Türk Tarım ve Doğa Bilimleri Dergisi 8(2): 444–452, 2021
https://doi.org/10.30910/turkjans.882584

TÜRK TARIM ve DOĞA BİLİMLERİ DERGİSİ

TTDB

TURKISH JOURNAL of AGRICULTURAL and NATURAL SCIENCES

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Araştırma Makalesi

Effect of Boron Fertilization on Hollow Stem Development in Broccoli

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Received: 18.02.2021 Received in revised: 24.03.2021 Accepted: 08.04.2021

Abstract

This research was carried out to determine the effect of boron fertilization on the hollow stem development in broccoli under field conditions, in 2016-2017. In the study, three broccoli cultivars (*Brassica oleracea* var. *italica*, Plenk cvs. 'Batavia F_1', 'Burney F_1' and 'Lucky F_1') were used as plant material. In addition, boron was applied at 0, 1, 2, 3 kg B ha^{-1}. It was determined that the effect of boron applications on the hollow stem development in broccoli varied according to the cultivars and boron doses. It was clearly said that the most sensitive cultivar to the development of the hollow stem is Burney F_1 (35%) and the most resistant cultivar is Lucky F_1 (15%). The percentage of the hollow stem was the highest in control in all cultivars used in this study. It has been determined that the effect of boron applications reduces the percentage of hollow stem formation at different rates, although it varies according to the cultivars. According to the results of the research, Lucky F_1 and 3 kg B ha^{-1} boron application can be recommended for broccoli growers to overcome the formation of the hollow stem that is an important physiological disorder in broccoli, especially in similar ecologic conditions.

Anahtar kelimeler: Boron, broccoli, hollow stem, vegetative growth

Bor Gübrelemesinin Brokkolide Kof Gövde Oluşumu Üzerine Etkisi

Öz

Bu araştırma, bor gübrelemesinin brokolide kof gövde oluşumu üzerine etkisini belirlemek amacıyla 2016-2017 yıllarında tarla koşullarında yürütülmüştür. Çalışmada bitkisel materyal olarak üç brokoli çeşidi (*Brassica oleracea* var. *italica,* Plenk cvs. 'Batavia F_1', 'Burney F_1' ve 'Lucky F_1') kullanılmıştır. Ayrıca 0, 1, 2, 3 kg B ha^{-1-} olacak şekilde bor uygulaması yapılmıştır. Bor uygulamalarının brokolide kof gövde gelişimine etkisinin çeşitlere ve bor dozlarına göre değiştiği belirlenmiştir. Kof gövde oluşturmaya en duyarlı çeşidin Burney F_1 (% 35), en dayanıklı çeşidin ise Lucky F_1 (% 15) olduğu tespit edilmiştir. Bu araştırmada, en yüksek kof gövde oranı kullanılan çeşitlerin tamamında kontrolde belirlenmiştir. Bor uygulamalarının etkisinin çeşitlere göre değişmekle birlikte değişen oranlarda kof gövde oluşum oranını düşürdüğü tespit edilmiştir. Araştırma sonuçlarına göre, özellikle benzer ekolojik koşullarda brokoli üreticilerine önemli bir fizyolojik bozukluk olan kof gövde sorununun üstesinden gelebilmeleri için Lucky F_1 çeşidi ve 3 kg B ha^{-1} bor uygulaması önerilebilir.

Key words: Bor, brokkoli, kof gövde, vegetatif büyüme.

Introduction

Broccoli (*Brassica oleracea* L. var. *italica* Plenck.) is a member of the Cruciferae (Brassicaceae) family which is considered to be Italy as its gene center by many researchers (Vural et al., 2000). Broccoli is morphologically similar to cauliflower. The parts considered as vegetables are composed of coloured and immature flowers and thick and fleshy flower stems. The parts that form the immature flower outline are composed of small lateral heads consisting of the main head formed at the end of the growth point and then the lateral shoots emerging from between the leaf and stem (Doğru et al., 2016).

Broccoli, which is not very selective in terms of soil demand, can be grown easily in mineral and organic soils with sufficient irrigation and fertilization. Since the nutrient uptake of broccoli from the soil is high, when the right fertilization is not carried out in boron poor soils (Hussain et al.2012), occur broccolis with the hollow stem. One of the most important issues about increase of yield and the quality of plant growth is balanced fertilization (Kılıç and Korkmaz, 2012; Korkmaz et al., 2021). Approximately 60% of the arable land in the world is considered unsuitable for crop production owing to the inadequacy of some important plant nutrients (Bukvic et al., 2003). One of the most common mineral element stress is boron deficiency and it negatively affects the plant growth and development in agricultural soils (Ozkutlu et al., 2017). Boron is an element that is required in trace amounts by vegetables and other plants (Yazıcı and Korkmaz, 2020). Since broccoli is one of the vegetable species that is extremely sensitive to boron deficiency, its boron requirement is quite high. Boron fertilization plays an essential role in broccoli cultivation to obtain better quality and increase yield, and reduce the development of hollow stem (Hussain et al.2012). Boron deficiency has been determined to cause a physiological disorder known as hollow stem formation in broccoli (Boersma et al. 2009). The formation of a hollow stem, which occurs mostly in summer and autumn plantings, begins following the initiation of the central inflorescence, the "center bud." It is a physiological disorder that continues with the formation of elliptical transverse spaces in the tissues that gradually expand so that the stem remains hollow in the future. Although there is no color change in these parts, which are not visible from the outside during the plant development, the color change may develop during transportation and marketing (Zink, 1968). This is an undesirable situation that reduces the shelf life of broccoli and is an important quality problem. In some cases, the hollow stem emerges from the lack of boron and causes browning of the stem, necrosis in the leaves, and discoloration in the broccoli heads. Besides, boron deficiency causes the formation of the hollow stem in many Cruciferae species, as well as many anatomical, physiological, and biochemical changes (Hussain et al., 2012). Plant density, hot weather, high-dose nitrogen fertilization, and boron deficiency are among the main reasons for the formation of the hollow stem (Moniruzzaman et al., 2007). Boersma et al. (2009) reported that boron is not the main factor in the formation of hollow stem, but boron deficiency is effective together with high growth rate in the formation of hollow stem in broccoli. It was stated that fast-growing broccoli cultivars tend to form more hollow stem in the studies conducted on broccoli (Zink, 1968; Hipp, 1974).

Many studies have been conducted on the factors affecting the formation of hollow stem in broccoli. In the researches, the effects of environmental conditions, plant growth, nitrogen doses, boron, borax, sulfur, molybdenum, zinc, planting time and density, seedling age, growth regulators (NAA, GA3) were determined on the formation of hollow stem in broccoli. In the researches, the effects of environmental conditions, plant growth, nitrogen doses, boron, borax, sulfur, molybdenum, zinc, planting time and density, seedling age, and growth regulators were determined on the development of the hollow stem in broccoli (Patel et al., 2017; Jakhar et al., 2018; Sheokand et al., 2018; Farooq et al., 2018; Verma et al., 2018). However, there were not enough studies about the effects of boron applications on hollow stem development in broccoli in Turkey. Therefore, this research was carried out to determine the effect of boron fertilization on the hollow stem development in broccoli.

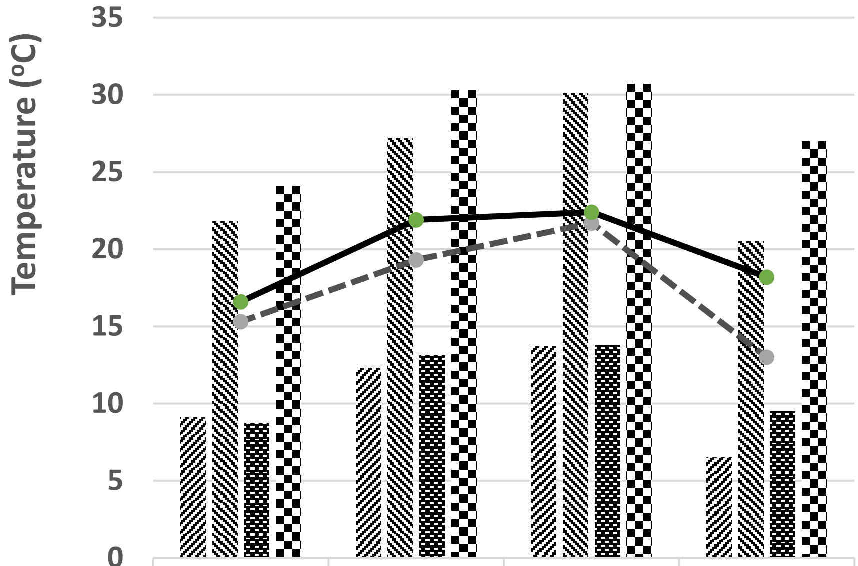
Material and Methods

This research was carried out in the experimental area belonging to Atatürk University, Plant Production Application, and Research Centre in 2016 and 2017. Temperature values of the experimental area where the research was conducted are presented in Figure 1.

The soil of the experimental area in 2016-2017 had a loamy texture having 27.65% sand, 36.96% silt and 35.39% clay. Some of the other soil chemical characteristics were as follows: pH 6.97 and 7.11; organic matter 1.73% and 1.78%; available P 10.74 mg kg^{-1} and 11.02 mg kg^{-1}; total nitrogen content 0.30%, 0.26%; amount of potassium 376 mg kg^{-1} and 325 mg kg^{-1} and the amount of B was 1.2 mg kg^{-1} and 0.8 mg kg^{-1} in experiment years, respectively.

In the study, three broccoli cultivars (*Brassica oleracea* var. *italica*, Plenk cvs. 'Batavia F_1', 'Burney F_1' and 'Lucky F_1') were used as plant material and supplied by the Turkish seed company, Metgen Seed Corporation.

Seed sowing for seedling production was carried out in an unheated glasshouse in multi-seedling pots filled with peat on May 24 in 2016, and on May 22 in 2017. The seedlings having formed 4-6 true leaves, were maintained at an inter row spacing of 30 cm and intra row spacing of 45 cm on 24 June in 2016 and 29 June in 2017, taking into account the researches about broccoli in previous years (Yaralı et al., 2007; Kaymak et al., 2009). The seedling planting was done in 2 x 2 m plots and 24 seedlings in each plot.



	June	July	August	September
2016 Min. Air Temp. 2016	9.1	12.3	13.7	6.5
2016 Max. Air Temp. 2016	21.8	27.2	30.1	20.5
2017 Min. Air Temp. 2017	8.7	13.1	13.8	9.5
2017 Max. Air Temp. 2017	24.1	30.3	30.7	27.0
2016 Avarage Air Temp. 2016	15.3	19.3	21.7	13.0
2017 Avarage Air Temp. 2017	16.6	21.9	22.4	18.2

Figure 1. The maximum, minimum and average air temperature (°C) of the experimental area during the June-September period.

All plots were fertilized 200 kg N ha^{-1} and 200 kg P_2O_5 ha^{-1}, as ammonium nitrate (AN) and, triple super phosphate (TSP) respectively (Yaralı and Güvenç, 2006; Yaralı et al., 2007; Kaymak et al., 2009). In addition, boron (Etidot-67, 20.8% B) was applied at 0, 1, 2, 3 kg B ha^{-1}. With the boron application, half of the N and all of the P_2O_5 were applied at the time of planting, while the other half of the N was applied in the period when it started to bud initiation about one month after the seedling planting.

Irrigation was carried out homogeneously in an average of 6-8 days, taking into account the air temperatures and rainfalls during the growing period, without making any difference between the plots. Weed control was done mechanically.

The broccoli heads, which come in marketable size, were harvested by cutting from the place where the heads joined the stem with the help of a knife (Açıkgöz and Şalk, 2000). In all the cultivars tested in the experiment, plant height (cm), stem diameter (cm), dry matter content of stem (%), and the percentage of the hollow stem (%) was determined using 12 heads in each replication.

The experimental design of these experiments was a completely randomized block design with 3 replications. ANOVA was applied to the data obtained in this study and Duncan's multiple range tests was used to compare the differences between the means. Besides, correlation coefficients (r) between the percentage of the hollow stem and plant height, stem diameter, and dry matter content of stem were determined.

Results and Discussion

It was determined that the plant height varied according to the cultivars and boron doses in 2016 and 2017 (Table 1). The effect of boron doses on plant height was found to be statistically significant in 2016 and insignificant in 2017 in Batavia F_1, while it was not found to be statistically significant in Burney F_1 and Lucky F_1 in both experiment years. Also, plant height values varied between 24.7 cm and 34.0 cm. In addition, it was determined that the cultivar x boron interaction was significant at the 5% level. As a matter of fact, when the mean values of cultivars were examined, it was determined that the highest plant height was in Burney F_1 with 29.3 cm.

Table 1. The effect of boron applications on plant height in broccoli cultivars (cm)

	B doses	Years			
Cultivars	kg B ha^{-1}	2016	2017	Mean	Mean
Batavia F_1	0	34.0 a**	26.0 ^{NS}	30.0 ^{NS}	28.0 B*
	1	32.7 ab	24.7	28.7	
	2	29.3 bc	24.9	27.1	
	3	27.6 c	27.4	27.5	
Burney F_1	0	31.5 ^{NS}	27.9 ^{NS}	29.7 ^{NS}	29.3 A
	1	30.3	26.6	28.5	
	2	31.4	28.5	29.9	
	3	30.3	27.2	28.8	
Lucky F_1	0	29.3 ^{NS}	27.8 ^{NS}	28.6 ^{NS}	28.9 AB
	1	29.7	28.4	29.1	
	2	30.7	28.3	29.5	
	3	33.0	28.7	30.9	
Mean	0	31.6	27.2	29.4 ^{NS}	
	1	30.9	26.6	28.7	
	2	30.3	27.2	28.9	
	3	29.9	27.8	29.0	

*Significant at $P < 0.05$, **Significant at $P < 0.01$, NS: Non significant at $P < 0.05$.

When Table 2 was examined, the effect of boron applications on the stem diameter of broccoli will be seen. The effect of boron doses on stem diameter was not found to be statistically significant in all cultivars except the Lucky F_1 in 2017. Also, it was determined that the cultivar x boron interaction was not also statistically significant. Beyond, the highest stem diameter was determined in control and 3 kg ha^{-1} boron application in Batavia F_1 (4.6 cm) in 2017, and the lowest stem diameter in Burney F_1 (3.6 cm) in 2016 with 1 kg B ha^{-1} boron application. Also, considering the average boron applications, it was seen that the highest stem diameter was 4.1 cm, and the cultivar with the highest stem diameter (4.3 cm) was Batavia F_1 (Table 2).

The effect of boron applications on the dry matter content of stem of broccoli cultivars was presented in Table 3. Although the effect of boron applications on dry matter content of stem varies according to cultivars and boron doses, it was found statistically significant only in 2016 for Batavia F_1 and Lucky F_1. Also, it was determined that the cultivar x boron interaction was insignificant. However, it was determined that the dry matter content of stem varied between 5.95% (1 kg B ha^{-1}) and 9.91% (control). When general mean values were taken into consideration, the effect of boron doses on the dry matter content of stem was determined to be insignificant, while the difference between the cultivars was statistically significant ($P < 0.01$).

The percentage of hollow stem varies according to the cultivars and boron doses (Table 4). The effect of boron doses on the percentage of the hollow stem was found to be statistically insignificant in the Batavia F_1 in both experiment years, while it was found to be statistically significant in 2016 and insignificant in 2017 in the Burney F_1. The effect of boron applications was found to be statistically significant in Lucky F_1 in both experiment years. According to the mean values of cultivars, it was clearly said that the most sensitive cultivar to the development of the hollow stem is Burney F_1 (35%) and the most resistant cultivar is Lucky F_1 (15%). In the study, the highest rates of the hollow stem were determined in control for all cultivars. However, the effects of boron doses varied according to the sensitivity of cultivars to form a hollow stem. For example, in Lucky F_1, which seems to be the most resistant cultivar, although the ratio of hollow stem varies according to the boron doses, the formation of hollow stem at the highest boron dose (3 kg B ha^{-1}) was not detected in both experiment years (Figure 2). In addition to these, the percentage of the hollow stem in the Lucky F_1 varied between 0 and 45%. Similarly, although no hollow stem was determined in the

Burney F1 in the application of 3 kg B ha^{-1} boron in 2016, the percentage of the hollow stem in 2017 was determined as 30% at the same dose. In the Batavia F1, the percentage of the hollow stem varied between 12% and 45%.

Table 2. The effect of boron applications on the stem diameter of broccoli cultivars (cm)

Cultivars	B doses kg B ha^{-1}	Years 2016	2017	Mean	Mean
Batavia F1	0	4.2 NS	4.6 NS	4.4 NS	4.3 A**
	1	3.9	4.5	4.2	
	2	4.0	4.4	4.2	
	3	3.9	4.6	4.3	
Burney F1	0	3.7 NS	4.3 NS	4.0 NS	4.0 B
	1	3.6	4.3	4.0	
	2	3.8	4.3	4.1	
	3	3.7	4.3	4.0	
Lucky F1	0	3.7 NS	4.2 ab*	3.9 NS	4.0 B
	1	3.8	4.1 b	3.9	
	2	3.8	4.5 a	4.2	
	3	3.9	4.3 ab	4.1	
Mean	0	3.9	4.4	4.1 NS	
	1	3.8	4.3	4.0	
	2	3.9	4.4	4.1	
	3	3.8	4.4	4.1	

*Significant at $P < 0.05$, **Significant at $P < 0.01$, NS: Non significant at $P < 0.05$.

Table 3. The effect of boron applications on the dry matter content of stem of broccoli cultivars (%)

Cultivars	B doses kg B ha^{-1}	Years 2016	2017	Mean	Mean
Batavia F1	0	6.00 b*	9.35 NS	7.68 NS	7.77 B**
	1	6.87 a	9.13	8.00	
	2	6.33 ab	9.03	7.68	
	3	6.37 ab	8.35	7.36	
Burney F1	0	6.35 NS	6.86 NS	6.60 NS	6.89 C
	1	6.33	8.07	7.20	
	2	6.61	7.45	7.03	
	3	6.33	7.21	6.77	
Lucky F1	0	7.67 a*	9.91 NS	8.79 a*	8.12 A
	1	5.95 b	9.00	7.48 b	
	2	6.67 ab	9.28	7.97 ab	
	3	6.92 ab	9.78	8.35 ab	
Mean	0	6.67	8.71	7.69 NS	
	1	6.39	8.74	7.56	
	2	6.54	8.58	7.56	
	3	6.54	8.45	7.50	

*Significant at $P < 0.05$, **Significant at $P < 0.01$, NS: Non significant at $P < 0.05$.

Table 4. The effect of boron applications on the hollow stem development of broccoli cultivars (%)

Cultivars	B doses kg B ha^{-1}	Years 2016	2017	Mean	Mean
Batavia F_1	0	45 ^{NS}	43 ^{NS}	44 a*	26 AB**
	1	20	24	22 ab	
	2	12	26	19 ab	
	3	16	18	17 b	
Burney F_1	0	61 a*	68 ^{NS}	65 a*	35 A
	1	11 b	29	20 b	
	2	37 ab	41	39 b	
	3	- ^{z}	30	15 b	
Lucky F_1	0	45 a*	27 a*	36 a*	15 B
	1	18 b	8 b	13 b	
	2	13 b	7 b	10 b	
	3	-	-	-	
Mean	0	51	46	48 A**	
	1	16	20	18 B	
	2	21	25	23 B	
	3	5	16	11 B	

*Significant at $P < 0.05$, **Significant at $P < 0.01$, NS: Non significant at $P < 0.05$.
'-' ^{z} indicates that the hollow stem did not develop, i.e. data could not be collected.

The plant height varies according to broccoli cultivars and boron doses. As a result of the research, it was determined that the lowest plant height was 24.7 cm and the highest plant height was 34.0 cm. As a matter of fact, Işık (2011) determined that the plant height of broccoli cultivars varies between 41.70 cm and 55.57 cm. In addition, it has been reported that plant height can reach up to 65 cm in studies where varying boron and nitrogen doses are applied together (Singh et al., 2015; Chand and Singh ,2017). Chowdhury et al. (2019) stated that lime and boron applications also affect the plant height of broccoli and the applications increased the plant height by 18.04%. Similarly, Ain et al. (2016) reported that boron doses in broccoli were effective on plant height, while the highest plant height was 39.31 cm in 0.25% boron application, while the lowest plant height was obtained from 32.30 cm and 1% boron application. However, Moniruzzaman et al. (2007) stated that boron applied at a dose of 1.5 kg ha^{-1} and above on plant height is more effective.

Although there is enough research about the effects of boron applications on growth and development parameters and some other quality properties of broccoli, researches on the effect of boron on the dry matter content of broccoli are limited. However, it is known that the dry matter content of broccoli varies according to the cultivar, nitrogen doses, seedling age, mulch application, and plant density (Everaarts, 1994; Rembialkowska, 2003; Roni et al., 2014; Kosterna, 2014). For example, Everaarts (1994) and Roni et al. (2014) reported that the amount of dry matter content of broccoli decreased due to the increase in nitrogen dose. In addition, Kosterna (2014) declared that the dry matter content of broccoli varied according to the mulch material and the dry matter content varied between 6.86% and 8.71%. Yaralı et al. (2007) determined that the dry matter content of broccoli was affected by the seedling age and the dry matter content varied between 8.74% and 15.91%.

In the research, it has been determined that while the percentage of the hollow stem was determined at the highest in control in both experiment years, the effect of boron applications varies according to the cultivars and boron doses. As a result of the researches, it was reported that the hollow stem, which is one of the main quality criteria, is a physiological disorder. The hollow stem in broccoli is related to the environment, cultivar, and the nitrogen and boron content of the soil Shattuck and Shelp 1987; Tremblay 1989). It has been stated that boron applications can reduce the formation of the hollow stem but cultivars and environmental conditions also affect the development of the hollow stem (Shattuck and Shelp 1987). For example, Moniruzzaman et al. (2007) reported that when 1.5 kg ha^{-1} boron and

100 kg ha^{-1} nitrogen were applied together, the lowest rate of the hollow stem was determined. In addition, it has been reported that boron is not exactly the main factor in the formation of the hollow stem, but boron deficiency is effective in the formation of the hollow stem in broccoli cultivars with high growth rates (Boersma et al. 2009). As a matter of fact, it has been determined that a medium level of B application in broccoli production (1.0 kg ha^{-1}) can keep the hollow stem at the lowest level without affecting the yield (Hussain et al.2012). Plus, while a statistically significant and positive (r = 0.336*) relationship was determined between the hollow stem ratio and the stem diameter, no statistically significant relationship was found between plant height, dry matter content, and hollow stem ratio.

Figure 2. Development of hollow stem in tested broccoli cultivars. **A**: Batavia F_1-Control, **B**: Batavia F_1-3 kg B ha^{-1}, **C**: Burney F_1-Control, **D**: Burney F_1-3 kg B ha^{-1}, **E**: Lucky F_1-Control, **F**: Lucky F_1-3 kg B ha^{-1}.

Conclusion

Consequently; based on the findings obtained in this research, Burney F_1 was determined to be the most sensitive cultivar for the hollow stem, and Lucky F_1 is the most resistant cultivar to the hollow stem formation. In addition to these, it was determined that the ratio of the hollow stem was the highest in control in all cultivars used in this study. It has been determined that the effect of boron applications reduces the percentage of hollow stem formation at different rates, although it varies according to the cultivars. According to the results of the research, Lucky F_1 and 3 kg B ha^{-1} boron application can be recommended for broccoli growers to overcome the formation of the hollow stem that is an important physiological disorder in broccoli, especially in similar ecologic conditions.

Acknowledgement: The authors would like to thank to ETİMADEN for providing the ETIDOT-67.

Conflict of Interest Statement: We declare that we have no conflict of interest.

Researchers' Contribution Rate Statement

Summary: The authors declare that they have contributed equally to the manuscript.

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