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Effect of Additional Boron Fertilization on Growth and Yield of Broccoli (*Brassica oleracea* L. var. *italica* Plenck)

Brokkoli (*Brassica oleracea* L. var. *italica* Plenck)'de İlave Bor Gübrelemesinin Gelişme ve Verim Üzerine Etkisi

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ABSTRACT

This work was conducted to examine the effect of different boron doses on broccoli growth and yield under field conditions, in 2016–2017. In the study, three broccoli cultivars (*Brassica oleracea* var. *italica*, Plenk cvs. "Batavia F_1," and "Burney F_1" and "Lucky F_1") were used as plant material. In addition, Etidot-67 (20.8% B), a type of commercial boron fertilizer, was applied at 0 kg ha^{-1} (control), 5 kg ha^{-1} (B-1), 10 kg ha^{-1} (B-2), and 15 kg ha^{-1} (B-3). In all the cultivars used in the experiment, head diameter and length (cm), dry matter content of head (%), mean head weight (g), and yield (t ha^{-1}) were determined. The lowest value of head diameter was determined in B-1 (9.5 cm) and the highest value was obtained in B-3 (12.8 cm). Similarly, the head length ranged from 8.2 cm to 10.2 cm according to boron doses. The dry matter content of the head varied between 5.9% and 12.5%. In addition, while the head weight values ranged from 130.3 g (control) to 386.4 g (B-2), the yield changed from 7.8 t ha^{-1} (control) to 23.2 t ha^{-1} (B-2). Also, yield and yield components of broccoli cultivars were affected by boron [Etidot-67 (20.8% B)] applications. According to the results of the research, broccoli can be produced successfully with 10 kg ha^{-1} additional boron (Etidot-67) application. Also, all of the cultivars used in this research, especially Batavia F_1, can be recommended to the broccoli producer in similar climatic conditions.

Keywords: Boron doses, broccoli, cultivar, yield components

ÖZ

Bu çalışma, brokkolide ilave bor gübrelemesinin gelişme ve verim üzerine etkisini incelemek amacıyla 2016–2017 yıllarında yürütülmüştür. Çalışmada üç brokkoli çeşidi (*Brassica oleracea* var. *italica*, Plenk cvs. 'Batavia F_1', 'Burney F_1' ve 'Lucky F_1') bitkisel materyal olarak kullanılmıştır. Ayrıca ticari bir bor gübresi olan Etidot-67 (% 20,8 B) ile 0 (kontrol), 5 (B-1), 10 (B-2), 15 (B-3) kg ha^{-1}. dozlarında ilave gübreleme yapılmıştır. Araştırmada kullanılan çeşitlerin tamamında baş çapı ve uzunluğu (cm), baş kuru madde içeriği (%), ortalama baş ağırlığı (g) ve verim (t ha^{-1}) belirlenmiştir. En düşük baş çapı değeri B-1'de (9,5 cm), en yüksek değer ise B-3'te (12,8 cm) belirlenmiştir. Benzer şekilde baş uzunluğu bor dozlarına göre 8,2 ile 10,2 cm arasında değişmiştir. Başta kuru madde miktarı ise %5,9 ile %12,5 arasında belirlenmiştir. Ayrıca, baş ağırlığı değerleri 130,3 g (kontrol) ile 386.4 g (B-2) arasında değişirken, verimin 7,8 t ha^{-1} (kontrol) ile 23,2 t ha^{-1} (B-2) arasında değiştiği tespit edilmiştir. Brokkoli çeşitlerinin verim ve verim bileşenleri bor [Etidot-67 (%20,8 B)] uygulamalarından etkilenmiştir. Araştırma sonuçlarına göre 10 kg ha^{-1} ilave bor (Etidot-67) uygulaması ile brokkoli yetiştiriciliği başarılı bir şekilde yapılabilir. Bu araştırmada kullanılan tüm çeşitler, özellikle Batavia F_1, brokoli üreticisine benzer iklim koşullarında tavsiye edilebilir.

Anahtar Kelimeler: Bor dozları, brokkoli, çeşit, verim bileşenleri

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Introduction

Broccoli production in Turkey began in little amounts and areas since the beginning of the 1900s, but it began to increase in the 2000s, and statistical data have been recorded since 2004. As a matter of fact, broccoli production was 8500 tons in a 571-ha production area in 2005, reaching the level of approximately 95 000 tons in a 4665-ha production area in 2019. The most important producer cities of Turkey are İzmir, Antalya, Manisa, Mersin, Bursa, Samsun, and Eskişehir, respectively. These mentioned production areas achieve 94% of the total broccoli production of Turkey (TÜİK, 2021).

Broccoli, one of the cool climate vegetables, is highly resistant to low temperatures and can be grown easily in areas with temperate climates. However, broccoli, which is highly tolerant of high temperatures compared to other *Brassicaceae* species, can also be easily produced in subtropical climates. Broccoli is not very selective in terms of temperature requirement during the vegetative development period, and high-quality main head formation occurs in the temperature range of 12–20°C. While the growth and development slow down at 5°C, the compact structure of the head deteriorates in broccoli when temperatures rise above 25°C. As long as the temperatures do not drop suddenly and in the period following an acclimation period, broccoli can last for a short time at −7°C without being injured. Besides, grown-up broccoli plants are more resistant to freezing temperatures than young seedlings (Bjorkman & Pearson, 1998; Tindall, 1992; Webaum, 2015). In addition, nutrient management such as fertilization with nitrogen and micronutrients is an important practice to increase the yield and quality of broccoli.

Nitrogen fertilization has an important role in broccoli cultivation for high main head yield (Babik & Elkner, 2002). It has been determined that there is an increase in yield with the increase in nitrogen dose to a certain level in broccoli (Bowen et al., 1998); however, high nitrogen doses cause some physiological disorders such as hollow stem formation (Bélec et al., 2001; Tremblay, 1989). Boron fertilization is also recommended for high yield and quality in broccoli in addition to usual nitrogen fertilization. Indeed, Moniruzzaman et al. (2007) determined that boron fertilization in addition to nitrogen fertilization increased plant height, number of leaves per plant, leaf size, main head weight, and yield in broccoli. Similarly, Saha et al. (2010) found that foliar applications of boron also increase the yield of the main head in broccoli. In addition, it has been determined that 1.0 kg ha^{-1} additional boron application may be suitable for high yield in broccoli (Hussain et al., 2012). The combined use of zinc and boron has also been found to provide appreciable increases in the growth, yield, and quality of broccoli in suitable climatic conditions (Ain et al., 2016).

If the correct fertilization is not made in soils especially poor in boron since the nutrient uptake of broccoli is high (Hussain et al., 2012), yield and quality losses can occur. For this reason, the importance of balanced fertilization is revealed once again to increase yield and plant growth quality (Korkmaz et al., 2021). This situation supports the view that approximately 60% of the world's arable land is not suitable for crop production due to a lack of some important plant nutrients (Bukvić et al., 2003). Boron is an element that vegetables and other plants need in trace amounts (Yazıcı & Korkmaz, 2020). Besides the essential requirement of boron for plant growth, one of the most common mineral element stresses is boron deficiency in the plant production areas, and boron deficiency negatively affects both plant growth and development (Özkutlu et al., 2017). Although broccoli is a high-value vegetable crop in the world, there is a lack of research to show the effects of boron on broccoli, especially in field conditions. Therefore, the present experiment was conducted to examine the effect of different boron doses on broccoli (*Brassica oleracea* L. var. *Italica* Plenck) growth and yield.

Methods

This study was undertaken in the experimental area belonging to Atatürk University, Plant Production Application, and Research Centre in 2016 and 2017. Detailed information about the air temperature data of the research area was conducted as shown in Figure 1.

The soil analyses were made as described in the study by Esringü et al. (2011). The soil of the research area had a loamy texture having 27.65% sand, 36.96% silt, and 35.39% clay in 2016 and 2017. The other soil chemical characteristics were pH 6.97 and 7.11, organic matter 1.73% and 1.78%; available phosphorous 10.74 mg kg^{-1} and 11.02 mg kg^{-1}, total nitrogen content 0.30% and 0.26%, the amount of potassium 376 mg kg^{-1} and 325 mg kg^{-1}, and the amount of boron was 1.2 mg kg^{-1} and 0.8 mg kg^{-1} in 2016 and 2017, respectively. Three broccoli cultivars (*Brassica oleracea* var. *italica*,

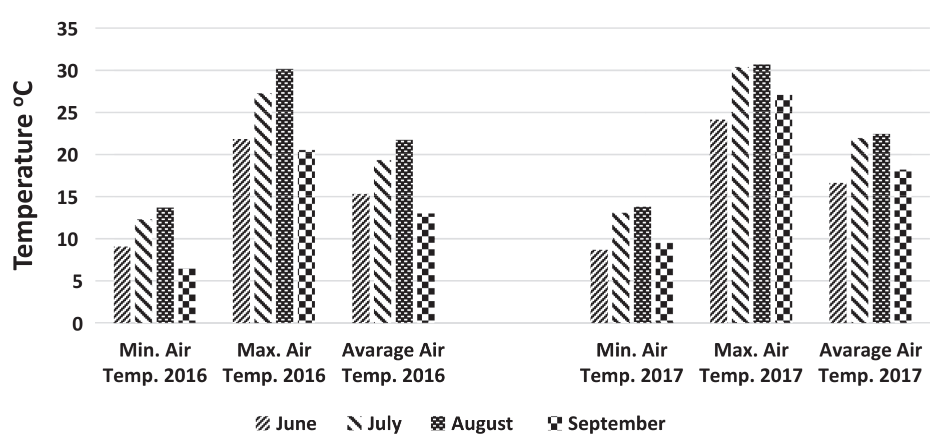

Figure 1.
The Air Temperature (°C) of the Research Area During The June–September Period in 2016 and 2017.

Plenk cvs. “Batavia F_1,” and “Burney F_1,” and “Lucky F_1”) were tested in this study and were supplied by the Metgen Seed Corporation.

Seed sowing for seedling production was carried out in an unheated glasshouse in multiple seedling pots filled with peat on May 24, 2016, and on May 22, 2017. Previous studies about broccoli have been taken into consideration, and seedlings that formed 4–6 true leaves on June 24, 2016, and June 29, 2017, were planted at an inter-row spacing of 30 cm and intra-row spacing of 45 cm (Kaymak et al., 2009; Yaralı et al., 2007). Seedling planting was carried out in 4 m^2 (2 m × 2 m) plots and with 24 seedlings per plot.

All plots received 200 kg nitrogen (N) ha^{-1} and P_2O_5 ha^{-1} each of ammonium nitrate and triple super phosphate, respectively (Kaymak et al., 2009; Yaralı & Güvenç, 2006; Yaralı et al., 2007). In addition, Etidot-67 (20.8% B), a type of commercial boron fertilizer, was applied at 0 kg ha^{-1} (control), 5 kg ha^{-1} (B-1), 10 kg ha^{-1} (B-2), 15 kg ha^{-1} (B-3). Indeed, Etidot-67 was developed as a result of R&D projects carried out by Eti Maden in 2010 to expand the use of boron and boron products in agricultural areas. With all of the boron and P_2O_5, half of the N was applied at the time of planting. The remaining part of N was applied about 1 month after the seedling planting when broccoli started to bud initiation.

Irrigation was made homogeneously in an average of 6–8 days. In addition, air temperatures and rainfalls during the growing period were taken into account while irrigation was carried out. 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 a knife (Açıkgöz & Şalk, 2000). In all the cultivars used in the experiment, head diameter and length (cm), dry matter content of head (%), mean head weight (g), and yield (t ha^{-1}) were determined using 12 heads in each replication.

A completely randomized block design with three replications was used as the experimental design of the experiment. Analysis of variance was applied to the data obtained in this study, and Duncan’s multiple range test was used to compare the differences between the means.

Results

The effects of boron fertilization on the main head diameter and length of broccoli cultivars are shown in Figures 2 and 3. The effect of boron fertilization on head diameter and length was not statistically significant. On the other hand, the mean value of head diameter and length varied depending on treatments. As seen in Figures 2 and 3, there was a numerical change in head diameter and length. And also, the lowest value of head diameter was determined in B-1 (9.5 cm) and the highest value was obtained in B-3 (12.8 cm) in Lucky F_1. When cultivars are taken into consideration, head diameters were between 11.0 cm (Lucky F_1) and 11.3 cm (Batavia F_1) and were not statistically significant. Similarly, the head length ranged from 8.2 cm to 10.2 cm according to the boron doses. The mean head length of cultivars changed from 9.2 (Lucky F_1) cm to 9.7 cm (Burney F_1) and the differences between mean values of head length of cultivars were statistically significant (Figure 2, $p < .05$).

The affected broccoli heads from deficiency of boron become shapeless, smaller in size, and bitter in taste, which adversely affects the marketable properties (Thapa et al., 2016). Moniruzzaman et al. (2007) reported that boron applications affected the head diameter positively, and the maximum head diameter was obtained from the application of 1.5 kg B ha^{-1} and 2.0 kg B ha^{-1}. In addition, it was declared that the combined applications of sulphur and boron affected the head diameter and plant height and increased the head diameter and plant height due to the increase in the applied dose (Farooq et al., 2018). Similarly, it was reported that the combined use of zinc and boron increased the head length and diameter of broccoli (Mahmoud et al., 2019). On the other hand, Thapa et al. (2016) reported that the head size changed according to the boron doses and the highest head diameter (21.67 cm) was obtained in 18 kg ha^{-1} boron application. Additionally, Tan et al. (1999) reported that the head diameter in broccoli was between 9.3 cm and 12.4 cm.

The effect of boron applications on the dry matter content of the head of broccoli cultivars was shown in Figure 4. Although the effect of boron applications on dry matter content of the head varied according to cultivars and boron doses, the effect of boron fertilization on the dry matter content of the head was not statistically significant ($p < .05$). Also, it was determined that the cultivar × boron interaction was not statistically significant. However, the dry matter content of the head varied between 5.9% and 12.5%. When general mean values of cultivars were taken into consideration, the mean dry matter content of the head of cultivars ranged from 9.1 (Batavia F_1) cm to 10.2 cm (Burney F_1) and the difference between the cultivars was statistically significant ($p < .05$).

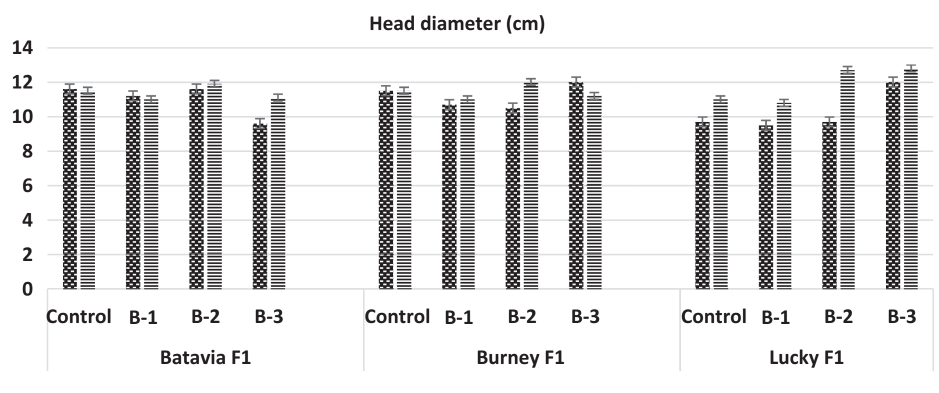

Figure 2.
The Effect of Boron Applications on the Head Diameter of Broccoli (cm) (NS at p < .05). NS = non significant.

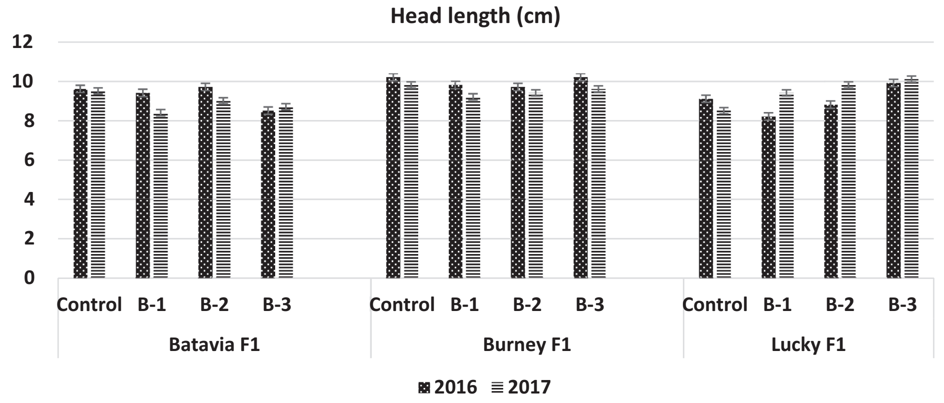

Figure 3.
The Effect of Boron Applications on Head Length of Broccoli (cm) (differences between boron doses were non-significant at p < .05; differences between cultivars were significant at p < .05).

Qiong et al. (2002) stated that in different crops boron fertilizer can significantly increase the photosynthetic activity of leaves and cause more dry matter accumulation. For example, maximum dry matter yield in cotton was achieved by the addition of 3.0 kg B ha^{-1} (Ahmed et al., 2011). Similarly, Ruiz et al. (1998) and Shelp (1993) reported that the increase in the dry matter content may result from the activation of some essential processes with the boron nutrient such as cell elongation and division, as well as nucleic acid metabolisms. Indeed, Islam et al. (2005) reported that the dry matter content of head varied from 8.18% to 10.97% with the application of different levels of boron fertilizer on different genotypes of broccoli. Also, the head dry weight of broccoli was affected significantly from the different doses of boron and the highest head dry weight was recorded with boron at 15 kg ha^{-1} (Chowdhury et al., 2019). Additionally, the combined use of boron and other micronutrients affects the dry matter content of broccoli. For example, when zinc and boron were applied together, while the highest total plant dry matter was recorded, the lowest value was determined in control (Mahmoud et al., 2019). On the other hand, it is known that the dry matter content of broccoli was affected by not only boron applications but also varies according to the cultivar, nitrogen doses, seedling age, mulch application, and plant density (Everaarts, 1994; Kosterna, 2014; Rembialkowska et al., 2003; Roni et al., 2014; Yaralı et al., 2007). Therefore, although it was stated in previous studies that boron has an effect on the dry matter content of broccoli heads, it was concluded that the dry matter content of broccoli heads was due to the cultivar difference rather than the boron doses in this study.

Discussion and Conclusion

In the research, the head weight and yield vary according to the cultivars and boron doses (Table 1). While the effect of boron doses on head weight and yield was statistically significant in 2016 in all cultivars, it was not statistically significant in 2017. Considering the general mean values of the cultivars, the highest head weight was determined in Batavia F_1 (267.1 g) and the lowest head weight (205.8 g) in Burney F_1. Similarly, the highest yield was obtained from Batavia F_1 (16.0 t ha^{-1}) and the lowest head weight (12.4 t ha^{-1}) in Burney F_1. Although the highest head weight and yield values were obtained from B-2 and B-3 applications according to the control in all cultivars in 2016 and 2017, the highest head weight and yield were determined in B-2 (Burney F_1) in 2016. In addition, while the head weight values ranged from 130.3 g (control) to 386.4 g (B-2), the yield changed from 7.8 t ha^{-1} (control) to 23.2 t ha^{-1} (B-2). When the general mean of boron applications was taken into consideration, the head weight and yield increased due to the increase in boron doses. Also, the lowest head weight and yield value were determined in control with 197.5 g and 11.9 t ha^{-1}, while the highest head weight and yield were determined in B-2 with 273.5 g and 16.4 t ha^{-1}, respectively. In addition, the

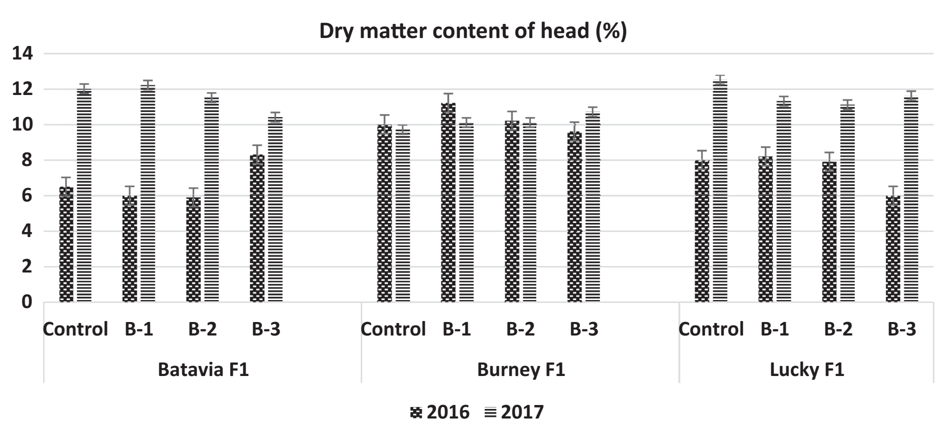

Figure 4.
The Effect of Boron Applications on Dry Matter Content of Head Broccoli (%) (differences between boron doses were non-significant at p < .05; differences between cultivars were significant at p < .05).

Table 1.
The Effect of Boron Applications on Head Weight (g) and Yield (t ha^{-1}) of Broccoli

		2016	2017		
Cultivars	**Applications^z**	**Head Weight (g)**		**Mean (year)**	**Mean**
	Control	130.3^{c**}	263.3^{NS}	196.8^{b**}	
Batavia F_1	B-1	245.1^{b}	291.6	268.4^{ab}	267.1^{A**}
	B-2	386.4^{a}	300.7	343.6^{a}	
	B-3	189.2^{bc}	329.9	259.6^{ab}	
	Control	168.5^{b*}	197.6^{NS}	183.1^{b*}	
Burney F_1	B-1	194.7^{ab}	213.6	204.2^{ab}	205.8^{B}
	B-2	178.5^{b}	216.9	197.7^{ab}	
	B-3	256.9^{a}	219.8	238.4^{a}	
	Control	159.3^{b*}	266.0^{NS}	212.6^{b*}	
Lucky F_1	B-1	200.4^{ab}	277.4	238.9^{ab}	254.6^{A}
	B-2	244.4^{ab}	311.7	278.1^{ab}	
	B-3	260.7^{a}	317.0	288.9^{a}	
	Control	152.7	242.3	197.5^{C**}	
Mean	B-1	213.4	260.9	237.2^{B}	
	B-2	269.8	276.5	273.1^{A}	
	B-3	235.6	288.9	262.3^{AB}	
		Yield (t ha^{-1})			
	Control	7.8^{c**}	15.8 ^{NS}	11.8^{c**}	
Batavia F_1	B-1	14.7^{b}	17.5	16.1^{b}	16.0^{A**}
	B-2	23.2^{a}	18.0	20.6^{a}	
	B-3	11.4^{bc}	19.8	15.6^{bc}	
	Control	10.1^{c*}	11.9 ^{NS}	10.9^{b*}	
Burney F_1	B-1	11.7^{ab}	12.8	12.3^{ab}	
	B-2	10.7^{b}	13.0	11.9^{ab}	12.4^{B}
	B-3	15.4^{a}	13.2	14.3^{a}	
	Control	9.6^{c*}	15.9 ^{NS}	12.8^{b*}	
Lucky F_1	B-1	12.0^{ab}	16.7	14.3^{ab}	
	B-2	14.7^{ab}	18.7	16.7^{a}	
	B-3	15.6^{a}	19.0	17.3^{a}	15.3^{A}
	Control	9.2	14.5	11.9^{C**}	
Mean	B-1	12.8	15.7	14.2^{B}	
	B-2	16.2	16.6	16.4^{A}	
	B-3	14.1	17.3	15.7^{AB}	

*Significant at $p < .05$.
**Significant at $p < .01$
NS = non significant at $p < .05$.
^{Z}-Etidot-67 (20.8% B) applications: 0 (control), 5 (B-1), 10 (B-2), 15 (B-3) kg ha^{-1}.

Cultivar × Boron interactions of head weight and yield were determined statistically significant ($p < .01$).

Although the yield varies according to the cultivars and boron doses, while the B-2 and B-3 boron applications increased the yield, the lowest yield values were obtained in control in all cultivars in this research. Various researchers reported that the yield of broccoli is affected by the cultivars, nitrogen doses, seedling age, planting time, and plant density (Aktaş et al., 1999; Hussain et al., 2012; Singh et al., 2015; Yaralı et al., 2007; Yoldaş & Eşiyok, 2004). Boron applications are also affecting the yield of broccoli (Moniruzzaman et al., 2007) and boron fertilization is also recommended for high yield and quality in broccoli in addition to usual nitrogen fertilization. Indeed, boron deficiency is very common in brassica species and deficiency causes many anatomical, physiological, and biological changes because it is known that boron plays important role in many biochemical processes in plants such as carbohydrates metabolism and transport of sugar through membranes, tissue development, and formation of cell walls, and help in cell division (Farooq et al., 2018; Hussein, 2002; Thapa et al., 2016). Pizetta et al. (2005), in their studies with broccoli, cabbage, and cauliflower, obtained positive results in growth, development, and yield due to the increase in boron dose, thus showing the positive relationship between boron application and increase in yield of *Brassicaceae* species. In addition, Thapa et al. (2016) reported that boron application increased the growth and yield of the crops and the requirement of boron in vegetables is generally greater than other crops. Indeed, Moniruzzaman et al. (2007) reported that 1.5 kg ha^{-1} and above the doses of boron increased head weight and yield. Similarly, Hussain et al. (2012) argued that 180 kg ha^{-1} N and 1.0 kg ha^{-1} additional boron application are suitable for obtaining higher yield in broccoli. Farooq et al. (2018) also reported that optimum level of boron was 1.5 kg ha^{-1} for higher yield in broccoli. In another study, boron doses were investigated and as a result, it was determined that while the lowest values were determined in the control, different boron applications caused significant differences in the development and yield of broccoli (Singh et al., 2015). In addition, Saha et al. (2010) reported that foliar applications of boron also increase the yield of the main head in broccoli. The applications of 18 kg ha^{-1} borax and 1.8 kg ha^{-1} ammonium molybdate and .5% boron and zinc have also been found to provide appreciable increases in yield of broccoli (Ain et al., 2016; Thapa et al., 2016). and Yang et al. (2000) also obtained significantly maximum head yield in broccoli by the application of boron. The findings obtained in the research support the opinions that although boron is an element that vegetables need in trace amounts, in addition to the essential requirement of boron for the growth of plants, its deficiency affects both plant growth and yield negatively (Özkutlu et al., 2017; Yazıcı & Korkmaz, 2020).

Consequently, the results of this study suggest that broccoli had increased the growth characteristics, yield, and yield components with additionally B-2 (10 kg ha^{-1}) or B-3 (15 kg ha^{-1}) boron applications [Etidot-67 (20.8% B)]. The effect of boron applications changed according to the cultivars and the highest yield was determined in Batavia F_1 in B-2 (10 kg ha^{-1}) boron (Etidot-67) application. According to the results of the research, broccoli can be produced successfully with 10 kg ha^{-1} additional boron (Etidot-67) application. Also, all of the cultivars used in this research, especially Batavia F_1, can be recommended to the broccoli producer.

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Teşekkürler: Yazarlar, ETIDOT-67'yi sağladığı için ETİMADEN'e teşekkür eder.

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