2

Egypt. J. Agron. **Vol. 44**, No. 1, pp. 11-18 (2022)

Egyptian Journal of Agronomy
http://agro.journals.ekb.eg/

Influence of Foliage Applied Boron on Yield and Related Traits of Bread Wheat (*Triticum aestivum* L.)

Saba Iqbal[(1)#], Muhammad Farooq[(2)], AsmatUllah[(1)], Muhammad Luqman[(1)], Ayesha Malik[(3)], Kashif Munir[(4)], Nawal Zafar[(4)]

[(1)]Agronomic Research Station, Khanewal, Pakistan; [(2)]Department of Plant Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khoud, Oman; [(3)]Soil and Water Conservation Research Station, Fateh Jang, Pakistan; [(4)]Ayub Agricultural Research Institute, Faisalabad, Pakistan.

BORON (B) is an essential micronutrient for higher plants. However, in calcareous soils its availability is low due to adsorption; therefore, foliar application of B is considered a feasible approach. There exists a very narrow range between deficiency and excess. This study was designed to optimize the B concentration in a foliar spray and to determine the influence of foliar application of boronon improving grain yield and yield related wheat (*Triticum aestivum*) traits. Two concentrations of B foliar spray i.e. 0.01 and 0.05M B solutions (using borax as source of boron) and a water foliar application (control) were compared on two wheat cultivars: Faisalabad-2008 and Lasani-2008. Foliar fertilization treatments and control were applied 50 days after sowing. Foliar application of 0.01M B solution had significantly improved wheat yield and yield related parameters. Greater productive tillers (33.12 per pot), spike length (8.64cm), spikelets per spike (17.29), grains per spike (42.23), 100-grains weight (4.90g), grain yield (7.03g per pot) and biological yield (11.92 g per pot) were recorded where plants were foliar sprayed with 0.01M B solution than control (water spray). The 0.05M B solution application was toxic and suppressed growth and yield of wheat. In conclusion, B foliage applied 0.01M at 50 days after sowing may help to overcome the plant B requirements and improve grain yield of bread wheat.

Keywords: Boron, Foliar application, Wheat, Yield, Yield components.

Introduction

Boron (B) is a plant essential element necessary for proper physiological functioning; such as plant proper cell membrane functioning and cell wall integrity (Shireen et al., 2018). Hence; growth and metabolism are adversely affected by B deficiency. The important physiological functions of plants where B is critical, included cell wall and membrane functioning along with its integrity and across membrane fluxes of ions (i.e. Ca^{2+},Rb^{+},PO_4^{3-}, K^{+},H^{+}), elongation and division of cell, metabolism of carbohydrate and nitrogen, source to sink transfer of sugar, transport besides metabolism of phenols, ascorbic acid, polyamines, indole acetic acid, nucleic acid, plasma lemma bound enzymes, and cytoskeletal proteins (Shireen et al., 2018). Therefore, its deficiency restricts apical meristem and root growth (owing to limited cell division), appearance of brittle leaves, reduced photosynthetic activity attributable to reduced chlorophyll contents, across membrane ion transport disruption, reduction in lignin and phenolic metabolism, thus, increase in their contents and eventually yield of crop is reduced (Brown et al., 2002; Goldbach et al., 2007; Zhou et al., 2014; Wang et al., 2015). Moreover, reproductive performance of plants is also altered by B limitation which results in alteration in modes of flowering and fruiting. Major effects of B insufficiency on reproductive development are shriveled and empty anthers,

#Corresponding author email: sabaiqbal87@gmail.com
Received 20/01/2022; Accepted 10/05/2022
DOI : 10.21608/AGRO.2022.117329.1301
©2022 National Information and Documentation Center (NIDOC)

bursting of pollen tube, loss of pollen viability, flower bud abscission, fruit set failure. Reduction in photosynthate transport causes premature fruit dropping which eventually results in reduced yield (Dell & Huang, 1997; Marschner, 2012). Above discussed signs of B deficiency on vegetative and reproductive phases of plant growth suggest that the reproductive phase is impacted more than the vegetative phase (Shireen et al., 2018).

Soil B deficiency is an eminent nutrient disorder in various countries of world, including Pakistan (Rashid et al., 1997; Bashir & Bantel, 2005; Rashid & Rafique, 2017). In soils of Pakistan the basic cause of B deficiency is the calcareous/ alkaline nature of soil (pH range 7.5 to 8.5) and small soil organic matter contents. Soils with these characteristics cover approximately 22 million hectare of cultivated land in Pakistan (Rashid & Rafique, 2017). In alkaline/calcareous soils, plants are unable to acquire the micronutrients as their availability is reduced due to adsorption and immobilization (Khan et al., 2010, 2013). The prevailing soil conditions along with rare use of B fertilizer by farmers and more demand of B by high yielding crops are the main causes of B deficiency in crops. Another most important cause of B deficiency in Pakistan soils is its climate, most of the areas are arid and semi-arid climates except the north mountain areas (Rafiq, 1996) which receive abundant rainfall during monsoon season (July to August) that results in leaching of B below root zone. Since dry periods during crop growth period slow down the root absorption of B as the main way of acquiring B in plants is the mass flow which requires appropriate soil moisture conditions. In addition, one more cause of soil B deficiency is the conditions of flooded fields during rice growth, which also cause B to leach out of the root zone (Rafiq, 1996).

Boron deficiency disturbs wheat growth and productivity but vegetative growth is less impacted by B deficiency (Del & Huang, 1997) than its reproductive growth. In wheat, B deficiency causes sterility (Rawson, 1996; Subedi et al., 1997a, 1997b) because of under developed pollen and anthers coupled with disruption of pollen germination (Cheng & Rerkasem, 1993). Hence; in B deficient soils, yield loss attributed to wheat sterility is a major concern (Shorrocks, 1997). However, despite its involvement in plant growth and development its toxicity sometimes becomes major concern and also results in failure of crop productivity. Boron has very narrow threshold level between its deficiency and toxicity (Dell & Huang, 1997). Therefore, in semi-arid areas its soil availability shortage and excess are both common crop production problems. Hence; to obtain optimum growth and profitable yield it is necessary to only apply appropriate amounts of B to wheat crop (Aziz et al., 2019).

Boron is widely applied to plants using either soil or foliar applications (Shireen et al., 2018). However, on calcareous soils the soil application of micronutrients is not advisable (Watersa & Renuka, 2011) as calcareous soils cause rapid fixation of micronutrients and reduce their availability (Rashid & Ryan, 2004; Majidi et al., 2010). In calcareous soils the more feasible approach is foliar application which is also more economical and efficient (Pandey & Gupta, 2012). However, due to the narrow range of B deficiency and excess for plant growth, and as we know, little dose optimization of B for foliar spraying has been studied and foliar application optimization is needed to achieve desirable results, therefore, this study was performed to optimize foliar spray concentration of B in order to obtain the best possible yield in wheat grains.

Materials and Methods

Experimental details

Experiment was carried out in glasshouse located at University of Agriculture Faisalabad, Pakistan. Two factors were studied: (i) Wheat cultivars and (ii) Various concentrations of B solutions for foliar spray. Two varieties were used: Faisalabad-2008 and Lasani-2008. Two concentrations of B foliar spray were used, 0.01 and 0.05M. Water foliar spray was the control. Foliar fertilization of B solution as well as control was applied 50 days after sowing (DAS) (Zaodoks stage 2). Source of B for foliar fertilization was Borax ($Na_2B_4O_7$) (MERCK, purity = 98%) which is 11% B. A complete randomized design was followed to lay out the experiment. Experimental treatments were replicated four times.

Crop husbandry

Soil filled earthen pots were used for sowing of seed and ten seed from each treatment were sown in earthen pots. Physico-chemical attributes of the soil used in this experiment were examined following the standard procedures and protocols given in manual of International Center for Agricultural Research in the Dry Areas (ICARDA, 2001). Following above mentioned protocols the soil used in this study was sandy loam, with 8.10 pH, 0.35dS m^{-1} EC, 0.20 mmole $100g^{1}$ exchangeable sodium, 0.89% organic matter, 0.06% N, 6.50ppm P, 168.00ppm K, 0.80 ppm Zn, 0.60ppm B and 6.75ppm Fe.

After attaining constant emergence, the seedlings were thinned into five seedlings per pot untill harvest. Fertilizers nitrogen (N), phosphorous (P) and potassium (K) were applied according to soil analysis report i.e., 0.5:0.45:0.38g NPK per kg soil. The source of NPK were urea (46% N), single super phosphate (SSP: 18% P) and sulfate of potash (SOP: 50% K). All the fertilizers were applied as basal dose. Irrigation was applied twice a week to maintain the water field capacity. The plants were harvested after attaining harvest maturity.

Observations and measurements

Productive tillers from each pot were counted and averaged to calculate the average productive tillers per pot. Five spikes from each pot were selected randomly and each was counted for their number of spikelets and number of grains and their average was calculated. For 100-grains weight, 100 grains from each treatment were counted and weighted separately using a weighing balance. To record grain yield (g per pot), plants from each pot harvested, threshed and grains were weighted using a weighing balance.

Data were analyzed statistically using Statistix 8.1 as well as by employing analysis of variance (Steel et al., 1997). Means were separated at 5% probability level by using the least significance difference (LSD).

Results

With all B foliar spray treatments (exception of harvest index) significantly ($P \leq 0.05$) affected yield related traits and yield (Table 1). However, in wheat varieties the significant ($P \leq 0.05$) difference was only in the length of the spikes, spikelets per spike and grains per spike (Table 1). Whereas the interaction of B foliar application treatments and wheat cultivars was non-significant ($P \leq 0.05$) for all documented yield related traits and yield (Table 1). More productive tillers were recorded for the 0.01M B foliar solution than control in both wheat cultivars (Table 2). Likewise longer spikes with greater spikelets per spike and grains per spike were also noted in the treatment were 0.01M B was applied as foliar spray than control (Tables 2, 3). However between cultivars, cultivar Faisalabad-2008 had longer spikes as well as higher spikelets per spike and grains per spike than cultivar Lasani-2008 (Tables 2, 3). Likewise a bolder grain with higher 100-grain weight was noted in the same treatment (0.01M B solution) as compared with control in both wheat cultivars (Table 3). The higher number of productive tillers, grains per spike and 100-grains weight in the treatment where 0.01M B solution was applied as foliar spray caused higher wheat grain yield than control (Table 3). Likewise higher biological yield was also recorded by the treatment were 0.01M B was applied as foliar spray however that was statistically at par with the control (Table 4). Moreover all yield related traits and yield were negatively affected/ suppressed by the treatment where 0.05M B solution was applied as foliar spray (Tables 2, 3, 4).

TABLE 1. Analysis of variance for the influence of foliage applied boron on grain yield and yield related traits in two wheat cultivars

SOV	DF	Mean sum of squares							
		PT	SL	SPS	GPS	GW	GY	BY	HI
Cultivars (C)	1	1.04^{ns}	5.92^{**}	23.70^{**}	148.13^{**}	0.0004^{ns}	2.24^{ns}	2.17^{ns}	78.05^{ns}
Treatments (T)	2	182.29^{**}	1.80^{**}	7.20^{**}	5.03^{**}	0.08^{**}	13.64^{*}	14.72^{*}	267.07^{ns}
C×T	2	7.29^{ns}	0.19^{ns}	0.78^{ns}	4.87^{ns}	0.0^{ns}	0.27^{ns}	0.24^{ns}	2.99^{ns}
Error	18	73.26	0.24	0.98	6.14	0.01	3.00	3.03	87.74
Total	23								

SOV= Source of variation; DF= Degree of freedom; ns= Non-significant; *= Significant at P 0.05; **= Significant at P 0.01; PT= Productive tillers; SL= Spike length; SPS= Spikelets per spike; GPS= Grains per spike; GW= 100-grain weight; GY= Grain yield; BY= Biological yield; HI= Harvest index.

TABLE 2. Influence of foliage applied boron (B) on number of productive tillers, spike length and number of spikelets in two wheat cultivars

Treatment	Productive tillers (per pot)			Spike length (cm)			Spikelets per spike		
	FSD-08	LS-08	Mean (T)	FSD-08	LS-08	Mean (T)	FSD-08	LS-08	Mean (T)
Control	30.00	30.00	30.00B	8.31	7.64	7.97B	16.62	15.27	15.94B
0.05M B	22.50	25.00	23.75C	8.38	7.08	7.73B	16.76	14.16	15.46B
0.01M B	33.75	32.50	33.12A	9.15	8.14	8.64A	18.3	16.28	17.29A
Mean (C)	28.75	29.17		8.61A	7.62B		17.23A	15.24B	

Figures sharing the same case letters, for a parameter, do not differ significantly at $P \leq 0.05$; FSD-08= Faisalabad-2008; LS-08= Lasani-2008; C= Cultivars; T= Treatments.

TABLE 3. Influence of foliage applied boron (B) on grains per spike, 100-grain weight and grain yield of two wheat cultivars

Treatment	Grains per spike			100-grain weight (g)			Grain yield (g per pot)		
	FSD-08	LS-08	Mean (T)	FSD-08	LS-08	Mean (T)	FSD-08	LS-08	Mean (T)
Control	41.55	38.18	39.86B	4.73	4.66	4.7C	5.9	5.32	5.61AB
0.05M B	41.9	35.41	38.65B	4.8	4.82	4.81B	4.55	4.29	4.41B
0.01M B	45.75	40.71	43.23A	4.86	4.93	4.90A	7.52	6.53	7.03A
Mean (C)	43.07A	38.10B		4.8	4.8		5.99	5.38	

Figures sharing the same case letters, for a parameter, do not differ significantly at $p \leq 0.05$; FSD-08= Faisalabad-2008; LS-08= Lasani-2008; C= Cultivars; T= Treatments.

TABLE 4. Influence of foliage applied boron (B) on biological yield and harvest index of two wheat cultivars

Treatment	Biological yield (g per pot)			Harvest index (%)		
	FSD-08	LS-08	Mean (T)	FSD-08	LS-08	Mean (T)
Control	10.63	9.98	10.31AB	55.41	50.39	52.90
0.05M B	9.34	9.11	9.22B	48.08	45.16	46.62
0.01M B	12.38	11.46	11.92A	59.61	56.72	58.16
Mean (C)	10.79	10.18		54.36	50.76	

Figures sharing the same case letters, for a parameter, do not differ significantly at $P \leq 0.05$; FSD-08= Faisalabad-2008; LS-08= Lasani-2008; C= Cultivars; T= Treatments.

Discussion

The application of the 0.01M B dose through the leaves improved wheat yield and yield-related parameters. However, a higher dose of B, 0.05M B solution, reduced yield-related traits and yields, revealing the toxicity of a higher B dose to wheat crop due to narrow deficiency and B toxicity range in wheat (Abou Seeda et al., 2021). The application of the optimal B dose (0.01M B solution) on the leaves increased the number of productive tillers (Table 2). Rehman et al. (2015) reported that applying the optimal dose of B through the seed coat accelerates the growth of leaves and tillers of rice (*Oryza sativa* L.), while increase in the appearance of the leaves and tillers indicates that there is a close relationship between both of these traits. This might be due to B's involvement in cell wall formation (Hu & Brown, 1994; Matoh, 1997), plus functioning and integrity of cell membrane (Goldbach et al., 2001; Brown et al., 2002). Improvement in tillering using the optimal dose of B may also be attributable to the function of B in cell wall synthesis, cell division (Mouhtaridou et al., 2004) and in the metabolism of several important biological molecules (Goldbach et al., 2001).

Also, the improvement in spike length of wheat cultivars might be attributed to the B association in the growth of meristems (Marschner, 1995) due to its involvement in elongation and division of cell (Huang et al., 2014). Disruption of cell division in the absence of B results from defects in the cell wall formation that inhibits cells from organizing for mitosis (Whittington, 1959). Boron governs the binding of two RG-II polysaccharides (Kobayashi et al., 2004; O'Neill et al., 2004) in the cell wall of plant. The porosity (Fleischer et al., 1999) and the tensile strength that affects plant cell wall relaxation/ elongation (Ryden et al., 2003) is controlled by this RG-II-B complex. In addition, cell wall elongation is also controlled by various genes that control several cell wall modifying enzymes (Cosgrove, 1999). The performance of these genes is reduced in B-deficient conditions (Camacho-Cristóbal et al., 2008).

Nonetheless longer spikes eventually give rise to higher number of spikelets per spike in wheat; a higher number of spikelets per spike were recorded by the foliar fertilization of B. In addition, higher grains per spike were also recorded as a result of the foliar fertilization of B (Table 3), as absence of B affects the setting of grains in wheat due to abnormalities in stigma functions and pollen growth (Rerkasem et al., 1993); while the presence of B manages it (Rehman et al., 2012). Boron also affects the pollen grains viability (Huang et al., 2000); the tube that emerges from pollen grains during fertilization also needs B to maintain structure of its cell wall and can burst even in the deficiency of B (Brown et al., 2002). Cell expansion is also inhibited under B deficiency (Hu & Brown, 1994). All the above mentioned effects of B deficiency during reproductive phase result in inhibition of fertilizer that ultimately results in low grain setting in wheat, because B is required for seed setting, a higher number of grains per spike may be attributed to that (Dear & Lipsett, 1987; Noppakoonwong et al., 1997).

Similarly, the use of B also caused heavier grains than control, resulting in a higher weight of 100 grains (Table 3). This may be due to the role of B in photosynthesis (Abou Seeda et al., 2021). Boron affects photosynthesis by reducing the area of photosynthesis and changing leaf components (Dell & Huang, 1997; Wang et al., 2007). It also decreases net photosynthesis by reducing soluble proteins and chlorophyll contents of leaves thus; resulting loss of photosynthetic enzyme activity blocks the Hill reaction (Sharma & Ramchander, 1990; Cakmak & Römheld, 1997; Brown et al., 2002). Moreover, B is also involved in the metabolism of sugars, so increasing the accumulation of sugar in the leaves in conditions of B deficiency may result in a reduced regulation of photosynthesis (Wimmer & Eichert, 2013). Lower number of stomata and stomatal aperture due to poor leaf expansion in B deficient plants results in less stomatal conductivity to CO_2 also inhibits photosynthesis (Furlani et al., 2003; Sharma & Ramchandra, 1990). Chloroplast structure as well as functioning of chloroplast thylakoid membrane is disrupted by B deficiency hence, photosynthesis is reduced significantly owing to limited assimilation of CO_2 (Pandey & Pandey, 2008). Grain weight was also improved by the foliar fertilization of B as B is involved in source to sink partitioning and transfer of assimilates (Reddy et al., 2003).

Boron application also resulted in higher grain yield as in wheat grain yield depends upon number of productive tillers, grains per spike and 100-grain weight although all of these traits were amended by B (Table 3). Higher accumulation of photo-assimilates by B could also be the cause of higher grain yield (Arif et al., 2006). Underdevelopment of pollens and anthers as a result of B deficiency impairs grain setting in wheat thus, reduced grain yield (Cheng & Rerkasem, 1993). Moreover as B is involved in flowering, pollen grain and tube formation, viability of pollen grains as well as grain setting hence, all these positive attributes of B resulted in higher grain yield by B foliar fertilization (Subedi et al., 1997a). In another study it was also reported that B improves grain yield by improving grain setting and grain filling process of wheat (Uddin et al., 2008). Moreover, vigorous growth and better tillering also resulted in a higher biological yield (Table 4).

However higher concentration of B foliar spray resulted in suppressing of yield and yield contributing traits (Tables 2, 3, 4). It was also reported by several other authors that higher dose of B not only reduced yield but also reduce plant height, number of grains per spike, 1000-grain weight and dry matter production (Christensen, 1934; Eaton, 1944; Cartwright et al., 1984; Nable, 1988; Paull et al., 1988; Paull et al., 1991; Mahalakshmi et al., 1995; Yau et al., 1995; Rehman et al., 2006) due to higher dose of B.

Conclusion

Hence, it can be concluded that a B solution of 0.01M concentration should be foliar sprayed at 50 days after sowing in wheat to increase wheat productivity especially where soil tests show reduced B availability.

References

Abou Seeda, M.A., Abou El-Nour E.A.A., Yaseen, A.A., Hammad, S.A. (2021) Boron, structure, functions and its interaction with nutrients in plant physiology: a review. *Middle East Journal Agricultural Research,* **10**, 117-179.

Arif, M., Chohan, M.A., Ali, S., Gul, R., Khan, S. (2006) Response of wheat to foliar application of nutrients. *Journal of Agriculture and Biological Sciences,* **1**, 30-34.

Aziz, M.Z., Yaseen, M., Abbas, T., Naveed, M., Mustafa, A., Hamid, Y., Saeed, Q., Ming-gang, M. (2019) Foliar application of micronutrients enhances crop stand, yield and the biofortification essential for human health of different wheat cultivars. *Journal of Integrated Agriculture,* **18**, 1369-1378.

Bashir, E.L., Bantel, R. (2005) Soil Science.National Book Foundation, Islamabad, Pakistan.

Brown, P.H., Bellaloui, N., Wimmer, M.A., Bassil, E.S., Ruiz, J., Hu, H., Pfeffer, H., Dannel, F., Romheld, V. (2002) Boron in plant biology. *Plant Biology,* **4**, 205-223.

Cakmak, I., Römheld, V. (1997) Boron deficiency-induced impairments of cellular functions in plants. *Plant and Soil,* **193**, 71-83.

Camacho-Cristóbal, J.J., Rexach, J., González-Fontes, A. (2008) Boron in plants: deficiency and toxicity. *Journal of Integrative Plant Biol,* **50**, 1247-1255.

Cartwright, B., Zarcinas, B.A., Mayfield, A.H. (1984) Toxic concentrations of boron in a red-brown earth at Gladstone,South Australia. *Australian Journal of Soil Research,* **22**, 261-272.

Cheng, C., Rerkasem, B. (1993) Effects of boron on pollen viability in wheat. In: *"Plant Nutrition from Genetic Engineering to Field Practice"*, Barrow, N.J. (Ed.), pp. 405-407. Kluwer Academic Publishers: Dordrecht.

Christensen, J.J. (1934) Non-parasitic leaf spots of barley. *Phytopathology,* **24**, 726-742.

Cosgrove, D.J. (1999) Enzymes and other agents that enhance cell wall extensibility. *Annual Review of Plant Physiology and Plant Molecular Biology,* **50**, 391-417.

Dear, B.S., Lipsett, J. (1987) The effect of boron supply on the growth and seed production of subterranean clover (*Trifolium subterraneum* L.). *Australian Journal of Agricultural Research,* **38**, 537-546.

Dell, B., Huang, L.B. (1997) Physiological response of plants to low boron. *Plant and Soil,* **193**, 103-120.

Eaton, F.M. (1944) Deficiency, toxicity and accumulation of boron in plants. *Journal of Agricultural Research,* **69**, 237- 277.

Fleischer, A., O'Neill, M.A., Ehwald, R. (1999) The pore size of non graminaceous plant cell walls is rapidly decreased by borate ester cross-linking of the pectic polysaccharide rhamnogalacturonan II. *Plant Physiology,* **121**, 829-838.

Furlani, A.M.C., Carvalho, C.P., de Freitas, J.P. Verdial, M.F.(2003) Wheat cultivar tolerance to boron deficiency and toxicity in nutrient solution. *Scientia Agricola,* **60**, 359-370.

Goldbach, H.E., Yu, Q., Wingender, R., Schulz, M., Wimmer, M., Findeklee, P., Baluska, F. (2001) Rapid response reactions of roots to boron deprivation. *Journal of Plant Nutrition and Soil Science,* **164**, 173-181.

Goldbach, H., Huang, L., Wimmer, M.(2007) Boron functions in plants and animals: recent advances in boron research and open questions. In: "*Advances in Plant and Animal Boron Nutrition"*, Xu, F., Goldbach, H.E., Brown, P.H., Bell, R.W., Fujiwara, T., Hunt, C.D., Goldberg, S., Shi, L. (Eds.), pp. 3-25. Springer: Dordrecht.

Hu, H., Brown, P.H. (1994) Localization of boron in cell walls of squash and tobacco and its association with pectin evidence for a structural role of boron in the cell wall. *Plant Physiology,* **105**, 681-689.

Huang, L., Pant, J., Dell, B., Bell, R.W. (2000) Effects of boron deficiency on anther development and floret fertility in wheat (*Triticum aestivum* L.). *Annals of Botany,* **85**, 493-500.

Huang, J.H., Cai, Z.J., Wen, S.X., Guo, P., Ye, X., Lin, G.Z., Chen, L.S. (2014) Effects of boron toxicity on root and leaf anatomy in two citrus species differing in boron tolerance. *Trees,* **28**, 1653-1666.

ICARDA (2001) "*Soil and Plant Analysis Laboratory Manual*", International Center for Agricultural Research in the Dry Areas. Ryan, J., Estefan, G., and Rashid, A. (Eds.), 172p.

Khan, M.S.A., Akram, M., Qazi, M.(2010) Calibration of shahid's analytical method for adulterated zn-edta fertilizers by ion chromatography and atomic absorption spectroscopy. *Journal of the Chemical Society of Pakistan,* **32**, 613-619.

Khan, M.S.A., Qazi, M.A., Khan, N., Mian,S., Ahmed, N.(2013) Comparison of three analytical methods for separation of mineral and chelated fraction from an adulterated zn-edta fertilizer. *Journal of the Chemical Society of Pakistan,* **35**, 345-347.

Kobayashi, M., Mutoh, T., Matoh, T.(2004) Boron nutrition of cultured tobacco BY-2 cells: IV: Genes induced under low boron supply. *Journal of Experimental Botany,* **55**, 1441-1443.

Mahalakshmi, V., Yau, S.K., Ryan, J., Peacock, J.M. (1995) Boron toxicity in barley (*Hordeum vulgare* L.) seedlings in relation to soil temperature. *Plant and Soil,* **177**, 151-156.

Majidi, A., Rahnemaie, R., Hassani, A., Malakouti, M.J. (2010) Adsorption and desorption processes of boron in calcareous soils. *Chemosphere,* **80**, 733-739.

Marschner, H. (1995) Functions of mineral nutrients: micronutrients. In:"*Mineral Nutrition of Higher Plants"*, pp. 313-404. London: Academic Press.

Marschner, H. (2012) "*Mineral Nutrition of Higher Plants*". 3rd ed. Academic Press: London, UK.

Matoh, T. (1997) Boron in plant cell walls. *Plant and Soil,* **193**, 59-70.

Mouhtaridou, G.N., Sotiropoulos, T.E., Dimassi, K.N., Therios, I.N. (2004) Effects of boron on growth, and chlorophyll and mineral contents of shoots of the apple rootstock MM 106 cultured *in vitro. Biologia Plantarum,* **48**, 617-619.

Nable, R.O. (1988) Resistance to boron toxicity amongst several barley and wheat cultivars: A preliminary examination of the resistance mechanism. *Plant and Soil,* **112**, 45-52.

Noppakoonwong, R.N., Rerkasem, B., Bell, R.W., Dell, B., Loneragan, J.F. (1997) Diagnosis and prognosis of boron deficiency in black gram (*Vigna mungo* L.) in the field by using plant analysis. In: "*Boron in Soils and Plants"*, Bell, R.W., Rerkasem, B. (Eds.), pp. 89-94. Kluwer Academic Publishers, Dordrecht, The Netherlands.

O'Neill, M.A., Ishii, T., Albersheim, P., Darvill, A.G. (2004) Rhamnogalacturonan II: structure and function of a borate-linked cell wall pectic polysaccharide.*Annual Review of Plant Biology,* **55**, 109-139.

Pandey, D.K., Pandey, N. (2008) Screening of wheat genotypes for their susceptibility to boron deficiency. *Research in Environment and Life Sciences,* **1**, 37-42.

Pandey, N. Gupta, B.(2012) The impact of foliar boron lanes sprays on reproductive biology and seed quality of black gram. *Journal of Trace Elements in Medicine and Biology,* **27**, 58-64.

Paull, J.G., Rathjen, A.J., Cartwright, B. (1991) Major gene control of tolerance of bread wheat (*Triticum aestivum* L.) to high concentrations of soil boron. *Euphytica,* **55**, 217-228.

Paull, J.G., Cartwright, B., Rathjen, A.J. (1988) Responses of wheat and barley genotypes to toxic concentrations of soil boron. *Euphytica,* **39**, 137-144.

Rafiq, M. (1996) Soil resources of Pakistan. In: "*Soil Science"*, Rashid, A., Memon, K.S. (Eds.), pp. 439-470. National Book Foundation, Islamabad.

Rashid, A., Ryan, J. (2004) Micronutrients constraints to crop production in soils with mediterranean type characteristics: A review. *Journal of Plant Nutrition,* **27**, 959-975.

Rashid, A., Rafique, E. (2017) Boron deficiency diagnosis and management in field crops in calcareous soils of Pakistan: a mini review. *Boron,* **2**, 142-152.

Rashid,A.,Rafique,E.,Bughio,N.(1997)Micronutrient deficiencies in rainfed calcareous soils of Pakistan. III. Boron nutrition of sorghum. *Communications in Soil Scienceand Plant Analysis,* **28**, 441-454.

Rawson, H.M. (1996) The developmental stage during which boron limitation causes sterility in wheat cultivars and the recovery of fertility. *Australian Journal of Plant Physiology,* **23**, 709-717.

Reddy, N.Y.A., Shaanker, R.U., Prasad, T.G., Kumar, M.U. (2003) Physiological approaches to improving harvest index and productivity in sunflower. *Helia,* **26**, 81-90.

Rehman, A.U., Farooq, M., Cheema, Z.A., Wahid, A.(2012) Seed priming with boron improves growth and yield of fine grain aromatic rice. *Plant Growth Regulators,* **68**, 189-201.

Rehman, A., Farooq, M., Nawaz, A., Rehman, A., Iqbal, S.(2015) Soil application of boron improves the tillering, leaf elongation, panicle fertility, yield and its grain enrichment in fine-grain aromatic rice. *Journal of Plant Nutrition,* **38**, 338-354.

Rehman, S., Park, T.I., Kim, Y.J., Seo, Z.W., Yun, S.J. (2006) Inverse relationship between boron toxicity tolerance and boron contents of barley seed and root. *Journal of Plant Nutrition,* **29**, 1779-1789.

Rerkasem, B., Netsangtip, R., Lordkaew,S., Cheng, C.(1993) Grain set failure in boron deficient wheat. *Plant and Soil,* **155/156**, 309-312.

Ryden, P., Sugimoto-Shirasu, K., Smith, A.C., Findlay, K., Reiter, W.D., McCann, M.C. (2003) Tensile properties of Arabidopsis cell walls depend on both a xyloglucan cross-linked microfibrillar network and rhamnogalacturonan II-borate complexes. *Plant Physiology,* **132**, 1033-1040.

Sharma, P.N., Ramchandra, T. (1990) Water relations and photosynthesis in mustard plants subjected to boron deficiency. *Indian Journal of Plant Physiology,* **33**,150-154.

Shireen, F., Nawaz, M.A., Chen, C., Zhang, Q., Zheng, Z., Sohail, H., Sun, J., Co, H., Huang, Y., Bie, Z. (2018) Boron: Functions and approaches to enhance its availability in plants for sustainable agriculture. *International Journal of Molecular Sciences,* **19**,1-20.

Shorrocks, V.M.(1997) The occurrence and correction of boron deficiency. *Plant and Soil,* **193**, 121-148.

Steel, R.G.D., Torriwa, J.H., Dickey, (1997) "*Principles and Procedures of Statistics: A Biometric Approach*". 3rd ed. McGraw Hill Book Co. Inc., New York, USA.

Subedi, K.D., Budhathoki, C.B., Subedi, M. (1997a) Variation in sterility among wheat (*Triticum aestivum*. L) cultivars in response to boron deficiency in Nepal. *Euphytica,* **95**, 21-26.

Subedi, K.D., Budhathoki, C.B., Subedi, M .(1997b) Response of wheat genotypes to sowing date and boron fertilization aimed at controlling sterility in a rice–wheat rotation in Nepal. *Plant and Soil,* **188**, 249-256.

Uddin, M.N., Islam, M.S., Islam, A.B. (2008) Effect of boron on wheat at different boron application methods. *Journal of Subtropical Agricultural Research and Development,* **6**, 483-486.

Wang, Y., Shi, L., Cao, X., Xu, F. (2007) Plant boron nutrition and boron fertilization in China. In:"*Advances in Plant and Animal Boron Nutrition*", Xu, F., Goldbach, H.E., Brown, P.H., Bell, R.W., Fujiwara, T., Hunt, C.D., Goldberg, S., Shi, L.(Eds.), pp. 93-101. Springer Netherlands.

Wang, N., Yang, C., Pan, Z., Liu, Y., Peng, S. (2015) Boron deficiency in woody plants: various responses and tolerance mechanism. *Frontiers in Plant Science,* **6**, 1-14.

Watersa, B.M., Renuka, P.S. (2011) Moving micronutrients from the soil to the seeds: Genes and physiological processes from a biofortification perspective. *Plant Science,* **180**, 562-574.

Whittington, W.J. (1959) The role of boron in plant growth: II. The effect on growth of the radicle. *Journal of Experimental Botany,* **10**, 93-103.

Wimmer, M.A., Eichert, T. (2013) Mechanisms for boron deficiency mediated changes in plant water relations. *Plant Science,* **203**, 25-32.

Yau, S.K., Nachit, M.M., Ryan, J., Hamblin, J. (1995) Phenotypic variation in boron toxicity tolerance at seedlingstage in durum wheat (*Triticum durum* L). *Euphytica,* **83**, 185-191.

Zhou, F.G., Peng, S.A., Liu, Y.Z., Wei, Q.J., Han, J., Islam, M.Z. (2014) The physiological and nutritional responses of seven different citrus rootstock seedlings to boron deficiency. *Trees,* **28**, 295-307.