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EFFECT OF IRON, BORON AND ZINC APPLICATIONS ON YIELD AND QUALITY TRAITS OF SOME SOYBEAN CULTIVARS (*Glycine max* (L.) Merr.)

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Abstract
This research was conducted in 2019 at Tekirdag Namik Kemal University, Faculty of Agriculture, Field Crops Department, Research and Experimental area. It was aimed to determine of effect of iron, boron and zinc applications on yield and quality traits in some soybean cultivars. The experiment was carried out as a split plot design based on RCBD with three replications, in which cultivars constituted the main plot with three cultivars (Arısoy, Safir and Bravo), and micronutrients and their combinations constituted the sub-plot (control, Fe, B, Zn, Fe+B, Fe+Zn, B+Zn and Fe+B+Zn). The micronutrients were applied to the plant by foliar spraying in the V3-V5 period. In the study plant height, first pod height, pod number per plant, seed number per pod, 100 seed weight, seed yield, oil content and crude protein content were investigated. The results showed that foliar micronutrients significantly increased the values for all traits. According to research findings, seed yield values of cultivars changed between 304.93-382.62 kg da^{-1}, oil content values 12.51-17.16% and crude protein content values 37.82-42.30% and showed a wide variation. In terms of cultivar x micronutrient interaction, the highest seed yield was obtained from the Fe+B, Fe+Zn and Fe+B+Zn applications in Safir variety (395.01, 393.55 and 396.42 kg da^{-1}, respectively). The crude protein content, which is the most important character in soybean, varied between 36.79-43.14%, but this difference was not found to be statistically significant for interaction. It was concluded that micronutrients had significant and positive effects on yield and quality characteristics of soybean.

Keywords: Soybean, micronutrients, yield, quality.

1. INTRODUCTION

Soybean (*Glycine max* (L.) Merr.) is one of the primary oil and legume crops the worldwide. It is a crop that feeds the world with its industrial uses and product variety. Soybean is the main product in terms of vegetable oil for humans and protein source for livestock in the world (Dass et al. 2022). The total production of soybean was 353 463 735 t in the world in 2020. The highest amount of production was in Brasil with 121 797 712 t, following countries with the 112 549 240 t in USA, 48 796 661 t in Argentina, 19 600 000 t in China, 11 226 000 t in India and 11 024 460 t in Paraguay (FAO, 2020).

Micronutrient is an important input for productive crop production. Iron is a very important micronutrient for the normal growth and development of soybean. (Fageria, 2007). It also plays a considerable role in the formation of some nodule proteins (Moran et al., 1997). Boron is essential for all plant growth and is known to promote flowering, pollen germination, grain fill, and yield

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(Ahmad et al., 2009). The role of boron in soybeans include, proper root growth, increased root nodule development for nitrogen (N) fixation, increased branching and flowering, decreased bloom abortion resulting in increased pod set and better seed development and grain yield (Bellaloui et al., 2013). Zinc is one of the essential micronutrients required for optimum plant growth and plays a crucial role in metabolism. It is required in minor but critical concentration for the functioning of plants physiological functions like photosynthesis, seed production, growth regulation and disease resistance (Solanki, 2016).
The main objective of the this study was to determine the iron, boron and zinc applications on yield and quality traits in some soybean cultivars.

2. MATERIALS AND METHODS

The research was conducted in 2019 at Tekirdag Namik Kemal University, Agriculture Faculty, Department of Field Crops, Research and Experimental area. The experimental area's soil characteristics were clayey (C), slightly alkaline (pH=7.10), and had sufficient phosphorus, rich in potassium but low in organic matter (1.33 %). The total rainfall at growing period of soybean (April to September) was 109.9 mm and mean monthly temperature 20.7 °C in experimental area in 2019. In this context, the soil and climate properties of the experimental area are partially sufficient and suitable for soybean.
The experiment was carried out as a split plot design based on Randomized Complete Block Design with three replications, in which cultivars constituted the main plot with three cultivars (Arısoy, Safir and Bravo), and micronutrients and their combinations constituted the sub-plot (control, Fe, B, Zn, Fe+B, Fe+Zn, B+Zn and Fe+B+Zn). The soybean seeds were sown by hand with the rate of 8 kg da^{-1} on plots with 5 rows of 5 m length with spacing of 45 cm within the rows on April 18, 2019. Nitrogen and phosphorous were applied prior to seed sowing at the rate of 25 kg urea and 80 kg diammonium phosphate (DAP) per hectare, respectively. The iron (Fe) 2500 ppm, boron (B) 3000 ppm and zinc (Zn) 3000 ppm were applied. The micronutrients were applied to the plant by foliar spraying in the V3-V5 period. The plants have four/six nodes with three trifoliates fully unfolded in this stage. In the study plant height, first pod height, pod number per plant, seed number per pod, 100 seed weight, seed yield, oil content and crude protein content were investigated.
The soybeans were harvested by hand on September 16, 2019. The data were determined on 10 randomly selected plants from each plot. The oil content was calculated by making two readings in each plot on a 25 g seed NMR device (Collins et al., 1967). The crude protein content of each soybean sample was analyzed using the Kjeldahl method AOAC (1990).
Results were analyzed by TARIST software for analysis of variance. The means of treatments were compared using LSD test with MSTAT-C (MSTAT, 1989).

3. RESULTS AND DISCUSSIONS

The results of the variance analysis showed that significant effect cultivars and micronutrients ($p<0.01$), and also the interaction effect of cultivar x micronutrients on plant height, first pod height, pod number per plant, 100 seed weight, seed yield and oil content were at a level 1 % ($p<0.01$). In addition, cultivar x micronutrients interaction was not found statistically significant in terms of crude protein content ($p>0.05$).
The results of micronutrients means showed that the highest plant height obtained from Fe+B+Zn applications with 65.84 cm (Table 1). Interactions between micronutrients and cultivar the highest plant height were obtained from Safir cultivar by Fe+B+Zn applications (82.53 cm). The plant

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height of soybean is effected considerably by the genetic and environmental factors (Ting et al., 1946; Yang et al., 2021). Shinde et al. (2015) reported that plant height ranged from 50.60 to 55.32 cm with micronutrient application (B, Fe and Zn).

First pod height is crucial characters in soybean that affects mechanized harvesting (Jiang et al., 2018). The results of micronutrients means showed that the highest first pod height was in the control plot with 15.07 cm (Table 1). This value was followed by B (14.40 cm) and Fe (14.38 cm) application. Bakal et al. (2017) reported that average first pod height values of soybean cultivars ranged from 17.1 to 22.6 cm in main crop and also 15.0-20.6 cm in double crop growing seasons. These results are associated with our results.

The seed yield of soybean consists of some characters, including the pod number per plant, seed number per pod, and 100 seed weight (Liu, 2010). The results of micronutrients means showed that the highest pods number per plant was in the B+Zn applications with 64.47 pod (Table 1). Interactions between micronutrients and cultivar the highest pod number per plant were obtained from Safir cultivar by Fe+B+Zn applications (83.00 pod). The soybean has the ability to produce 600 pods per plant, but it can produce average 50-100 pods under suitable conditions. Many researches emphasize that pods number per plant values of soybean cultivars ranged from 40 to 70 pods (Raghuveer and Chandranath, 2017; Li et al., 2022). It can be said that the reason for the difference between the results of the researchers and our results is the difference in the cultivars.

Table 1. Agronomic and quality traits of soybean cultivars

Charact.	Cultivars	Micronutrients								Means
		Control	Fe	B	Zn	Fe+B	Fe+Zn	B+Zn	Fe+B+Zn	
Plant height (cm)	Arısoy	58.60 **fg**	59.13 **ef**	56.90 **ı**	57.60 **hı**	59.00 **ef**	57.80 **gh**	59.80 **e**	59.47 **ef**	58.53 **b**
	Safir	80.50 **cd**	80.20 **d**	80.70 **bcd**	81.47 **b**	80.53 **cd**	81.07 **bcd**	81.13 **bc**	82.53 **a**	81.02 **a**
	Bravo	47.40 **n**	50.33 **lm**	51.07 **l**	49.87 **m**	50.13 **m**	52.93 **k**	52.47 **k**	55.53 **j**	51.22 **c**
	Means	62.17 **e**	63.22 **cd**	62.89 **de**	62.98 **de**	63.22 **cd**	63.93 **bc**	64.47 **b**	65.84 **a**	
	$LSD_{0,05}$:	Cultivar: 1,038; Micronutrient: 0,948; Cultivar x Micronutrient: 0,899								
First pod height (cm)	Arısoy	14.53 **fg**	15.00 **cde**	14.20 **g**	13.47 **h**	11.33 **j**	10.60 **k**	11.93 **ı**	9.47 **l**	12.57 **b**
	Safir	16.33 **a**	14.73 **def**	15.80 **b**	14.47 **fg**	16.20 **ab**	14.60 **efg**	15.07 **cd**	15.33 **c**	15.32 **a**
	Bravo	14.33 **fg**	13.40 **h**	13.20 **h**	13.33 **h**	11.73 **ıj**	12.07 **ı**	11.33 **j**	10.73 **k**	12.52 **b**
	Means	15.07 **a**	14.38 **b**	14.40 **b**	13.76 **c**	13.09 **d**	12.42 **de**	12.78 **e**	11.84 **f**	
	$LSD_{0,05}$:	Cultivar: 0,400; Micronutrient: 0,424; Cultivar x Micronutrient: 0,402								
Pod number per plant	Arısoy	45.80 **lm**	48.53 **k**	46.67 **kl**	54.87 **ıj**	53.00 **j**	58.20 **gh**	62.73 **ef**	66.87 **d**	54.58 **b**
	Safir	54.33 **ıj**	56.07 **hı**	62.73 **ef**	63.60 **f**	60.33 **fg**	69.67 **c**	75.07 **b**	83.00 **a**	65.60 **a**
	Bravo	38.53 **o**	40.87 **no**	43.00 **n**	43.40 **mn**	41.13 **no**	42.73 **n**	55.60 **hıj**	58.13 **gh**	45.43 **c**
	Means	46.22 **g**	48.49 **fg**	50.80 **ef**	53.96 **d**	51.49 **de**	56.87 **c**	64.47 **a**	69.33 **b**	
	$LSD_{0,05}$:	Cultivar: 1,930; Micronutrient: 2,861; Cultivar x Micronutrient: 2,714								
Seed number per pod	Arısoy	2.20	2.40	2.20	2.40	2.20	2.27	2.27	2.40	2.29 **b**
	Safir	3.00	2.93	2.87	2.73	2.87	2.80	2.80	3.00	2.88 **a**
	Bravo	2.53	2.40	2.33	2.20	2.20	2.27	2.27	2.47	2.33 **b**
	Means	2.57	2.57	2.47	2.44	2.42	2.44	2.44	2.62	
	$LSD_{0,05}$:	Cultivar: 0,077								

The results of cultivars means showed that the highest seed number per pod was obtained from Safir cultivar (2.88). In the micronutrients and cultivar interaction, the seed number per pod ranged from 2.20 to 3.00, but this difference was not statistically significant. Healthy soybean plants produces average about 2.5 seeds per pod (Davidson, 2015; Lindsey, 2015). Also, Shabnam et al. (2020)

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reported that the seed number per pod of soybean ranged from 2.42 to 2.57 seeds with different B level. Our results were found within the limits reported by these researchers.

100 seed weight is a very complicated quantitative trait of yield in soybean (Zhao-ming et al., 2011). In addition, 100 seed weight is one of the most important yield components in soybean (Liu et al., 2018). The results of micronutrients means showed that the highest 100 seed weight was in the Fe+Zn applications with 16.12 g (Table 1). Interactions between micronutrients and cultivar the highest 100 seed weight were obtained from Safir cultivar by Fe+Zn and B+Zn applications (16.53 and 16.42 g, respectively). Adie and Krisnawati (2017) indicated that 100 seed weight of soybean ranged from 13.90-20.23 g in subtropical conditions. Heidarian et al. (2011) reported that Zn+Fe combination treatment produced maximum 100 seed weight (20.0 g) and minimum 100 seed weight was obtained by control treatment (14.4 g). These results are associated with our results.

The results of micronutrients means showed that the highest oil content was in the Fe+B+Zn applications with 15.25% (Table 1). Interactions between micronutrients and cultivar the highest oil content were obtained from Bravo cultivar by Fe+B+Zn applications (17.73%). Aytaç et al. (2007) determined that oil content of soybean varied between 17.36 and 18.98% with the application of zinc at different doses. Hamurcu et al. (2019) reported that the oil content of soybean genotypes ranged from 16.51 to 22.15% with B application. It can be said that the reason for the difference between the results of the researchers and our results is the difference in the cultivars and micronutrients doses.

Table 1. Continue

Charact.	Cultivars	Micronutrients								Means
		Control	Fe	B	Zn	Fe+B	Fe+Zn	B+Zn	Fe+B+Zn	
100 seed weight (g)	Arısoy	15.44 **k**	15.50 **jk**	15.95 **efg**	15.54 **jk**	15.49 **jk**	15.72 **ı**	15.49 **jk**	15.58 **j**	15.59 **c**
	Safir	16.15 **d**	16.15 **d**	15.99 **e**	16.32 **bc**	16.24 **cd**	16,53 **a**	16.42 **ab**	16.19 **d**	16.25 **a**
	Bravo	15.84 **gh**	15.74 **hı**	15.96 **ef**	15.92 **efg**	16.02 **e**	16.11 **d**	15.85 **fg**	15.96 **ef**	15.93 **b**
	Means	15.81 **cd**	15.79 **d**	15.97 **b**	15.93 **bc**	15.92 **bc**	16.12 **a**	15.92 **bc**	15.91 **bcd**	
	$LSD_{0,05}$:	Cultivar: 0,193; Micronutrient: 0,121; Cultivar x Micronutrient: 0,114								
Oil content (%)	Arısoy	14.39 **g**	14.71 **f**	15.23 **e**	14.75 **f**	14.72 **f**	14.69 **fg**	14.61 **fg**	15.21 **e**	14.79 **b**
	Safir	12.18 **j**	12.48 **ıj**	12.57 **hı**	12.57 **hı**	12.61 **hı**	12.47 **ıj**	12.34 **ıj**	12.82 **h**	12.51 **c**
	Bravo	15.42 **e**	17.29 **c**	17.36 **bc**	17.52 **abc**	16.83 **d**	17.61 **ab**	17.49 **abc**	17.73 **a**	17.16 **a**
	Means	13.99 **d**	14.82 **bc**	15.05 **ab**	14.95 **abc**	14.72 **c**	14.92 **abc**	14.81 **bc**	15.25 **a**	
	$LSD_{0,05}$:	Cultivar: 0,400; Micronutrient: 0,331; Cultivar x Micronutrient: 0,313								
Seed yield (kg da^{-1})	Arısoy	333.12 **g**	346.57 **ef**	350.09 **de**	343.62 **f**	350.48 **de**	355.64 **d**	353.59 **d**	367.93 **c**	350.13 **b**
	Safir	368.41 **c**	374.21 **b**	379.22 **b**	374.80 **b**	395.01 **a**	393.55 **a**	379.39 **b**	396.42 **a**	382.63 **a**
	Bravo	297.87 **m**	299.42 **lm**	302.46**klm**	303.64 **jkl**	305.79 **ıjk**	308.99 **hıj**	309.80 **hı**	311.44 **h**	304.93 **c**
	Means	333.13 **e**	340.06 **d**	343.92 **cd**	340.68 **d**	350.43 **b**	352.73 **b**	347.59 **bc**	358.59 **a**	
	$LSD_{0,05}$:	Cultivar: 1,989; Micronutrient: 5,853; Cultivar x Micronutrient: 5,553								
Protein content (%)	Arısoy	37.65	37.94	38.32	37.36	39.07	38.98	38.82	39.72	38.48 **b**
	Safir	41.28	41.74	41.97	42.22	42.36	42.63	43.08	43.14	42.30 **a**
	Bravo	36.79	37.25	37.59	37.52	38.10	38.23	38.37	38.69	37.82 **c**
	Means	38.57 **d**	38.98 **cd**	39.29 **c**	39.04 **cd**	39.84 **b**	39.95 **b**	40.09 **ab**	40.52 **a**	
	$LSD_{0,05}$:	Cultivar: 0,331; Micronutrient: 0,526								

The seed yield of soybean consists of some characters, including the pod number per plant, seed number per pod, and 100 seed weight (Liu, 2010). The results of micronutrients means showed that the highest seed yield was in the Fe+B+Zn applications with 358.59 kg da^{-1} (Table 1). In terms of cultivar x micronutrient interaction, the highest seed yield was obtained from the Fe+B, Fe+Zn and

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Fe+B+Zn applications in Safir variety (395.01, 393.55 and 396.42 kg da^{-1}, respectively). Ghasemian et al. (2010) determined that 4 kg da^{-1} zinc and manganese led to the highest seed yield (339.7 and 336.7 kg da^{-1}), respectively. In addition, Singh et al. (2017) reported that the seed yield of soybean ranged from 367.8 to 407.5 kg da^{-1} with different Zn level.

The crude protein content, which is the most important character in soybean, varied between 36.79-43.14% in cultivar x micronutrients interaction was not found statistically significant ($p>0.05$). The results of micronutrients means showed that the highest crude protein content was obtained from the B+Zn and Fe+B+Zn applications with 40.09% and 40.52%, respectively (Table 1). Aytaç et al. (2007) indicated that crude protein content of soybean varied between 33.25 and 35.03% with the application of zinc at different doses. Shinde et al. (2015) reported that crude protein content ranged from 39.21 to 39.62% with different micronutrient application (B, Fe and Zn).

4. CONCLUSIONS

When the results are evaluated as a whole, the micronutrients had significant and positive effects on yield and quality characteristics of soybean. It showed positive results in triple combination (Fe+B+Zn), especially in terms of oil and protein content. Minor increases in oil and protein content are critical for the economic value of soybean. Therefore, it is necessary to develop agronomic research such as micronutrient application and sensitive fertilization.

The data suggests that micronutrients and their combinations can be recommended at suitable concentration for soybean cultivation.

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