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INDIVIDUAL AND COMBINED EFFECTS OF FOLIAR IRON, ZINC AND BORON APPLICATIONS ON YIELD AND MINERAL NUTRITION OF SUGAR BEET

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Abstract

Foliar application is a succesful way for a plant microelement nutriton under calcareous conditions. Study was aimed to evaluate the effects of foliar micronutrient applications on yield, mineral nutrition and some quality parameters of sugar beet. For this, solutions containing 500, 500 and 250 ppm of Fe, Zn and B and their combinations (Fe+Zn, Zn+B, Fe+B, Fe+Zn+B) were foliar applied. Compared to control, Fe+B combinations increased the root and root+leaf yield by 54% and 68%. The highest leaf Fe was obtained with Fe application, and the highest Zn and B were obtained from the Zn+B. The highest root Fe, Zn and B were obtained from Fe+Zn, Zn and B applications, respectively. Positive effects of the applications on other nutrients were determined. The highest polar sugar and total soluble solids were obtained from the Fe+B and the highest reducing sugar was recorded from Zn and B applications. Zn, B, and all combinations containing B significantly increased the α-amino N content. As conlusion, foliar application of Fe, Zn and B positively affected sugar beet nutrition and thus increased yield and quality.

Key words: *foliar ferilization, micronutrients, sugar beet, yield and quality.*

INTRODUCTION

Sugar beet (*Beta vulgaris* L.) is a biennial herb in the Chenopodiaceae family (Song et al., 2019), and is the world's second-largest sugar crop and beet has also become a popular energy crop in recent years (Muir & Anderson, 2022). Approximately 180 million tons of sugar are consumed worldwide annually, and approximately 25% of this sugar is produced by processing sugar beets (Keller et al., 2021). More recently, sugar beet has gained prominence as a crucial resource for ethanol production as a biofuel (Rinaldi & Vonella, 2006). World sugar beet production was nearly 252.9 million tons and the most important producers of sugar beet were Russia (33.9 million tons), the United States of America (USA) (30.5 million tons), Germany (28.6 million tons), France (26.2 million tons), and Turkey (23 million tons) in 2020 (FAO, 2022). Over 30% of world soils suffer from the deficiency of one or more micronutrients, a trend which is deteriorating (Sillanpaa, 1982), with the passage of time. There are numerous reports about the role of micronutrients in enzymatic responses, plant metabolism and assimilation of carbon, nitrogen and different compounds, sugar translocation, cellular division, water regulation, conductivity, and consequently, higher photosynthetic capacity and productivity of the plants (Shiemshi, 2007). Plants require some nutrients for optimum growth, among which trace elements like boron (B), iron (Fe) and zinc (Zn) are important nutrient elements for the growth and develoment of sugar beet and their deficiencies in soil can affect the performance of macronutrients (Xue et al., 2014).

Zinc is essential element for ideal crop production and satisfying yield performances due to its involvement in many biochemical processes in plant metabolism. It take place or regulates many enzimatic reactions. Zinc is required for maintaining phytohormones, vitamins, and amino acids level in the plant tissues and chlorophyll biosynthesis (Marschner, 2011). By promoting the root and shoot growth of plant it aguements the uptake of nutrients through the roots (Leite et al., 2020). These modifications stimulate plant enzymes and hormones, suppress diseases, heat stress, and frost damage by promoting antioxidants activity (Seydabadi & Armin, 2014). Due to most enzymes that play key roles in carbohydrates metabolism are activated by Zinc, the most required elements in the carbohydrates metabolism is Zn. The activity of these enzymes decreases in Zn deficient conditions. In different studies, foliar application of Zn alone or together with B and Mo increased the photosynthetic pigments contents, yield and some quality parameters such as sucrose percentage, purity percentage, sugar yield of sugar beet (Zewail et al., 2020). Iron (Fe), has metabolic importance in plants due to it takes parts in many physiological roles. Because of it plays critical role in metabolic processes such as DNA synthesis, respiration, and photosynthesis Fe is an essential micronutrient for almost all living organisms. Further, many metabolic pathways are activated by iron, and it is a prosthetic group constituent of many enzymes (Rout & Sahoo, 2015). Iron is a component of the active groups of various enzymes. Its one of the best known function is to be a part of prostatic groups of hemin enzymes. Although Fe is not included in the structure of the chlorophyll molecule, it plays many roles in the synthesis of chlorophyll and the process of photosynthesis. It plays a role as an electron carrier in energy metabolism, especially in relation to oxidation and the respiratory chain (Marschner, 2011). Of all crops, sugar beet has one of the largest requirements of B. So, B is the most important trace element required by sugar beet, because when it is not supplied in sufficient quantities, root yield and quality are seriously reduced (Draycott & Christenson, 2003). It has significant role in plant cell wall formation and cell division (Miah et al., 2020). It accelerates the translocation of sugars to the storage and growing parts (Allen et al., 2007; Ewais et al., 2020; Kandil et al., 2020). As their importance on plants is briefly stated above, for a high quality and high yield, sugar beet must receive sufficient amounts of these nutrients. Roots are the main way for plants to uptake nutrients. However, they can also take in various nutrients through their leaves. Micro element availability is associated with soil types and many soil physicochemical properties. Although foliar fertilization is seen as an additional support application to root nutrition, it is an extremely indispensable fertilization method under some conditions. It is known that various fertilizers, especially micro element fertilizers, are successfully applied via leaves when the soil has unfavourable conditions. In soils with high pH and excessive calcareous soils, which generally limit the availability of micro elements from the soil, foliar application gives quite successful results. Again, with foliar fertilization, the negative interaction of micro elements with other elements found in excess in the soil is also avoided (Fahad et al., 2014; Lucena, 2000).

In this study it was aimed to investigate individual and combined effects of foliar Fe, Zn and B applications on mineral nutrition, yield and some quality parameters of sugar beet grown on a calcareous soil.

MATERIALS AND METHODS

Field experiment was conducted during the 2023 growing seasons under field conditions in Burdur, Turkiye. The soil of the experimental area has an clayey-loam texture having slightly alkaline pH and high $CaCO_3$ content. The experimental soil is sufficient in terms of macro nutrients and cooper. On the other hand, iron content is medium, zinc and boron contents are around the deficient levels. Some properties of the experimental soil were given in Table 2. Soil texture, $CaCO_3$ and organic matter were measured with methods of Bouyoucos (1951), Allison & Moodie (1965) and Walkley & Black (1934) methods, respectively. The pH and EC values of the soil were determined using pH-EC meter. Available P in the soil was determined spectirofotometricaly (Olsen, 1954). Exchangeable K, Ca, Mg (Jackson 1962), and DPTA-extractable microelements (Lindsay and Norvell, 1978) were determined using inductively coupled plasma (ICP). Soil B concentrations were measured using ICP after the hot extraction of soil in 0.01 M $CaCl_2$ (Kacar, 2009; Erdal et al., 2016).

As plant material, Cesira which is videlly used variety for sugar beet cultivation in the region was used. $FeSO_4.7H_2O$, $ZnSO_4.7H_2O$ and H_3BO_3 were used as Fe, Zn and B sources. The treatments and application dasages are given in Table 2. Weather conditions during the experiment are summarized in Figure 1.

Table 1. Some properties of experimental soil

Properties		Evaluation	References
Texture		Clayey-loamy	
pH (1/2.5)	7.9	Silightly alkaline	(Richards, 1954)
EC (1/2.5, ds/m)	0.3	No saline	
Organic matter (%)	2.4	Modarate	
$CaCO_3$ (%)	16	High	
P (ppm)	25	Sufficient	(FAO, 1990)
K (ppm)	600	Sufficient	
Ca (ppm)	7000	Sufficient	
Mg (ppm)	280	Sufficient	
Fe (ppm)	3.5	Modarate	(Lindsay & Norwell, 1969)
Zn (ppm)	0.6	Deficient	
Cu (ppm)	2.5	Sufficient	
B (ppm)	0.4	Deficient	(Keren & Bingham, 1985)

Table 2. Treatments and application dosages

Treatments	Application dosages
Control	Water spraying
Fe	500 ppm
Zn	500 ppm
B	250 ppm
Fe+Zn	500 ppm Fe + 500 ppm Zn
Zn+B	500 ppm Zn + 250 ppm B
Fe+B	500 ppm Fe + 250 ppm B
Fe+Zn+B	500 ppm Fe + 500 ppm Zn + 250 ppm B

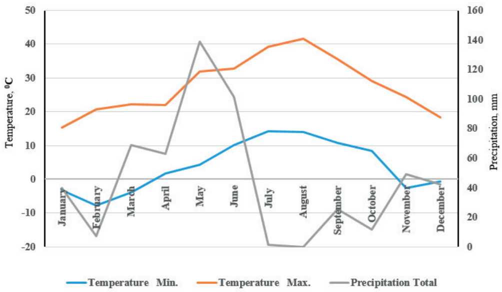


Figure 1. Temperatures and precipitations recorded during growing season

As basal fertilisation 6 kg N/da (Urea), 6 kg P/da (Tripl super phosphate) and 4.5 kg K/da (Potassium sulphate) were applied to the soil and mixed before sawing. Sawing was carried out with a five line mibzer arranged 45 x 15 cm spacings.

Before foliar fertilization, the experimental area was divided into 2 m long plots with 5 rows. Experiment was arranged with 3 replications, and the subjects were randomly distributed to the plots according to the randomized plots experiment design. Foliar applications of micro nutrients were performed 2 times with 15 days intervalls after the plants had 4-5 foliages. Water was sprayed to the control groups. In order to determine the effects of applications on the nutritional status of the plants, leaf samples were collected 3 weeks after following the second application. For leaf analysis, samples were washed with top and pure water then dried at 65±5°C and were grounded. Afterwards, samples were wet digested with microwave oven and filled up to 50 ml with pure water. Total nitrogen was analyzed according to Kjeldahl method. Phosphorus concentrations of samples were determined with a spectrophotometer (Shimadzu UV-1208) at 430 nm according to the vanadomolybdo phosphoric acid method. Potassium, Ca, Mg, Fe, Cu, Zn, and Mn concentrations were determined using atomic absorption spectrophotometer. Boron concentration of the leaf was measured using the same filtrate with ICP (Mills & Jones, 1996). To determine root weight and some quality characteristics, 10 plants from each plots were pulled out then brought up the laborotary immididatelly. In laboratory, roots were washed with water and weighted. After leves were separated from the root, some quality parameters were performed. Root weights were detemined by taking the avarages of ten roots.

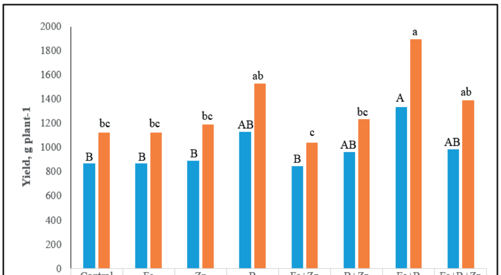
Total soluble solids (TSS) of beet juice were determined by using digital refractometer. The concentrations of sucrose and α -amino nitrogen were determined from beet brei. Sucrose percentage (%) was determined polarimetrically on lead acetate extract of fresh macerated roots by using automatic polarimeter (ATAGO AP 300, Japan), and α-amino nitrogen content was determined spectrophotometrically according to bluenumber method (ICUMSA, 2007).

Statistical analysis was performed using the MSTAT program for a one-way analysis of variance to determine significant differences at the 0.01% level. A Tukey test was conducted to identify significant differences among the treatments.

RESULTS AND DISCUSSIONS

Effect of treatments on yield of sugar beet

The yield of sugar beet has been affected by foliar applications of different micronutrients. As given in Figure 2, root and root+leaf weights were varied between 844 and 1335 g and 1042 and 1893 g per plant, respectively. While the most effective treatment was the combined application of Fe and B (Fe+B); control, Fe, Zn and Fe+Zn treatments were found to be the most ineffective treatments. The same treatments showed similar effect on the Root+leaf weights and Fe+B treatment was found the most effective. According to these results, it was observed that there was a difference of approximately 1.5 times for root and 1.8 times for root+leaf between the highest and lowest yield values. Results of both yield values showed that B and B combined other micro element combinations showed superior effects comparing to other treatments which B not included.



	Control	Fe	Zn	B	Fe+Zn	B+Zn	Fe+B	Fe+B+Zn
Root	866	866	889	1130	844	961	1335	983
Root+leaf	1122	1122	1190	1527	1042	1235	1893	1390

Fe: 500 ppm, Zn: 500 ppm, B:250 ppm, *means sharing the same latter are not significantly different (*P*>0.05)

Figure 2. Effect of foliar micro element treatments on the yield of sugar beet

Effect of treatments on mineral nutrition of sugar beet

Differences among the treatments on micro-element concentrations of leaf and root were found to be significant (Table 3). The lowest Fe, Mn, Zn, Cu and B concentrations in leaf were 60, 40, 31, 10.7 and 175 ppm, respectivelly. On the other hand the highest walues were 85 ppm for Fe, 53 ppm for Mn, 54 ppm for Zn, 16.3 ppm for Cu and 329 ppm for B.

Table 3. Effect of foliar micronutrient applications on microelement concentrations of sugar beet (mg kg^{-1})

Treatments	Fe	Mn	Zn	Cu	B
		Leaf			
Control	60 B	40 B	31 C	10.7 C	175 E
Fe	85 A	46 AB	33 C	16.3 A	202 DE
Zn	69 ABC	50 A	50 AB	13.7 B	183 E
B	72 AB	52 A	31 C	16.0 A	245 CD
Fe+Zn	77 AB	48 AB	43 B	16.3 A	266 BC
Zn+B	66 B	53 A	54 A	16.3 A	329 A
Fe+B	69 ABC	45 AB	31 C	12.7 BC	294 AB
Fe+Zn+B	61 B	46 AB	38 BC	11.3 C	313 A
			Root		
Control	313 AB*	12.5 A	41 B	24.5 B	14.7 B
Fe	313 AB	12.5 A	41 B	24.5 B	19.1 A
Zn	162 C	9.5 B	52 A	32.5 A	14.3 B
B	162 C	9.5 B	38 BC	26.5 B	19.8 A
Fe+Zn	335 A	9.5 B	51 A	35.0 A	14.5 B
Zn+B	132 C	12.5 A	37 BC	31.5 A	14.0 B
Fe+B	212 BC	7.0 C	36 C	21.0 B	16.5 AB
Fe+Zn+B	216 ABC	8.5 BC	47 AB	30.5 A	15.1 B

Fe: 500 ppm, Zn: 500 ppm, B:250 ppm, *means sharing the same latter are not significantly different (*P*>0.05)

When the results of sugar beet leaf micro elements were examined, it was revealed that the applications of Fe, Zn and B elements increased the amounts in the leaf. While the highest Fe content determined in the leaf was obtained with only 500 ppm Fe application, the second highest Fe content was obtained at the end of Fe+Zn application. On the other hand, low Fe values were measured in Fe+B and Fe+Zn+B mixtures. It was shown that the Fe concentration determined in the root increased in the application where Fe was together with Zn. Micro element concetrations in root varied between 132 and 335 ppm for Fe, 7.0 and 12.5 ppm for Mn, 36 and 52 ppm for Zn, 21.0 and 35.0 ppm for Cu and 14.3 and 19.8 ppm for B. The highest Fe concentrations was obtained with the combined applications of Fe and Zn (335 ppm) and followed by Fe applied and control (313 ppm) condition. While Fe+B and Fe+Zn+B combined treatments resulted in lower Fe concentrations the lowest Fe (132 ppm) were measured from the plants treated with Zn+B mixed appication. It was observed that Zn and B applications alone were among the applications that negatively affected the Fe conentration of the root. Foliar microelement applications either had no effect or had a negative effect on the Mn concentration of root. Comparing the control, while the applications of Zn, B, Fe+Zn, Fe+B and Fe+Zn+B negatively affected root Mn concentrations, Fe and Zn spreyings did not affect. Individual application of Zn and its combination with Fe (Zn+Fe) gave the highest Zn concentrations in root with the values of 52 and 51 ppm, respectively and followed by Fe+Zn+B with 47 ppm. The lowest Zn values were obtained in applications containing B alone and Zn+B and Fe+B combinations, and the values obtained from these applications were even below the control. Three of foliar fertilizations (Fe, B, Fe+B) did not effect root Cu concentration when compared the control and the lowes Cu (21 ppm) in root was measured from the plants treated with Fe+B. On the other hand Zn, Fe+Zn, Zn+N and Fe+Zn+B applications showed the positive impact on root Cu concentration. The highest Cu (35 ppm) was reached with the application Fe+Zn mixture. The highest B (19.8 ppm) was measured from the plants treated with solely B containg solution. The second highest B (19.1 ppm) was obtained with Fe application. The lowest root B concentration was obtained from the plants sprayed with Zn mixed with B. Compared to control, foliar application of Fe, Zn, B and their combinations showed a positive impact on leaf macronutrient concentrations generally. Leaf N, P K, Ca and Mg concentrations were found to be as 3.4%, 0.27%, 2.46%, 0.37% and 0.39% under control conditions. These values increased to 4.4 and 4.3% for N with Fe+B and Fe treatments, to 0.34% for P with Fe, Zn and Fe+Zn treatments, to 3.32% for K with Zn+B treatment, to 0.53% for Ca with Zn and Fe+Zn treatments and to 0.49% for Mg with Zn+B treatment. Leaf microelement applications either had no effect or had a negative effect on root N, P and Mg concentrations. On the other hand, root K and Ca concentrations were positively affected by Fe+Zn and Fe+Zn+B applications (Table 4).

Table 4. Effect of foliar micronutrient treatments on macroelement concentrations of sugar beet

Treatments	N	P	K	Ca	Mg
			Leaf		
Control	3.4 C	0.27 B	2.46 CD	0.37 B	0.39 B
Fe	4.3 A	0.34 A	2.60 C	0.43 AB	0.44 AB
Zn	3.7 BC	0.34 A	2.57 C	0.53 A	0.39 B
B	3.9 B	0.30 AB	2.56 C	0.46 AB	0.48 AB
Fe+Zn	3.7 BC	0.34 A	2.84 B	0.53 A	0.39 B
Zn+B	3.6 BC	0.27 B	3.32 A	0.50 AB	0.49 A
Fe+B	4.4 A	0.31 AB	2.30 D	0.36 B	0.47 AB
Fe+Zn+B	3.9 B	0.31 AB	2.42 CD	0.43 AB	0.42 AB
			Root		
Control	1.0 AB	0.42 AB	1.36 B	0.14 B	0.36 AB
Fe	1.0 AB	0.42 AB	1.36 B	0.14 B	0.36 AB
Zn	0.9 B	0.41 B	1.49 AB	0.15 AB	0.41 AB
B	0.9 B	0.38 B	1.64 AB	0.16 AB	0.37 AB
Fe+Zn	1.1 A	0.43 AB	2.12 A	0.21 A	0.45 A
Zn+B	1.0 AB	0.49 A	1.99 AB	0.19 AB	0.42 AB
Fe+B	1.0 AB	0.37 B	1.74 AB	0.17 AB	0.32 B
Fe+Zn+B	0.89 B	0.38 B	1.80 AB	0.18 AB	0.44 A

Fe: 500 ppm, Zn: 500 ppm, B:250 ppm, *means sharing the same latter are not significantly different (P>0.05)

Effect of treatments on some quality parameters sugar beet

The effects of foliar Fe, Zn and B spreying on some qulity parameters of root are presented in Table 5. Foliar applications of Zn, B, Zn+B, Fe+B and Fe+Zn+B significantly increased of α-amino N content up to 35% compared to control. On the other hand, Fe and Fe+Zn combination did not have significant affect. The most effective spreying on these increase was found to be sole B application. Foliar Zn and B individual treatments led to increase of reducing sugar content by up to 41 and 53%, respectively compared to control. The other treatments did not effect on reducing sugar contents in roots. Polar sugar content significantly increased with Fe+B (15.4%), Fe+Zn+B (15.0%) and Fe (15.0%) applications while it was around 14.0-14.6% under other treatments. Among the applications, only Fe+B mix treatments increased the TSS content, while Fe+Zn applications caused a decrease in TSS.

Table 5. Effect of foliar micronutrient treatments on α-amino N, reducing sugar, polar sugar and TSS values of root

Treatments	α-amino N (mmol 100 g^{-1})	Reducing sugar (%)	Polar sugar (%)	TSS (%)
Control	3.88 C	0.32 C	14.2 BC	20.0 BC
Fe	3.88 C	0.34 C	15.0 AB	21.1 AB
Zn	4.71 AB	0.45 AB	14.4 BC	19.7 BCD
B	5.22 A	0.49 A	14.6 ABC	19.2 CD
Fe+Zn	3.98 BC	0.39 BC	14.0 C	18.0 D
Zn+B	4.66 AB	0.37 C	14.4 BC	20.0 BC
Fe+B	4.76 A	0.38 BC	15.4 A	21.8 A
Fe+Zn+B	4.70 AB	0.39 BC	15.0 AB	19.5 BCD

Fe: 500 ppm, Zn: 500 ppm, B:250 ppm, TSS: total soluble solids, *means sharing the same latter are not significantly different (P>0.05)

Looking at the yield values, it was seen that the most effective individual application on both total yield and root yield was B. This situation shows that sugar beet responds more to B fertilization. This situation can be related to the low B content of the esperimental area. Again, it can be related to the fact that sugar beet is one of the plants with a high B requirement and therefore its need for B is higher than other micro elements. This can be explained with the specific effect of B on sugar beet growth. Draycott (2008) emphasized the crucial role of B as a trace element for sugar beet, as its inadequate supply can severely reduce root yield and quality. Also, other foliar spreyings containing B combinations with Fe and Zn showed positive impact on the yield of sugar beet. According to Masri & Hamza (2015), a higher concentration of micronutrients mixture resulted in a significant increase of 21.54% and 23.81% in sugar beet root weight, 28.00% and 24.40% in root yield, and 76.50% and 60.61% in sugar yield during the first and second growing seasons, respectively.

According to Mills & Jones (1996) micro nutrient sufficinecy ranges levels in sugar beet are between between 60-140 ppm for Fe, 26-600 ppm for Mn, 10-80 ppm for Zn and 30-200 for B. In other study (Haneklaus & Schnug 1998). it was raported that sufficiency ranges for Fe, Mn, Zn, Cu and B were between 80-200 ppm, 20-50 ppm, 40-60 ppm, 10-20 ppm and 24-40 ppm, respectively. Depending on the above sufficiency ranges, it can be said that leaf micronutrient concentrations for Fe and Zn under control conditions were around the criticial levels, and they increased up to sufficency levels with Fe, and Zn applications alone and their Fe+Zn and Zn+B combinations. However, triple combinations Fe, Zn and B did not affect positively leaf Fe and Zn concentrations. This may be due the triple competition of competition during leaf entry and transport stages (Adamec, 2002). On the other hand, non-favouarble properties such as pH and EC of multi-element solutions used for spraying may be effective on this subject (Erdal, 2023). Contrary to Fe and Zn, it has been observed that two or three microelement mixtures including

B are more effective on plant B nutrition than its individual effect. This may be positive effect of Fe and Zn on B nutrition of plant. Similarlly, in a study it was found that Fe, B and Zn foliar application increased their own concentrations and accompaning micro elements of cowpea

(Salih, 2013). Results showed that although Cu and Mn fertilization were not done, Fe, Zn and B spraying lead to increase their concentrations in leaves, althouh they were not sprayed. This situation can be explained by the fact that plants benefit more from other nutrients as a result of increased plant growth resulting from microelement fertilization. When a general evaluation is made, the results obtained show that the best application on leaf Fe content is the application of Fe alone, while the mixture of Fe with Zn also contributes to the plant's Fe nutrition. Similarly, in a study conducted by Fouda & Abd-Elhamied (2017), it was reported that both individual and combined application of Zn and Fe positively affected the Fe and Zn nutrition of cowpea. Niyigaba et al., (2019) and Pal et al. (2021) reported that Fe was slightly improved by an application of Zn in wheat and chickpea. It was observed that the amount of Zn in the root increased depending on the amount of Zn in the leaf. A possible reason for this increment is that foliar-applied can be readily translocated into other organs such as grain and root (Haslett et al., 2001; Erenoglu et al., 2011). An increase of Fe by Zn application was also reported by Wang et al. (2015), where the foliar application of Zn resulted in a significant increase in Fe concentration. Despite a strong negative correlation between Zn and Fe we did not observed strong negative effect of Zn on Fe nutrition of sugar beet especially for root. This may be related to concentrations of nutrient in the solution and source of nutrients etc. Increase in Fe concentration can olso be related improved plant metabolism and growth which encouruge more Fe uptake under Zn applied condition (Singh et al., 2013). Application of Zn together B was the most effective on the leaf Zn concentrations followed by the sole application of Zn. Having the same or higher effect of Zn+B with solely Zn treatment can be explained that B did not affect or increased Zn absorption of leaf. Similarly, Zn deficiency enhanced B concentration in wheat (*Triticum aestivum*) grown on Zn deficient soils (Singh et al, 1990). Sinha et al., (2000) noted a synergistic interaction between Zn and B in mustard (*Brassica nigra*) when both nutrients. Hosseini et al. (2007) reported that there was a significant B and Zn interaction on corn growth and tissue nutrient concentration which were rate dependent. They declare that in general, the effect was antagonistic in nature on nutrient concentration and synergistic on plant growth. As in Zn, the highest B was obtained when it was applied as mixture of Zn. The reasons of this can be explained with the similar approaches as mentioned for Zn. Although they did not applied as fertilizers, concentrations of Mn and Cu in the leaf and root increased with foliar Fe, Zn and B applications in most cases. This can be explained more nutrient uptake from the soil because of enhanced plant metabolism and growth with foliar fertilization. Foliar applications of Fe, Zn ad B lead to increase of these nutrient in root as well. While the highes B and Zn were translocated when the they were applied alone, the highest Fe translocation was determined from combined application of Fe and Zn. Sole application of Fe played a significant role on B translocation as much as sole B application. This can be explained by the fact that iron nutrition promotes the plant's B uptake from the soil and B translocation from leaf to root. Previous research has reported the synergistic effect of Zn and Cu (Aref, 2012; Xia *et al.* 2019). Zinc may have facilitated the uptake and translocation of Mn and B within the plant, either directly or indirectly through physiological processes. This resulted in increase in leaf Mn content with Zn application (Stewart et al., 2021). Further studies are required to elucidate these mechanisms and enhance our understanding. Results of leaf macronutrien cocentrations showed that the lowest values were determined from the control plants generally. Althought not for all treatments, individual applications of Zn, Fe and B and their mixtures increased the macro element concentrations of beet leaves on the macro elements determined in the leaf. These increases were approximately 20% for N, P and Ca and approximately 26% for potassium compared to the control. As in expressed by Marschner (2011), this may be due to the positive impact of foliar micronutrient fertilization on macronutrient concentrations are likely due to increased root growth induced by micronutrients (Srivastava et al., 2016). It was observed that foliar micro element fertilization had no effect on N and P, which are macro elements determined in the root, whereas Fe+Zn application had a positive effect on K, Ca and

Mg, and Fe+Zn+B application had a positive effect on Mg concentration in root. These increases macronutrients in the leaf and root of sugar beet with foliarly applied micronutrients can be explained with the increased plant growth and metabolisms resulting more nutrient uptakes from the soil it grown (Mengel & Kirkby, 1987; Kacar & Katkat, 2010; Marschner, 2011; Erdal, 2023). Results showed that B application had an specific effect on the of α-amino N concentratin of sugar beet. Similarlly, Nemeata Alla (2017) indicated that increasing levels of B foliar application increased α-amino N connet of sugar beet regularlly. As mentioned preivios studies, most of other quality parameters have been affected by foliar micronutrients especcially B and their combinations. These results can be explained with the privite role of B and other micrunutrients on sugar metabolism (de Oliveira Gondim et al., 2015; Rahımı et al., 2016; Rahimi et al., 2018; Pişkin, 2022).

It is thought that the high α-amino N content in B and Fe+B applications is related to the fact that these applications also significantly increase leaf N concentration. In fact, excessive N fertilization in sugar beet causes an increase in the α-amino N ratio. Excess N taken into the plant is accumulated as α-amino N in the beet top to be used later when needed. Excessive N addition was also reported to be responsible for high α-amino N concentrations in sugar beet roots (Hassan & Mostafa, 2018). Some researchers have also reported that B applications increase the amino N content in sugar beet (El- Kammash, 2007; Abbas et al., 2014). It has also been reported that foliar Fe and B applications increased the α-amino N content in sugar beet (Aghdam & Valilue, 2023). Sugar accumulates in the roots in the form of sucrose as a product of photosynthesis and sucrose is cleaved, mainly by sucrose synthase and converted into reducing sugars (glucose + fructose) for use in metabolic activity (El-Geddawy et al., 2024). The increase in the amount of reducing sugar with Zn and B applications in the study was probably due to the increase in metabolic activity in sugar beet. Boron through its role in cell wall synthesis, water uptake in plants; and Zn by activation of enzymes, strengthening of cell wall and cell division play an important role on yield and quality (Kuldip Kumar & Rajpaul Yadav, 2016). Increased nutrient uptake in different application of micronutrients might be responsible for the enhancement of sugar percentage and TSS because it has been established that there is a positive correlation between plant nutrient uptake and sugar content (Lehrsch et al., 2014; Zewail et al., 2020). Boron plays a significant role in vital activities of plants, e.g., the metabolism and translocation of sugars and hydrocarbon-containing compounds (Armin and Asgharipour, 2012). Thus, this may increase photosynthesis capacity, and the allocation of more assimilates to the metabolism of sugar synthesis in plants like sugar beets (Zewail et al., 2020; Nasar et al., 2021). The role of Fe in chloroplast ultra-structure, protein and lipid composition of thylakoid membranes, in addition Fe enhance electron transport capacity in thylakoidsand ATP formation (Arulanantham et al., 1990), consequently enhance growth, yields and quality of sugar beet (Abdelaal et al., 2015; Masri & Hamza, 2015 and Rassam et al., 2015). Amin et al. (2013) reported that the sugar yield increased from 8.64 tons per hectare in the control treatment to 8.79 and 9.17 tons per hectare with one and two foliar sprays of low consumption elements, respectively. Yarnia et al. (2008) also reported that the use of low consumption elements caused a 46% increase in sucrose yield compared to the control treatment. Abdelaal et al. (2015) revealed that spraying with B, Fe, Zn and Mn as mixture recorded the highest sucrose percent, root and sugar yields. Manal (2011) showed that spraying with solution of micronutrients mixture (B + Zn + Mn + Fe) significantly increased sucrose % and yields of root and sugar.

CONCLUSIONS

As conlusion, it can be said that foliar application of micronutrients positively affected the growth of sugar beet. While foliar Fe, Zn and B and their combination primarily increased the plant Fe, Zn and B concentrations, foliar sprayings also had a positive effect on some other nutritional elements which are not included nutrient solutions. In addition, micronutrient foliar spreyings espicially B and its combinations with Fe and Zn positivelly affected some root quality paramerets. Another noteworthy result is that there was no strict antogonism among the nutrients when applied from the leaves which we expected to have an antagonistic effects under soil conditions.

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