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# Foliar Boron Application and Row Spacing Effects on Growth, Yield and Protein Contents of Lentil (*Lens culinaris* Medic.)

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## ABSTRACT

Sufficient supply of foliar boron is essential for the appropriate productivity of lentil, particularly in poorly fertile soil. Therefore, field experiments were carried out at two locations (Maru and Mushaqar) in Jordan during the winter growing season 2021/2022 to evaluating the impact of foliar boron levels (0, 0.2, 0.3, and 0.6%) on the physiology, growth, yield, and grain protein contents of the local lentil variety (Jordan 2) under different row spacing (17.5 and 35 cm). The results revealed that the Maru location outperformed another location for increasing transpiration rate, plant height, days to flowering, yield, and yield attributes while reducing protein contents. Row spacing of 35 cm had significantly higher physiological performance, yield, and yield attributes than row spacing of 17.5 cm, except for instantaneous water use efficiency, straw yield, and thousand seed weight. Foliar 0.2% boron was the best treatment since it increased total chlorophyll content, stomatal conductance, transpiration, photosynthetic rate, and protein content by 9.5, 39.9, 22.2, 25.9, and 11.2%, respectively. Furthermore, foliar 0.2% boron improved grain yield higher at row spacing of 35 cm than those at row spacing of 17.5 cm. However, foliar 0.6% boron decreased grain yield by 8.5% and 3.6% at row spacing 35 cm and 17.5 cm, respectively, indicating this high concentration of boron acts as toxicity. Overall, it is highly recommended to use foliar rates of boron ranging between 0.2% and 0.3% to enhance the seed yield and protein content of lentils at different row spacing. These results suggest that optimum row spacing and foliar boron are useful approaches for lentil's sustainability in semiarid areas.

**Keywords:** protein content, photosynthesis, row spacing, foliar boron, lentil.

## INTRODUCTION

Lentils (*Lens culinaris* Medic.) are comestible and profitable crops that belong to the family Fabaceae. Lentil is desired since it has a valued chemical structure and health-stimulating characteristics. Besides, this crop has a good source of proteins and fibers for both humans and livestock (Ninou et al., 2019). The seeds usually have between 24% and 32% protein, 1.1% fat, and 59% carbohydrates (Faris et al., 2013; Kahraman, 2016). In Jordan, lentil is considered to be the most important legume crop after chickpea that is grown as a winter crop under rainfed conditions (Turk et al., 2003). The area cultivated for rainfed lentils in Jordan was 277.2 ha, with a production of 346.6 tons (Ministry of Agriculture, 2022). Lentil yields in Jordan are among the lowest worldwide because the productivity is not adequate for meeting local consumption (Yasin et al., 1995). In addition, low and fluctuating rainfalls with poor management practices play a crucial role in decreasing the yield. Lentil crops are very sensitive to both high temperatures and water stresses, mainly at the flowering stage, which significantly decrease the grain yield (Sita et al., 2017).

Lentil production is limited by the absence of appropriate managing practices, which has triggered an incessant reduction of micronutrients as intensive crops are cultivated (Fageria et al., 2002). Therefore, the application of foliar micronutrients might have a main role in enhancing lentil yield. However, foliar application may not totally substitute for the application of nutrients into the soil; nevertheless, it could improve the uptake of nutrients by the plants (Kannan, 2010). Foliar application of micronutrients can easily and rapidly help the consumption of nutrients through osmotic diffusion and penetrating to the leaf cells through stomata (Nayak et al., 2020).

Boron (B) is a crucial minor element that is required for improving plant reproduction, yield, and quality (Kayata et al., 2024). It increases stomatal opening and gas exchange regulation and also facilitates the transport of carbohydrates, which are necessary for cell elongation and differentiation (Elahi et al., 2024). In addition, B plays a fundamental role in the translocation of sugars, nitrogen fixation, and synthesis of proteins (Singh et al., 2014). However, B insufficiency in the soil is one of the universal problems for plant growth (Oktem, 2022). Boron lack usually causes plant sterility and reduced germination of pollen grains. As a result, there was an increased drop of flowers and a decreased set of fruits (Subasinghe et al., 2003). However, the range is too slight between the toxicity and adequacy of B. Extra amounts of B are identified to delay regular plant growth and yield (Khurana and Arora, 2012).

Row spacing (Rs) is considered vital crop management that could be used for achieving the highest production per unit of land area (Zuo et al., 2024). Optimum Rs can confirm a proper growth of the crops through the effectiveness of solar radiation, nutrients, and water (Ouji et al., 2016). However, too wide Rs could efficiently fail in exploiting the natural resources, while very narrow Rs might result in severe inter and intra competition of Rs. Several studies have revealed that the Rs of 30 cm had a superior positive effect on the production of lentils, when compared with either wider or narrower Rs (Singh et al., 2009; Faqeer et al., 2020; Devi et al., 2022).

The study hypothesized that optimum Rs with foliar B application would effectively increase the physiological performance of lentil and, in consequence, improve the grain yield and quality. Yet, few researches are presented concerning the impact of foliar B on lentil's growth, yield and quality under different Rs. Therefore, our study was designed for evaluating the physiology, yield and protein content of lentil under two rainfed locations in Jordan, using Rs of 17.5 cm and 35 cm, with different foliar B levels.

## MATERIALS AND METHODS

### Locations study

A field experiment was carried out during the winter season 2021–2022 under dryland farming conditions at two locations namely Maru Agricultural Research Station (located in Maru, Irbid at 32$^o$ 35'4.7" Latitude, and 35$^o$54'0.3" Longitude, with 589 m altitude) and Mushaqar Agricultural Research Station (located in Mushaqar, Madaba at 3$^o$45'16.3" Latitude, 35$^o$48'1.5" Longitude, with 796.3 m altitude). The average rainfall in Maru and Mushaqar was 400 and 305 mm, respectively. Typical Mediterranean climate conditions prevailed at these locations as hot and dry summer. Table 1 shows the soil analysis, while Table 2 displays the weather data for both experimental sites.

**Table 1.** Soil characteristic of the experimental sites

| Soil properties | Unit | Maru | Mushaqar |
|---|---|---|---|
| P | ppm | 11.9 | 12.5 |
| K | ppm | 385.9 | 566.2 |
| Boron | mg/kg (dry weight) | < 5.0 | < 5.0 |
| $CaCO_3$ | % | 2.6 | 18.2 |
| Total N | % | 0.098 | 0.081 |
| Organic matter | % | 1.23 | 0.83 |
| PH | - | 7.8 | 7.7 |
| EC | dS/m | 0.64 | 0.91 |
| Clay | % | 50.4 | 51.2 |
| Silt | % | 37.9 | 35.6 |
| Sand | % | 11.7 | 13.2 |
| Texture | - | Clay | Clay |

**Table 2.** Weather data during the growing seasons of 2021–2022 for both locations

| Maru | | | | Mushaqar | |
|---|---|---|---|---|---|
| Year | Month | Temperature (°C) | Rainfall (mm) | Temperature (°C) | Rainfall (mm) |
| 2021 | Nov. | 14.8 | 9 | 13.6 | 13.2 |
| | Dec. | 9.6 | 103.5 | 8.3 | 57.4 |
| 2022 | Jan. | 7.5 | 119 | 6.9 | 150.9 |
| | Feb. | 8.4 | 62 | 7.5 | 29.2 |
| | Mar. | 12.2 | 103 | 10.9 | 35.8 |
| | Apr. | 17.1 | 3 | 15.7 | 0 |
| | May | 20.8 | 0 | 19.5 | 0 |
| Total | | - | 399.5 | - | 286.5 |
| Mean | | 12.9 | - | 11.8 | - |

## Treatments and experimental design

The experimental design was a split-plot with three replicates. Two Rs (17.5 cm and 35 cm) were considered as a main plot, while the sub-plots comprised foliar sprays of boron as 0% (control), 0.2%, 0.3%, and 0.6%. However, data for both experimental sites were combined to investigate if there are any significant differences between locations. Foliar B was applied borax form ($Na_2B_4O_7.10H_2O$, % B = 11.3%). Each sub-plot had received about 5 liters of foliar solution. A local red medium lentil variety (Jordan 2) was used at both experimental sites. Foliar B was sprayed during the anthesis growth stage.

## Crop management

The plot area was 120 $m^2$ (5 × 24 m), while area of each sub-plot was 10 $m^2$. The rate of seeds was 14 g $m^{-2}$ which sown by mechanical planter in depth of 7 cm. Seeds of lentil variety were planted on 14 December, 2021 and 15 December, 2021 for Maru and Mushaqar experimental sites, respectively. However, plants were harvested on 2 June, 2022 and 27 May, 2022 for Maru and Mushaqar experimental sites, respectively. During the growing season, lentil seeds were sown after wheat. The crop was fertilized with 5 g $m^{-2}$ of di-ammonium phosphate (DAP). Weeds were regularly controlled by hand after sowing.

## Physiological measurements

A portable handheld photosynthesis system (CI-340 Handheld Photosynthesis system, CID Bio-Science, Inc. Camas, WA 98607, USA) was used for measuring leaf net photosynthetic rate (A), transpiration rate (E), and stomatal conductance ($g_s$). In addition, a portable chlorophyll meter (SPAD 502 Chlorophyll Meter, Spectrum Technologies Inc., Plainfield, IL, USA) was used to measure total chlorophyll content. These physiological measurements were conducted after foliar B application from the developed upper leaves during flowering stage on March, 2022. Instantaneous water use efficiency ($WUE_i$) was calculated as A/E.

## Measurements of plant growth and grain yield

Days to 50% flowering (DF) and plant height (PH) were recorded. Plants were harvested at the end of May 2022 at both locations. A square quadrate (1 $m^2$) was set at the central rows for measurement of grain yield (GY), straw yield (SY), biological yield (BY = GY + SY), and harvest index (HI = GY/BY). Pod number/ plant and seed number/ plant were also determined.

## Grain crude protein (CP) analysis

According to method of Baethgen and Alley (1989), percentage of grain CP were analyzed by multiplying total N values by 6.25. For each treatment, the analyses were conducted triplicate.

## Statistical analysis

A Statistix 8.1 (Analytical Software, 2005) program was used for analysis of variance (ANOVA). All means were separated by honestly significant differences (HSD) at a P value < 0.05, and one way ANOVA was used when there was a significant interaction.

## RESULTS

### Weather data

Accumulated rainfall for Maru location was 39.4% higher than that for Mushaqar during the growing season 2021–2022 between December and May. During the pre-anthesis stage, lentils had received about 293.5 mm at Maru and 250.7 mm at Mushaqar. However, lentils had received around 70 mm more rainfall at Maru during the post-anthesis stage. At vegetative stage, the average temperature differed from 7.5 to 9.6 °C for Maru, and from 6.9 to 8.3 °C for Mushaqar, while it varied from 12.2 to 20.8 °C for Maru and 10.9 to 19.5 °C for Mushaqar from anthesis until harvest stage (Table 2).

### The main effects on physiological parameters of lentil

Transpiration rate (E) was only significantly higher in the Maru location by 7.9% than in the Mushaqar location. Row spacing (Rs) at 35 cm had significantly increased SPAD, $g_s$, E, and A by 2.7%, 11.7%, 5.4%, and 8.4%, respectively, when compared with Rs at 17.5 cm (Table 4). Foliar B treatments at 0.2% and 0.3% significantly improved the physiological parameters when compared with controls (0%). For example, B at 0.2% had increased SPAD, $g_s$, E, and A by 9.5%, 39.9%, 22.2%, and 25.9%, respectively. However, foliar B at 0.6% had significantly reduced SPAD by 3.4%, but it increased instantaneous water use efficiency ($WUE_i$) by 6.2%. Furthermore, B at 0.6% had no significant effect on other physiological parameters (Table 3).

### The main effects on growth, yield, and yield components of lentils

Maru location had significantly higher growth, yield, and yield components of lentils than Mushaqar location (Table 4) except for HI and for 1000 – seed weight per plant ($TSW^{-plt}$). For instance, PH, GY, PN, and SW were increased by 6.7%, 31%, 22.8%, and 29.4%, respectively, in Maru location. Row spacing (Rs) at 35 cm had significantly higher BY, GY, HI, PN, SN, and SW by 4.6%, 8.8%, 3.8%, 18.4%, 11.6%, and 16.7%, respectively, than Rs at 17.5 cm (Table 4). Growth and yield parameters of lentils were significantly higher when foliar B was sprayed at 0.2% treatment than those sprayed at 0.3% treatment, except for BY, SY, HI, and PN. However, foliar B at 0.6% had significantly lower growth and yield than foliar B at either 0.2% or 0.3%, except for DF and SY. In general, foliar B applied at 0.6% significantly inhibited GY and yield components of lentils when compared with controls. For

**Table 3.** Main effect of location, row spacing (Rs), and foliar boron (B) treatments on some physiological parameters of lentil

| Main effect | SPAD values | $g_s^a$ (mol $H_2O/m^2$ $S^{-1}$) | E (mmol$H_2O/m^2S^{-1}$) | A (μmol $CO_2/m^2$ $s^{-1}$) | $WUE_i$ (mmol $CO_2$ / mol $H_2O$) |
|---|---|---|---|---|---|
| Location | | | | | |
| Maru | 42.52 $^{a*}$ | 0.433 $^a$ | 8.36 $^a$ | 11.01 $^a$ | 1.321 $^a$ |
| Mushaqar | 40.45 $^a$ | 0.377 $^a$ | 7.75 $^b$ | 10.15 $^a$ | 1.312 $^a$ |
| HSD $_{(0.05)}$ | 2.75 | 0.06 | 0.60 | 1.46 | 0.14 |
| Row spacing | | | | | |
| 17.5 cm | 40.92 $^b$ | 0.383 $^b$ | 7.85 $^b$ | 10.15 $^b$ | 1.301 $^a$ |
| 35 cm | 42.04 $^a$ | 0.428 $^a$ | 8.27 $^a$ | 11.00 $^a$ | 1.332 $^a$ |
| HSD $_{(0.05)}$ | 0.86 | 9.961$^{E-03}$ | 0.23 | 0.32 | 0.04 |
| Foliar B | | | | | |
| 0% | 40.08 $^b$ | 0.346 $^c$ | 7.47 $^c$ | 9.50 $^c$ | 1.274 $^b$ |
| 0.2% | 43.88 $^a$ | 0.484 $^a$ | 9.13 $^a$ | 11.96 $^a$ | 1.313 $^{ab}$ |
| 0.3% | 43.26 $^a$ | 0.435 $^b$ | 8.51 $^b$ | 11.23 $^b$ | 1.326 $^{ab}$ |
| 0.6% | 38.72 $^c$ | 0.356 $^c$ | 7.12 $^c$ | 9.63 $^c$ | 1.353 $^a$ |
| HSD $_{(0.05)}$ | 0.90 | 0.014 | 0.39 | 0.40 | 0.055 |

**Note:** [a]gs: stomatal conductance; E: transpiration rate; A: net photosynthesis rate; WUEi: instantaneous water use efficiency. *HSD: honestly significant difference at $p < 0.05$ probability level using Tukey's test. Different letters within the same columns indicate significant differences.

**Table 4.** Main effect of location, row spacing, and foliar boron treatments on growth, yield and yield components of lentil

| Main effect | PH[a] (cm) | DF | BY (kg ha$^{-1}$) | GY (kg ha$^{-1}$) | SY (kg ha$^{-1}$) | HI | PN$^{-plt}$ | SN$^{-plt}$ | SW$^{-plt}$ (g) |
|---|---|---|---|---|---|---|---|---|---|
| Location | | | | | | | | | |
| Maru | 43.1 $^{a*}$ | 116.9 $^{a}$ | 4915.7 $^{a}$ | 1084.0 $^{a}$ | 3831.8 $^{a}$ | 0.2203 $^{a}$ | 24.8 $^{a}$ | 43.4 $^{a}$ | 2.2 $^{a}$ |
| Mushaqar | 40.4 $^{b}$ | 113.8 $^{b}$ | 3754.1 $^{b}$ | 827.3 $^{b}$ | 2959.3 $^{b}$ | 0.2201 $^{a}$ | 20.2 $^{b}$ | 35.0 $^{b}$ | 1.7 $^{b}$ |
| HSD $_{(0.05)}$ | 2.56 | 1.98 | 315.13 | 61.72 | 204.82 | 0.0201 | 3.28 | 1.08 | 0.15 |
| Row spacing | | | | | | | | | |
| 17.5 cm | 41.3 $^{a}$ | 115.1 $^{a}$ | 4236.7 $^{b}$ | 915.3 $^{b}$ | 3309.7 $^{a}$ | 0.2161 $^{b}$ | 20.6 $^{b}$ | 37.1 $^{b}$ | 1.8 $^{b}$ |
| 35 cm | 42.2 $^{a}$ | 115.7 $^{a}$ | 4433.1 $^{a}$ | 996.0 $^{a}$ | 3481.3 $^{a}$ | 0.2243 $^{a}$ | 24.4 $^{a}$ | 41.4 $^{a}$ | 2.1 $^{a}$ |
| HSD $_{(0.05)}$ | 0.93 | 1.42 | 155.01 | 36.41 | 173.3 | 1.674$^{E-03}$ | 2.46 | 1.67 | 0.068 |
| Foliar boron | | | | | | | | | |
| 0% | 37.9 $^{d}$ | 118.3 $^{a}$ | 4216.4 $^{b}$ | 909.6 $^{c}$ | 3236.8 $^{b}$ | 0.2153 $^{bc}$ | 22.7 $^{a}$ | 38.8 $^{b}$ | 1.9 $^{c}$ |
| 0.2% | 45.6 $^{a}$ | 113.0 $^{c}$ | 4533.7 $^{a}$ | 1054.5 $^{a}$ | 3504.8 $^{ab}$ | 0.2325 $^{a}$ | 23.5 $^{a}$ | 43.5 $^{a}$ | 2.3 $^{a}$ |
| 0.3% | 43.6 $^{b}$ | 113.0 $^{c}$ | 4467.6 $^{a}$ | 1005.0 $^{b}$ | 3536.6 $^{a}$ | 0.2253 $^{ab}$ | 22.9 $^{a}$ | 39.8 $^{b}$ | 2.0 $^{b}$ |
| 0.6% | 39.9 $^{c}$ | 117.2 $^{b}$ | 4122.0 $^{b}$ | 853.6 $^{d}$ | 3303.9 $^{ab}$ | 0.2077 $^{c}$ | 20.9 $^{b}$ | 34.9 $^{c}$ | 1.6 $^{d}$ |
| HSD $_{(0.05)}$ | 1.11 | 0.95 | 219.41 | 21.04 | 273.71 | 0.0114 | 1.68 | 2.15 | 0.11 |

**Note:** [a] PH – plant height; DF – days to flowering; BY: biological yield; GY – grain yield; SY – straw yield; HI – harvest index; PN-plt – pod number per plant; SN-plt – seed number per plant; SW-plt – seed weight per plant; HSD – honestly significant difference at $p < 0.05$ probability level using Tukey's test. Different letters within the same columns indicate significant differences.

example, foliar B applied at 0.6% significantly decreased GY and PN by 6.2% and 7.9%, respectively (Table 4).

## Interaction effects on some growth and physiological parameters

There was a significant interaction effect between Rs and foliar B treatments on BY and GY of lentil (Figure 1). Foliar B at 0.2% had significantly increased BY of lentil by 9.2% at Rs 35 cm, and 5.8% at Rs 17.5 cm. Foliar B at 0.3% had only significantly 7.5% higher BY at Rs 35 cm. However, foliar B at 0.6% had only significantly decreased BY at Rs 35 cm by 6.4% (Figure 1A). Foliar B at 0.2% and 0.3% had significantly increased GY at Rs 35 cm (17.5% and 11.2%, respectively) and at Rs 17.5 cm (14.2% and 9.7%, respectively). Conversely, foliar B at 0.6% had significantly decreased GY by 8.5% and 3.6% at Rs 35 cm and 17.5 cm, respectively (Figure 1B). There was a significant interaction effect between location and foliar B treatments on some growth and physiological parameters of lentil (Figure 2). Foliar B at 0.2% and 0.3% had significantly shortened DF at both experimental locations. However, foliar B at 0.6% had significantly reduced DF in Maru, but not in Mushaqar (Figure

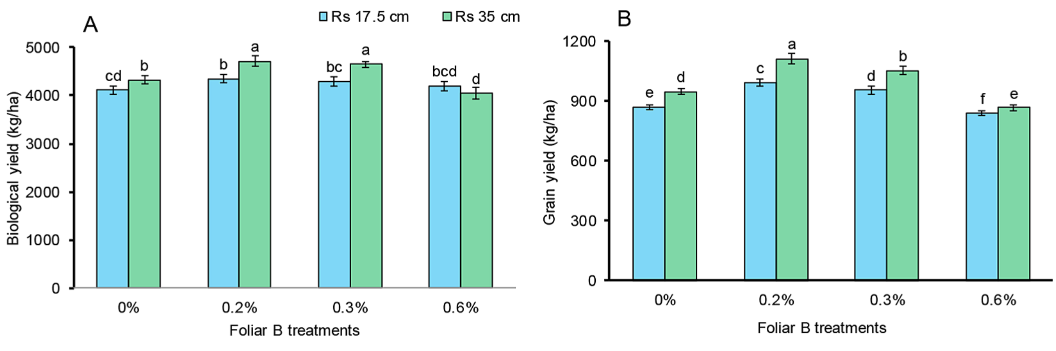


**Figure 1.** Row spacing (Rs) x foliar boron treatments interaction effect on (A) biological yield and (B) grain yield for lentil grown in both locations. Means followed by the same letters are not significantly different at P value of 0.05%. Error bars show standard errors, n = 3

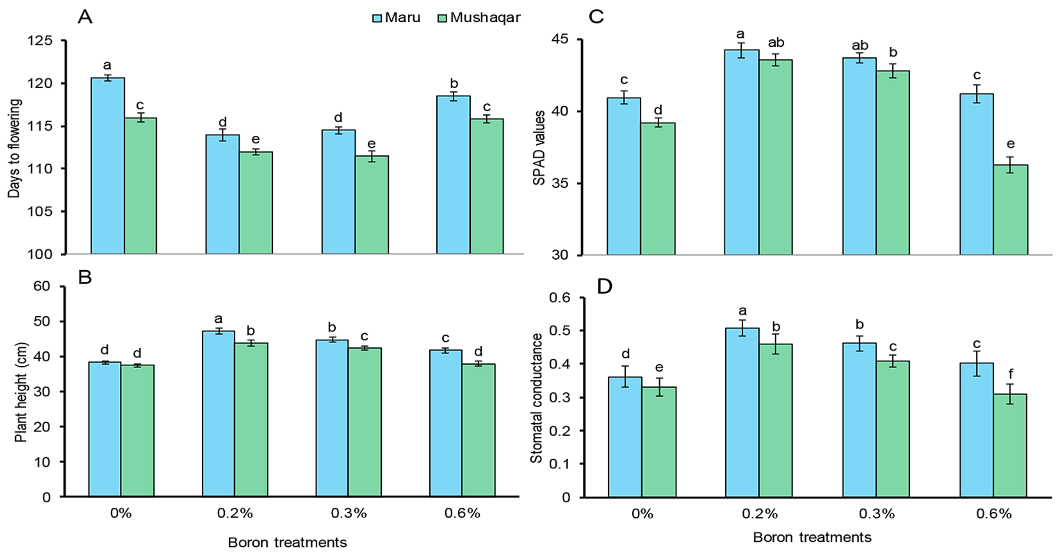


**Figure 2.** Location x foliar boron treatments interaction effect on (A) days to flowering (B) plant height (C) total chlorophyll content by SPAD and (D) stomatal conductance for lentil grown under both row spacing. Means followed by the same letters are not significantly different at P value of 0.05%. Error bars show standard errors, n = 3

2A). Moreover, foliar B at 0.2% and 0.3% had significantly increased PH in Mushaqar location by 16.9% and 13.1%, respectively, and in Maru location by 23.4% and 16.7%, respectively. However, foliar B at 0.6% had significantly increased PH in the Maru location but not in the Mushaqar location (Figure 2b). Similarly, foliar B at 0.2% and 0.3% had significantly increased SPAD values in Mushaqar location by 11% and 9.2%, respectively, and in Maru location by 8% and 6.7%, respectively. However, foliar B at 0.6% had no significant effect in Maru location, although it significantly reduced SPAD values in Mushaqar location by 7.6% (Figure 2c). Foliar B at 0.2% and 0.3% had significantly increased $g_s$ in Mushaqar location by 39.4% and 23.7%, respectively, and in Maru location by 40.5% and 27.6%, respectively. However, foliar B at 0.6% had significantly increased $g_s$ in Maru location by 11% and decreased in Mushaqar location by 6% (Figure 2d). There was a significant interaction effect between location and Rs on PH of lentil (Figure 3). Rs 35 cm had significantly increased PH by 5.7% in the Mushaqar location when compared with Rs 17.5 cm. However, Rs had no significant effect on PH in the Maru location (Figure 3).

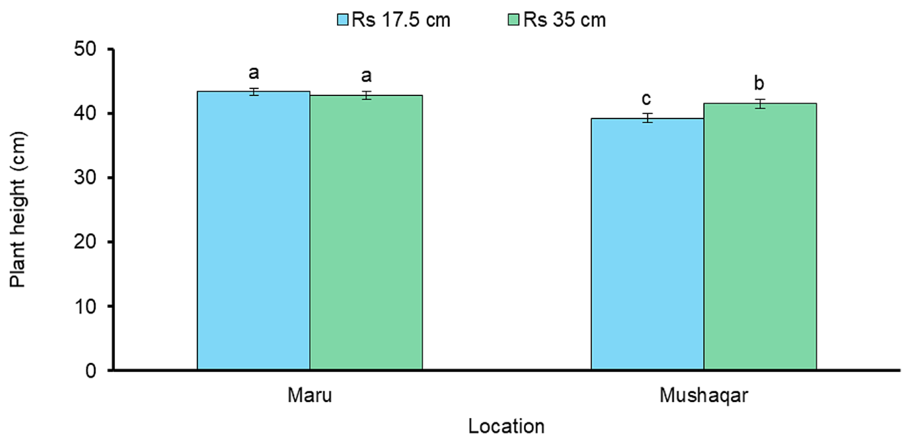


**Figure 3.** Location x row spacing (Rs) interaction effect on plant height for lentil grown under different foliar boron treatments. Means followed by the same letters are not significantly different at P value of 0.05%. Error bars show standard errors, n = 3

### Effects on crude protein content (PC) of lentil

Mushaqar had significantly 9% higher PC than Maru location (Figure 4). However, Rs had no significant effect on protein content. Foliar B at 0.2% and 0.3% had significantly increased PC by 11.2% and 7.2%, respectively. However, foliar B at 0.6% had significantly decreased PC by 1.6% (Figure 4). There was a significant interaction effect between location and foliar B treatments on PC (Figure 5). Foliar B at 0.2% and 0.3% had significantly increased PC in Mushaqar location by 16% and 10%, respectively, and in Maru location by 6% and 4%, respectively. However, foliar B at 0.6% had significantly decreased PC only in the Maru location (Figure 5).

## DISCUSSION

Effects of foliar boron (B) applications were determined under different row spacing (Rs) on the physiology, growth, yield, and protein contents of lentils at two locations. In this study, foliar

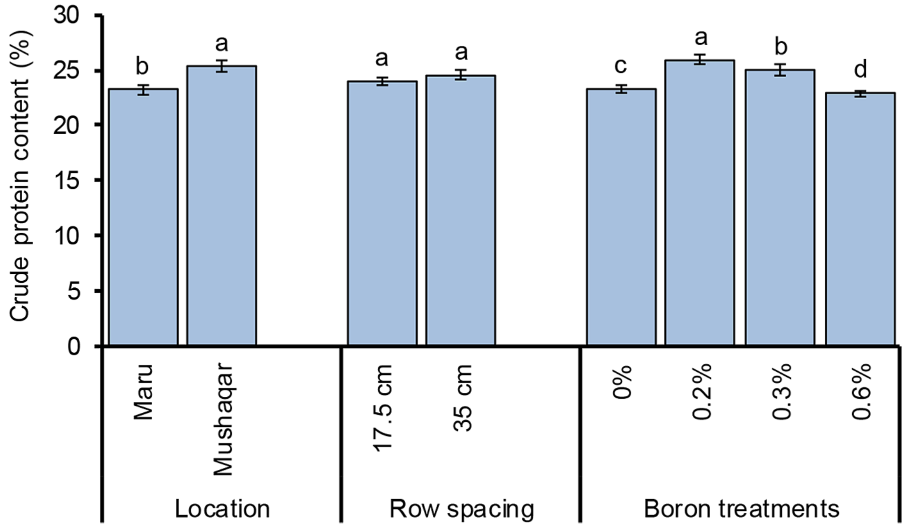


**Figure 4.** Main effect of location, row spacing, and foliar boron treatments on crude protein content of lentil. Means followed by the same letters are not significantly different at P value of 0.05%. Error bars show standard errors, n = 3

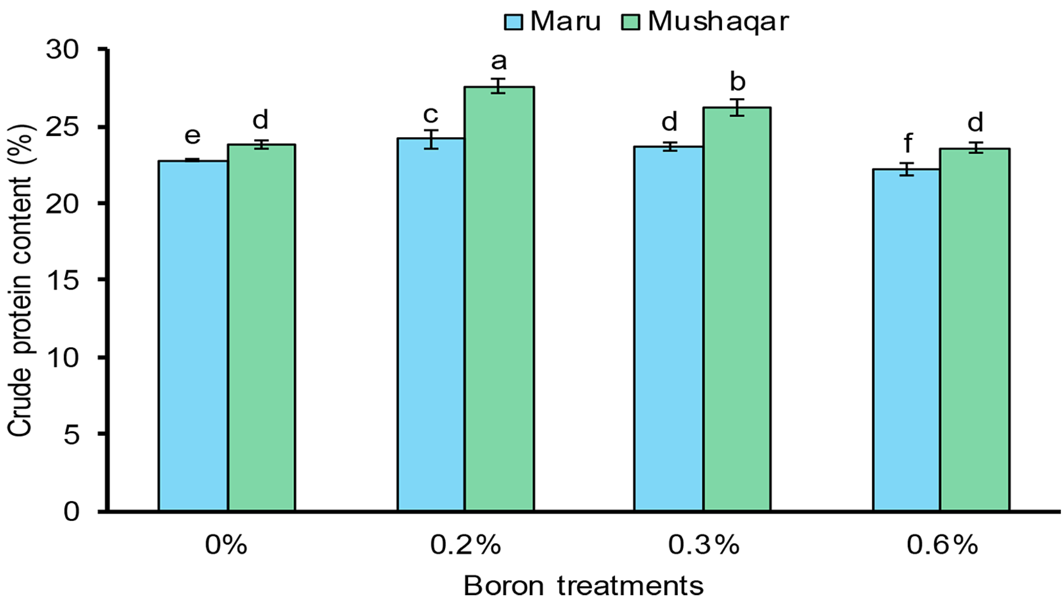


**Figure 5.** Location x foliar boron treatments interaction effect on crude protein content of lentil. Means followed by the same letters are not significantly different at P value of 0.05%. Error bars show standard errors, n = 3

B applications at certain concentrations have a positive impact on GY, which may be explained due to higher requirements for B at the flowering stage. However, increasing foliar B concentration beyond the optimum level had a negative (toxic) impact on growth and yield. There were no differences between Maru location and Mushaqar location in terms of physiological responses of lentils under different Rs and foliar B treatments except for transpiration rate (E), where Maru had a higher E than Mushaqar. Higher rainfall in Maru may explain this difference. Mushaqar is representative of dry areas of the Madaba region (the west-central part of Jordan) where drought stresses are frequent, whereas Maru is representative of more favorable areas of the Irbid region (northwestern Jordan). Harvest index and 1000-seed weight (TSW) did not differ significantly between locations, indicating that these characters were affected by crop management rather than the environment. However, GY was greater in Maru than in Mushaqar.

Row spacing had a direct effect on physiological parameters, yield attributes, and the yield of lentils. Row spacing at 35 cm had considerably improved all measured physiological parameters when compared with those at 17.5 cm. It could be due to optimal plant coverage in the field, which enabled further aeration, better light interception, and higher photosynthetic activity. Our results were in agreements with the outcomes of Vyas and Khandwe (2014). Declining of the net photosynthetic rate at narrower Rs might be due to decreased composition of pigments and $g_s$. As $g_s$ increases, the diffusion of $CO_2$ into leaves increases, which ultimately advances photosynthesis. Thus, biomass and crop yield are improved (Saraswathi and Paliwal, 2011).

Row spacing at 30 cm improved the yield and yield components of lentils, as the yield was compensated by a higher plant population. However, the competition for available resources among the crops might be greater with narrower Rs, resulting in a decrease in individual performances and therefore a lower yield. Optimum Rs at 30 cm have efficiently utilized the growth resources, mainly solar radiation, as compared to narrow Rs (Singh et al., 2009; Devi et al., 2022). The increase of Rs from 17.5 to 35 cm increased pod and seed numbers per plant. This increase might be due to a higher branching in wider Rs. These results were in agreement with earlier studies by Idris (2008) and Ouji et al. (2016) who found that increasing grain yield was due to a greater number of pods per plant. The seed number per plant is widely correlated with the number of pods per plant. Therefore, these traits are considered important yield attributes. In this study, the shorter plant height at narrow Rs (Figure 3) may have been due to the relatively lower soil moisture in the Mushaqar location, in turn limiting nutrient accumulation and photosynthesis. Similar results were obtained by Bernhard and Below (2020).

Boron has a direct role for many of physiological and biochemical processes during the crop growth. It can optimize the synthesis of proteins, improving activity of photosynthesis and enhancing stomatal opening (Stavrianakou et al., 2006). However, increasing levels of B cause a decrease in physiological and growth parameters (Choudhary et al., 2020). Physiological, growth, and yield parameters of lentils were maximally improved at 0.2% foliar B when compared to control. However, 0.6% foliar B significantly reduced SPAD values, grain yield, and yield components. Wasaya et al. (2017) indicated that the chlorophyll content and grain yield were increased after B application. However, Flores et al. (2017) showed that B application had no effects in chlorophyll content of common beans. High levels of B decreased chlorophyll contents of wheat crop (Catav et al., 2018). Excess B application may increase B concentrations in the cytoplasm, leading to the high development of $NAD^+$ complexes, which affects photosynthesis (Brdar-Jokanović, 2020). In this study, high levels of B application (0.6%) reduced total chlorophyll content and stomatal conductance only at the Mushaqar location. Thus, lentils at the Maru location showed a greater physiological tolerance to a high level of boron.

This study showed that the grain yield of lentils was almost twice as improved as the straw yield when foliar B was applied at 0.2%. A higher increase in GY than SY with foliar B might be due to the significant role of B in seed formation (Khurana and Arora, 2012). However, the grain yield of lentils was reduced at 0.6% foliar B, but not for straw yield. This decrease in grain yield at a high level of B may be associated with significant reductions in pod number, seed number, and seed weight. For both experimental locations, biological yield and grain yield were improved at Rs 35 cm when foliar B was applied at either 0.2% or 0.3%, while they were reduced at the high level of B treatment. Moreover, biological yield was only increased at Rs 17.5 cm when foliar B was applied at 0.2%, while grain yield was increased at both 0.2% and 0.3% foliar B (Figure 1). Therefore, this study showed the superiority of 0.2% foliar B for improving yields at different Rs, while 0.6% foliar B acts as a toxic level. In this study, 0.2% and 0.3% foliar B had positively affected 1000 – seed weight could be due to a higher utilization of starch, resulting in improved grain set, which increases size of the grain (Oktem, 2022). The greatest plant height during this study was achieved when foliar B was applied at optimal levels. Similar results were achieved by Dixit and Elamathi (2007) and Praveena et al. (2018). Furthermore, all foliar B treatments reduced DF when compared with controls. Similar results were informed by Reza et al. (2023) on the mungbean crop.

In this study, Mushaqar had significantly higher grain protein contents (PC) than Maru. It could be related to climatic factors, since rainfall was lower than in Maru. Similarly, Oktem and Oktem (2019) reported that the PC of the grains improved as drought increased. However, PC was unaffected by Rs. A similar finding was obtained by Jafroudi et al. (2007) in common beans. Furthermore, the PC of the lentil crop increased at optimal levels of foliar B application. The increase in PC with B application might be attributed to an increase in the activity of enzymes involved in the protein synthesis of legumes (Singh et al., 2015; Kulhary et al., 2017). Foliar B application improves PC of grains due to the substantial impact of B on enzymes, which are responsible alteration of assimilation into grains (Rehman et al., 2019). However, 0.6% foliar B application had a negative impact on PC. The highest level of B could not improve the PC in the lentil crop, which may be due to poor grain yield (Singh et al., 2015).

## CONCLUSION

Grain yield of lentil was significantly higher in Maru location than Mushaqar location due to the more favorable water conditions. However, the protein content was significantly higher in Mushaqar location, which suggests that increasing water stress can increase protein content in lentils as a way to adapt to the stress, rather than allocating resources to produce more grains. Foliar boron application at low levels ameliorated the growth, physiology, grain yield, and quality of lentils in the semiarid region of Jordan. The highest grain yield was obtained by row spacing of 35 cm when combined with 0.2% foliar boron, while the lowest grain yield was obtained by row spacing of 17.5 cm combined with 0.6% foliar boron, which is considered a toxic level for the crop. By considering these findings, farmers and crop managers can optimize their lentil production by adjusting row spacing and foliar boron application rates to achieve optimal yields while avoiding toxicity issues.

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