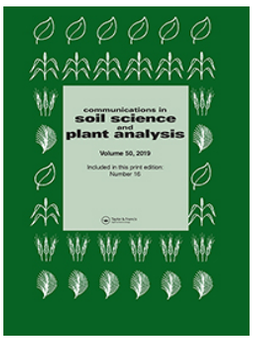

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Communications in Soil Science and Plant Analysis

ISSN: 0010-3624 (Print) 1532-2416 (Online) Journal homepage: https://www.tandfonline.com/loi/lcss20

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To cite this article: Erman Beyzi, Adem Güneş, Mehmet Arslan & Aziz Şatana (2019) Effects of Foliar Boron Treatments on Yield and Yield Components of Fenugreek (*Trigonella foenum graecum* L.): Detection by PCA Analysis, Communications in Soil Science and Plant Analysis, 50:16, 2023-2032, DOI: 10.1080/00103624.2019.1648661

To link to this article: https://doi.org/10.1080/00103624.2019.1648661

COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
2019, VOL. 50, NO. 16, 2023–2032
https://doi.org/10.1080/00103624.2019.1648661

Effects of Foliar Boron Treatments on Yield and Yield Components of Fenugreek (*Trigonella foenum graecum* L.): Detection by PCA Analysis

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ABSTRACT

In this study, effects of foliar boron treatments on yield and yield components of fenugreek plants were assessed with the aid of principal component analysis (PCA) analysis. Experiments were conducted over the experimental fields of Erciyes University Agricultural Research and Implementation Center during the summer growing seasons of the years 2017 and 2018. Gürarslan fenugreek variety was used as the plant material of the experiments. Four different foliar boron (H_3BO_3) doses (control, 100, 200, 400, and 800 mg lt^{-1}) were applied to fenugreek plants. Plant height, number of branches per plant, number of pods per plant, number of seeds per pod, pod length, the first pod height, thousand-seed weight, biological yield, seed yield, and harvest index were measured. Variance analysis revealed that only the seed yield of 2017 was significant ($p < .05$) and the other parameters were not found to be significant ($p > .05$). PCA analysis was performed to classify and characterize boron doses based on yield and yield components of fenugreek plants. PC1 and PC2 explained about 82% in total variation in 2017 and about 83% in 2018. In both years of the experiments, the greatest biological and seed yields were obtained from 800 mg lt^{-1} boron treatments. Therefore, 800 mg B lt^{-1} was recommended to get high seed yield from fenugreek plants.

ARTICLE HISTORY
Received 14 May 2019
Accepted 23 July 2019

KEYWORDS
Boron treatment; fenugreek; principal component analysis (PCA); plant height; seed yield; thousand seed weight; trigonella foenum graecum

Introduction

Fabaceae are economically valuable family of flowering plants, including soybean (*Glycine max*), chickpea (*Cicer arietinum*), pea (*Pisum sativum*), alfalfa (*Medicago sativa*), trefoil (*Onobrychis sativa*), and peanut (*Arachis hypogaea*) (Rahman and Parvin 2014). Fenugreek with a widespread use is also included in this family. Fenugreek is a herbaceous annual medicinal and aromatic plant (Dar and Uddin 2018).

Fenugreek is used for various purposes. Protein-rich seeds are used as spice, leaves are used as vegetable (Grower, Yadav, and Vats 2002; Kumar and Chopra 2012). Fenugreek plants are also used as forage crop (Acharya, Thomas, and Basu 2006) or as medicinal plant (Er and Yıldız 1997). Pharmacologically, fenugreek plants have anti-flatulent, expectorant, anti-carcinogenic, antiviral, and antioxidant effects (Ahmad et al. 2016; Moradi Kor and Moradi 2013).

Boron significantly influences yield, growth, and development of cultural plants (Güneş et al. 2017). Boron also plays a significant role in nodule development of leguminous plants (Bolanos, Brewin, and Bonilla 1996). Seed production of plants is significantly influenced by

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boron deficiency (Güneş et al. 2017). Seed formation is greatly hindered by boron deficiency (Dell and Huang 1997).

It was reported in previous studies that boron treatments had significant effects on yield of onion (Acharya et al. 2015; Manna and Maity 2016), garlic (Nasreen et al. 2009), peanut (El-Kader and Mona 2013), tobacco (Tariq et al. 2010), sunflower (Ceyhan et al. 2008; Öztürk et al. 2010), and several edible legumes such as bean (Harmankaya et al. 2008) and chickpea (Ceyhan et al. 2007) as well.

The main use of principal component analysis (PCA) is to convert the original variables into new axes called orthogonal main components (Silici and Karaman 2014; Smith 1991). PCA analysis was performed to classify and characterize boron doses based on yield and yield components of fenugreek plants. Although there are some studies about the effects of boron treatments on yield of leguminous crops, number of studies on fenugreek is quite limited. Therefore, this study was conducted to investigate the effects of boron treatments on yield and yield components of fenugreek with the aid of PCA.

Materials and methods

Material

Gürarslan fenugreek variety registered by Ankara University Agricultural Faculty Field Crops Department was used as the plant material of the present study.

Field experiments

Experiments were conducted over the experimental fields of Erciyes University Agricultural Research and Implementation Center (38°42′ 57″ N, 35°32′ 52″ E; 1083 m) during the summer growing seasons of the years 2017 and 2018. Sowing was performed on 27.03.2017 in the first year and on 20.03.2018 in the second year. Experiments were conducted in "randomized blocks design" with four replications. Each plot had 3-m-long five rows with 30 cm spacing. Each plot had a size of 4.5 m^2.

According to the literature study, optimum boron application dose was determined as 200 mg lt^{-1} in fenugreek plant (Kumar et al. 2010). Therefore, in this study, four different boron (H_3BO_3) doses (control, 100, 200, 400, and 800 mg lt^{-1}) were applied to fenugreek plants. Base fertilizers were applied at sowing and dressing fertilizers were applied after plant emergence as to have 5 kg da^{-1} N and 5 kg da^{-1} P_2O_5. Hand weeding was performed with the emergence of the plants. Irrigations were performed to prevent drought effects. Climate parameters of the research site are provided in Table 1 and soil characteristics are provided in Table 2. The pH of the soil used in the experiment was slightly alkaline. Lime content of soil was limy (FAO 1990). Organic matter of soil were very low, available phosphorus levels were low and low salt contents (Table 2).

Table 1. Climate parameters of the research site (years 2017 and 2018).

	T (°C)		P (mm)		RH (%)	
Months	2017	2018	2017	2018	2017	2018
March	6.9	10.0	47.7	93.5	60.4	61.2
April	10.9	12.7	24.7	18.5	52.9	51.7
May	14.8	16.7	56.9	45.9	58.9	61.2
June	19.8	20.4	55.1	58.2	54.8	56.7
July	24.4	24.1	np	0.3	38.4	45.0

np, no precipitation; T, average monthly temperature; P, total monthly precipitation; RH, average monthly relative humidity

Table 2. Soil properties of the research site.

Texture	Clay-loam
pH	7.72
Organic matter (%)	0.87
Lime (%)	3.24
P_2O_5 (kg da^{-1})	2.56
EC (mmhos)	0.21

Boron treatments

Specified foliar boron doses were applied in liquid forms in two equal aliquots just before flowering period on 11.05.2017 and 15.05.2017 in the first year and on 08.05.2018 and 14.05.2018 in the second year.

Harvest

Manual harvests were performed on 17 July 2017 in the first year and on 11 July 2018 in the second year. Side rows were omitted as to consider side effects and harvest was performed from three inner rows (2.7 m^2).

Following the harvest, plant height, number of branches per plant, number of pods per plant, number of seeds per pod, pod length and the first pod heights were measured over 10 plants randomly selected from each plot. When determining the number of branches, the side branches connected to the main stem were measured. For thousand-seed weight, 4 × 100 seed groups were taken from the seeds of each plot, they were weighed and averaged, then the average value was multiplied by 10 to get 1000-seed weight. Biological yield was determined through weighing all plants of each plot and seed yield was determined through weighing the seeds of all plants of a plot. Harvest index was calculated as (seed yield/biological yield) × 100.

Statistical analysis

Experimental data were subjected to analysis of variance in accordance with "randomized blocks design" separately for each year with the aid of MSTAT-C statistical software. Means were compared with the aid of Duncan's multiple range test (Düzgüneş et al. 1987). PCA was performed with the aid of XLSTAT software statistical and data analysis solution (Boston, MA, USA, https://www.xlstat.com) (Addinsoft 2019).

Results and discussion

Experimental data were subjected to variance analysis separately for each year. Only the seed yield was found to be significant ($p < .05$) in 2017 and the other investigated parameters were not found to be significant ($p > .05$). Mean values for investigated parameters are provided in Table 3.

Plant height

Plant heights were not found to be significant in both years ($p > .05$) (Table 3). Plant heights varied between 53.65 and 58.18 cm in 2017 and between 64.79 and 71.25 cm in 2018. The greatest plant height (58.18 cm) was obtained from 800 mg lt^{-1} boron treatment in 2017 and from 200 mg lt^{-1} boron treatments (71.25 cm) in 2018. As compared to the control treatments, plant heights increased with boron treatments in 2018. Pariari, Khan, and Imam (2009) indicated increasing plant heights with increasing boron doses and reported plant heights as between 50.25 and 65.75 cm. The present findings were similar with the results of

Table 3. Effects of boron treatments on agronomic traits of fenugreek.

Boron doses (mg lt^{-1})	PH		NB		NP		FPH		NS	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
0	54.03	64.79	2.35	4.53	6.33	11.03	28.36	29.11	11.83	11.34
100	57.66	67.84	3.00	4.15	8.10	11.13	27.99	29.76	12.14	11.19
200	53.65	71.25	2.38	4.40	7.18	10.25	27.46	34.04	11.72	11.11
400	54.60	70.64	2.43	4.60	7.58	10.00	27.93	33.33	11.66	10.04
800	58.18	65.95	2.63	4.58	8.63	9.93	29.29	29.63	12.74	10.98
CV (%)	7.58	9.28	18.75	5.53	14.03	23.31	8.25	11.89	8.30	9.58
Boron doses (mg lt^{-1})	**PL**		**TSW**		**BY**		**SY**		**HI**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
0	12.95	13.49	14.03	18.21	492.84	1076.30	126.48b	251.83	25.73	23.34
100	13.10	13.14	14.29	17.54	557.28	1037.90	136.88b	217.62	24.55	21.05
200	12.98	13.23	13.26	16.48	563.21	1084.32	135.51b	250.62	24.08	23.21
400	12.81	13.02	14.04	17.70	586.48	1045.37	143.29ab	251.30	24.50	24.15
800	13.23	13.59	13.70	18.57	690.37	1138.15	159.88a	259.07	23.93	22.88
CV (%)	4.63	5.95	8.42	6.98	16.60	11.35	9.45	12.12	9.02	8.41

PH, plant height; NB, number of branches per plant; NP, number of pods per plant; FPH, first pod height; NS, number of seeds per pod; PL, pod length; TSW, thousand-seed weight; BY, biological yield; SY, seed yield; HI, harvest index; CV, coefficient of variation; LSD (Boron-2017): 20.44; small letters show different groups at 5% level.

Pariari, Khan, and Imam (2009). Previous researchers also reported increasing plant heights with boron treatments as compared to control treatments without boron in chickpea (Ceyhan et al. 2007), sunflower (Ceyhan et al. 2008), common bean (Harmankaya et al. 2008), soybean (Adkine et al. 2011), cotton (Rahman et al. 2019), garlic (Nasreen et al. 2009), and onion (Manna and Maity 2016). In the previous studies, Ceyhan et al. (2007) reported the plant heights of chickpea as between 35.7 and 37.9 cm; Ceyhan et al. (2008) indicated the plant heights of sunflower as between 115.3 and 120.6 cm; Harmankaya et al. (2008) reported the average plant height of common bean as 66.4 cm; Adkine et al. (2011) indicated the average plant height of soybean as 38.87 cm; Rahman et al. (2019) reported the plant heights of cotton as between 83.17 and 85.08 cm; Nasreen et al. (2009) indicated the average plant heights of garlic as 62.3 cm in the first year and 60.8 cm in the second year and Manna and Maity (2016) reported the plant heights of onion as between 53.50 and 63.93 cm.

Number of branches per plant

According to variance analysis, number of branches per plant was not found to be significant in both years ($p > .05$). Number of branches per plant varied between 2.35–3.00 branches plant^{-1} in 2017 and between 4.15–4.60 branches plant^{-1} in 2018. The greatest number of branches per plant was obtained from 100 mg lt^{-1} boron treatment (3.00 branches plant^{-1}) in 2017 and from 400 mg lt^{-1} boron treatment (4.60 branches plant^{-1}) in 2018. As compared to control treatments, an increasing number of branches per plant were reported with boron treatments in soybean (Adkine et al. 2011) and in fenugreek plants (Pariari, Khan, and Imam 2009). In previous studies, Adkine et al. (2011) reported the average number of branches plant^{-1} of soybean as 12.43 and Pariari, Khan, and Imam (2009) indicated the number of primary branches of fenugreek as between 6.50 and 8.50.

Number of pods per plant

Number of pods per plant was not found to be significant in both years ($p > .05$). Number of pods per plant varied between 6.33–8.63 in 2017 and between 9.93–11.13 in 2018. The greatest number of pods per plant was obtained from 800 mg lt^{-1} boron treatments (8.63 pods plant^{-1}) in 2017 and from 100 mg lt^{-1} boron treatments (11.13 pods plant^{-1}) in 2018 (Table 3). As compared to the control treatments, number of pods per plant increased with all

boron doses in 2017, but number of pods per plant was lower in all boron doses (except for 100 mg lt^{-1} boron treatment) than the control treatments in 2018. Again as compared to the control treatments, increasing number of pods per plant was reported with boron treatments in chickpea (Ceyhan et al. 2007), common bean (Harmankaya et al. 2008), peanut (El-Kader and Mona 2013), fenugreek (Pariari, Khan, and Imam 2009) and soybean (Adkine et al. 2011). In previous studies, Ceyhan et al. (2007) reported the pods per plant of chickpea as between 28.1 and 29.5 number; Harmankaya et al. (2008) reported the average pods per plant of common bean as 22.7 number; Pariari, Khan, and Imam (2009) indicated the number of pods per plant of fenugreek as between 27.30 and 33.10; Adkine et al. (2011) reported the average number of pods $plant^{-1}$ of soybean as 62.67 and El-Kader and Mona (2013) reported the average number of pods $plant^{-1}$ of peanut as 40.

The first pod height

Variance analysis revealed that the first pod heights were not significant ($p > .05$) in both years (Table 3). The first pod heights varied between 27.46–29.29 cm in 2017 and between 29.11–34.04 cm in 2018. The greatest first pod height was obtained from 800 mg lt^{-1} boron treatments (29.29 cm) in 2017 and from 200 mg lt^{-1} boron treatments (34.04 cm) in 2018. In previous study, Cirak et al. (2006) reported the first pod heights of soybean as between 16.03 and 20.37 cm.

Number of seeds per pod

According to variance analysis, number of seeds per pod was not also found to be significant in both years ($p > .05$). Number of seeds per pod varied between 11.66–12.74 in 2017 and between 10.04–11.34 in 2018. The greatest number of seeds per pod was obtained from 800 mg lt^{-1} boron treatments (12.74 seeds pod^{-1}) in 2017 and from the control treatment (11.34 seeds pod^{-1}) in 2018 (Table 3). In a previous study, Pariari, Khan, and Imam (2009) reported the number of seeds per pod as between 11.90 and 14.50 seeds pod^{-1}.

Pod length

According to variance analysis, pod lengths were not found to be significant in both years ($p > .05$). Pod lengths varied between 12.81–13.23 cm in 2017 and between 13.02–13.59 cm in 2018. The greatest pod lengths were obtained from 800 mg lt^{-1} boron treatments in both years (13.23 cm in 2017 and 13.59 cm in 2018) (Table 3). Tania, Uddin, and Sarkar (2019) indicated that boron treatments increased pod length of mungbean as compared to the control treatments. In previous study, Tania, Uddin, and Sarkar (2019) reported the pod lengths of mungbean as between 6.99 and 7.86 cm.

Thousand-seed weight

According to variance analysis, thousand-seed weights also were not found to be significant in both years ($p > .05$). Thousand-seed weights varied between 13.26–14.29 g in 2017 and between 16.48–18.57 g in 2018. The greatest thousand-seed weight was obtained from 100 mg lt^{-1} boron treatments (14.29 g) in 2017 and from 800 mg lt^{-1} boron treatments (18.57 g) in 2018. El-Kader and Mona (2013) indicated that boron treatments increased thousand-seed weight of peanut as compared to the control treatments. In previous study, El-Kader and Mona (2013) reported the average hundred-seed weight of peanut as 79.51 g.

Biological yield

According to variance analysis, biological yields were not found to be significant in both years ($p > .05$). Biological yields varied between 492.84–690.37 kg da^{-1} in 2017 and between 1037.90–1138.15 kg da^{-1} in 2018. The greatest biological yields were obtained from 800 mg lt^{-1} boron treatments in both years (690.37 kg da^{-1} in 2017 and 1138.15 kg da^{-1} in 2018). Maqbool et al. (2018) indicated that boron treatments increased biological yield of mungbean as compared to the control treatments. In previous study, Maqbool et al. (2018) reported the biological yields of mungbean as between 6256.11–6863.67 kg ha^{-1} in the first year and 6196.79–6826.77 kg ha^{-1} in the second year.

Seed yield

Seed yields were found to be significant in 2017 ($p < .05$; $p = .0405$) and insignificant in 2018 ($p > .05$) (Table 3). Seed yields varied between 126.48–159.88 kg da^{-1} in 2017 and between 217.62–259.07 kg da^{-1} in 2018. The greatest seed yields were obtained from 800 mg lt^{-1} boron treatments in both years (159.88 kg da^{-1} in 2017 and 259.07 kg da^{-1} in 2018). As compared to the control treatments, increasing seed yields were reported with boron treatments in chickpea (Ceyhan et al. 2007), sunflower (Ceyhan et al. 2008), common bean (Harmankaya et al. 2008), fenugreek (Pariari, Khan, and Imam 2009), peanut (El-Kader and Mona 2013), and cotton (Rahman et al. 2019). In the previous study, Ceyhan et al. (2007) reported the grain yields of chickpea as between 1258.3 and 1510.9 kg ha^{-1}; Ceyhan et al. (2008) indicated the grain yields of sunflower as between 3.10 and 3.29 t ha^{-1}; Harmankaya et al. (2008) reported the average seed yield of common bean as 4063.7 kg ha^{-1}; El-Kader and Mona (2013) reported the average seed yield of peanut as 1176 kg fed^{-1}, Rahman et al. (2019) reported the seed yields of cotton as between 0.56 and 0.69 t ha^{-1}. There were differences in the biological and seed yields of both years. Such differences were mostly attributed to precipitations, temperatures and soil characteristics.

Harvest index

Variance analysis revealed that harvest index was not significant in both years ($p > .05$) (Table 3). Harvest index values varied between 23.93–25.73% in 2017 and between 21.05–24.15% in 2018. The greatest harvest index was obtained from the control treatment (25.73%) in 2017 and from 400 mg lt^{-1} boron treatments (24.15%) in 2018. Except for 400 mg lt^{-1} boron treatment of 2018, harvest index values of all boron treatments were lower than the values of control treatments. Tania, Uddin, and Sarkar (2019) indicated that boron treatments increased harvest index of mungbean as compared to the control treatments. In previous study, Tania, Uddin, and Sarkar (2019) reported the harvest indexes of mungbean as between % 26.46–40.21.

Table 4. Eigenvalues and percentage of variance for investigated parameters of PCA analysis.

	PC1		PC2		PC3		PC4	
	2017	2018	2017	2018	2017	2018	2017	2018
Eigenvalue	6.162	4.195	2.036	4.063	1.144	1.145	0.659	0.597
Variability (%)	61.616	41.949	20.358	40.634	11.437	11.446	6.589	5.971
Cumulative %	61.616	41.949	81.974	82.584	93.411	94.029	100.000	100.000

Table 5. Factor loadings for investigated parameters of PCA analysis.

	PC1		PC2		PC3		PC4	
	2017	2018	2017	2018	2017	2018	2017	2018
PH	**0.917**	0.587	0.388	**−0.772**	−0.084	−0.219	0.024	−0.105
NB	0.587	**0.742**	**0.613**	0.614	−0.500	0.216	0.173	0.161
NP	**0.937**	**−0.865**	−0.029	−0.210	−0.317	0.139	−0.147	0.434
FPH	**0.710**	**0.756**	0.162	−0.591	0.673	−0.274	−0.128	0.062
NS	**0.934**	**−0.761**	0.125	0.260	0.291	−0.540	0.163	0.249
PL	**0.839**	−0.242	0.134	**0.926**	0.161	−0.287	0.502	0.039
TSW	0.004	−0.183	**0.910**	**0.789**	−0.085	0.552	−0.405	−0.196
BY	**0.891**	0.177	−0.395	**0.815**	0.031	−0.483	−0.224	−0.268
SY	**0.889**	**0.719**	−0.329	0.650	0.064	−0.160	−0.312	0.187
HI	**−0.659**	**0.872**	0.596	0.249	0.458	0.134	−0.016	0.399

PH, plant height; NB, number of branches per plant; NP, number of pods per plant; FPH, first pod height; NS, number of seeds per pod; PL, pod length; TSW, thousand-seed weight; BY, biological yield; SY, seed yield; HI, harvest index

Principal component analysis (PCA)

Eigenvalues and variance percentages of PCA analysis are provided in Table 4 and factor loadings are provided Table 5. Larrigaudiere et al. (2004) indicated that variance explanation ratios over 70% were sufficient in PCA analysis. PC1 and PC2 explained 81.97% of total variation in 2017 and 82.58% in 2018. In 2017, PC1 explained 61.61% and PC2 explained 20.35% of total variation. In 2018, PC1 explained 41.94% and PC2 explained 40.63% of total variation. According to Kaiser rules, eigenvalues of greater than 1.0 are accepted as the descriptor of the variance in a data set (Kaiser 1960). In 2017, present eigenvalues of PC1 (6.162), PC2 (2.036) and PC3 (1.144) were greater than 1.0. The greatest eigenvalue was obtained from PC1 (6.162). In 2018, present eigenvalues of PC1 (4.195), PC2 (4.063) and PC3 (1.145) were greater than 1.0. The greatest eigenvalue was obtained from PC1 (4.195).

PC1 was found to be related to plant height, number of pods per plant, the first pod height, number of seeds per pod, pod length, biological yield, seed yield and harvest index in 2017 and was found to be related to number of branches per plant, number of pods per plant, the first pod height, number of seeds per pod, seed yield and harvest index in 2018. PC2 was found to be related to number of branches per plant and thousand-seed weight in 2017 and was found to be related to plant height, pod length, thousand-seed weight and biological yield in 2018 (Table 5).

PCA graphs for yield and yield components of the years based on boron treatments are presented in Figure 1. It can be said that especially 800 mg lt^{-1} boron application dose in 2017 and 2018 is effective on seed and biological yields of fenugreek (Figure 1).

Correlation matrix is provided in Table 6. In 2017, there were significant positive correlations between plant height and number of seeds per pod (r = 0.885), between number of seeds per pod and pod length (r = 0.929) and between biological yield and seed yield (r = 0.993) (p < .05). In 2018, there were significant positive correlations between plant height and the first pod height (r = 0.954), between number of branches per plant and seed yield (r = 0.928) and between number of branches per plant and harvest index (r = 0.893) (p < .05).

Conclusions

In this study, effects of foliar boron treatments on yield and yield components of fenugreek plants were assessed with the aid of PCA analysis. According to present PCA analysis, PC1 and PC2 explained about 82% of total variation in 2017 and about 83% in 2018. Fenugreek is mostly produced for seeds. Therefore, greater seed yields are desired in fenugreek cultivation.

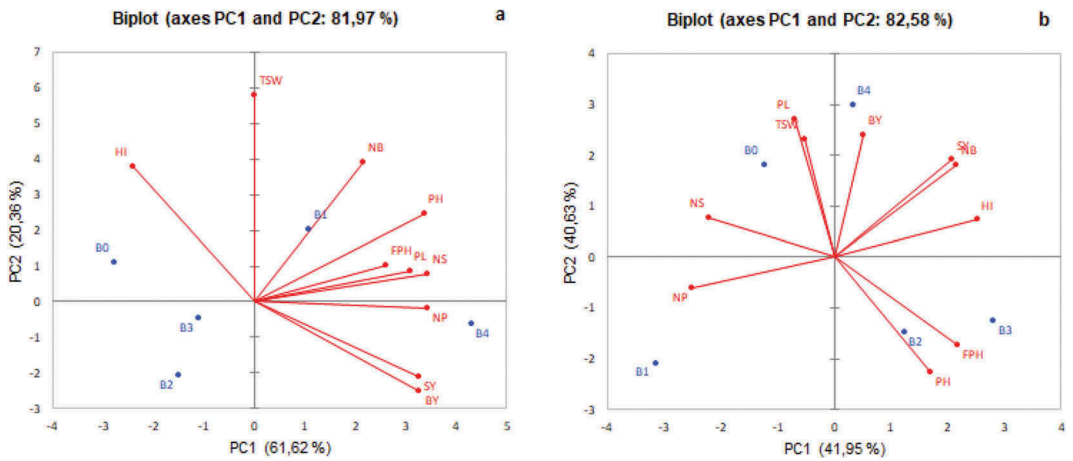

Figure 1. PCA graphs of boron treatments for yield and yield components of the years (2017 (a) and 2018 (b)).

PH, plant height; NB, number of branches per plant; NP, number of pods per plant; FPH, first pod height; NS, number of seeds per pod; PL, pod length; TSW, thousand-seed weight; BY, biological yield; SY, seed yield; HI, harvest index; BO, 0 mg lt^{-1}; B1, 100 mg lt^{-1}; B2, 200 mg lt^{-1}; B3, 400 mg lt^{-1}; B4, 800 mg lt^{-1}

Table 6. Correlation analysis for the investigated parameters according to years.

	PH	NB	NP	FPH	NS	PL	TSW	BY	SY	HI
	2017									
PH	**1**	0.823	0.871	0.655	**0.885**	0.820	0.354	0.656	0.675	−0.412
NB		**1**	0.665	0.157	0.508	0.581	0.532	0.227	0.234	−0.253
NP			**1**	0.466	0.755	0.658	0.064	0.869	0.867	−0.777
FPH				**1**	0.859	0.661	0.145	0.618	0.661	−0.060
NS					**1**	**0.929**	0.027	0.755	0.757	−0.410
PL						**1**	−0.092	0.587	0.555	−0.407
TSW							**1**	−0.268	−0.176	0.508
BY								**1**	**0.993**	−0.805
SY									**1**	−0.748
HI										**1**
	2018									
PH	**1**	−0.103	−0.422	**0.954**	−0.556	−0.798	−0.817	−0.391	−0.065	0.249
NB		**1**	−0.670	0.149	−0.481	0.334	0.437	0.484	**0.928**	**0.893**
NP			**1**	−0.542	0.637	−0.008	−0.016	−0.508	−0.699	−0.615
FPH				**1**	−0.566	−0.648	−0.768	−0.231	0.215	0.501
NS					**1**	0.589	−0.003	0.270	−0.245	−0.572
PL						**1**	0.609	0.840	0.482	−0.003
TSW							**1**	0.397	0.257	0.033
BY								**1**	0.685	0.186
SY									**1**	0.842
HI										**1**

PH, plant height; NB, number of branches per plant; NP, number of pods per plant; FPH, first pod height; NS, number of seeds per pod; PL, pod length; TSW, thousand-seed weight; BY, biological yield; SY, seed yield; HI, harvest index; * $p < 0.05$ significant in bold.

Present findings revealed that 800 mg lt^{-1} boron treatments had the greatest seed yields in both years. Since increasing yields were observed with increasing boron doses (Figure 2), an optimum dose was not identified. Therefore, further studies are recommended to be conducted utilizing greater boron doses. However, based on present findings, foliar 800 mg lt^{-1} boron treatment could be recommended to get high seed yield from fenugreek plants.

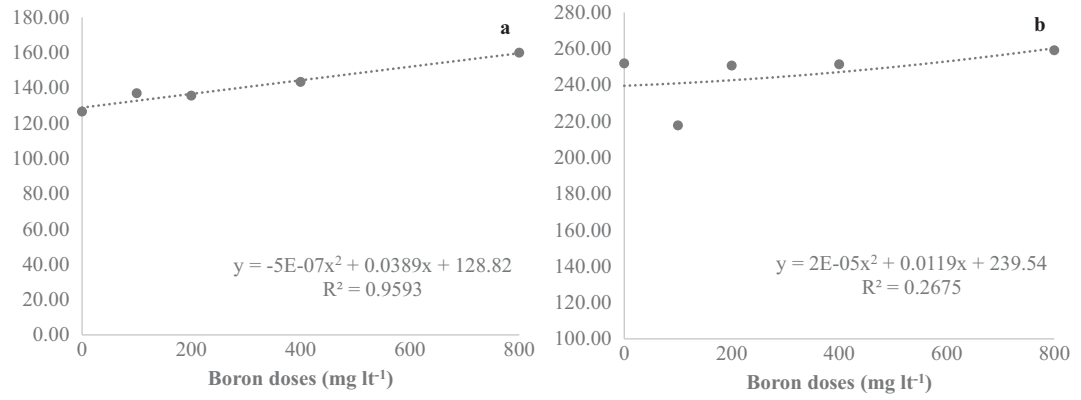

Figure 2. Regression graphs of 2017 (a) and 2018 (b) for seed yield.

Funding

This work was supported by Scientific Research Projects Department of Erciyes University [grant number FBA-2016–6998].

References

Acharya, S. N., J. E. Thomas, and S. K. Basu. 2006. Fenugreek: An "old world" crop for the "new world". *Biodiversity* 7 (3–4):27–30. doi:10.1080/14888386.2006.9712808.

Acharya, U., K. Venkatesan, T. Saraswathi, and K. S. Subramanian. 2015. Effect of zinc and boron application on growth and yield parameters of multiplier onion (*Allium cepa* L. var aggregatum Don.) var. CO (On)5. *International Journal of Research* 2 (1):757–65.

Adkine, P. M., D. D. Mankar, V. M. Khandait, V. L. Bhandare, and S. M. Nawlakhe. 2011. Effect of boron, molybdenum and potassium nitrate on growth, yield and economics of soybean. *Journal of Soils and Crops* 21 (1):116–23.

Ahmad, A., S. S. Alghamdi, K. Mahmood, and M. Afzal. 2016. Fenugreek a multipurpose crop: Potentialities and improvements. *Saudi Journal of Biological Sciences* 23:300–10. doi:10.1016/j.sjbs.2015.09.015.

Bolanos, L., N. J. Brewin, and I. Bonilla. 1996. Effects of boron on rhizobium-legume cell-surface lnteractions and nodule development. *Plant Physiology* 110:1249–56. doi:10.1104/pp.110.4.1249.

Ceyhan, E., M. Önder, M. Harmankaya, M. Hamurcu, and S. Gezgin. 2007. Response of chickpea cultivars to application of boron in boron deficient calcareous soils. *Communications in Soil Science and Plant Analysis* 38 (17):2381–99. doi:10.1080/00103620701588734.

Ceyhan, E., M. Önder, Ö. Öztürk, M. Harmankaya, M. Hamurcu, and S. Gezgin. 2008. Effects of application boron on yields yield component and oil content of sunflower in boron deficient calcareous soils. *African Journal of Biotechnology* 7 (16):2854–61.

Cirak, C., M. S. Odabas, K. Kevseroglu, E. Karaca, and A. Gulumser. 2006. Response of soybean (*Glycine max*) to soil and foliar applied boron at different rates. *Indian Journal of Agricultural Sciences* 76 (10):603–06.

Dar, T. A., and M. Uddin. 2018. Synergistic cross-talk of kinetin and phosphorus augments morpho-physiological parameters and alkaloid yield of. *Trigonella Foenum-graecum. Indian Journal of Plant Physiology* 23 (3):599–608. doi:10.1007/s40502-018-0394-4.

Dell, B., and L. Huang. 1997. Physiological Response of Plants to Low Boron. *Plant and Soil* 193:103–20. doi:10.1023/A:1004264009230.

Düzgüneş, O., T. Kesici, O. Kavuncu, and F. Gürbüz. 1987. *Araştırma ve Deneme Metotları (İstatistik Metotları II)*. 1021, Ders Kitabı: 295, Ankara (in Turkish): Ankara Üniv. Ziraat Fak. Yayınları.

El-Kader, A., and G. Mona. 2013. Effect of sulfur application and foliar spraying with zinc and boron on yield, yield components, and seed quality of peanut (*Arachis hypogaea* L.). *Research Journal of Agriculture and Biological Sciences* 9 (4):127–35.

Er, C., and M. Yıldız. 1997. *Tütün, ilaç ve baharat bitkileri*, II. Baskı (in Turkish): Ankara Üniversitesi Tarla Bitkileri Bölümü.

FAO. 1990. *Micronutrient, assesment at the country level, an intemational study*, 63. Rome: FAO Soils Bulletin.

Grower, J. K., S. Yadav, and V. Vats. 2002. Medicinal plants of India with anti-diabetic potential. *Journal of Ethnopharmacology* 81:81–100. doi:10.1016/S0378-8741(02)00059-4.

Güneş, A., S. Gezgin, K. Kalınbacak, H. Özcan, and İ. Çakmak. 2017. The Importance of boron for plants. *Journal of Boron* 2 (3):168–74.

Harmankaya, M., M. Önder, M. Hamurcu, E. Ceyhan, and S. Gezgin. 2008. Response of common bean (*Phaseolus vulgaris* L.) cultivars to foliar and soil applied boron in boron deficient calcareous soils. *African Journal of Biotechnology* 7 (18):3275–82.

Kaiser, H. F. 1960. The Application of Electronic-Computers to Factor-Analysis. *Educational and Psychological Measurement* 20 (1):141–51. doi:10.1177/001316446002000116.

Kumar, J. N. U., R. Chatterjee, P. K. Chattopadhyay, and D. K. Das. 2010. Effect of boron and zinc on growth, yield and quality of fenugreek (*Trigonella foenum-graecum* L.). *Indian Agriculturist* 54 (1/2):71–75.

Kumar, V., and A. K. Chopra. 2012. Fertigation effect of distillery effluent on agronomical practices of *Trigonella foenum-graecum* L. (Fenugreek). *Environmental Monitoring and Assessment* 184 (3):1207–19. doi:10.1007/s10661-011-2033-7.

Larrigaudiere, C., I. Lentheric, J. Puy, and E. Pinto. 2004. Biochemical characterisation of core browning and brown heart disorder in pear by multivariate analysis. *Postharvest Biology and Technology* 31 (1):29–39. doi:10.1016/S0925-5214(03)00132-7.

Manna, D., and T. K. Maity. 2016. Growth, yield and bulb quality of onion (*Allium cepa* L.) in response to foliar application of boron and zinc. *Journal of Plant Nutrition* 39 (3):438–41. doi:10.1080/01904167.2015.1109099.

Maqbool, R., W. Ali, M. A. Nadeem, and T. Abbas. 2018. Boron application in clay-loam soil for improved growth, yield and protein contents of Mungbean in water-stresses. *Sains Malaysiana* 47 (1):51–58. doi:10.17576/jsm.

Moradi Kor, N., and K. Moradi. 2013. Physiological and pharmaceutical effects of fenugreek (*Trigonella foenum-graecum* L.) as a multipurpose and valuable medicinal plant. *Global Journal of Medicinal Plant Research* 1:199–206.

Nasreen, S., M. N. Yousuf, A. N. M. Mamun, S. Brahma, and M. M. Haquc. 2009. Response of garlic to zinc, boron and poultry manure application. *Bangladesh Journal of Agricultural Research* 34 (2):239–45. doi:10.3329/bjar.v34i2.5795.

Öztürk, Ö., E. Ceyhan, M. Önder, M. Harmankaya, M. Hamurcu, and S. Gezgin. 2010. Micronutrient contents in leaves of sunflower cultivars grown with different boron doses. *Helia* 33 (53):215–20. doi:10.2298/HEL1053215O.

Pariari, A., S. Khan, and M. N. Imam. 2009. Influence of boron and zinc on increasing productivity of Fenugreek seed (*Trigonella foenum graecum* L.). *Journal of Crop and Weed* 5 (2):57–58.

Rahman, A. H. M. M., and M. I. A. Parvin. 2014. Study of medicinal uses on fabaceae family at Rajshahi, Bangladesh. *Research in Plant Sciences* 2 (1):6–8.

Rahman,M. T., M.M. Haque, M. G. G. Mortuza, M. S. Hossain, and M. S. N. Chowdhury. 2019. Altering growth characters and seed cotton yield under foliar application of boron. *International Journal of Plant & Soil Science* 27 (2):1–5. doi:10.9734/ijpss/2019/v27i230073.

Silici, S., and K. Karaman. 2014. Chemometric approaches for the characterization of Turkish rhododendron and honeydew honeys depending on amino acid composition. *Journal of Liquid Chromatography & Related Technologies* 37 (6):864–77. doi:10.1080/10826076.2012.758149.

Smith, G. L. 1991. Principal component analysis: An introduction. *Anal. Proc.* 28:150–51.

Tania, S. A., F. M. J. Uddin, and M. A. R. Sarkar. 2019. Responses of selected mungbean (*Vigna radiata* L.) varieties to boron fertilization. *Fundamental and Applied Agriculture* 4 (1):655–60. doi:10.5455/faa.815.

Tariq, M., A. Akbar, Lataf-ul-Haq, and A. Khan. 2010. Comparing application methods for boron fertilizer on the yield and quality of tobacco (*Nicotiana tabacum* L.). *Communications in Soil Science and Plant Analysis* 41 (13):1525–37. doi:10.1080/00103624.2010.485234.