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Effect of Iron and Boron Interaction on Yield and Nutrient Contents of Chickpea (*Cicer arietinum* L.)*

Demir ve Bor İnteraksiyonunun Nohutun (*Cicer arietinum* L.) Verim ve Besin Elementi İçerikleri Üzerine Etkisi

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Abstract: Iron and boron are essential elements in plant development. The effect of both elements on plant growth and nutrient content were tried to be determined by field study. The study was carried out with three replications according to factorial experiment design in randomized blocks in the research area of Van Yüzüncü Yıl University, Department of Field Crops. At the end of the study, changes in yield and yield criteria and grain macro and micronutrient content were examined. Iron applications only affect the biological yield of the yield criteria, whereas the chickpea straw N, P, K, Mg, Fe, Mn, Zn, Cu and grain P, Mg, Fe, Zn and B contents were affected. The effect of boron application on second branch count, number of pods and fertile number of pods, while straw nutrient content P, Mg, Zn, B and grain nutrient elements P, K, Ca, Mg, Fe, Mn, Zn, B were found to be affected. It was determined that the boron and iron doses to be applied to nutrient contents and yield were 0.25 kg B da^{-1} and 10 kg Fe da^{-1}.

Keywords: Soil, Chickpea, Yield, Fertilizer, Iron, Boron

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Öz: Demir ve bor bitki gelişiminde önemli elementlerdir. Her iki elementinde bitki büyümesine ve bitki besin elementi içeriğine etkisi arazi çalışmasıyla belirlenmeye çalışılmıştır. Araştırma Van Yüzüncü Yıl Üniversitesi Tarla Bitkileri Bölümü araştırma alanında faktöriyel deneme desenine göre tesadüf bloklarında üç tekerrürlü olarak yürütülmüştür. Çalışma sonunda verim ve verim kriterlerindeki değişimler ile tane makro ve mikro besin içerikleri incelenmiştir. Demir uygulamaları verim kriterlerinden sadece biyolojik verimi etkilerken, nohut sapının N, P, K, Mg, Fe, Mn, Zn, Cu ve tane P, Mg, Fe, Zn ve B içerikleri etkilenmiştir. Bor uygulamasının ikinci dal sayısı, bakla sayısı ve fertil bakla sayısı üzerine etkisi önemli olarak belirlenirken, nohut sapının besin elementi içeriğinde P, Mg, Zn, B ile tane besin elementlerinden P, K, Ca, Mg, Fe, Mn, Zn ve B içerikleri üzerine öenmli etkisi belirlenmiştir. Besin elementi içeriği ve bitki verimi açısından uygulanacak uygun bor ve demir dozlarının 0.25 kg B da^{-1} ve 10 kg Fe da^{-1} olduğu belirlenmiştir.

Anahtar Kelimeler: Toprak, Nohut, Verim, Gübreleme, Demir, Bor

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INTRODUCTION

Nutrition of humans depends on plant and animal foods, so the nutrient content of these foods is of great importance. Micronutrient elements stand out for ideal life and physiological functions. Widespread global micronutrient deficiencies (MNDs) are a major risk, especially for pregnant women and young children. It causes weak growth, mental disorders, perinatal complications and an increase in mortality because of the diseases (Bailey et al., 2015). The main causes of hidden hunger, which affects more than 2 billion people worldwide and is characterized by micronutrient deficiencies, are iron, vitamin A and iodine deficiencies (Yılmaz and Yılmaz, 2025). The fact that 2/3 of the world's population is confronted with one or more nutrient deficiencies has brought about the widespread research for solving these problems in human nutrition by performing biofortification of the plants used in agricultural production agronomically and genetically with chemical or organic fertilizers (Orman and Kaplan, 2017). Soils used for agricultural activities around the world prevent the desired levels of plant yields from growing for one or more reasons, the same negative effect is also seen on desired levels of nutrient contents. The world population is expected to be 7.5 billion for now and 9.2 billion in 2050 (Anonymous, 2019a). On the other hand, world agricultural areas are expected to be 443 million hectares (Anonymous, 2019b) and this population increase is expected to increase the agricultural need by 40-70%. As a result, we are facing food safety as an important problem (Anonymous, 2019a). The biofortification technique that introduces a new approach in fertilization, reveals a situation different from the known agricultural production methodology (Orman and Ok, 2016). The most common micronutrient deficiency is observed especially in iron and zinc elements. Biofortification is aimed at increasing the content of micronutrient elements that can be used biologically in edible parts of agricultural products and to reduce malnutrition and hidden hunger (Singh et al., 2016). It is estimated that more than 60% of the world's population suffers from iron deficiency, more than 30% from zinc deficiency, more than 30% from iodine deficiency and more than 15% from selenium deficiency (White and Broedley, 2009). Iron deficiency causes anemia in particular and causes deterioration of the functions of the endocrine and immune systems (de Benoist et al., 2008; Bailey et al., 2015). The incidents such as climate change, erosion, urbanization, industrialization, chemical pollution, salinity, acidification that agricultural areas are exposed to and the insufficiency of agricultural areas in feeding the population, make it necessary to make more efficient use of existing areas (Anonymous, 2019c). All these factors negatively affect the biofortification of the plants grown. Biofortification studies are mostly focused on Fe and Zn (Singh et al., 2016). Although the total iron content of agricultural soils is between 20-40 g kg^{-1} (Cornell and Schwertmann, 2003), the iron content that can be taken is 10^{-20}-10^{-6} mg L^{-1} in mineral soils, and 10^{-4}-10^{-3} mg L^{-1} in organic soils (Kacar and Katkat, 1998). Soil properties that determine the behavior of iron in the soil are generally pH with redox potential (Colombo et al., 2014). The lower the pH of the soil solution, the higher the amount of soluble iron (Robin et al., 2008). In contrast, the higher the pH of the soil solution, the lower the soluble iron content will be. Therefore, iron deficiency is an important problem in calcareous soils (Mengel et al. 2001; Güneş et al., 2013). Increased yield and nutrient content have been reported with iron fertilizer applications both from leaf and soil against iron deficiency (Çimrin et al., 2000; Gökmen Yılmaz et al., 2012; Akgül et al., 2013).

Boron, first reported in 1923 as essential for the cell structure of plants (Warington, 1923), is a non-metallic micro element. The metabolic activities of boron in plants serve as a part of sugar transport, cell wall synthesis, lignification, cell wall structure integrity, carbohydrate metabolism, ribose nucleic acid (RNA) metabolism, respiration, indole acetic acid (IAA) metabolism, phenol metabolism and cell membranes (Welch, 1995; Ahmad et al., 2009; Güneş et al., 2013). In humans, it affects the skeletal and immune system and energy metabolism (Velioğlu and Şimşek, 2003). Factors affecting the roots and boron uptake of plants are soil texture, alkalinity/calcification, pH, clay minerals, organic matter content, amount of other nutrients, irrigation type, soil water content, boron content of soil solution and plant variety. In addition, boron uptake is a non-metabolic event (Welch et al., 1991; Brown and Hu, 1998; Ahmad et al., 2012). Critical value of boron content of soils is 1.0 mg kg^{-1} (Reisenaur et al., 1973) for normal growth of plants, whereas this value is 0.5 mg kg^{-1} (Keren and Bingham, 1985) in cereals. Significant increases in yield (Kausar et al., 1988; Seth and Singh, 1985; Zada and Afzal, 1997; Soylu et al., 2005) and content of some nutrients (Lopez-Lefebre et al., 2002; Shaaban et al., 2004; Ahmed et al., 2011; Aref, 2012; Ekinci et al., 2015) are reported due to boron applications. It has been reported by studies that zinc and potassium, when applied more than necessary in the environment, increase boron intake (Smithson and Herthcote, 1976; Woodruff et al., 1987) while zinc decreases it (Pilbeam and Kirkby, 1983). In a study conducted by Atsak and Çirka (2024) on bean plants, the effect of boron on heavy metals was investigated and it was determined that increasing doses of boron applications increased iron uptake in the plant. In another study conducted on black-eyed peas, the plant's iron uptake varied because of the interaction between increasing doses of boron and heavy metals (Çirka, 2023).

It was determined by Zada and Afzal (1997) that iron and boron applications did not show positive effect on yield and yield criteria when applied together and boron applications were more effective alone. On the other hand, it has been reported that the highest values have been reached in case of application of foliar boron and iron together (Rawashdeh and Sala, 2013; Gürel and Başar, 2016). In another study, it was reported that the application of iron and boron together with the seed caused a decrease in germination but increased the yield (Mirshekari, 2012).

In this study, the effects of the application of iron and boron applications to soil separately or together on the yield and yield criteria of chickpea and the biofortification of stem and grain samples were investigated.

MATERIAL AND METHOD

Materials

This study was carried out in the trial areas of the Faculty of Agriculture in the campus area of Van Yüzüncü Yıl University in the summer of 2015. Inoculant (*Rhizobium ciceri*) obtained from Ankara Soil, Fertilizer and Water Research Institute was applied to South Yellow chickpea seeds used in the experiment. South Yellow (ILC-482) chickpea cultivar used in the experiment was improved in 1983 by GAP International Agricultural Research and Training Center and registered in 1986. Plant height is 40-45 cm, height of first pod is 20-26 cm, number of pods per plant is 17-27, number of pods is 1-1,5 and the 100-grain weight is 28-31 g. Its plant growth is semi-horizontal, grain color is cream, grain type is ram and it is a winter and drought resistant early variety.

Climate Characteristics of The Research Site

The trial location is the area of the Faculty of Agriculture in the campus of Van Yüzüncü Yıl University. The study was conducted in the summer of 2015. Long-term average and climatic data of the months covering the periods in which the study was conducted are given in Table 1. The annual rainfall of the region in which the research is conducted is 297.2 mm and the average temperature is 16.6 ^{0}C and the average relative humidity is 49.98%. The rainfall in 2015 growing season is 116.5 mm. The average temperature is 16.6 ^{0}C, the average relative humidity is 58.28% (Anonymous, 2015).

Table 1. Monthly and long-term average values of some climatic characteristics of Van Province in 2015 during the growing period of Chickpea.

Çizelge 1. 2015 yılına ait Van ili nohut yetiştirme periyodunda bazı iklim özelliklerinin aylık ve uzun dönem ortalama değerleri.

Months	Rainfall (mm)	Avr.Years	Temperature (C^{0})	Avr.Years	Relative humidity (%)	Avr.Years
April	66.9	165.7	8.9	8.8	49.4	68.5
May	21.1	99.9	13.7	13.0	42.6	62.7
June	23.4	25.3	19.8	18.9	35.7	53.1
July	5.1	6.3	24.0	22.7	72.2	48.8
Total	116.5	297.2	66.4	63.4	199.9	233.1
Average	29.13	74.3	16.6	15.85	49.98	58.28

Soil Characteristics of The Research Site

Some physical and chemical analysis results of soil samples taken from 0-30 cm depth in the research area are given in Table 2. When the soil analysis results are examined, it is observed that the soil of the trial area has loamy structure, it is not salty, has a slightly alkaline reaction, it is very lime in terms of lime content, it has too little organic material content, its nitrogen content is insufficient, phosphorus content is high, potassium and copper contents are sufficient, iron and zinc content is deficient (Düzgüneş et al. 1987). The boron content of the trial site was reported to range from 1.0 to 2.0 mg kg^{-1}. This information is specified in the "Turkey Boron Map" provided by the National Boron Research Institute (BOREN).

Table 2. Some physical and chemical soil analysis results of field trials.
Çizelge2. Deneme toprağının bazı fiziksel ve kimyasal analiz sonuçları.

Depth	Texture		pH	Lime	O.M.	N	P	K	Fe	Cu	Zn
		%					mg kg^{-1}				
0-30 cm	Loamy	0.033	7.80	19.59	0.69	0.034	17.90	459	0.2	0.92	0.68

Methods

The experiment was established as a field study in the trial area of the Department of Field Crops in Van Yüzüncü Yıl University. The experiment was conducted according to the factorial experiment design in randomized blocks with three replications. South Yellow variety was used as the material. Planting frequency was 60 seeds per m^2 (Toğay et al., 2005).

During the planting, urea (46% N) and DAP (18% N, 46% P_2O_5) were spread to the soil by hand as nitrogen 4 kg da^{-1} and 6 kg P_2O_5 da^{-1} and rake was used to mix it in the soil. In the experiment, seed planting was carried out by hand with 30 cm and 4-5 cm above the row. The parcel size was 1.5 m x 4 m = 6 m^2. The experiment consisted of a total of 27 parcels. There is a 1-meter gap between the parcels and a 2-meter gap between the blocks. Iron sulphate ($FeSO_4.7H_2O$) was used as the applied iron doses of Fe_0;0, Fe_1;5, Fe_2;10 kg Fe da^{-1} and boric acid (H_3BO_3) was used as applied boron doses of B_0;0, B_1;0.25, B_2;0.50 kg B da^{-1}. Both iron and boron doses were carefully spread on the plot surfaces before seed sowing and then mixed with a rake. The trial area was periodically observed. As weeds emerged in the field, weed control was carried out mechanically by plucking out the weeds on the rows by hand and grubbing up the weeds between the rows. At the time of the harvest, 0.5-meter areas were removed from parcel heads and one row from each side is deducted. Then the assessments were made on an area of 1.2 m x 3m = 3.6 m^2. The experiment was carried out under dry farming conditions. Sowing was carried out in the third week of April (20.04.2015), and the crop was harvested in full maturity in the last week of July (24.07.2015).

Nutrient Analysis in Plant Samples

At the end of the experiment, plant samples taken from each parcel were brought to the laboratory and separated into stems and grains. The separated stem and grain samples were dried in the oven at 70 ^{0}C until they reach constant weight. The dried samples were milled with a plant grinding mill and made ready for analysis according to Kacar and Inal (2008). The obtained extracts were read in the Van Yüzüncü Yıl University Central Research Laboratory using Atomic Absorption Spectrophotometer for K, Ca, Mg, Fe, Mn, Zn and Cu elements and ICP-OES instrument for boron. Nitrogen analysis was determined by micro-Kjeldahl method and phosphorous extracts were determined spectrophotometrically according to yellow color method (Kacar ve Inal, 2008).

Yield and Yield Criteria's

The yield components of 10 plants taken from each plot representing that plot were determined according to Tosun and Eser (1975). Biological and grain yields were calculated as yield per decare by harvesting the plants in the middle and weighing them carefully in the laboratory after removing lots from each side and reducing 50 cm from each head of the parcel. Harvest index was determined by ratio of grain yield to biological yield.

Chemical Analysis of Soil Sample

The soil sample taken according to Jackson (1958) from the trial area was placed in a plastic bag and brought to the laboratory. After drying under appropriate conditions in the laboratory, it was hammered with a wooden mallet and passed through a 2 mm sieve and stored in plastic boxes with lids during the analysis. In soil samples, the analyses of structure, pH, salt, lime, organic matter and N, P, K, Fe, Mn, Zn and Cu elements were made according to the methods specified by Kacar (1994). Total nitrogen analysis in soil samples was determined by micro kjehldahl method, and available phosphorus analysis was determined by spectrophotometer. Exchangeable K and available Fe, Mn and Zn elements were determined with the ICP-OES instrument.

Statistical Analysis

Whether the effects of iron and boron applications on yield and nutrient content were significant was determined by two-way analysis of variance with the help of CoStat statistical package program. The parameters found to be significant in the analysis of variance were subjected to Student-t (LSD) test and the minimum significant difference between the applications was determined (Düzgüneş et al., 1987).

RESULTS AND DISCUSSION

Effect of Iron and Boron Applications on Yield and Yield Criteria

The results of variance analysis of the effects of iron and boron applications on chickpea yield and yield criteria are given in Table 3. The averages of the effects of applications on yield and yield criteria are given in Tables 4. The BxFe interaction, which has an important effect on number of pods and number of fertile pods, is given in Figures 1 and 2.

Table 3. Results of variance analysis of the effects of boron and iron applications on chickpea yield and yield criteria.
Çizelge 3. Bor ve demir uygulamalarının nohut verimi ve verim kriterleri üzerindeki etkilerine ilişkin varyans analizi sonuçları.

Yield criterias	V.S.	D.F.	M.O.	F value
Plant height	Iron (Fe)	2	0.67	0.44 ns
	Boron (B)	2	1.81	1.22 ns
	BxFe	4	1.49	1.01 ns
First pod height	Iron (Fe)	2	2.735	2.81 ns
	Boron (B)	2	0.577	0.59 ns
	BxFe	4	0.648	0.67 ns
First branch number	Iron (Fe)	2	0.335	1.32 ns
	Boron (B)	2	0.087	0.34 ns
	BxFe	4	0.294	1.15 ns
Second branch number	Iron (Fe)	2	0.049	0.12 ns
	Boron (B)	2	2.020	4.84*
	BxFe	4	0.464	1.11 ns
Pods number	Iron (Fe)	2	3.766	1.55 ns
	Boron (B)	2	37.254	15.29 **
	BxFe	4	7.340	3.01 *
Fertile pods number	Iron (Fe)	2	2.170	0.99 ns
	Boron (B)	2	34.854	15.99**
	BxFe	4	7.484	3.43*
Biological yield	Iron (Fe)	2	481.34	3.87*
	Boron (B)	2	3.957	0.03 ns
	BxFe	4	148.14	1.19 ns
Grain yield	Iron (Fe)	2	143.72	3.08 ns
	Boron (B)	2	4.21	0.04 ns
	BxFe	4	20.09	0.81 ns
Harvest index	Iron (Fe)	2	0.425	0.14 ns
	Boron (B)	2	0.633	0.21 ns
	BxFe	4	2.002	0.66 ns

*, %5; **, %1; ns, non significant.

As can be seen in Table 3, the number of branches ($p \leq 0.05$), number of pods ($p \leq 0.01$) and fertile number of pods ($p \leq 0.01$) were affected by boron applications, while iron applications only had an effect on biological yields ($p \leq 0.05$). The effect of the interaction was determined only on the number of fertile pods. The effect of applications on other yield criteria was not determined (Tab. 3).

It has been found that boron and iron applications cause decreases in plant height compared to control, but these changes do not have a statistically significant effect. Plant height, which was 23.25 cm in control plants, increased to 24.11 cm in B_1 (0.50 kg B da^{-1}) application. The lowest plant height was obtained in B_0 (0 kg B da^{-1}) application as 23.25 cm (Table 4).

Compared to control plants, iron applications had a positive effect on first pod height, while boron applications had a negative effect. The first pod height was increased to 14.07 cm in Fe_2 (10 kg Fe da^{-1}) application and was measured as 12.97 cm in Fe_0 (0 kg Fe da^{-1}) (Table 4).

It has been found that boron and iron applications cause decreases in plant height compared to control, but these changes do not have a statistically significant effect. Plant height, which was 24.65 cm in control plants, decreased to 23.26 cm in B_1 (0.50 kg B da^{-1}) application and 23.35 cm in Fe_2 (10 kg Fe da^{-1}) application. The lowest plant height was obtained with B_1xFe_1 (0.25 kg B da^{-1}x5 kg Fe da^{-1}) interaction as 22.92 cm. Compared to control plants, iron applications had a positive effect on first pod height, while boron applications had a negative effect. The first pod height was increased to 14.73 cm in 10 kg Fe da^{-1} application and was measured as 13.24 cm in control. The most significant first pod height in boron x iron applications was measured with B_2xFe_2 (0.50 kg B da^{-1}x10 kg Fe da^{-1}) application as 14.15 cm (Fig. 1). The number of first branches decreased with iron applications compared to control. The number of first branches, which was 4.01 number $plant^{-1}$ at the control, decreased to 3.88 number $plant^{-1}$ and 3.33 number $plant^{-1}$ with 5 kg Fe da^{-1} and 10 kg Fe da^{-1} applications, respectively. This was a decrease of 22.8%. It was determined that there was an increase and then a decrease with boron applications. The first branch number increased to 3.94 number $plant^{-1}$ with 0.25 kg B da^{-1} boron application and decreased to 3.77 number $plant^{-1}$ with 0.50 kg B da^{-1} application (Table 4).

Table 4 Effects of iron and boron applications on average yield and yield criteria of chickpea.
Çizelge 4. Demir ve bor uygulamalarının nohutta ortalama verim ve verim kriterleri üzerine etkileri.

Treatments	PH	FPH	FBN	SBN	PN	FPN	BY	GY	HI
	cm		Number				Kg da^{-1}		%
Iron, kg da^{-1}									
0	23.74	12.97 b	4.01	3.58	15.22	14.71	95.3 b	47.3 b	49.6
5	23.30	13.54 ab	3.83	3.72	15.71	14.63	101.7 ab	50.7 ab	49.7
10	23.79	14.07 a	3.63	3.68	16.65	15.50	109.9 a	54.1 a	49.3
LSD(<0.05)	1.21	0.98	0.50	0.79	1.60	1.48	10.5	6.7	2.7
Boron, kg da^{-1}									
0.00	23.25	13.82	3.77	3.15 b	13.61 b	12.70 b	101.9	50.3	49.3
0.25	24.11	13.36	3.94	3.74 ab	16.73 a	15.82 a	103.1	51.1	49.4
0.50	23.46	13.40	3.77	4.09 a	17.23 a	16.32 a	102.0	50.8	49.8
LSD(<0.05)	1.21	0.98	0.50	0.79	1.60	1.48	10.5	6.7	2.73

a, b, c; Values followed by the different letters are significantly different, PH, Plant Height; FPH, First Pod Height; FBN, First Branch Number; SBN, Second Branch Number; PN, Pods Number; FPN, Fertile Pods Number; BY, Biological Yield; GY, Grain Yield; HI, Harvested Index.

The second branch number increased with both boron applications compared to control plants and had statistically significant effect. The number of second branches which was 3.15 number $plant^{-1}$ in control plants are respectively determined as 3.74 number $plant^{-1}$, and 4.09 number $plant^{-1}$ with 0.25 kg B da^{-1} and 0.50 kg B da^{-1} applications. These increases were 18.7%, and 29.8% respectively (Table 4).

Both the number of pods and the number of fertile pods increased with iron and boron applications compared to control. It was found that boron and boron x iron had statistically significant effects in these applications. The number of pods and fertile pods that were 13.61 No. $plant^{-1}$ and 12.70 No. $plant^{-1}$ in control plants respectively are detected as 17.23 No. $plant^{-1}$ and 16.32 No. $plant^{-1}$ respectively with 0.50 kg B da^{-1} applications. Compared to control plants, these increases were realized as 26.6% and 28.5% in boron applications respectively (Table 4).

Although iron, boron and boron x iron applications affect the biological yield and grain yield, only iron applications were found to be statistically significant. The biological yield which was 95.30 kg da^{-1} in control, raised to 101.7 kg da^{-1}, 109.9 kg da^{-1} with 5 and 10 kg Fe da^{-1} applications, and 47.3 kg da^{-1} in control, raised to 50.7 kg da^{-1}, and 54.1 kg da^{-1}, respectively with 0.25 kg B da^{-1} and 0.50 kg B da^{-1} applications. These increases were realized as 6.7%, 15.3%, 7.2% and 14.4% respectively (Table 4).

Although boron, iron and boron x iron applications have effects on harvest index, these changes are not found to be statistically significant. Even though the harvest index was 49.6% in control plants, it was detected as 49.7%, 49.3% respectively with 5 kg Fe da^{-1} and 10 kg Fe da^{-1}, and 49.3% in control plants, 49.4% and 49.8 % respectively with 0.25 kg B da^{-1} and 0.50 kg B da^{-1} applications (Table 4).

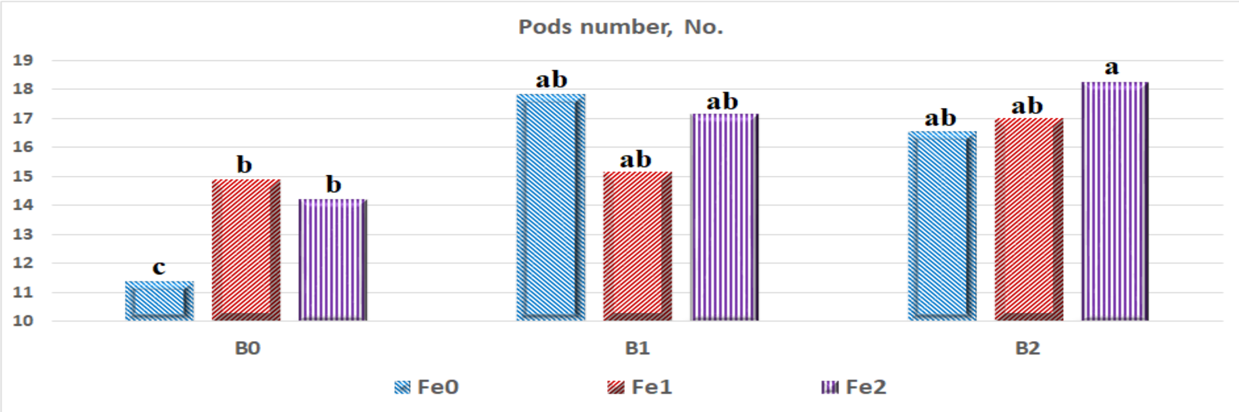

Figure 1. Effects of BxFe interactions on number of pods, B_0;0 kg B da^{-1}, B_1;0.25 kg B da^{-1}, B_2;0.50 kg B da^{-1}, Fe0; 0 kg Fe da^{-1}, Fe_1; 5 kg Fe da^{-1}, Fe_2;10 kg Fe da^{-1}, LSD (<0.05): 2.89.

Şekil 1. BxFe interaksiyonunun bakla sayısı üzerine etkisi.

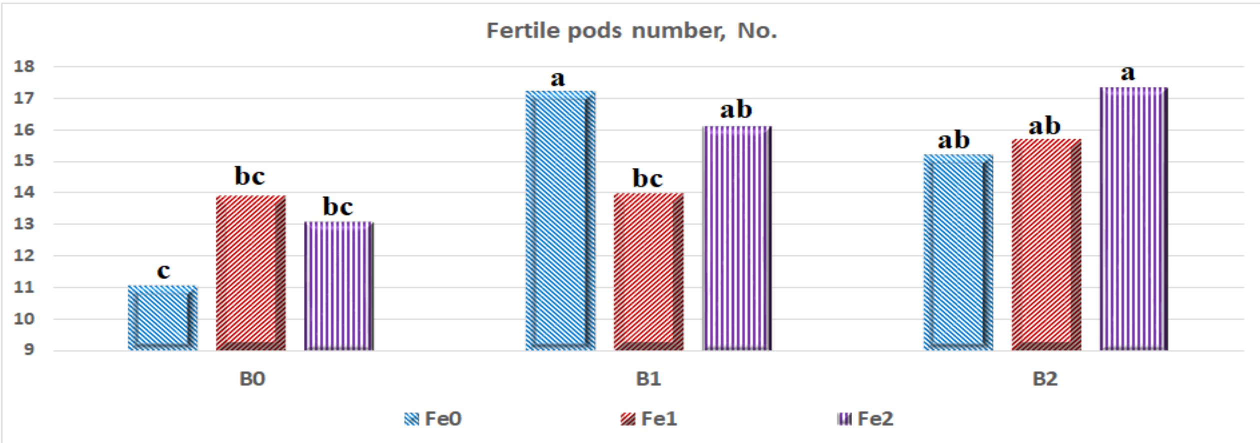

Figure 2. Effects of BxFe interactions on fertile pods number, B_0;0 kg B da^{-1}, B_1;0.25 kg B da^{-1}, B_2;0.50 kg B da^{-1}, Fe0; 0 kg Fe da^{-1}, Fe_1; 5 kg Fe da^{-1}, Fe_2;10 kg Fe da^{-1}, LSD (<0.05):2.62.

Şekil 2. BxFe interaksiyonunun fertile bakla sayısı üzerine etkisi.

The highest value in boron x iron interaction both number of pods and number of fertile pods were obtained with 18.25 and 17.33 No. plant^{-1} in B_2xFe_2 (0.50 kg B da^{-1}x10 kg Fe da^{-1}) application. An increase of 60.2/56.3% was observed in comparison to control treatments (B_0xFe_0) (Figure 1, 2).

Effect of B and Fe Applications on Chickpea Straw and Grain Nutrient Contents

The results of variance analysis of the effects of iron and boron applications on chickpea straw and grain nutrients are given in Tables 5 and 6. The effects of applications on nutrient contents of chickpea straw and grain are given in Tables 7. and 8. The BxFe interactions, which have an important effect on the straw and grain nutrient contents, are given in Figures 3, 4, 5, 6, 7 and 8.

While iron (FE) application had an effect at $P \leq 0.01$ level on chickpea stem N, P, K and B contents and effect at $P \leq 0.05$ level on Mg, Fe, Mn and Zn contents, boron (B) application had an effect at $P \leq 0.01$ level on P, Mg, Zn and B contents. It was detected that iron application on chickpea grain P, Mg, Fe, Zn and B contents had a significant effect at *P*≤0.01 level, while boron application had a significant effect on P, K, Ca, Mg, Fe, Mn, Zn, Cu and B contents at *P*≤0.01 level. Boron x iron (BxFe) interaction was found to have effects on stem P (*p*≤0.01), grain Ca (*p*≤0.05), grain Mg (*p*≤0.01), stem Fe (*p*≤0.05), grain Zn (*p*≤0.05) and stem Cu (*p*≤0.01) contents (Tab. 4, 5).

Table 5. The results of variance analysis of the effects of boron and iron applications on the straw and grain macro element contents of chickpea.

Çizelge 5. Nohutun sap ve tane makro element içerikleri üzerine bor ve demir uygulamalarının etkilerine ait varyans analizi sonuçları.

Elements	Organs	V.S.	D.F.	M.O	F value
N	Straw	Iron (Fe)	2	0.106	7.45 **
		Boron (B)	2	0.012	0.87 ns
		BxFe	4	0.005	0.33 ns
	Grain	Iron (Fe)	2	0.0112	0.74 ns
		Boron (B)	2	0.0035	0.23 ns
		BxFe	4	0.0067	0.44 ns
P	Straw	Iron (Fe)	2	129016	12.66**
		Boron (B)	2	516100	28.76**
		BxFe	4	99499	10.36**
	Grain	Iron (Fe)	2	1223377	13.69 **
		Boron (B)	2	2959572	26.62 **
		BxFe	4	98251	0.84 ns
K	Straw	Iron (Fe)	2	22701744	7.15 **
		Boron (B)	2	3672597	1.16 ns
		BxFe	4	1507395	0.48 ns
	Grain	Iron (Fe)	2	1088233	1.22 ns
		Boron (B)	2	5535958	6.23 **
		BxFe	4	593876	0.67 ns
Ca	Straw	Iron (Fe)	2	2195184	1.02 ns
		Boron (B)	2	5529074	2.56 ns
		BxFe	4	2011710	0.93 ns
	Grain	Iron (Fe)	2	51974	1.49 ns
		Boron (B)	2	334902	9.58 **
		BxFe	4	111864	3.20 *
Mg	Straw	Iron (Fe)	2	371063	3.76 *
		Boron (B)	2	1956428	19.83 **
		BxFe	4	174058	1.76 ns
	Grain	Iron (Fe)	2	2343292	55.02 **
		Boron (B)	2	336545	7.90 **
		BxFe	4	427561	10.04 **

*, %5; **, %1; ns, non significant.

As can be seen in Table 7, both iron and boron applications caused a decrease in the nitrogen content of chickpea straw compared to control. Nitrogen content, which was 1.696% in control plants was detected as 1.481% representing a lowest value in Fe_1 applications. It was found that there was a decrease of 14.5% compared to control.

Straw potassium content increased with iron applications compared to control, whereas in boron applications, it decreased. Straw K content which was 1.989% in control increased to 2.289% with Fe_2 application. These changes were detected as 15.1%. While straw Ca content increased with boron and iron applications. The effect of iron and boron applications on straw calcium content was not statistically significant (Table 7).

Table 6. The results of variance analysis of the effects of boron and iron applications on the straw and grain micro element contents of chickpea.
Çizelge 6. Nohutun sap ve tane mikro element içerikleri üzerine bor ve demir uygulamalarının etkilerine ait varyans analizi sonuçları.

Elements	Organs	V.S.	D.F.	M.O	F value
Fe	Straw	Iron (Fe)	2	28139	12.19 **
		Boron (B)	2	4702	2.03 ns
		BxFe	4	8074	3.50 *
	Grain	Iron (Fe)	2	5770	54.66 **
		Boron (B)	2	3323	31.49 **
		BxFe	4	298	2.83 ns
Mn	Straw	Iron (Fe)	2	23.895	4.20 *
		Boron (B)	2	6.004	1.05 ns
		BxFe	4	13.689	2.40 ns
	Grain	Iron (Fe)	2	9.245	1.16 ns
		Boron (B)	2	65.130	8.18 **
		BxFe	4	19.767	2.48 ns
Zn	Straw	Iron (Fe)	2	25.055	4.42 *
		Boron (B)	2	102.105	18.05 **
		BxFe	4	10.750	1.90 ns
	Grain	Iron (Fe)	2	228.647	13.12 **
		Boron (B)	2	328.005	18.82 **
		BxFe	4	61.759	3.54 *
Cu	Straw	Iron (Fe)	2	0.064	0.03 ns
		Boron (B)	2	1.166	0.53 ns
		BxFe	4	23.648	10.69 **
	Grain	Iron (Fe)	2	11.234	3.05 ns
		Boron (B)	2	32.028	8.70 **
		BxFe	4	10.455	2.81 ns
B	Straw	Iron (Fe)	2	18.481	8.08 **
		Boron (B)	2	350.259	153.15 **
		BxFe	4	0.477	0.48 ns
	Grain	Iron (Fe)	2	814.78	11.75 **
		Boron (B)	2	514.11	7.42 **
		BxFe	4	25.06	0.36 ns

*, %5; **, %1; ns, non significant.

Table 7. Effects of iron and boron applications on average macro nutrients of chickpea.
Çizelge 7. Nohutun ortalama makro besin elementleri üzerine demir ve bor uygulamalarının etkileri.

Treatments	Nitrogen %		Phosphorous mg kg^{-1}		Potassium %		Calcium %		Magnesium mg kg^{-1}	
	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain
Iron, kg da^{-1}										
0	1.696 a	4.695	578 b	3589 b	1.989 b	0.899	0.863	0.173	2748 b	1279 b
5	1.481 b	4.647	585 b	4092 a	2.048 b	0.969	0.874	0.179	2912 ab	1698 a
10	1.559 b	4.716	901 a	4403 a	2.289 a	0.929	0.954	0.188	3152 a	682 c
LSD(<0.05)	0.119	0.123	156	333	0.178	0.094	0.147	0.019	314	207
Boron, kg da^{-1}										
0.00	1.621	4.663	374 a	3366 b	2.124	0.847 b	0.809	0.158 b	2411 b	1393 a
0.25	1.552	4.697	785 a	4377 a	2.165	0.949 a	0.960	0.190 a	3102 a	1255 a
0.50	1.562	4.698	905 a	4340 a	2.039	1.001 a	0.921	0.192 a	3299 a	1011 b
LSD(<0.05)	0.119	0.123	156	333	0.178	0.094	0.147	0.019	314	207

a, b, c; Values followed by the different letters are significantly different.

It was determined that straw phosphorus content increased in boron, iron and boron x iron applications compared to control. Straw P content that was 578 mg kg^{-1} in control, raised to 901 mg kg^{-1} in Fe_2 application. This increase was 55.9%. Straw phosphorus content increased with boron applications. While it was 374 mg kg 1 in control, it increased by 785 mg kg 1 and 905 mg kg 1 with B_1 and B_2 applications, respectively. These increases were 109.8% and 141.9% (Table 7). The lowest value in boron x iron interaction was determined as 300 mg kg^{-1} in B_0xFe_0 application, while the highest straw phosphorus content was determined as 1155 mg kg^{-1} in B_2xFe_2 application. This increase was realized as 285.0% (Figure 3).

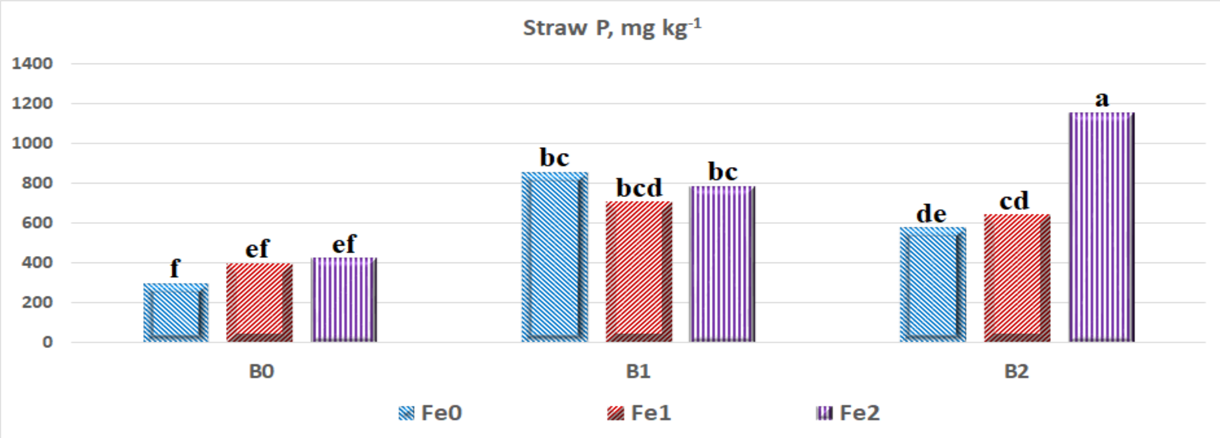

Figure 3 Effects of BxFe interactions on straw phosphorous content, B_0;0 kg B da^{-1}, B_1;0.25 kg B da^{-1}, B_2;0.50 kg B da^{-1}, Fe0; 0 kg Fe da^{-1}, Fe_1; 5 kg Fe da^{-1}, Fe_2;10 kg Fe da^{-1}, LSD (<0.05): 270.

Şekil 3. BxFe interaksiyonunun sap fosfor içeriği üzerine etkisi.

Straw Mg content of boron and iron applications were found to increase compared to control. Straw Mg content, which was 2748 mg kg^{-1} in the control, increased to 2921 mg kg^{-1}, and 3152 mg kg^{-1} in Fe_1, and Fe_2 applications, respectively. These increases were realized as 6.0% and 14.7% respectively. Straw magnesium content increased with boron applications. While 2411 mg kg^{-1} in control, 3102 mg kg^{-1} and 3299 mg kg^{-1} increased with B_1 and B_2 administration. These increases were realized as 28.6% and 36.8%, respectively (Table 7).

Table 8 Effects of iron and boron applications on average micronutrients of chickpea.

Çizelge 8. Nohutun mikro besin elementleri üzerine demir ve bor uygulamalarının etkileri.

Treatments	Iron		Manganese		Zinc		Copper		Boron	
	mg kg^{-1}									
	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain
Iron, kg da^{-1}										
0	500 b	89.1 c	21.9 a	23.0	26.9 b	46.9 b	16.5	17.8 b	8.33 b	58.3 b
5	574 a	121.6 b	19.1 b	24.1	29.0 ab	53.8 a	16.3	19.3 ab	10.33 a	65.8 b
10	610 a	138.9 a	19.1 b	25.0	30.2 a	56.7 a	16.5	19.9 a	11.11 a	77.2 a
LSD(<0.05)	48	10.3	2.4	2.9	2.4	4.2	1.5	1.9	1.5	8.3
Boron, kg da^{-1}										
0.00	542	97.4 c	20.0	21.6 b	26.2 b	45.6 b	16.8	16.8 b	3.44 c	59.7 b
0.25	556	116.4 b	20.9	27.0 a	27.4 b	57.1 a	16.2	19.9 a	10.44 b	66.9 ab
0.50	587	135.9 a	19.2	23.6 b	32.5 a	54.7 a	16.2	20.3 a	15.89 a	74.8 a
LSD(<0.05)	48	10.3	2.4	2.9	2.4	4.2	1.5	1.9	1.5	8.3

a, b, c; Values followed by the different letters are significantly different.

It was determined that iron application had significant effect on chickpea straw Fe content. The iron content, which was 500 mg kg^{-1} in the control, increased to 610 mg kg^{-1} with Fe_2 application and this amounted to 22.0% (Table 8). Boron x iron application also increased straw iron content. In the boron x iron interaction, the lowest straw iron value was determined as 436 mg kg^{-1} in B_1xFe_0 application, while the highest straw iron content was determined as 622 mg kg^{-1} in B_2xFe_2 application. This increase was 61.4% (Figure 4).

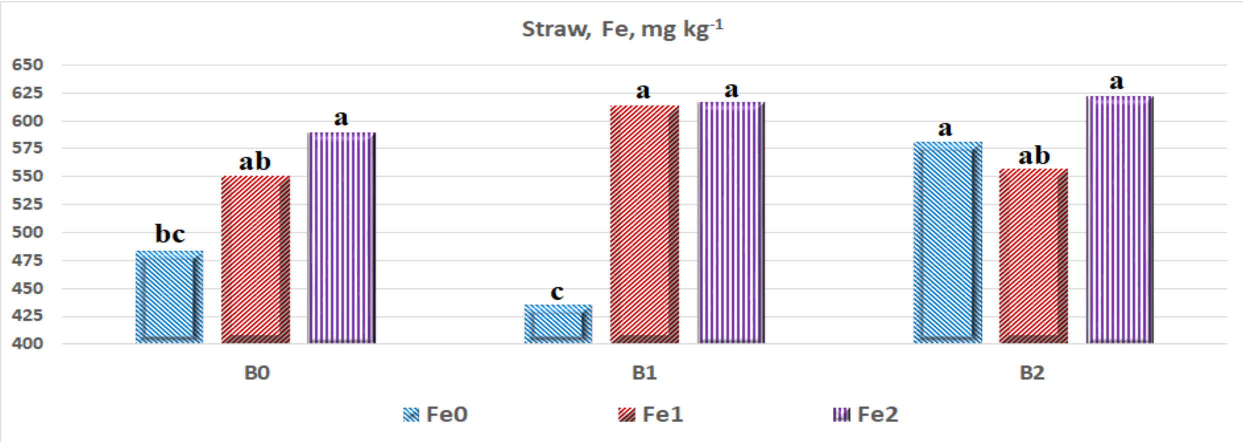

Figure 4. Effects of BxFe interactions on straw iron content, B_0;0 kg B da^{-1}, B_1;0.25 kg B da^{-1}, B_2;0.50 kg B da^{-1}, Fe0; 0 kg Fe da^{-1}, Fe_1; 5 kg Fe da^{-1}, Fe_2;10 kg Fe da^{-1}, LSD (<0.05): 83.

Şekil 4. BxFe interaksiyonunun sap demir içeriği üzerine etkisi.

Straw Mn content decreased with iron application compared to control. Mn content of chickpea straw which was 21.9 mg kg^{-1} in the control decreased to 19.1 mg kg^{-1} with Fe_2 application and this decrease was 14.7% (Table 8).

Straw Zn content increased with boron, iron and boron x iron applications compared to control. Straw zinc content increased with iron applications. While it was 26.9 mg kg^{-1} in the control, 29.0 mg kg^{-1} and 30.2 mg kg^{-1} increased with Fe_1 and Fe_2 applications. These increases were 7.8% and 12.3%, respectively. Straw zinc content increased with boron applications. While it was 26.2 mg kg^{-1} in the control, 27.4 mg kg^{-1} and 32.5 mg kg^{-1} increased with B_1 and B_2 applications. These increases were 4.6% and 24.0%, respectively (Table 8).

Chickpea straw B content increased with boron and iron applications. Straw boron content, which was 8.33 mg kg^{-1} in in the control, increased by 10.33 mg kg^{-1} and 11.11 mg kg^{-1} with Fe_1 and Fe_2 applications. These increases were 24.0% and 33.4%, respectively. Straw boron content, which was 3.44 mg kg^{-1} in in the control, increased by 10.44 mg kg^{-1} and 15.89 mg kg^{-1} with B_1 and B_2 applications. These increases were 203.5% and 361.9%, respectively (Table 8).

The effects of iron applications on chickpea's grain nitrogen, potassium and calcium contents were not found to be significant. Boron applications, on the other hand, had a significant effect on phosphorus, potassium, calcium and magnesium contents, except nitrogen (Table 5). Grain phosphorus content increased from 3589 mg kg^{-1} (Fe_0) to 4403 mg kg^{-1} (Fe_2) with increasing iron applications. This increase was 22.7%. Similarly, the grain phosphorus content increased with boron applications, from 3366 mg kg^{-1} in B_0 application to 4340 mg kg^{-1} in B_2 application. This increase was realized as 28.9% (Table 7).

A statistically significant increase in grain potassium and calcium contents were determined only with boron application. While grain K and Ca contents were 0.847% and 0.158%, respectively, in B_0 application, it increased to 1.001% and 0.192%, respectively, with B_2 application. These increases were 18.2% and 21.5% (Table 6). Boron x iron interaction had a statistically significant effect on grain calcium content (Table 4).

Although the effect of iron and boron applications on the copper content of chickpea straws was statistically insignificant, the BxFe interaction had a significant effect (Table 6). While the lowest straw copper value in the boron x iron interaction was determined as 14.3 mg kg^{-1} in B_2xFe_0 application, the highest straw copper content was determined as 20.6 mg kg^{-1} in B_0xFe_0 application. This difference was 44% (Figure 5).

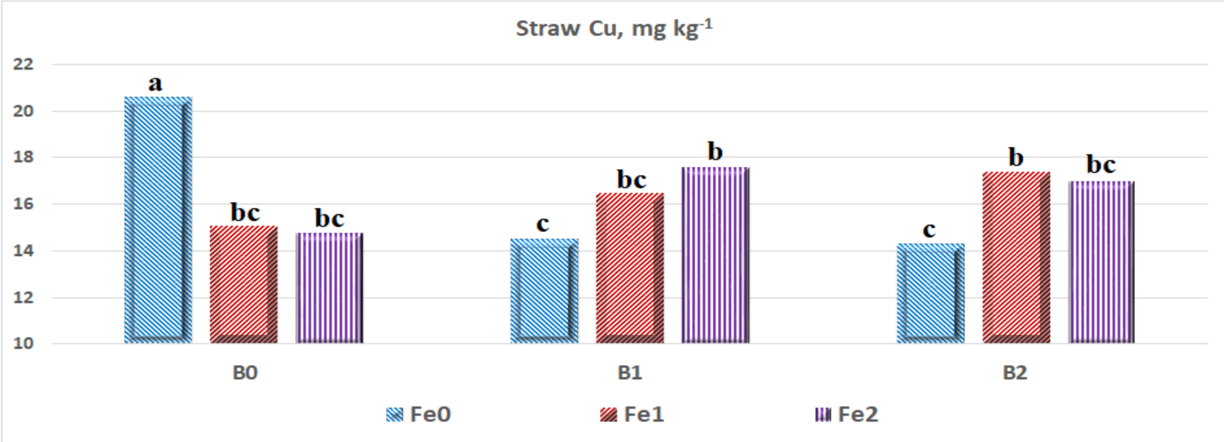

Figure 5. Effects of BxFe interactions on straw copper content, B_0;0 kg B da^{-1}, B_1;0.25 kg B da^{-1}, B_2;0.50 kg B da^{-1}, Fe0; 0 kg Fe da^{-1}, Fe_1; 5 kg Fe da^{-1}, Fe_2;10 kg Fe da^{-1}, LSD (<0.05): 2.57.

Şekil 5. BxFe interaksiyonunun sap bakır içeriği üzerine etkisi.

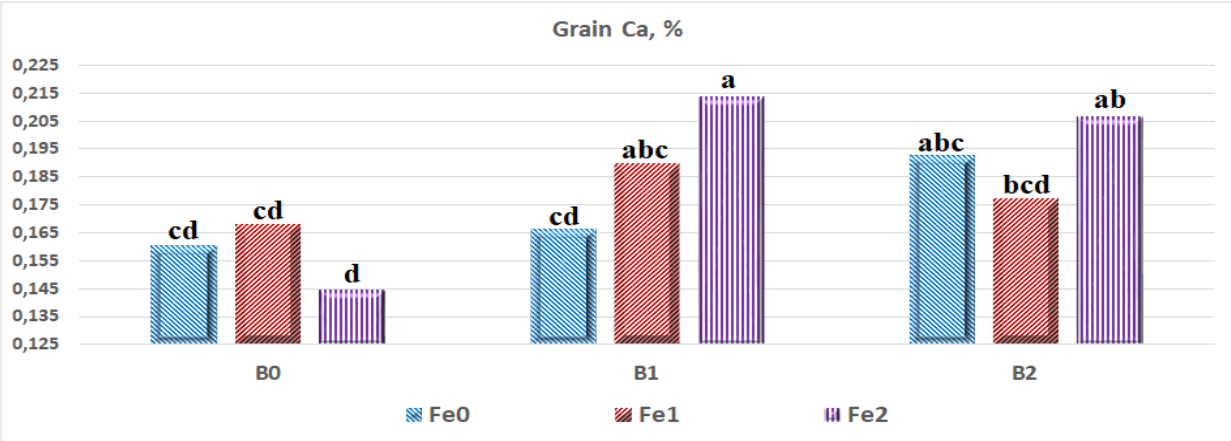

Figure 6. Effects of BxFe interactions on grain calcium content, B_0;0 kg B da^{-1}, B_1;0.25 kg B da^{-1}, B_2;0.50 kg B da^{-1}, Fe0; 0 kg Fe da^{-1}, Fe_1; 5 kg Fe da^{-1}, Fe_2;10 kg Fe da^{-1}, LSD (<0.05): 323.

Şekil 6. BxFe interaksiyonunun tane kalsiyum içeriği üzerine etkisi.

The lowest grain calcium content was determined as 1445 mg kg^{-1} in B_0xFe_2 application, while the highest grain calcium content was determined with 2138 mg kg^{-1} in B_1xFe_2 application. There was a difference of 47.9% between these two applications (Figure 6).

A statistically significant decrease was determined in grain magnesium content with both iron and boron applications. While grain Mg content was 1279 mg kg^{-1} in Fe_0 application, it decreased to 682 mg kg^{-1} with Fe_2 application. This decrease was 87.5%. Grain magnesium content was determined as 1393 mg kg^{-1} in B_0 application, while it was determined as 1011 mg kg^{-1} in B_2 application. This decrease was 37.8% (Table 7). Grain magnesium content was affected by boron x iron interaction (Table 4). The lowest grain magnesium content was 747 mg kg^{-1} in B_2xFe_0 interaction, the highest grain magnesium content was determined with 2092 mg kg^{-1} in B_0xFe_1 interaction. 180.0% difference was determined between these two (Figure 7).

While the grain iron, zinc, and boron contents of chickpeas were statistically significantly affected by both iron and boron applications, the grain manganese and grain copper content were statistically significantly affected only by boron application. Boron x iron interaction had a statistically significant effect only on grain zinc (Table 7).

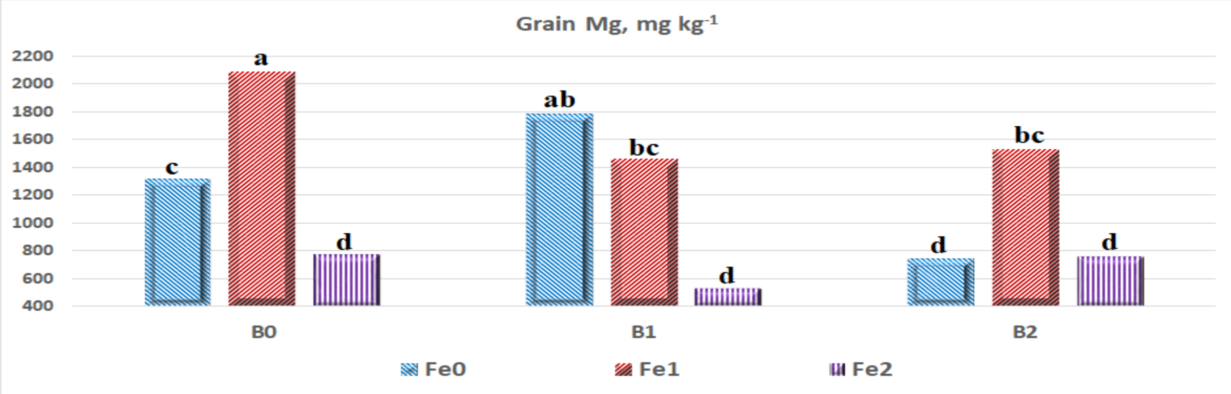

Figure 7. Effects of BxFe interactions on grain magnesium content, B_0;0 kg B da^{-1}, B_1;0.25 kg B da^{-1}, B_2;0.50 kg B da^{-1}, Fe0; 0 kg Fe da^{-1}, Fe_1; 5 kg Fe da^{-1}, Fe_2;10 kg Fe da^{-1}, LSD (<0.05): 357.

Şekil 7. BxFe interaksiyonunun tane magnezyum içeriği üzerine etkisi.

Grain iron content increased with increasing iron applications. The grain iron content, which was 89.1 mg kg^{-1} in Fe_0 treatment, was determined as 138.9 mg kg^{-1} with Fe_2 treatment. An increase of about 55.9% was achieved here. A similar situation was obtained in the boron application. The grain iron content, which was 97.4 mg kg^{-1} in B_o application, increased to 135.9 mg kg^{-1} with B_2 application and this increase occurred at the level of 39.5% (Table 8).

Grain manganese content increased only with increasing boron applications. The grain manganese content, which was 21.6 mg kg^{-1} in B_0 application, was determined as 27.0 mg kg^{-1} with B_1 application and 23.6 mg kg^{-1} in B_2 treatment. There was a difference of 25.0% between B_o and B_1 applications (Table 8).

Zinc content of chickpea grain increased with iron and boron applications. While grain zinc content was determined as 46.9 mg kg^{-1} and 45.6 mg k^{-1} in Fe_0 and B_0 applications, respectively, it reached the highest value in Fe_2 and B_1 applications, respectively, as 56.7 mg kg^{-1} and 57.1 mg kg^{-1} (Table 8). When the effect of boron x iron interaction was examined, the lowest grain zinc content was found as 39.8 mg kg^{-1} in B_0xFe_0 interaction, and the highest grain zinc content was 66.8 mg kg^{-1} in B_1xFe_2 interaction. There was a difference of 67.8% between these two values (Figure 8).

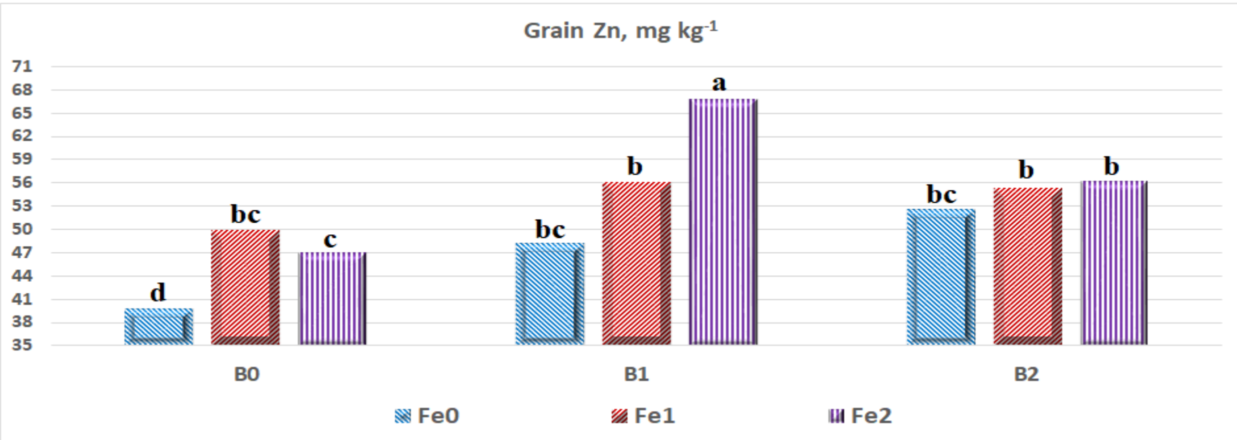

Figure 8. Effects of BxFe interactions on grain zinc content, B_0;0 kg B da^{-1}, B_1;0.25 kg B da^{-1}, B_2;0.50 kg B da^{-1}, Fe0; 0 kg Fe da^{-1}, Fe_1; 5 kg Fe da^{-1}, Fe_2;10 kg Fe da^{-1}, LSD (<0.05): 7.23.

Şekil 8. BxFe interaksiyonunun tane çinko içeriği üzerine etkisi.

Copper content of chickpea grain increased with iron and boron applications. While grain Cu content was determined as 17.8 mg kg^{-1} and 16.8 mg k^{-1} in Fe_0 and B_0 applications, respectively, it reached the highest value in Fe_2 and B_2 applications, respectively, as 19.9 mg kg^{-1} and 20.3 mg kg^{-1} (Table 8).

Chickpea grain boron content increased with both iron and boron applications. While grain boron content was determined as 58.3 mg kg^{-1} in Fe_0 application, it was determined as 77.2 mg kg^{-1} in Fe_2 application. 32.4% increase was achieved here. The grain boron content increased with increasing boron doses, the lowest grain boron content was 59.7 mg kg^{-1} in B_0 application, and the highest grain boron content was 74.8 mg kg^{-1} in B_2 application. Between these two values was determined a difference of 25.3% (Table 8).

DISCUSSION

As a result of the study, which investigated the effect of iron and boron applications on the biofortification of chickpea stem and grain organs, it was determined that application of iron and boron applications separately or together was effective on second branch number, number of pods, fertile pod number and biological yield. This may be due to the genetic characteristics of the plant, or the positive or negative factors brought about by the synergistic or antagonistic relationships between the nutrients. As a matter of fact, in similar studies, it was reported that the effects of iron or boron applications on the yield and yield components differed in applications where they were applied separately or together (Bayrak et al., 2005; Gülümser et al., 2005; Yıldırım, 2016; Erdemci et. al., 2017; Janmohammadı et al., 2017; Kuldeep et al., 2018). Factors such as low relative humidity, low precipitation and high temperature due to unfavorable environmental conditions between March and June, affect the yield; and water is of great importance in the uptake of nutrients by plant roots (Çetin et al., 1999).

When the effects of iron applications on the nutrient contents of chickpea were examined, it was determined that P, K, Mg, Fe, Zn and B contents increased and N, Ca, Mn and Cu contents decreased compared to control plants. When the effects of iron applications on grain nutrient contents were examined, it was determined that N, P, Mg, Fe, Zn and B contents increased and K, Ca, Mn and Cu contents decreased compared to control plants (Figure 4, 5, 6, 7). The pH value in 81.2% of the soils in Turkey is above 7 (Ülgen and Yurtsever, 1995). This limits the intake of other micronutrient elements as well as the iron intake of the plants. The deficiency of micro nutrients, especially iron and zinc, is a global problem (Monreal et al. 2016). Some cultivated plants have special mechanisms to increase the uptake of nutrients such as iron in situations like this (Kacar and Katkat, 1998; Keuskamp et al. 2015). However, this situation causes a decrease in the yields of plants and biofortification does not reach the desired levels. In this context, it is reported that ferrous fertilizer applications cause increases and decreases in nutrient content of cultivated plants (Ghasemi-Fasaei and Ronaghi, 2008; Habib, 2009; Morovat et al., 2019). This is undoubtedly due to antagonistic relations between iron and some elements.

It was determined that boron applications caused an increase in chickpea stem P, Ca, Mg, Fe, Zn and B contents and decrease in its N, K, Mn and Cu contents. Boron applications caused an increase in P, K, Ca, Mg, Fe, Zn and B contents and decrease in N, Mn and Cu contents in BxFe interaction. Boron and boron x iron (BxFe) applications, except for grain magnesium content, were found to cause an increase in N, P, Ca, Mg, Fe, Mn, Zn, Cu and B contents (Figure 4, 5, 6, 7). It is reported in the studies of Ahmed et al. (2011) that boron applications increase N, P, K, Cu, Zn and Fe content. It was reported that the increase in the dry matter of the plant with boron application encourages the intake of more nutrients (Qiong et al., 2002). Similarly, Nasar et al. (2018) reported that boron and molybdenum applications increased yield and nutrient content of peanuts. Boron may have contributed to the increase in yield and nutrient content by taking part in the protein and fat synthesis in the plant (Devi et al. 2012). In the study where boron, zinc, sulfur and phosphorus applications were performed separately or together, it was reported by Tripath et al. (2020) that there is an increase in yield and nutrients of chickpea.

CONCLUSION

As a result, it was determined that both iron and boron applications had positive effects on the stem and grain biofortifications of chickpea. According to the results of soil analysis in terms of yield and yield criteria of chickpea, it is predicted that iron and boron applications will be beneficial when applied together. As a result of our study, the most suitable dose in terms of biological yield, grain yield and biofortification was determined as 0.25 kg B da^{-1} and 10 kg Fe da^{-1} (B_1xFe_2).

CONFLICT OF INTEREST

There is no disagreement between the authors.

DECLARATION OF AUTHOR CONTRIBUTION

MHÖ: Gathered the information, analyzed the data the manuscript. FS: conceptualized and designed the study, wrote and checked the final draft

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