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Effects of Varieties and Micronutrients Fertilization on the Production of Quality Bean in Selected Areas of Southern Ethiopia

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Abstract

Zinc and Iron are essential trace elements for plants, animals, and humans, and their deficiencies cause a health risk and can slow physiological processes associated with illness and death in the developing world. Experiments were conducted in Taba, Halaba, and Butajira in a quadruple factorial design on farmers' fields to evaluate the response of haricot bean varieties to different Zn and Fe levels. The two factors for zinc experiment were the concentration of zinc fertilizer (0, 0.5, 1, or 1.5%) and the haricot bean variety (Nasir, Ibado, Hawassa Dume, or Sari-1), and the factors for iron experiment include haricot bean varieties (Nasir, Ibado, Hawassa Dume, and Sari-1) and Fe fertilizer (0, 1, 2, and 3% solution). Zinc sulfate ($ZnSO_4·7H_2O$) and Iron sulfate ($FeSO_4.7H_2O$) were sprayed on the leaves, and nitrogen (N) and phosphorus (P) were applied to the soil equally for all treatments just before planting, using urea and triple super phosphate (TSP), respectively. Haricot beans were planted in rows with a spacing of 10 cm between plants and 40 cm between rows. Plant height, number of pods per plant, number of seeds per pot, 1000 seed weight, and biomass and grain yields were determined. Leaves and seeds from each treatment plot were analyzed for their Zn and Fe contents. The results indicated that haricot bean production varied significantly among varieties both in yield parameters and tissue Zn and Fe concentrations, with the highest grain yield being produced by Nasir and Hawassa Dume. Nasir also produced the highest seed Zn and Fe; therefore, it was found to be the best variety both in quantity and quality. Haricot bean production also varied significantly among locations, with the highest grain yield at Butajira. The application of increasing levels of Zn and Fe fertilizers significantly increased tissue Zn and Fe concentrations. The growing seasons also significantly affected haricot bean production in terms of yield parameters and tissue Zn and Fe concentrations. In conclusion, Zn and Fe concentrations varied among haricot bean varieties, and Zn and Fe fertilization enriches haricot bean with the elements and hence improves its quality.

Keywords: Concentration, Leaf Zn and Fe, Seed Zn and Fe, Zn and Fe fertilization, Tissue Zn and Fe, Haricot bean varieties

Introduction

Iron and Zinc are essential trace elements for plants, animals, and humans (Aref, 2012; Ai-qing et al., 2013; Alloway, 2008). They are essential for chlorophyll production, photosynthesis, and energy transfer within plants (Singh, 2004**)**. Zinc is a component in more than 300 enzymes participating in the synthesis and degradation of carbohydrates, lipids, proteins, and nucleic acids as well as in the metabolism of other micronutrients (FAO, 2001; Imtiaz *et al.,* 2010; Hafeez et al., 2013; Kobraee et al., 2011). It activates growth and development in infants, children and teenagers, accelerates cell division, enhances the immune system, protects the body from illnesses and fights infections, and it can reduce the duration and severity of a common cold or halt diarrhea (Imtiaz *et al.,* 2010). It is one of the most abundant trace elements in the human body with optimum dietary intake of 15 mg day^{-1} for adult (Hafeez et al., 2013). Iron is essential for human health with a dietary intake of 13.161 mg day^{-1} in countries where diets include animal protein (Rubio et al., 2009). Imtiaz et al. (2010) suggested an adequate daily dietary intake for young and adults might range from 10 to 60 mg. They also warned that high consumption of cereal-based foods of low Fe contents poses a health risk and can slow physiological processes.

Micronutrient deficiencies in soil limit crop production and have negative effect on human nutrition and health. The World Health Organization (WHO) has estimated that over three billion people in the world suffer from micronutrient malnutrition (WHO, 2002; Long *et al.,* 2004) and the most commonly deficient elements in the diet of humans are Fe and Zn (Franca and Ferrari, 2002). According to White and Broadley (2009) and WHO (2012), dietary deficiency of Zn and Fe affects more than two billion people worldwide, mostly pregnant women and children below the age of five. Together with protein deficiencies, shortages of Fe and Zn are prevalent in food in sub-Saharan Africa (SSA), a region where beans are primary staple food crop (Welch and Graham, 2004). The addition of haricot bean can improve Zn and Fe contents of cereal and tuber-based diets as they provide high concentration of Zn (25-50 mg kg^{-1}) (FAO, 2001) and all of the Fe that humans require (Nchimbi-Msolla and Tryphone , 2010). *Phaseolus vulgaris* L. is an important leguminous crop of great nutritional status to poor communities in African countries. It is nicknamed "poor man's protein" due to its potential role in the daily diet of the poor who cannot afford expensive animal protein. Haricot bean is susceptible to Fe and Zn deficiencies (Goh and Karamanos, 2003; Singh, 2004; Hossein et al., 2008; Imtiaz et al., 2010) though genotypes vary in response to the application of these nutrients (Tryphone and Nchimbi-Msolla, 2010).

It is crucial to increase the Fe and Zn contents of food grains to raise food quality and thereby improve human health. Cakmak (2002) also pointed out that increasing the concentrations of Fe and Zn in grains is a high priority research task, and would greatly contribute to the alleviation of deficiencies of these minerals in human populations worldwide. He also indicated that fertilization of plants via soils or foliar applications is one important strategy to increase micronutrient concentrations in grains. Therefore, the problem of Fe and Zn deficiencies in plants and humans can be addressed by application of fertilizers containing these minerals in deficient soils, and identifying haricot bean varieties that accumulate relatively high levels of the minerals. The objective of this study was to investigate the influence of haricot bean varieties and Fe and Zn fertilization on the quality the produce.

Materials and methods

The experiment was executed in a quadruple factorial experiment on farmers' fields with randomized complete block design (RCBD). The experiments were carried out separately for Fe and Zn. Each experiment encompasses two factors namely fertilizer and varieties. Zn fertilizers included 0, 0.5, 1 and 1.5% $ZnSO_4.7H_2O$ solution, whereas Fe fertilizers covered 0, 1, 2, and 3% $FeSO_4.7H_2O$ solution. Nasir, Ibado, Hawassa Dume, and Sari-1 were the haricot bean varieties used for both experiments. One percent $ZnSO_4.7H_2O$ and $FeSO_4.7H_2O$ solution was prepared by adding one kilogram of $ZnSO_4.7H_2O$ and $FeSO_4.7H_2O$ in to 100 L of water (Pivot, 2003). The experimental sites were located near Halaba (Latitude: 07°20'34.5" and Longitude: 38°06'30.0"), Taba (Latitude: 07°01'01.9" and Longitude: 37°53'57.6"), and Butajira (Latitude: 08°12'25.9" and Longitude: 38°27'33.2"). The types of soils were: Haplic Luvisols (Humic) in Butajira; Andic Lixisols (Humic) in Halaba; and Haplic Lixisols (Siltic) in Taba (Abay et al., 2015). The soil properties of each site are indicated in Table 1.

Table 1 Selected Physico-chemical properties of the soils of three sites

Soil properties	Butajira soil	Halaba soil	Taba soil
Textural class	Clay loam	Clay loam	Clay loam
pH (H_2O)	7.40	7.70	7.47
Organic Carbon (%)	2.05	2.35	2.35
DTPA Zn (mg kg^{-1})	0.49	1.33	1.80
DTPA Fe (mg kg^{-1})	1.26	1.60	1.50
Total N (%)	0.34	0.24	0.16
Available P (mg kg^{-1})	12.13	10.00	14.30

The $ZnSO_4{\cdot}7H_2O$ and $FeSO_4{\cdot}7H_2O$ contain 21% Zn and 20% Fe, respectively, (Tryphone and Nchimbi-Msolla, 2010). The $ZnSO_4{\cdot}7H_2O$ was sprayed at a volume of 100 Lha^{-1} on the plants three weeks and six weeks after the sowing date (Abdel-Mawgoud et al., 2011), whereas the $FeSO_4{\cdot}7H_2O$ was sprayed three times, at 15 day intervals, starting at 15 days after planting at a volume of 100 L ha^{-1} per each application date.

Nitrogen (N) and phosphorus (P) were applied equally for all treatments. Phosphorus was applied just before planting as TSP at 20 kg ha^{-1}P. Nitrogen was also applied just before planting as urea at 18 kg ha^{-1}N. Haricot bean was planted in rows with a spacing of 10 cm between plants and 40 cm between rows during the belg (short rain, which normally occurs during the months of March, April and May) and meher (long rain, which normally occurs during the months of June, July and August) seasons, with a plot size of 4 × 4 m. All appropriate management practices were carried out equally for all treatments. Plant height, number of pods per plant, number of seeds per pod, 1000 seed weight, and biomass and grain yields were recorded. Three fully developed leaves at the top of the plant during initial flowering and seeds were collected from each treatment plot, dried in an oven at 70 °C for 24 hours, then ground using a rotating sample mill. The ground plant materials were digested and analyzed for Fe and Zn contents according to the following procedures. A sample of 0.5 g was weighed with five digit sensitive balance into the digestion tube. Six ml of nitric acid (HNO_3) was added to each tube. The tubes were placed in a digestion block at 90 °C for 45 minutes. Five ml of hydrogen peroxide (H_2O_2) was added, in two splits (3 ml and 2 ml) while the samples were in the digestion block, and digested for another 65 minutes. Three ml of 6 *M* hydrogen chloride (HCl) was then added and the samples were digested until the solution had turned completely clear (after about 5 minutes). The tubes were removed from the block, cooled for 20 minutes, and shaken using a vortex. The digests were then transferred from the digestion tubes into dram vials, brought to 25 ml with deionized water, and stored. The concentration of Fe and Zn was analyzed using a Microwave Plasma Atomic Emission Spectrometer (MPAES) at 259.940 and 213.857 nm, respectively. Analysis of variance (ANOVA) was carried out using Proc GLM procedures in the SAS 9.3 program (SAS Institute Inc., Cary, NC USA) and Least Significant Difference (LSD) test was used for mean separation. All data from the two seasons and three locations were combined.

Results and Discussion

Results showed that haricot bean production varied significantly among locations (Table 2). The highest values for all yield, and yield parameters and seed Fe concentration were observed at Butajira except for biomass yield, which was highest at Halaba. The highest grain yield was 3553.6 kg ha^{-1} while the lowest, from Taba, was 2250.4 kg ha^{-1}. The highest concentrations of leaf Zn, seed Zn, and leaf Fe, 26.93, 29.52 mg kg^{-1} and 217 mg kg^{-1}, respectively, were observed at Halaba, while the lowest values were obtained at Taba. The highest seed Fe concentration (119.79 mg kg^{-1}) was recorded at Butajira, whereas the lowest (55.94 mg kg^{-}1) was obtained at Taba.

This could be because Zn and Fe absorption in Taba fields might be more affected by environmental factors than in Halaba. Nchimbi-Msolla and Tryphone (2010) reported that bean leaf and seed Zn concentrations were varied among locations due to the environments in which the crop was grown. However, under controlled conditions, where environmental factors have less effect, Zn and Fe absorption was higher in Taba than in Halaba that could be attributed to the higher contents of the minerals in Taba soils (Abay et al., 2015). Goh and Karamanos (2003) also found that yield and tissue Zn concentrations varied among locations. Generally, addition of Fe resulted in best haricot bean production at Butajira, in terms of both quantity and quality, which might be attributable to lower available Fe and higher total nitrogen in the experimental soil as compared to the other locations.

Table 2. Haricot beans yield, yield components, and tissue Zn concentrations as influenced by location and growing season.

Parameters	Location				Season			
	Butajira	Taba	Halaba	LSD (5%)	Belg	Meher	CV (%)	LSD (5%)
Plant height (cm)	46.6a	39.3c	43.4b	1.46	45.7a	40.4b	13.73	1.19
No. of branches per plant	4.6a	4.2b	3.9c	0.19	4.4a	4.1b	17.95	0.15
No. of pods per plant	19.3a	14.3b	14.3b	0.79	16.9a	15.0b	20.06	0.65
No. of seeds per pod	5.4a	5.1b	4.9b	0.17	5.4a	4.8b	13.33	0.14
Grain yield (kg ha^{-1})	3553.6a	2250.4b	2467.8b	277.6	3559.1a	1955.5b	23.92	226.66
Biomass (kg ha^{-1})	6798.5b	4523.1c	7804.4a	328.7	8500.4a	4250.2b	20.95	268.35
1000 seed wt.	342.1a	293.4b	264b	30.6	307.3a	292.3a	21.52	25.00
Leaf Zn (mg kg^{-1})	21.5b	19.1c	26.9a	1.3	21.6b	23.4a	17.95	1.06
Seed Zn (mg kg^{-1})	22.1b	22.0b	29.5a	1.5	23.6b	25.5a	18.39	1.20
Leaf Fe (mg kg^{-1})	151.4b	91.2c	217.0a	8.1	179.4a	127.0b	21.35	6.57
Seed Fe (mg kg^{-1})	119.8a	72.61b	55.9b	17.6	84.4a	81.1a	16.41	14.37

Means followed by the same letter(s) within a row are not significantly different at $P \leq 0.05$.

Growing season also significantly affected haricot bean production both in yield parameters and tissue Zn and Fe concentrations. Similar findings were reported by Ai-qing et al. (2013) on wheat in China. The highest (3559.1 kg ha^{-1}) and the lowest (1955.5 kg ha^{-1}) grain yields were observed during the belg and meher seasons, respectively. Plant height, number of branches per plant, pods per plant, and seeds per pod, and biomass yield were all significantly higher during the belg season than the meher season. The highest concentrations of leaf and seed Zn concentrations, 23.39 and 25.45 mg kg^{-1}, respectively, were observed in the meher season, but the highest tissue Fe concentrations were recorded in belg season (Table 2). These differences in tissue Zn concentrations across seasons might be due to dilution effects associated with higher yields and yield parameters during belg. Haricot bean production was better in belg than meher (long rain) season in terms of quantity, but there was no difference between the two seasons in quality with respect to seed Fe concentration. If concentration of Fe in leaf is considered, however, belg season is recommended (especially where haricot bean leaves can be consumed). The poor bean production in meher might be attributable to the higher rainfall (Ogola, 1991).

Haricot bean production, in terms of yield parameters and tissue Zn and Fe concentrations, varied among varieties (Table 4). Similar findings were reported by McKenzie et al. (2001) and Sebuwufu (2013) on haricot bean. The highest values for plant height (45.71 cm), biomass (6838.1 kg ha^{-1}), and 1000 seed weight (470.56 g), and lowest grain yield (2503.4 kg ha^{-1}) were observed with Ibado. The combination of highest biomass and lowest grain yield indicates that Ibado produces the highest straw yield, suggesting that it is a good supplier of animal feed. Hawassa Dume had the highest grain yield (3149.3 kg ha^{-1}), and it was significantly higher than that of Ibado and Sari-1, but not significantly different from the yield of Nasir. Nasir produced the highest branches per plant (4.38), pods per plant (17.76), seeds per pod (5.67), leaf Zn (23.69 mg kg^{-1}), and seed Zn (25.79 mg kg^{-1}). Therefore, it was found to be the best variety both in terms of quantity and quality. Muhamba and Nchimbi-Msolla (2010) also reported that leaf and seed Zn concentrations varied among haricot bean varieties in Tanzania, ranging from 15.7 to 78.3 mg kg^{-1}and from 19.00 to 56.13 mg kg^{-1}, respectively. Ai-Qing et al. (2013) reported that the grain Zn concentration varied among wheat varieties in China. Ghanbari et al. (2013) also reported that haricot bean genotypes varied in tissue Fe concentration. The highest leaf Fe (167.12 mg kg^{-1}) and seed Fe (86.46 mg kg^{-1}) were observed with Ibado and Nasir, respectively.

Table 4. Effects of varieties on the production and tissue Zn and Fe concentration of haricot beans

Parameters	Variety				CV (%)	LSD (5%)
	Nasir	Ibado	Hawassa Dume	Sari-1		
Plant height (cm)	42.38b	45.71a	41.74b	42.45b	13.73	1.68
No. of branches per plant	4.38a	3.93b	4.28a	4.41a	17.95	0.22
No. of pods per plant	17.76a	11.17b	17.22a	17.67a	20.06	0.91
No. of seeds per pod	5.67a	3.83c	5.52ab	5.45b	13.33	0.19
Grain yield (kg ha^{-1})	2870.4a	2503.4b	3149.3a	2506.1b	23.92	320.54
Biomass (kg ha^{-1})	6289.1b	6838.1a	6197.9b	6176.2b	20.95	379.50
1000 seed wt.	251.98b	470.56a	247.13b	229.61b	21.52	35.37
Leaf Zn (mg kg^{-1})	23.69a	22.75ab	21.97b	21.54b	17.95	1.50
Seed Zn (mg kg^{-1})	25.79a	23.87b	24.08b	24.40ab	18.39	1.70
Leaf Fe (mg kg^{-1})	152.54b	167.12a	138.32c	148.80b	21.35	9.29
Seed Fe (mg kg^{-1})	86.46a	59.27b	60.69b	64.69b	16.41	20.32

Means followed by the same letter(s) within a row are not significantly different at $P \leq 0.05$.

The application of increasing levels of Zn and Fe fertilizer significantly increased tissue Zn and Fe concentrations (Tables 5 and 6). Sharma and Bapat (2000) and Shaheen et al. (2007) reported that both the grain and straw Zn concentrations of wheat significantly increased with the application of Zn. Ai-Qing et al. (2011) and Ai-qing et al. (2013) also reported that the foliar application of Zn fertilizer significantly increased leaf and seed Zn concentrations, respectively, in wheat. Another report by Fageria et al. (2014) also indicated that Zinc concentration of tropical legume cover crops was increased with the addition of Zn to the soil. The highest concentrations of both leaf Zn (24.06 mg kg^{-1}) and seed Zn (25.97 mg kg^{-1}) were observed at the application of the highest level of zinc fertilizer (1.5%), whereas the lowest values of both leaf and seed Zn, 20.64 and 21.95 mg kg^{-1}, respectively, were recorded with no zinc fertilizer. These highest values of Zn in leaves and seeds were 16.57 and 18.31% higher, respectively, than the control. The value of seed Zn obtained with the application of 0.5% $ZnSO_4{\cdot}7H_2O$ was also 11.98% greater than the value obtained from the control. Although the highest seed Zn was observed at the application of 1.5% $ZnSO_4{\cdot}7H_2O$, it was not significantly higher than the values obtained at applications of 0.5 and 1% $ZnSO_4{\cdot}7H_2O$.

Table 5. Effect of Zn fertilization on the production and tissue Zn concentration of haricot beans

$ZnSO_4{\cdot}7H_2O$ (%)	Plant height (cm)	No. of branches per plant	No. of pods per plant	No. of seeds per pod	Grain yield (kg ha^{-1})	Biomass (kg ha^{-1})	1000 seed wt.	Leaf Zn (mg kg^{-1})	Seed Zn (mg kg^{-1})
0	42.86a	4.15ab	16.00ab	5.04a	2741.3a	6056.9b	291.61a	20.64c	21.95b
0.5	42.82a	4.23ab	16.10ab	5.15a	2810.0a	6388.9ab	306.70a	22.54b	24.58a
1	43.40a	4.29ab	15.86ab	5.23a	2810.0a	6395.4ab	294.57a	22.72ab	25.64a
1.5	43.20a	4.38a	16.41a	5.05a	2748.4a	6660.2a	306.39a	24.06a	25.97a
CV (%)	13.73	17.95	20.06	13.33	23.92	20.95	21.52	17.95	18.39
LSD (5%)	1.68	0.22	0.91	0.19	320.54	37950	35.37	1.50	1.70
P value									
$^{@}$V	<.0001	<.0001	<.0001	<.0001	<.0001	0.0015	<.0001	0.0278	0.1124
*Zn	0.8906	0.0753	0.2081	0.1891	0.9613	0.0213	0.7654	0.0002	<.0001
V × Zn	0.9537	0.6267	0.4146	0.1295	0.9937	0.6667	0.4314	0.7379	0.8878
$^{\#}$L	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
V × L	<.0001	0.0003	<.0001	0.0001	0.7260	<.0001	0.0008	0.0100	0.0010
Z× L	0.7644	0.5784	0.7161	0.5306	0.9905	0.1878	0.4164	<.0001	<.0001
V × Z× L	0.6092	0.3312	0.6925	0.0489	0.9846	0.5537	0.9135	0.9536	0.9558
$^{\$}$S	<.0001	0.0005	<.0001	<.0001	<.0001	<.0001	0.2387	0.0009	0.0031
V×S	0.0006	0.0429	0.0035	0.1179	0.0857	0.6264	1.0000	0.0825	0.0026
Z×S	0.5901	0.9074	0.8597	0.9266	0.9599	0.7784	1.0000	<.0001	0.0002
V×Z×S	0.9508	0.9972	0.8980	0.8922	0.9854	0.9998	1.0000	0.9198	0.8858
L×S	<.0001	<.0001	<.0001	0.0001	0.0073	<.0001	1.0000	<.0001	<.0001
V×L×S	0.0569	0.0119	0.0560	0.0795	0.0588	0.5084	1.0000	0.0002	0.0291
Z×L×S	0.6602	0.9409	0.6855	0.8924	0.8914	0.9861	1.0000	<.0001	<.0001
V×Z×L×S	0.9537	0.0727	0.7219	0.9793	0.9999	1.0000	1.0000	0.9974	0.9941

Means followed by the same letter(s) within a column are not significantly different at $P \leq 0.05$.

*Z = $ZnSO_4{\cdot}7H_2O$, $^{@}$V = variety, $^{\#}$L= location, $^{\$}$S=season

The highest seed weight (337.78 g) was observed at 3% $FeSO_4.7H_2O$, while the lowest value (240.76 g) was observed with zero Fe. The highest leaf and seed Fe concentrations, 195.60 and 89.18 mg kg^{-1}, respectively, were observed at 3% $FeSO_4.7H_2O$, while the lowest values, 149.89 and 28.72 mg kg^{-1}, respectively, were obtained at zero Fe fertilizer. Similarly, Yadav et al. (2013) reported a significantly increased fruit yield by application of Fe fertilizer to peach trees in India, and Kobraee et al. (2011) reported increased yield and tissue Fe concentration by application of Fe fertilizer to soybean in Iran. In contrast, Imakumbili et al. (2010) reported application of Fe fertilizer did not significantly affect seed Fe concentration of bean in Tanzania. Yet, in this Ethiopian field study, all interactions with different levels of Fe fertilizer did not significantly influence yield parameters and concentrations of tissue Fe. Application of different levels of Fe fertilizer in different varieties, locations, and seasons did not significantly influence haricot bean production in terms of quantity.

Table 6. Effects of Fe fertilization on yield, yield components and tissue Fe concentrations of haricot bean

$FeSO_4.7H_2O$ (%)	Plant height (cm)	no of branches per plant	No of pods per plant	No of seeds per pod	Grain yield ($kgha^{-1}$)	Biomass ($kgha^{-1}$)	1000 seeds weight (g)	Leaf Fe (mg kg^{-1})	Seed Fe (mg kg^{-1})
0	45.42a	4.68a	17.26a	5.18a	2792.93a	7072.5a	240.76b	149.89d	28.72d
1	45.20a	4.59a	16.17a	5.25a	2754.04a	6914.1a	241.87b	164.71c	49.53c
2	45.62a	4.58a	16.94a	5.09a	2744.2a	6933.6a	249.86b	175.58b	67.67b
3	45.22a	4.65a	16.69a	5.2a	2846.12a	6927.1a	337.78a	195.60a	89.18a
CV (%)	10.74	16.14	22.86	12.88	20.29	18.62	14.20	21.35	16.41
LSD (5%)	1.35	0.21	1.09	0.19	160.48	368.25	86.81	9.29	20.32
P value									
*V	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.3164	0.8880
Fe	0.0037	0.799	0.2513	0.3742	0.5874	0.8146	0.0806	0.0112	0.0453
V × Fe	0.2943	0.086	0.0562	0.1498	0.6749	0.1970	0.0176	0.9867	0.3958
$^@$L	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0535	<.0001	<.0001
V × L	<.0001	<.0001	<.0001	0.3644	<.0001	0.0204	0.0087	0.6135	0.6509
Fe × L	0.5200	0.8618	0.6790	0.0298	0.9475	0.1880	0.1069	0.5685	0.5381
V × Fe × L	0.6760	0.3486	0.6686	0.8620	0.5631	0.2544	0.0027	0.7482	0.1828
$^\#$S	<.0001	0.1725	<.0001	<.0001	<.0001	<.0001	0.6309	<.0001	0.6477
V × S	<.0001	0.745	0.0006	0.018	<.0001	0.2163	1.0000	0.1337	0.6271
Fe × S	0.2122	0.9670	0.6680	0.8117	0.2484	0.9912	1.0000	0.5359	0.4807
V × Fe × S	0.7508	0.3960	0.4864	0.7205	0.6678	0.9979	1.0000	0.9681	0.2481
L × S	<.0001	0.0078	<.0001	0.8494	<.0001	0.1051	1.0000	<.0001	<.0001
V × L × S	0.0002	0.0123	0.0016	0.1164	<.0001	0.9448	1.0000	0.7913	0.5150

Means followed by the same letter(s) within a column are not significantly different at $P \leq 0.05$ according to least significant difference (LSD) test. *V= variety; $^@$L=location; $^\#$S=season

Therefore, the application of 0.5% $ZnSO_4·7H_2O$ is recommended for producing better quality haricot beans. The amount of seed Zn obtained from the 0.5% application was 24.58 mg kg^{-1}, which is enough for 1.64 days per person (Hafeez et al., 2013), i.e., 1 kg of haricot beans produced with the application of 0.5% $ZnSO_4·7H_2O$ can supply a single person's Zn needs for 1.64 days. Fertilization with Zn did not significantly influence the yield and yield parameters of haricot beans. Ai-qing et al. (2013) also reported that the foliar application of Zn fertilizer did not significantly increase the grain yield of wheat in China. Contrarily, Kobraee et al. (2011) reported that Zn fertilizer significantly increased the yield of soybeans. However, the highest pods per plant and biomass yield were observed with an application of 1.5% zinc sulfate. Mahbobeh et al. (2011) reported that the foliar application of zinc sulfate increased the number of pods per plant in haricot beans. The authors attributed the increase to the positive effect of zinc sulfate on the formation of stamens and pollen. Since the haricot bean is a self-pollinated plant, as the activity of stamens increases, the flowers are more fertile and more pods can be produced per plant. Contrarily, Goh and Karamanos (2003) reported that foliar application of Zn significantly increased the yield of haricot beans compared to an unfertilized control.

Conclusions

The experiments revealed that haricot bean production varied significantly among locations and bean varieties in terms of yield parameters and tissue Zn and Fe concentrations. The highest values for yields and yield parameters were observed in soils of Butajira. Nasir and Sari-1 had the highest seed Zn, 20.13 and 20.14 mg kg^{-1}, respectively, while Hawassa Dume gave the highest grain yield (3149.3 kg ha^{-1}) though not significantly different from Nasir did (2870.4 kg ha^{-1}). The application of increasing levels of Zn and Fe fertilizers significantly increased tissue Zn and Fe concentrations. Although the highest seed Zn was observed with the application of 1.5% $ZnSO_4·7H_2O$, it was not significantly higher than the values obtained at applications of 0.5

and 1% $ZnSO_4·7H_2O$. Thus, 0.5% $ZnSO_4·7H_2O$ was the best rate for the quality bean production.

Generally, Fe fertilization resulted in best haricot bean production at Butajira both in quantity and quality, which could be attributed to lower available Fe and higher total nitrogen in the experimental soil as compared to the other locations. Nasir produced the highest grain yield and seed Fe concentration and was found to be best variety both in quality and quantity. The application of different levels of Fe fertilizer did not significantly influence yield and yield components of haricot bean varieties, but it significantly increased tissue Fe concentrations, the highest values being observed at 3% $FeSO_4.7H_2O$.

Zinc and Fe fertilization enriches haricot bean with the elements and hence improves its quality. Consequently, Nasir, 0.5% $ZnSO_4·7H_2O$ and 3% $FeSO_4.7H_2O$ were found to be the best variety, Zn and Fe rates, respectively, for quality production of haricot bean. Therefore, growing Nasir at 0.5% $ZnSO_4·7H_2O$ and 3% $FeSO_4.7H_2O$ can contribute to alleviate the deficiency of Zn and Fe in people who consume the crop as a major component of their diet. Therefore, supply of Zn and Fe from haricot beans can be improved through foliar application of Zn and Fe sulfate and selection of bean varieties with high capacity to accumulate Zn and Fe. The consumption of such haricot beans with high Zn and Fe content can significantly improve the Zn and Fe status of people who consume the crop as a major component of their diet.

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