.05); ***, ** and * significant at p<0.01, p<0.05 and p<0.10, respectively; and Ns, non-significant, by F-test.

application improves grains ear^{-1}. Similar results were obtained by Phomglosa et al. [38] reported that foliar application of boron increases the number of grains ear^{-1}.

The shelling percentage was influenced by various concentrations of foliar boron application at different growth stages in both the 2021 and 2022 cropping seasons (Table 3). The interactions of foliar boron and different growth stages had a significant effect on the shelling percentage of maize (Fig. 2(C, D)). Regarding foliar boron concentrations, it was noticed that the application of 1% foliar boron increased shelling percentage by 8.22 and 8.02% in 2021 and 2022, respectively, compared to the plots without boron being supplied. In the case of different growth stages shelling percentage was increased by 4.53% in 2021 and 5.10% in 2022, respectively, by boron application at tasseling stage as compared to untreated plots. Similar results were reported by Anjum et al. [7], who observed that application of foliar boron increased the shelling percentage of maize.

Data relating to the thousand-grain weight (TGW) of maize exhibit that foliar boron levels at different growth stages had significantly influenced TGW (Table 3). The interaction of foliar boron application and growth stages was found significant (Fig. 2(E, F)). Regarding boron foliar application, at different concentrations revealed that application of boron at 1% produced 7.03% and 8.14% maximum thousand-grain weight in both 2021 and 2022 study years respectively as compared to control. Likewise, in the case of different growth stages application of foliar boron at tasseling stage produced 9.32% and 9.74% thousand grain weight as compared to no boron-treated plots. The increase in B intake leads to an increase in grain weight because higher B availability enhances enzyme activation, which leads to an increase in the partitioning of nutrients from leaves to grains and an increase in grain weight [39]. These results are in line with the results of Thankur et al. [40] also recorded the maximum grain weight. Similarly, Shabbir et al. [31] reported that the application of boron resulted in a maximum thousand grain weight.

The biological yield was significantly influenced by various foliar boron concentrations at different growth stages in both the 2021 and 2022 cropping seasons (Table 3). Data pertaining to biological yield revealed that 1% foliar boron solution resulted in 25.16% and 25.81% maximum biological yield in both the 2021 and 2022 study years when compared with the treatments without boron application. Similarly, in different growth stages application of boron at the tasseling stage was observed to have a maximum biological yield of 13.26% and 7.44% in both 2021 and 2022 respectively, in comparison with no applied boron. The interaction of foliar boron and growth stages was found significant (Fig. 2(G, H)). These results are reassuring to the findings of Almosawy et al. [36], who noticed application of boron increased the biological yield of maize. Singh et al. [6] observed that a 1% foliar spray of boron significantly increased biological yield which might be due to the fact that boron applications increased the production of photosynthesis and chlorophyll which ultimately enhanced biological yield.

Different concentrations of boron and its foliar applications at various growth stages and their interactions had significant effects on the grain yield of maize (Fig. 2(I, J)). The grain yield of maize was

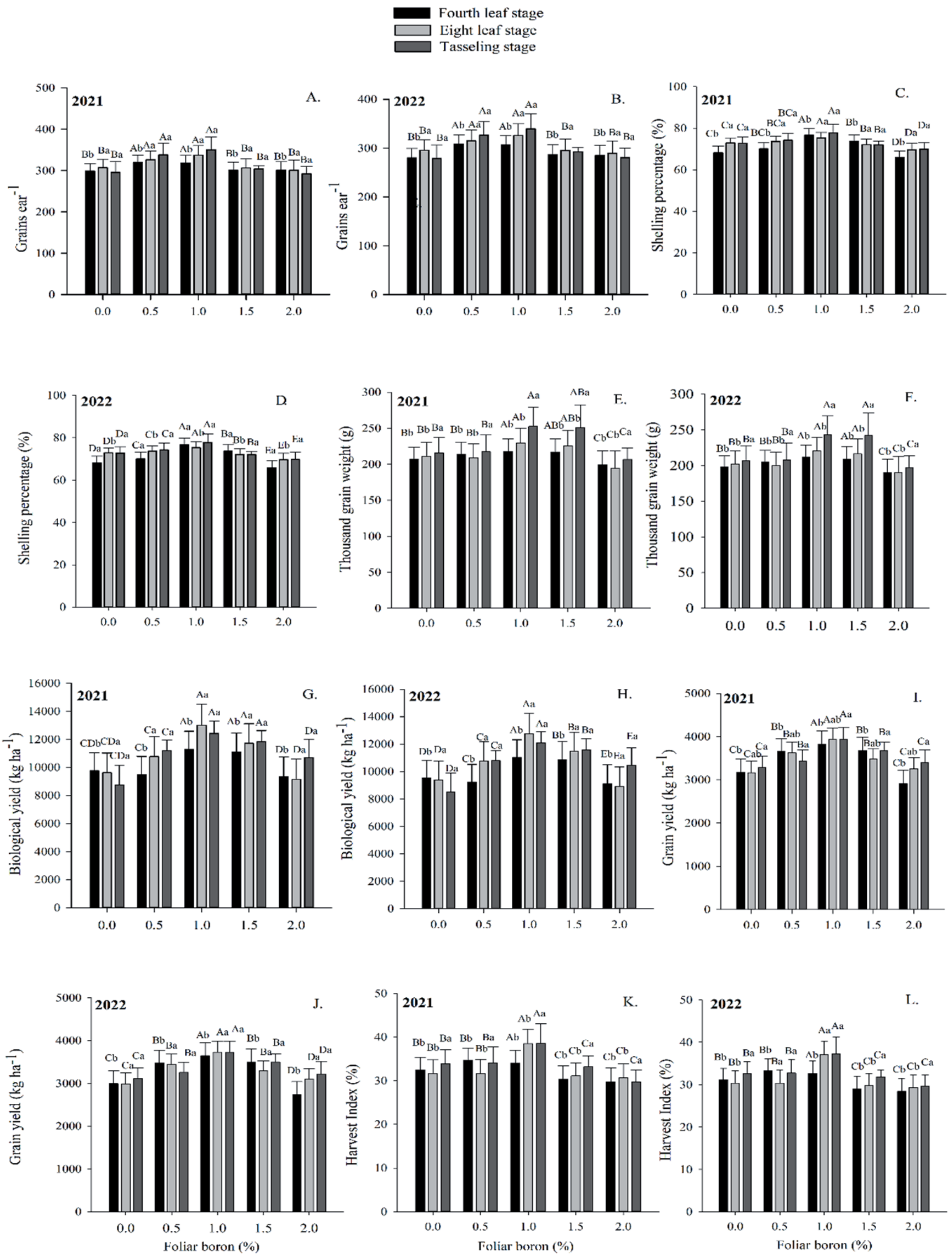

Fig. 2. Influence of various boron levels at different growth stages on maize yield attributes: (A and B) Grains ear^{-1} in 2021 and 2022; (C and D) shelling percentage (%) in 2021 and 2022; (E and F) thousand grain weight (g) in 2021 and 2022; (G and H) Biological yield (Kg ha^{-1}) in 2021 and 2022; (I and J) Grain yield (Kg ha^{-1}) in 2021 and 2022; and (K and L) Harvest index (%) in 2021 and 2022 respectively. The uppercase letters are used for foliar boron interactions within each growth stage of application, whereas lowercase letters are used for the growth stages within each boron application. The identical alphabetic letters do not differ from each other, as analyzed by LSD (Foliar boron application; $p<0.05$) and (growth stages; $p<0.05$) test for both years. Error bars indicate the standard error of the mean (n = 4 replications).

Table 4. Grain yield (kg ha^{-1}), harvest index (%), plants at harvest (ha^{-1}) and grain boron contents (mg kg^{-1}), as influenced by different concentrations of boron and their foliar applications on maize at various growth stages.

Foliar Boron (%)	Grain Yield (Kg ha^{-1})		Harvest Index (%)		Plants at harvest (ha^{-1})		Grain boron contents (mg kg^{-1})	
	2021	2022	2021	2022	2021	2022	2021	2022
0.0	3168 c	2989 c	32.1 b	30.8 b	63333 b	61667 a	10.5 e	10.8 e
0.5	3640 b	3461 b	33.1 b	31.8 b	65556 a	62778 a	15.0 d	15.9 d
1.0	3879 a	3687 a	36.2 a	34.9 a	65556 a	63889 a	22.4 b	23.3 b
1.5	3578 b	3399 b	30.7 c	29.4 c	62222 b	61667 a	31.0 a	30.4 a
2.0	3085 c	2919 d	30.2 c	28.9 c	63333 b	63333 a	17.7 c	18.6 c
LSD for B	95	80	1.3	1.1	1867	Ns	1.1	0.8
Fourth leaf stage	3449 b	3271 b	32.2 b	30.9 b	64000 a	62222 a	19.1 a	19.6 b
Eight leaf stage	3491 ab	3312 a	32.7 b	31.4 b	65333 a	63111 a	19.5 a	19.9 b
Tasseling stage	3548 a	3363 a	33.9 a	32.8 a	65556 a	61556 a	19.8 a	20.7 a
LSD for GS	73	62	1.0	0.8	ns	ns	ns	0.6
B x GS	***	***	**	***	ns	ns	**	*

Means in the column followed by different letters are significantly different (p-value≤0.05); ***, ** and * significant at p<0.01, p<0.05 and p<0.10, respectively; and Ns, non-significant, by F-test.

increased by 22.4 and 23.35% in 2021 and 2022, respectively by application of boron at 1% as compared to control. In different growth stages, grain yield was increased by 11.99 and 12.51% in 2021 and 2022, respectively, under the treatments with foliar-applied boron at the tasseling stage, when compared to the treatments without boron application. The increase in grain yield is mostly related to boron complimentary role in plant reproduction and vegetative growth [1]. Boron is directly involved in enzyme activation, protein synthesis, glucose metabolism and pollen generation which increase grains ear^{-1}, cob length and eventually increase grain yield [41]. Our results are reassuring with the findings of Almosawy et al. [36], who noticed that an increase in the supply of foliar boron improved the grain yield of maize plants. Alimuddin et al. [42], also documented that boron application enhanced grain yield of maize because boron has an important role in assimilating storage and hence influences grain formation.

Foliar boron application at various growth stages of maize has sufficiently enhanced the harvest index (Table 4). The findings of the present experiment signified that the application of foliar boron at different growth stages and their interactions have a significant influence on the harvest index (Fig. 2(k, l)). Regarding boron foliar application at various concentrations, it was observed that application of 1% foliar boron produced 12.77 and 13.31% maximum harvest index when compared to no treated boron plots. In different growth stages, application of foliar boron at tasseling stage resulted in a 5.60 and 6.49% maximum harvest index as compared to control treatments. The physiological capability of plants to translocate more food from source to sink is measured by the harvest index [43]. These results are in accordance with those of [44], who noted that boron foliar spray produced a maximum harvest index. Similar, results were also reported by Anjum et al. [7], who observed an increase in harvest index due to boron foliar application on maize.

The interaction of foliar boron application and growth stages was non-significant for plants at harvest in both 2021 and 2022 (Table 4). The plots treated with 1% foliar boron solution were seen to have 3.51% and 3.60% maximum plants at harvest in 2021 and 2022, respectively when compared with other treatments. Likewise, in the case of boron application at different growth stages, it was observed that 3.51% and 2.34% maximum plants were recorded in both the 2021 and 2022 study years respectively when compared with the control.

Data regarding grain boron contents exhibit that grain boron contents were significantly affected by various concentrations of foliar boron application and non-significantly affected by different growth stages (Table 4) in 2021 and 2022, respectively. The interaction of different concentrations and various growth stages had a significant effect (Fig 3(A, B)). Results revealed that boron application at 1.5% increased grain boron contents by 195% in 2021 and 181.48% in 2022. In the case of different growth stages application of boron at the tasseling stage increased grain boron contents by 88.57 and 91.66% respectively, in 2021 and 2022, as compared to untreated boron plots. Boron foliar application increases grain boron content because in plants it regulates assimilates translocation to grain,

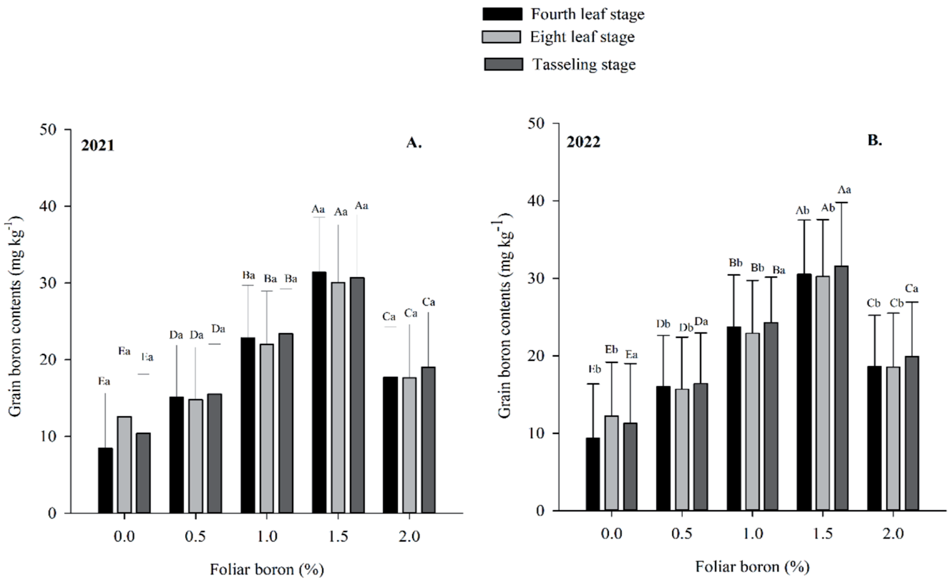

Fig. 3. The influence of various boron levels at different growth stages on maize quality parameter: (A, B) Grain boron contents in 2021 and 2022 respectively. The uppercase letters are used for foliar boron interactions within each growth stage of application, whereas lowercase letters are used for the growth stages within each boron application. The identical alphabetic letters do not differ from each other, as analyzed by LSD (Foliar boron application; $p<0.05$) and (growth stages; $p<0.05$) test for both years. Error bars indicate the standard error of the mean (n = 4 replications).

as boron maintains the integrity of the plasma membrane and supports the proper functioning of the enzymes that drop the starch contents in the leaves and encourage the translocation of photosynthates towards seeds [45], which ultimately increasing the boron content of the grains.

Conclusions

Based on the results, it is concluded that among the different boron levels, 1% foliar application significantly improved growth, yield and yield components of maize. Boron foliar application at the tasseling stage enhanced maize growth, yield and yield components. The performance in terms of growth and yield of maize in the plots that received foliar boron at the tasseling (VT) stage was superior to the plots that received foliar boron at the fourth leaf (V4) and eighth leaf (V8) stage. It is recommended that the application of 1% foliar boron at tasseling stage is recommended for optimum growth and higher productivity of maize under agroecological conditions of the study area.

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Conflict of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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