Journal of King Saud University – Science 34 (2022) 101768

Contents lists available at ScienceDirect

Journal of King Saud University – Science

journal homepage: www.sciencedirect.com

Original article

Boron Application in Yermosols Improves Grain Yield and Quality of Chickpea (*Cicer arietinum* L.)

Atique ur Rehman [a,*], Xiukang Wang [b,*], Abid Hussain [a], Rafi Qamar [c], Ahlam Khalofah [d,e], Mubshar Hussain [a,*]

[a] Department of Agronomy, Bahauddin Zakariya University, Multan, Pakistan
[b] College of Life Sciences, Yan'an University, Yan'an 716000, China
[c] Department of Agronomy, College of Agriculture, University of Sargodha, Pakistan
[d] Department of Biology, Faculty of Science, King Khalid University, P.O. Box 9004, Abha 61413 Abha, Saudi Arabia
[e] Research Center for Advanced Materials Science (RCAMS), King Khalid University, P.O. Box 9004, Abha 61413 Abha, Kingdom of Saudi Arabia

A R T I C L E I N F O

Article history:
Received 7 July 2021
Revised 24 October 2021
Accepted 10 December 2021
Available online 17 December 2021

Keywords:
Chickpea
Soil application
Photosynthesis
Grain quality
Boron

A B S T R A C T

Background: Boron (B) contents are decreasing in most of crop areas of semi-arid yermosols, hindering yield and quality of chickpea.
Objective: This study investigated the growth and quality alterations associated with soil applied B on chickpea in semiarid yermosols.
Method: A pot experiment was conducted using Yermosols soil with two chickpea cultivars (cv. Noor-2013 and Bittle-98) and five soil applied B concentration @ 0.00, 0.18, 0.27, 0.36 and 0.45 mg B kg^{-1}, as borax ($Na_2B_4O_7{\cdot}10H_2O$). Treatments arrangement was according to completely randomized design with factorial arrangements and each treatment was replicated five times.
Results: Soil applied B (0.45 mg B kg^{-1}) significantly ($P \leq 0.05$) improved plant height, number of pods and seeds per plant, 100-grain weight, grain and biological yield, chlorophyll contents, transpiration rate, stomatal conductance, water use efficiency, B uptake by roots, seed, leaves and shoot of plant body and grain protein, crud fiber, starch and total sugar in both cultivars of chickpea, but the degree of effects was varied between cultivars. The results indicated that studied traits of both cultivars were significantly ($P \leq 0.05$) decreased in B deficient treatments. Between cultivars, Noor-2013 recorded significant improvement ($P \leq 0.05$) in all parameters with 0.45 mg B kg^{-1} application compared than Bittle-98. Further, yield, yield attributing, physiological, B uptake by plants and grain quality parameters were positively correlated with each other except grain crude fiber.
Conclusion: Our findings conclude that the adequate concentration of B (0.45 mg B kg^{-1}) had pronounced effects on various growth, yield, physiological and grain quality traits.

1. Introduction

Chickpea (*Cicer arietinum* L.) is one of the prominent pulses and widely cultivated in the world after beans and soybean. In Pakistan, it's area under cultivation is 940 thousand hectares having annual seed production is 545 thousand tones (Govt. of Pakistan, 2019–2020). Chickpea average yield is lower in Pakistan than other chickpea growing countries. It is a well-adjusted crop in arid to semi-arid regions and is commonly cultivated on dry conditions (Kagan and Kayan, 2014). It is common and cheap protein source particularly for poor peoples of unindustrialized countries and thus can help to decrease malnutrition and improves human health. Chickpea has ability to bear low-risk in semi-arid environment due to its intensive rooting features (Rehman et al., 2014). Among different factors causing low yield, lack of balanced fertilization is the most important factor, especially deficiency of micronutrients (Borie et al., 2006). Boron (B) has significant microelement which is essential for crop growth, but quickly becoming scarce in soils (Tahir et al., 2009). However, Pakistani calcareous soils are B-

* Corresponding authors.
E-mail addresses: atiqjugg@gmail.com (A.ur Rehman), wangxiukang@yan.edu.cn (X. Wang), mubashiragr@gmail.com (M. Hussain).

Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

https://doi.org/10.1016/j.jksus.2021.101768
1018-3647/

deficient, that results in lower crop production and economic benefits (Atique-ur-Rehman et al., 2020). It has dominant role in cell growth, pollen tube development, membranes stability, grain development and fertilization (Zhao et al., 2001).

Boron deficiency and surplus leads to physiological and morphological disorder in crop plants (Kastori et al., 2008). Boron deficiency symptoms are poor root proliferation, inferior development of apical meristem, weak leaves growth, lower chlorophyll and photosynthetic rate, disturbance in ion channel; higher phenolic and lignin concentrations, and lower crop production (Wang et al., 2015). Boron deficiency leads to higher enzymatic and non-enzymatic oxidation reactions by using phenolic contents as substrate, outcomes in higher polyphenolic and quinine concentrations, which are hazardous for crop production (Hajiboland et al., 2013). Boron application is reported to have significant improvement in chickpea development and its scarcity cause destructive effects on chickpea production. Boron deficiency may be under alkaline soil, and accessibility lower at pH 6.5–7.0 or above on sandy soils or having lower organic content soils (Sims 2000). Hence, chickpea shows more response to the application of B as compared to other legumes, even though dissimilarity among chickpea cultivars correlated to B deficiency (Ahlawat et al., 2007). Boron application in soil is necessary when its concentration is less than 0.3 mg kg per ha (Ahlawat et al., 2007).

Deficiency of B may be corrected in a number of ways, however, soil and exogenous application strategy are more suitable way for effectiveness of microelements especially B (Rehman et al., 2019). Agronomic biofortification of micronutrients is easier and can be applied by exogenous spray, soil incorporation and seed coating methods (priming and coating) (Rehman et al. 2018a, 2018b). It has been observed that soil applied B showed significant role on chickpea dry matter production while foliar application has prominent effect on grain production (Padbhushan and Kumar, 2014).

In Pakistan, limited research was done to evaluate the consequence of B application in calcareous condition. Adjusting the B concentration in soil may be helpful for improving growth and production on calcareous Yermosols. The objective of present study was to surmise the response of chickpea to different concentrations of soil applied B on Yermosols. It was hypothesized that chickpea cultivars will exhibit changing behavior to soil applied B with improvement in grain yield and quality.

2. Materials and methods

The experiment was performed in a wire-house at Bahauddin Zakariya University, Multan (30.10 ºN, 71.25 ºE and 421 ft. altitude above sea level) in winter during 2017–18. Calcareous alluvial soil of 20 kg weight and 1.04 mg m^{-3} bulk density were added in earthen pots (25 cm × 40 cm), firstly the inner side of pots were enclosed with polyethylene sheet. Water holding and field capacity were kept with 33% and 70% through using de-ionized water respectively. Before performing study, different soil physico-chemical characteristics were determined. Soil texture was silty clay loam calculated through Hydrometer and fits to Sindhlianwali series (hyperthermic, sodic haplocambids) in USDA Haplic Yermosols classification. Soil pH was 8.3 recorded through pH meter (Beckman 45 Modal, US) and EC was 12 dS m^{-1} noted by EC meter (VWR Conductivity Meter DIG2052). Soil organic content was 0.78% (Walkely-Block method), N was 4.16% (Kjeldahl Method), extractable-P was 7.65% (Olsen's Method) and potassium was 270%. Soil analysis showed 0.24 mg kg^{-1} of B that it was deficient which determined through procedure modified by Wolf (1974). Environmental data of crop growing period during 2017–2018 is given in Table 1.

Two chickpea cultivars viz. Noor-2013 and Bittle-98 with five soil applied B concentration viz. B_0 (control), B_1: 0.18; B_2: 0.27; B_3: 0.36 and B_4: 0.45 mg B kg^{-1} were tested and each treatment was replicated five times. Borax ($Na_2B_4O_7 \cdot 10H_2O$) was used as source of B. Solution of different B concentrations were applied on dried soil than mixed into soil manually. Ten seeds were sown into each pot and kept five after 20 days after sowing. Soil moisture contents checked regularly and maintained up to 70%. Recommend doses of N and P @ 34 and 85 kg ha^{-1} were equally incorporated into the pots on soil weight basis. At maturity, pods were separated and air dried to detach seed and seed dried weight was recorded. Standard agronomic production practices were applied during growing period.

At maturity plant height (cm) and number of pods were measured. Pods were separated manually to find out seeds per pod and plant. Weight 100-grain was measured by using an analytical balance (Model Number: HC2204) after oven-drying at 70 °C for 24 h. Chlorophyll contents were determined after 45 days of sowing by 'SPAD-502′ chlorophyll meter. For measurements of transpiration and stomatal conductance, portable photosynthesis system (LI-6200, LI-COR, Inc., Lincoln, NE) was used. Water use efficiency (WUE) was calculated by dividing photosynthesis with transpiration rate. For determination of B contents in plants, mature plants were uprooted and separated into roots, shoots, leaves and seeds. Separated parts were cleaned with distilled water and dried for constant weight in a thermo-ventilated oven at 65 ± 5 °C. Material was crushed into a John Wiley mill and sieved through a 40 mesh screen. The powdered material was converted into ash by using muffle furnace at 550 °C for six hours. After that 0.36 N H_2SO_4 was added and the B concentration was determined by spectrophotometer at 420 nm wavelength using azomethine-H method (Bingham, 1982). Soluble protein (mg g^{-1} dry weight) content in the seed sample was estimated by Folin-Ciocalteau reagent method Lowry et al. (1951). For determination of B content in seed, 500 mg seed was milled in a pestle and mortor using 5–10 ml of potassium sodium tartarate buffer, subjected to centrifugation and the supernatant was collected. From extract, 0.2 ml was diluted up to 1 ml by addition of distilled water and allowed rest for ten minutes. Folin-Ciocalteau reagent (0.5 ml) was mixed into it and covered in dark at room temperature for 30 min. The concentration of blue color established was measured at 660 nm. Blank was prepared without plant sample and the absorbance was measured. Starch content in grains was estimated by Anthrone Reagent method (Sadasivam and Manickam, 1996). For this purpose, 0.5 g sample was standardized then centrifuged in 80% ethanol to eliminate sugars and continued to wash until green color of anthrone reagent developed. Filtrate was desiccated well into a water bath, consisted of 5 ml water and 6.5 ml of 52% perchloric acid, centrifuged at 0 °C for 20 min and supernatant was pooled repeatedly using fresh perchloric acid and made up to 100 ml. Distilled water was added in 0.1 ml supernatant and volume was made up to 1 ml, then 4 ml anthrone reagent was added and warmed into a water bath for eight minutes. It was air-cooled and green color intensity was read in spectrophotometer at 630 nm. Standard curve was prepared with standard glucose solution. Glucose content in sample was obtained from standard graph then multiplied by 0.9 factor to attain starch content. Starch contents were calculated by applying the procedure of Rong et al. (1996). The termination and gradation of sugar compounds from seeds were carried out by an Agilent 1100 series HPLC system (Agilent, USA), (Zeng et al., 2007).

Experimental treatments were set in completely randomized design with factorial arrangement. SAS software (Version 9.1; SAS Institute, Cary, NC, USA) (SAS Institute, 2008) was used for ANOVA on all traits and their means were marked by applying Duncan's multiple range test at significance (p less than 0.05) level of 5% (Steel, 1997). Analysis of correlation and scatter plot with lin-

Table 1
Environmental conditions during the study period 2017–18.

Months	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Atmospheric pressure at sea level (hPa)	Average relative humidity (%)	Total rainfall (mm)	Average wind speed (Km/h)	Mean monthly sunshine (Hours)
November 2017	18.3	22.2	13.8	1014.9	69.6	4.20	2.4	3.7
December 2017	14.6	20.4	8.9	1018.7	58.8	16.00	2.1	5.2
January 2018	13.4	19.7	7.6	1015.8	72.8	0.00	2.6	4.4
February 2018	17.7	22.8	12.2	1014.5	65.3	6.80	4.7	4.9
March 2018	24.7	30.3	16.7	1010.4	62.8	0.00	5.9	7.2
April 2018	28.5	36.1	22.8	1008.0	46.9	3.00	8.4	5.4

ear regression were prepared by applying Minitab (Version 12, State College, PA, USA) (Minitab, Inc. 1998) to evaluate the effect of studied traits particular on the achieved results.

3. Results

Soil applied 0.45 mg B kg^{-1} produced 13.5% taller plant height than control (Table 2). Similarly, no. of pods of Bittle-98 was measured 38.7% maximum than Noor-2013. Boron application of 0.45 mg kg^{-1} gave 15% more no. of pods. Among different treatments, Bittle-98 with 0.45 mg kg^{-1} had 47.9% higher no. of pods than Noor-2013 with B_0 (Table 2). Likewise, 0.45 mg B kg^{-1} had 34.8% significantly maximum no. of grains per pod than control. Cultivar Noor-2013 produced 24.6% more no. of grains per pod than Bittle-98 in different concentrations of B (Table 2). Cultivar Noor-2013 produced 41.5% more no. of grains per plant than Bittle-98 under different concentrations of B (Table 2). Regarding 100-grain weight, 0.45 mg kg^{-1} had 11.6% more grain weight than control. The cultivar Noor-2013 produced 43% heavier grains than Bittle-98 under different concentrations of soil applied B. Likewise, 0.45 mg B kg^{-1} produced 51.8% and 28.5% higher grain and biological yield than control, respectively. The cultivar Noor-2013 produced 31.2% and 3.4% higher grain and biological yield per plant than Bittle-98 under different concentrations of B, respectively (Table 3).

Boron applied @ 0.45 mg kg^{-1} produced 11.8% higher chlorophyll contents than control which was also significantly lower than other B concentrations. Between cultivars, Noor-2013 resulted 3.4% more chlorophyll contents than Bittle-98 (Table 4). Plants applied with 0.45 mg B kg^{-1} recorded 4.7% more transpiration rate than all other B concentrations. From both cultivars, transpiration rate of Noor-2013 had 0.73% higher than Bittle-98. Likewise, Noor-2013 with 0.45 mg kg^{-1} gave 5.7% higher transpiration rate than Bittle-98 with control and other treatments. Boron applied @ 0.45 mg kg^{-1} produced 36.9% higher stomatal conductance than control and other B concentrations. Moreover, Noor-2013 recorded 1.9% higher stomatal conductance than Bittle-98 (Table 4). A 7.7% higher WUE was recorded with 0.45 mg kg^{-1} than control and other treatments. Moreover, Noor-2013 with 0.45 mg kg^{-1} showed 10.9% higher WUE than Bittle-98 with control. Among both cultivars, 2.5% higher WUE was noted in Noor-2013 than Bittle-98 (Table 4).

Boron application @ 0.45 mg kg^{-1} recorded 74.3% more B content of roots than control. Among treatments, Noor-2013 with @ 0.45 mg kg^{-1} produced 76.1% higher B in roots than Bittle-98 with control (Table 5). Among various concentrations of B, 0.45 mg B kg^{-1} gave 40.1% more grain B contents than control. Noor-2013 and Bittle-98 with 0.45 mg kg^{-1} produced 41.5% more grain B contents than Bittle-98 and Noor-2013 with control (Table 5). Nonetheless, 0.45 mg B kg^{-1} produced 36.6% more B contents of

Table 2
Influence of soil applied boron on plant height, number of pods per plant, number of seeds per pod and number of seeds per plant of chickpea cultivars.

Treatments	Plant Height (cm)			Number of pods per plant			Number of seeds per pod			Number of seeds per plant		
	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean
B_0 = 0 mg B kg^{-1} of soil	56.00	48.58	52.29E	38.37i	62.60e	50.49E	0.98	0.79	0.88C	42.10	22.93	32.15E
B_1 = 0.18 mg B kg^{-1} of soil	58.03	50.58	54.25D	40.86h	66.00d	53.43D	1.10	0.88	0.99BC	44.55	24.90	34.73D
B_2 = 0.27 mg B kg^{-1} of soil	60.39	52.00	56.19C	42.12gh	69.00c	55.56C	1.26	0.95	1.07ABC	46.77	27.19	36.98C
B_3 = 0.36 mg B kg^{-1} of soil	63.10	53.55	58.32B	43.07g	71.31b	57.19B	1.35	1.04	1.19AB	51.03	30.31	40.67B43.83A
B_4 = 0.45 mg B kg^{-1} of soil	65.25	55.67	60.46A	45.25f	73.60a	59.42A	1.60	1.10	1.35A	53.75	33.90	
Mean	60.54A	52.06B		41.96B	68.50A		1.26A	0.95B		47.64A	27.85B	
LSD at 5 %	Cultivars (C): 0.51; Boron levels (B): 1.15; C × B: NS			Cultivars (C): 0.64; Boron levels (B): 1.02; C × B: 1.44			Cultivars (C): 0.12; Boron levels (B): 0.29; C × B: NS			Cultivars (C): 0.91; Boron levels (B): 1.45; C × B: NS		

Table 3
Influence of soil applied boron on 100-grain weight and grain and biological yield per plant of chickpea cultivars.

Treatments	100 grain weight (g)			Grain yield (g/plant)			Biological yield (g/plant)		
	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean
B_0 = 0 mg B kg^{-1} of soil	27.25	14.87	21.05E	9.73	7.27	8.50D	30.93	30.75	30.84D
B_1 = 0.18 mg B kg^{-1} of soil	27.66	15.88	21.77D	12.45	9.26	10.85C	33.35	34.20	33.77C
B_2 = 0.27 mg B kg^{-1} of soil	28.40	16.20	22.30C	14.64	10.15	12.40C	37.05	36.74	36.76B
B_3 = 0.36 mg B kg^{-1} of soil	28.95	16.75	22.85B	17.65	12.10	14.88B	39.95	38.32	39.14B
B_4 = 0.45 mg B kg^{-1} of soil	30.00	17.60	23.80A	21.66	13.60	17.63A	45.72	40.54	43.13A
Mean	28.53A	16.26B		15.23A	10.48B		37.36A	36.09B	
LSD at 5 %	Cultivars (C): 0.27; Boron levels (B): 0.43; C × B: NS			Cultivars (C): 1.39; Boron levels (B): 2.20; C × B: NS			Cultivars (C): 1.52; Boron levels (B): 2.41; C × B: NS		

Table 4
Influence of soil applied boron on chlorophyll contents, transpiration rate and stomatal conductance and water use efficiency of chickpea cultivars.

Treatments	Chlorophyll contents (SPAD)			Transpiration rate (mmol H_2O m^{-2} s^{-1})			Stomatal conductance (µmol H_2O m^{-2} s^{-1})			Water use efficiency (µmol CO_2 mol^{-1} H_2O day^{-1} m^{-2})		
	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean
B_0 = 0 mg B kg^{-1} of soil	40.77	38.81	39.79D	13.38g	13.18h	13.28E	2.38	2.34	2.36E	3.03ef	2.94g	2.99D
B_1 = 0.18 mg B kg^{-1} of soil	41.02	40.35	40.69C	13.52e	13.45f	13.49D	2.84	2.80	2.82D	3.05de	3.00ef	3.03C
B_2 = 0.27 mg B kg^{-1} of soil	43.46	41.98	42.71B	13.66d	13.57e	13.62C	3.00	2.92	2.96C	3.18b	3.09cd	3.14B
B_3 = 0.36 mg B kg^{-1} of soil	44.13	42.88	43.50B	13.80c	13.76c	13.78B	3.60	3.55	3.58B	3.20b	3.12bc	3.16B
B_4 = 0.45 mg B kg^{-1} of soil	46.15	44.06	45.10A	13.98a	13.89b	13.94A	3.77	3.71	3.74A	3.30a	3.17b	3.24A
Mean	43.10A	41.62B		13.67A	13.57B		3.12A	3.06B		3.15A	3.07B	
LSD at 5 %	Cultivars (C): 0.37; Boron levels (B): 0.84; C × B: NS			Cultivars (C): 0.01; Boron levels (B): 0.03; C × B: 0.06			Cultivars (C): 0.001; Boron levels (B): 0.038; C × B: NS			Cultivars (C): 0.01; Boron levels (B): 0.03; C × B: 0.06		

leaves in Noor-2013 than Bittle-98. The cultivar Noor-2013 recorded with 10.8% more B in leaves than Bittle-98 under various concentrations of B. Likewise, higher concentration of B in stalk was measured with 0.45 mg kg^{-1} that was 9% higher than control (Table 5).

Grain protein was significantly improved by B application and 0.45 mg kg^{-1} produced 2.9% higher grain protein than control. Moreover, 4.1% higher grain protein was recorded in Noor-2013 with 0.45 mg kg^{-1} than Bittle-98 with control (Table 6). Likewise, applied B significantly affected grain starch and 0.45 mg B kg^{-1} recorded 1.4% more grain starch than control. Overall, the cultivar Noor-2013 presented 0.3% higher grain starch than Bittle-98 (Table 6). Regarding grain total sugar, 0.45 mg kg^{-1} exhibited 4.5% higher grain total sugar than control. Contrarily, Bittle-98 without B produced 10% higher grain crude fiber than Noor-2013 and Bittle-98 with 0.45 mg B kg^{-1} (Table 6).

Significant and positive correlation was recorded between grain yield per plant and plant height (r = 0.99), no. of pods (r = 0.98); no. of grains per pod (r = 0.99); no. of grains per plant (r = 0.99); 100-grain weight (r = 0.99); biological yield per plant (r = 0.99); chlorophyll contents (r = 0.98); transpiration rate (r = 0.99); stomatal conductance (r = 0.98); WUE (r = 0.97); B uptake by roots (r = 0.91); B uptake by seed (r = 1.00); B uptake by leaves (r = 0.97); B uptake by stalk (r = 0.99); grain protein (r = 0.99); grain starch (r = 0.98) and grain total sugar (r = 0.98) (Table 7). Scatterplot with regression line was drawn among grain yield with all other parameters (Fig. 1). The regression line among grain yield with all parameters showed positive relationship except grain crude fiber. Scatterplot dots showed the variation of parameters with grain yield.

4. Discussion

Boron shortage is increasing and becoming a serious issue on calcareous soils (hyperthermic, sodic haplocambids) (Atique-ur-Rehman et al., 2020). Regardless of different concentrations and cultivars, considerable change was recorded in plant height of chickpea due to soil applied B (Table 2). Significant improvement in chickpea plant height of soil applied at 0.45 mg B kg^{-1} (Table 2) could be possible due to appropriate dose of boron, which is used as a part of many plant body functions. Deficiency of B reduces plant height as a result of depression in various physiological and growth parameters (Shrestha et al., 2019). Current findings are in line with Rehman et al. (2019) that crop with B incorporation supported in producing higher number of pods per plant. Suitable concentrations of B had prominent role in movement of photo assimilates from roots to other body parts and it also brings improvement in pollen tube development that leads to enhance number of seeds per pod (Silva et al., 2011). Significantly, higher 100-grain weight was recorded in 0.45 mg B kg^{-1} might be improvement in plant growth and less flower abortion. Experimental findings confirm the finding of Khatun et al. (2016) who found significant higher 100-grain weight in chickpea due to improvements of nutrients uptake that leads to healthy plant growth and flower development. Similarly, B had prominent role in fertilization that leads to enhance the grain filling rate, which encouraged to increase grain weight (Islam et al., 2017) (Table 3). Boron application brings improvement in flower formation and development, pollen formation, fertilization and seed development. Therefore, these improvements reduced the rate of flower and fruit shedding and ultimately resulted in higher number of pods and grain weight (Rehman et al., 2019).

Chlorophyll contents significantly improved with the increasing B concentration in the soil and maximum value was recorded with 0.45 mg B kg^{-1}. Moreover, some researchers reported that B had

Table 5
Influence of soil applied boron on boron uptake by roots, seed, leaves and stalk of chickpea cultivars.

Treatments	Boron uptake by roots (mg kg^{-1})			Boron uptake by seed (mg kg^{-1})			Boron uptake by leaves (mg kg^{-1})			Boron uptake by shoot (mg kg^{-1})		
	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean
B_0 = 0 mg B kg^{-1} of soil	12.00i	10.75j	11.38E	1.14e	1.10e	1.12E	26.16i	23.08j	24.62E	18.36e	14.46j	16.41E
B_1 = 0.18 mg B kg^{-1} of soil	30.15g	28.72h	29.44D	1.33d	1.30d	1.32D	31.45e	26.45h	28.95D	18.78d	14.86i	16.82D
B_2 = 0.27 mg B kg^{-1} of soil	37.00e	35.82f	36.41C	1.46c	1.41c	1.44C	32.72d	29.47g	31.10C	19.14c	15.30h	17.22C
B_3 = 0.36 mg B kg^{-1} of soil	41.76c	39.67d	40.72B	1.68b	1.63b	1.66B	34.14b	31.10f	32.62B	19.47b	15.90g	17.69B
B_4 = 0.45 mg B kg^{-1} of soil	44.96a	43.54b	44.25A	1.88a	1.85a	1.87A	36.43a	33.41c	34.92A	19.66a	16.40f	18.03A
Mean	33.17A	31.70B		1.50A	1.46B		32.18 A	28.70B		19.08A	15.38B	
LSD at 5 %	Cultivars (C):0.01; Boron levels (B): 0.03; C × B: 0.06			Cultivars (C): 0.01; Boron levels (B): 0.03; C × B: 0.06			Cultivars (C): 0.01; Boron levels (B): 0.03; C × B: 0.06			Cultivars (C): 0.08; Boron levels (B): 0.12; C × B: 0.18		

Table 6
Influence of soil applied boron on grain protein, grain crud fiber, grain starch and grain total sugar of chickpea cultivars.

Treatments	Grain protein (%)			Grain crud fiber (%)			Grain starch (mg kg^{-1})			Grain total sugar (%)		
	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean	Noor-2013	Bittle-98	Mean
B_0 = 0 mg B kg^{-1} of soil	11.88f	11.78 g	11.83E	5.90b	5.98a	5.94A	143.14	143.10	143.12E	5.33	5.29	5.31D
B_1 = 0.18 mg B kg^{-1} of soil	11.96de	11.88f	11.92D	5.80 cd	5.86bc	5.83B	143.39	143.32	143.36D	5.40	5.36	5.38C
B_2 = 0.27 mg B kg^{-1} of soil	12.02 cd	11.90ef	11.96C	5.70e	5.79d	5.75C	144.16	144.10	144.13C	5.47	5.41	5.44B
B_3 = 0.36 mg B kg^{-1} of soil	12.16b	11.98d	12.07B	5.50f	5.55f	5.53D	144.52	144.48	144.50B	5.50	5.42	5.46B
B_4 = 0.45 mg B kg^{-1} of soil	12.28a	12.08c	12.18A	5.38g	5.43g	5.41E	145.22	145.18	145.20A	5.58	5.53	5.56A
Mean	12.06A	11.92B		5.66B	5.72A		144.09A	144.04B		5.46A	5.40B	
LSD at 5 %	Cultivars (C): 0.01; Boron levels (B): 0.03; C × B: 0.06			Cultivars (C): 0.01; Boron levels (B): 0.03; C × B: 0.06			Cultivars (C): 0.01; Boron levels (B): 0.03; C × B: NS			Cultivars (C): 0.005; Boron levels (B): 0.03; C × B: NS		

Table 7
Correlation between yield and yield attributing, physiological, B uptake and grain quality characters of chickpea cultivars.

	PH	NPP	NSP	NSPP	GWT	GY	BY	CH	TRAN	SC	WUE	BUR	BUS	BUL	BUST	GP	GCF	GS
PH	1																	
NPP	0.99**	1																
NSP	0.99**	0.98**	1															
NSPP	0.99**	0.98**	0.99**	1														
GWT	0.99**	0.99**	0.99**	0.99**	1													
GY	0.99**	0.98**	0.99**	0.99**	0.99**	1												
BY	0.99**	0.99**	0.99**	0.99**	0.99**	0.99**	1											
CH	0.99**	0.98**	0.98**	0.98**	0.98**	0.98**	0.99**	1										
TRAN	0.99**	0.99**	0.99**	0.99**	0.99**	0.99**	0.99**	0.98**	1									
SC	0.98**	0.97**	0.97**	0.98**	0.96**	0.98**	0.96**	0.95**	0.98**	1								
WUE	0.98**	0.98**	0.96**	0.96**	0.97**	0.97**	0.98**	0.99**	0.97**	0.93**	1							
BUR	0.92**	0.96**	0.90**	0.90**	0.92**	0.91**	0.92**	0.91**	0.95**	0.92**	0.91**	1						
BUS	0.99**	0.98**	0.99**	0.99**	0.99**	1.00**	0.99**	0.98**	0.99**	0.98**	0.96**	0.92**	1					
BUL	0.97**	0.99**	0.96**	0.96**	0.97**	0.97**	0.97**	0.96**	0.98**	0.96**	0.96**	0.98**	0.97**	1				
BUST	0.99**	0.99**	0.98**	0.99**	0.98**	0.99**	0.99**	0.98**	0.99**	0.98**	0.97**	0.93**	0.99**	0.97**	1			
GP	0.99**	0.97**	0.99**	0.99**	0.99**	0.99**	0.99**	0.97**	0.98**	0.98**	0.95**	0.90**	0.99**	0.95**	0.98**	1		
GCF	−0.99**	−0.97**	−0.99**	−0.99**	−0.98**	−0.99**	−0.98**	−0.96**	−0.98**	−0.98**	−0.95**	−0.89**	−0.99**	−0.94**	−0.99**	−0.99**	1	
GS	0.99**	0.97**	0.98**	0.98**	0.98**	0.98**	0.99**	0.99**	0.97**	0.94**	0.99**	0.89**	0.98**	0.95**	0.985**	0.97**	−0.97**	1
GTS	0.98**	0.98**	0.98**	0.97**	0.99**	0.98**	0.99**	0.98**	0.98**	0.94**	0.98**	0.92**	0.98**	0.97**	0.975**	0.97**	−0.95**	0.98**

**. Correlation is significant at the 0.01 level 9two-tailed).
PH = Plant height; NPP = Number of pods per plant; NSP = Number of seeds per pod; NSPP = Number of seeds per plant; GWT = 100-grain weight; GY = Grain yield per plant; BY = Biological yield per plant; CH = Chlorophyll contents; TRAN = Transpiration rate; SC = Stomatal conductance; WUE = Water use efficiency; BUR = Boron uptake by roots; BUS = Boron uptake by seed; BUL = Boron uptake by leaves; BUST = Boron uptake by stalk; GP = Grain protein; GCF = Grain crud fiber; GS = Grain starch and GTS = Grain total sugar.

indirect relationship with photosynthesis (Liu et al., 2005). Our study agreed with the outcomes of Liu et al. (2005) who reported that soil applied B had higher photosynthetic rate of crop by support of cell membrane and photosynthate movement as well as larger leaf area. The smaller size of leaf is primarily cause for reduction in photosynthetic rate of chickpea under B deficiency. Present study showed minimum rate of transpiration, stomatal conductance and WUE in B deficiency than 0.45 mg B kg^{-1} which might be due to damage of vascular bundle by B_0 (Li et al., 2017). Statistically lower rate of transpiration rate and stomatal conductance in B_0 also lowered the WUE (Table 6). Pinho et al. (2010) supported our results and concluded that linear correlation exists in stomatal conductance and B concentrations. Han et al. (2008) reported that 0.45 mg B kg^{-1} improved stomatal conductance and decreased intercellular CO_2 absorption and resulting a considerable improvement in physiological characteristics. Boron contents were increased as increased concentration of B from 0.18, 0.27, 0.36 and 0.45 mg B kg^{-1} (Rehman et al., 2012). Boron deficiency quickly degenerated the appearance of genes in Arabidopsis of roots, hence, delayed the root development (Martín-

Rejano et al., 2011). The division of B contents among plant parts had considerable change with increasing B concentration. Boron was absorbed in the direction of leaf > shoot > root (Table 7) (Reid et al., 2004).

Improved grain protein, crude fiber, starch and total sugar supported by the results of Rehman et al., (2019), that soil applied B in chickpea cultivars improves the grain quality traits due to considerable role of B on enzymes which are responsible for the buildup

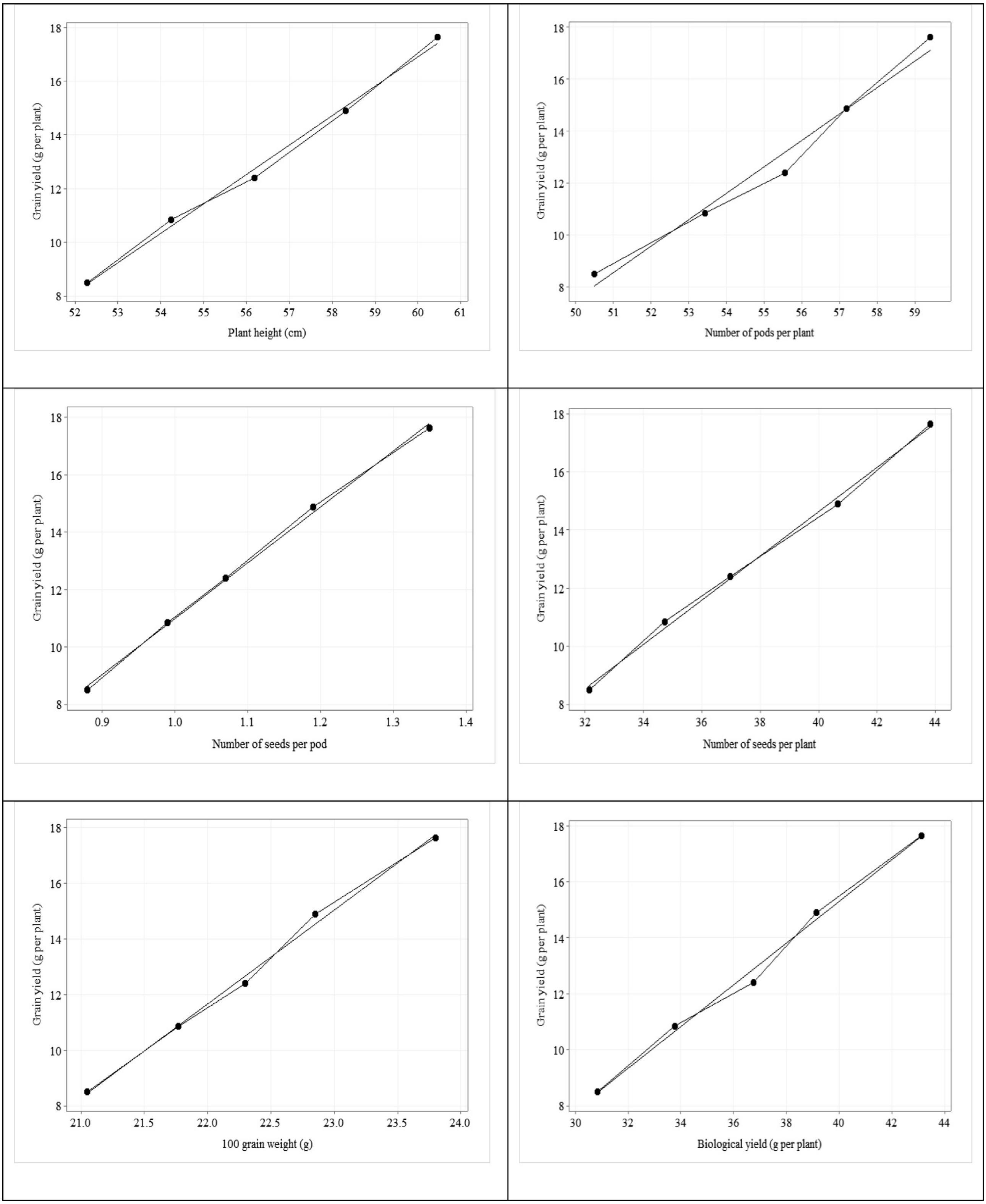

Fig. 1. Scatterplot with regression line of grain yield vs plant height, number of pods per plant, number of seeds per pod, number of seeds per plant, 100 grain weight, biological yield, chlorophyll contents, transpiration rate, stomatal conductance, water use efficiency, boron uptake by roots, boron uptake by seeds, boron uptake by leaves, boron uptake by shoot, grain protein, grain crud fiber, grain starch, grain total sugar.

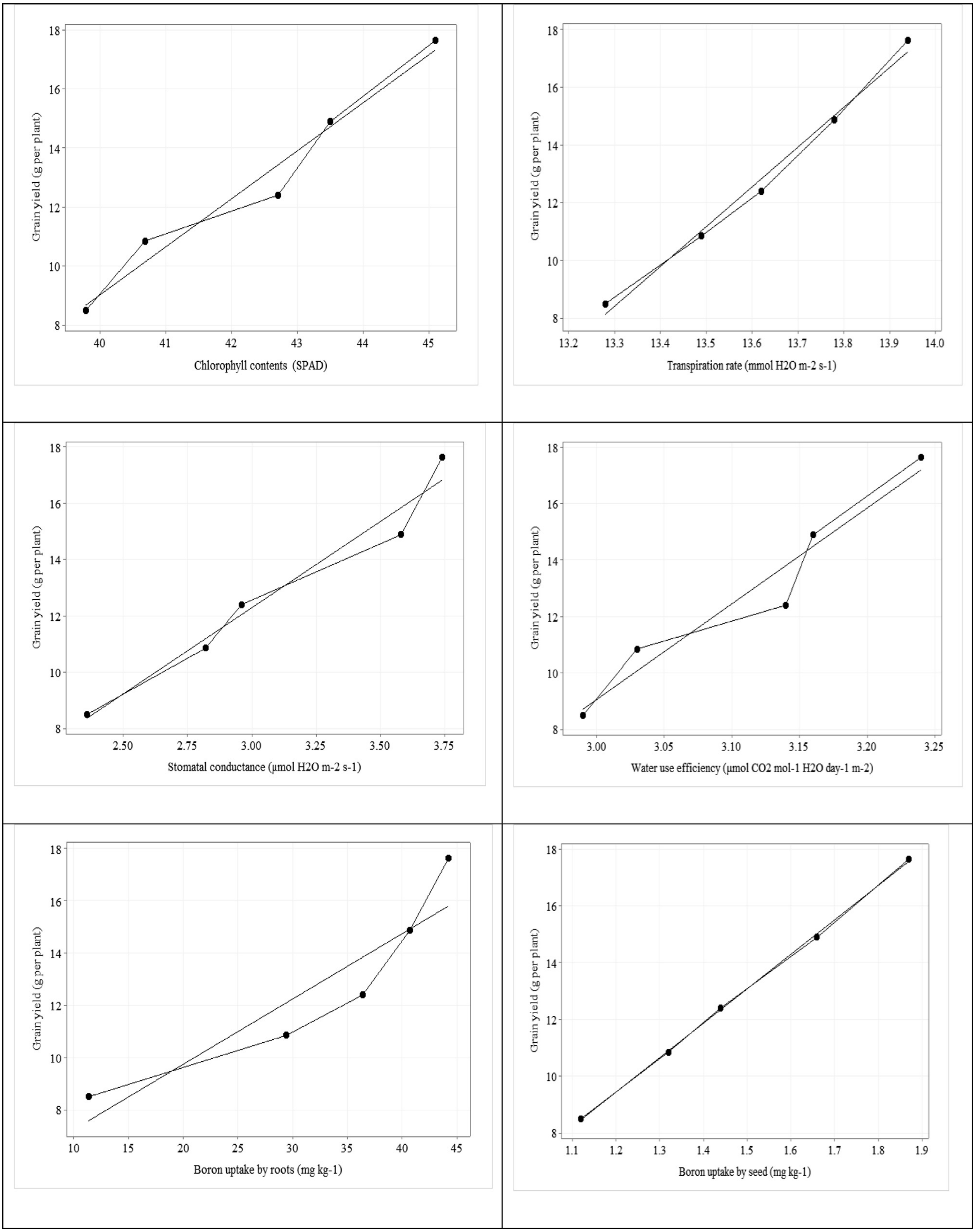

Fig. 1 (*continued*)

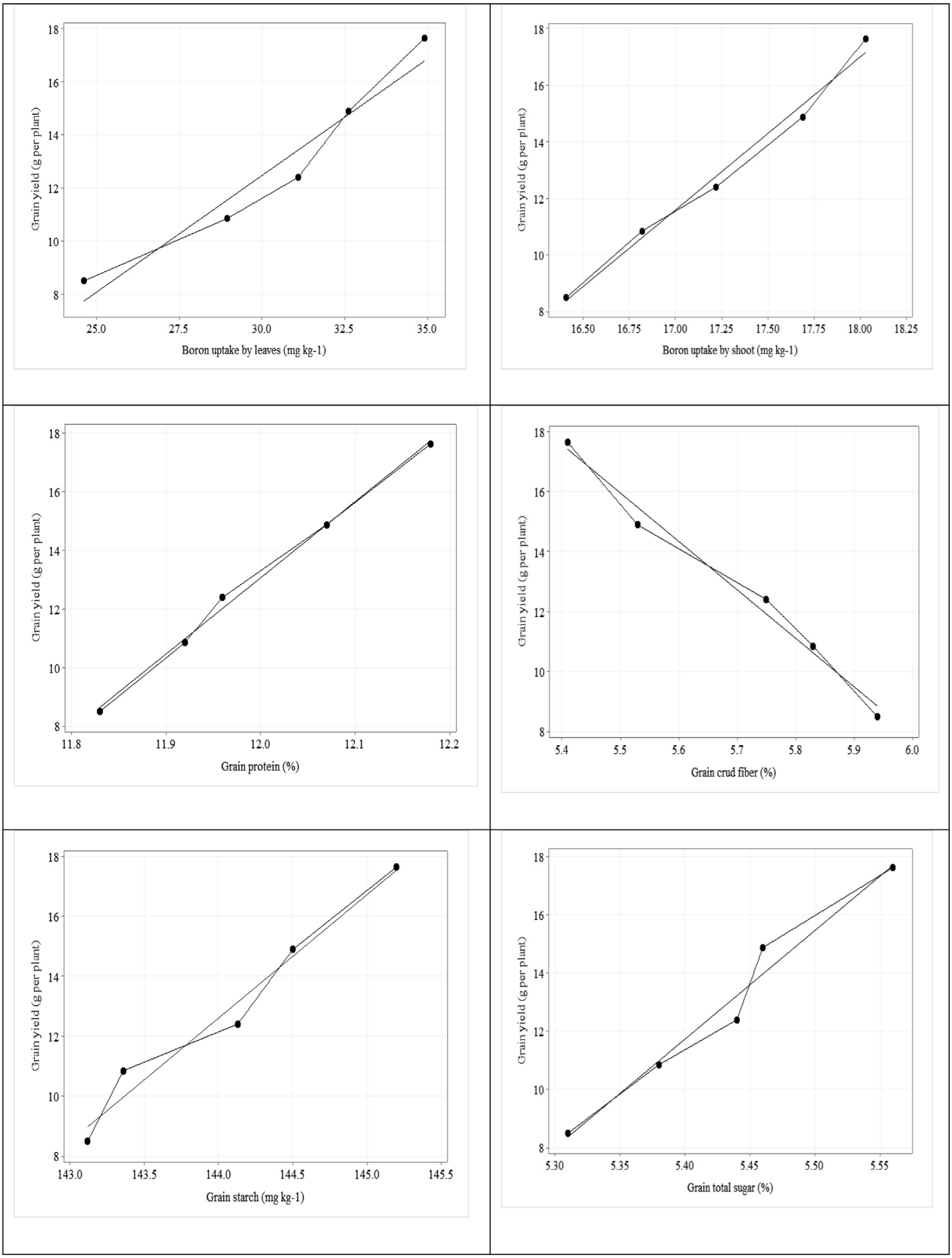

Fig. 1 (*continued*)

and alteration of assimilates into grains. Rehman et al. (2019) concluded that B application enhanced seed quality in form of storage, protein, fiber and starch. Genetic characteristics of cultivars is also responsible for improving grain quality traits (Bellaloui et al., 2009b). The improving development in quality traits by soil applied B (Rehman et al., 2019) could be the positive role of B on enzymes activities which are responsible for buildup and alteration of fatty acids (Bellaloui et al., 2009a).

5. Conclusion

Boron application to chickpea cultivars improved growth and grain production under semiarid region Yermosols. Application of B @ 0.45 mg B kg^{-1} remained better than other treatments.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to express their gratitude to the Research Center of Advanced Materials—King Khalid University, Saudi Arabia for support by grant number (KKU/RCAMS/G001/21). The publication of the present work is supported by the National Natural Science Foundation of China (51809224), Top Young Talents of Shaanxi Special Support Program. We acknowledge Bahauddin Zakariya University, Multan, Pakistan for financial assistance during the study.

References

Ahlawat, I.P.S., Gangaiah, B., Ashraf Z.M., 2007. Nutrient management in chickpea. In: Chickpea Breeding and Management (Yadav S.S., Redden R., Chen W., Sharma B., eds). CAB International, Wallingford, Oxon, United Kingdom. pp. 213-232. 10.1079/9781845932138.010.

Atique-ur-Rehman, Qamar, R., Hussain, A., Sardar, H., Sarwar, N., Javeed, H.M.R., et al., 2020. Soil applied boron (B) improves growth, yield and fiber quality traits of cotton grown on calcareous saline soil. PLoS ONE 15, (8). https://doi.org/10.1371/journal.pone.0231805 e0231805.

Bellaloui, N., Abbas, H.K., Gillen, A.M., Abel, C.A., 2009a. Effect of glyphosate– boron application on seed composition and nitrogen metabolism in glyphosate-resistant soybean. J. Agric. Food Chem. 57 (19), 9050–9056. https://doi.org/10.1021/jf901801z.

Bellaloui, N., Smith, J.R., Ray, J.D., Gillen, A.M., 2009b. Effect of maturity on seed composition in the early soybean production system as measured on near-isogenic soybean lines. Crop Sci. 49 (2), 608–620. https://doi.org/10.2135/cropsci2008.04.0192.

Bingham, F.T., 1982. Boron. In: Page, A.L., Ed., Methods of soil Analysis Part-2 Chemical and Mineralogical Properties. Am. Soc. Agron. 431-448. 10.2134/agronmonogr9.2.2ed.

Borie, F., Rubio, R., Rouanet, J.L., Morales, A., Borie, G., Rojas, C., 2006. Effects of tillage systems on soil characteristics, glomalin and mycorrhizal propagules in a Chilean Ultisol. Soil Till. Res. 88, 253–261 http://repositorio.uchile.cl/handle/2250/120585.

Govt. of Pakistan, 2019-2020. Economic Survey of Pakistan, Economic adviser's Wing, Finance Division, Government of Pakistan, Islamabad. pp 121.

Hajiboland, R., Bahrami-Rad, S., Bastani, S., 2013. Phenolics metabolism in boron-deficient tea [Camellia sinensis (L.) O. Kuntze] plants. Acta Biol. Hung. 64, 196–206. https://doi.org/10.1556/ABiol.64.2013.2.6.

Islam, M.S., El Sabagh, A., Hasan, K., Akhter, M., Barutcular, C., 2017. Growth and yield response of mungbean *(Vigna radiat*a L.) as influenced by Sulphur and boron application. Sci. J. Crop Sci. 6, 153–160. https://doi.org/10.14196/sjcs.v6i1.2383.

Kagan, S., Kayan, N., 2014. The influence of inoculation and nitrogen treatments on yield and yield components in chickpea (*Cicer arietinum* L.) cultivars. Legume Res. 37, 363–371. https://doi.org/10.5958/0976-0571.2014.00645.6.

Kastori, R., Maksimovic, I., Kraljevic-Balalic, M., Kobiljski, B., 2008. Physiological and genetic basis of plant tolerance to excess boron. Zb Mat srp prir nauk (114), 41–51. https://doi.org/10.2298/ZMSPN0814041K.

Khatun, A., Bhuiyan, M.A.H., Tahmid, A., 2016. Effect of fungicides on seed quality of lentil (*Lens culinaris* L.) during storage. Jahangirnagar Uni. J. Biol. Sci. 5, 51–56. https://doi.org/10.3329/jujbs.v5i2.32530.

Li, Y., Hou, L., Song, B., Yang, L., Li, L., 2017. Effects of increased nitrogen and phosphorus deposition on offspring performance of two dominant species in a temperate steppe ecosystem. Sci. Rep. 7, 1–11. https://doi.org/10.1038/srep40951.

Liu, P., Yang, Y.S., Xu, G.D., Shi, Y.H., Yang, Y.A., Kalin, R.M., 2005. The effect of molybdenum and boron in soil on the growth and photosynthesis of three soybean varieties. Plant Soil Environ. 51 (No. 5), 197–205. https://doi.org/10.17221/3574-PSE.

Lowry, O.H., Rosebrough, N.J., Farr, A.L., Randall, R.J., 1951. Protein measurement with the Folin phenol reagent. J. Biol. Chem. 193 (1), 265–275. https://doi.org/10.1016/S0021-9258(19)52451-6.

Martín-Rejano, E.M., Camacho-Cristóbal, J.J., Herrera-Rodríguez, M.B., Rexach, J., Navarro-Gochicoa, M.T., González-Fontes, A., 2011. Auxin and ethylene are involved in the responses of root system architecture to low boron supply in Arabidopsis seedlings. Physiol. Plant. 142: 170-178. Google Scholar.

Inc, M., 1998. MINITAB release 12 for windows. Brooks/Cole, Pacific Grove.

Padbhushan, R., Kumar, D., 2014. Influence of soil and foliar applied boron on green gram in calcareous soils. Int. J. Agric., Environ. Biotechnol. 7, 129. https://doi.org/10.5958/j.2230-732X.7.1.018.

Pinho, L.G.R., Campostrini, E., Monnerat, P.H., Netto, A.T., Pires, A.A., Marciano, C.R., Soares, Y.J.B., 2010. Boron deficiency affects gas exchange and photochemical efficiency (JPI test parameters) in green dwarf coconut. J. Plant Nutr. 33 (3), 439–451. https://doi.org/10.1080/01904160903470471.

Rehman, A.U., Ali, U.I., Qamar, R., Rehman, A., Hussain, M., Javeed, H.M.R., Ahmad, S., 2019. Boron foliage application mediates growth, oil yield and quality of sunflower in yermosols of southern Punjab. Intl. J. Agric. Biol., 21: 209–214. Google Scholar.

Rehman, A., Farooq, M., Ozturk, L., Asif, M., Siddique, K.H.M., 2018a. Zinc nutrition in wheat-based cropping systems. Plant and Soil. 422 (1-2), 283–315. https://doi.org/10.1007/s11104-017-3507-3.

Rehman, A., Farooq, M., Naveed, M., Nawaz, A., Shahzad, B., 2018b. Seed priming of Zn with endophytic bacteria improves the productivity and grain biofortification of bread wheat. Eur. J. Agron. 94, 98–107. https://doi.org/10.1016/jeja.2018.01.017.

Rehman, A., Farooq, M., Cheema, Z.A., Wahid, A., 2012. Seed priming with boron improves growth and yield of fine grain aromatic rice. Plant Growth Regul. 68, 189–201. https://doi.org/10.1007/s10725-012-9706-2.

Rehman, A., Farooq, M., Ali, H., Sarwar, N., Qamar, R., 2014. Thermal hardening improves germination and early seedling growth of chickpea. Asian J. Agric. Biol. 2 (1), 51–58.

Reid, R.J., Hayes, J.E., Post, A., Stangoulis, J.C.R., Graham, R.D., 2004. A critical analysis of the causes of boron toxicity in plants. Plant Cell Environ. 27, 1405-1414. Google Scholar.

Rong, L., Volenec, J.J., Joern, B.C., Cunningham, S.M., 1996. Seasonal changes in nonstructural carbohydrates, protein, and macronutrient in roots of alfalfa, red clover, sweet clover, and birds foot trefoil. Crop Sci. 36, 617–623. https://doi.org/10.2135/cropsci1996.0011183X003600030016x.

Sadasivam, S., Manickam., 1996. Biochemical methods. New Age Int. Pak. J. Bot. 36, 801–809. https://doi.org/10.4236/ojmc.2012.23011.

SAS Institute, 2008. SAS/STAT 9.1 User's Guide the Regular Procedure, (Book Excerpt). SAS Institute, Cary. Google Scholar.

Shrestha, A., Pradhan, S., Shrestha, J., Subedi, M., 2019. Role of seed priming in improving seed germination and seedling growth of maize (*Zea mays* L.) under rain fed condition. J. Agric. Nat. Res. 2, 265–273. https://doi.org/10.3126/janr.v2i1.26088.

Silva, C.A.T., Cagol, A., Silva, T.R.B., Nobrega, L.H.P., 2011. Boron application before sowing of sunflower hybrid. J. Food Agric. Environ. 9, 580-583. Google Scholar.

Sims, T.T., 2000. Soil fertility evaluation. In: Handbook of soil science (Summer M. E., ed). Boca Raton, Florida, USA, CRC Press. Pp. 113-154. Google Scholar.

Steel, R.G., 1997. Pinciples and procedures of statistics a biometrical approach (No. 519.5 S8). Google Scholar.

Tahir, M., Tanveer, A., Shah, T.H., Fiaz, N., Wasaya, A., 2009. Yield response of wheat (*Triticum aestivum* L.) to boron application at different growth stages. Pak. J. Life Soc. Sci. 7: 39-42. Google Scholar.

Wang, N., Yang, C., Pan, Z., Liu, Y., Peng, S.A., 2015. Boron deficiency in woody plants: various responses and tolerance mechanisms. Front. Plant Sci. 6, 916. https://doi.org/10.3389/fpls.2015.00916.

Wolf, B., 1974. Improvements in the azomethine-H method for the determination of boron. Commun. Soil Sci. Plant Anal. 5 (1), 39–44. https://doi.org/10.1080/00103627409366478.

Zeng, X., Li, Y., Sun, Y., Hong, Y., Liu, J., Xiang, X., Wang, K., 2007. Determination of free sugars by high performance liquid chromatography. Chin. J. Anal. Chem. 35, 930-938. Google Scholar.

Zhao, D., Oosterhuis, D.M., Bednarz, C.W., 2001. Influence of potassium deficiency on photosynthesis, chlorophyll content, and chloroplast ultrastructure of cotton plants. Photosynthetica. 39 (1), 103–109. https://doi.org/10.1023/A:1012404204910.