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Foliar Zinc Fertilization Improves Marketable Fruit Yield and Quality Attributes of Pomegranate

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ABSTRACT

Zinc (Zn) deficiency is commonly observed in pomegranate (*Punica granatum*) orchards. In this study the response of four commercial pomegranate cultivars to foliar Zn fertilization at a rate of 0.4% was evaluated in a two-years field experiment. Although, Zn fertilization did not significantly increase total fruit yield the unmarketable yield was significantly reduced. Fruit juice dry weight, density and concentration of solid materials and minerals were significantly increased by foliar application of Zn, which have important implications on fruit quality for pomegranate processing industries. Zn application significantly increased Zn concentration in leaf in all cultivars and fruit juice in three cultivars. However, seed Zn concentration was not affected in all cultivars. Based on the results, different cultivars respond differently to Zn fertilization under irrigation with saline water.

Key Words: Micronutrients; *Punica granatum*; Zinc deficiency; Zinc sulfate

INTRODUCTION

Pomegranate (*Punica granatum* L.) is a fruit tree well adapted to arid areas, where the summer is hot and dry and the winter is cold. Zinc (Zn) deficiency is commonly observed in pomegranate orchards of Iran (Taghavi, 2000; Daryashenas & Dehghani, 2006), India (Balakrishnan *et al.*, 1996; Raghupathi & Bhargava, 1998) and USA (LaRue, 1980), which are the three leading pomegranate producing countries. Zn fertilization is the most practical solution to Zn deficiency in orchards. Soil application of Zn increased hazelnut yield and quality in Turkey (Serdar *et al*., 2005). Fall application of urea and zinc sulfate decreased floral bud death and increased fruit set of sweet cherry (Glozer & Grant, 2006). Foliar application of Zn on date palms significantly increased fruit yield, fruit length and pulp weight, without significantly affecting seed characteristics (Khayyat *et al*., 2007).

The literature on Zn fertilization of pomegranate is scarce. Foliar application of 0.25% each of zinc sulfate, iron sulfate and manganese sulfate along with 0.15% boric acid increased pomegranate yield from 18.5 kg per tree in control to 26.37 kg per tree and juice content from 65.6% to 74.8% (Balakrishnan *et al*., 1996). In a field study on pomegranate in Iran, soil application of N, P and K (based on soil analysis), along with foliar application of 0.5% zinc sulfate, increased pomegranate yield more than 1.3 t ha^{-1} compared to control (Taghavi, 2000). The control was fertilized according to farmer's routine program, which did not include micronutrients such as Zn. Recently, biofertilization of pomegranate under harsh desert environment in Thar Desert of India, has imporved its yield and nutrition (Aseri *et al.*, 2008). Therefore, they may be new alternatives to soil and foliar application of fertilizers for pomegranate orchards.

Yazd Province, located in Central Plateau of Iran is the fifth largest producer of pomegranate in Iran, both in terms of area under cultivation and production. Zn deficiency is commonly observed in pomegranate orchards of this province (Daryashenas & Dehghani, 2006). Four cultivars are cultivated popularly in this province the responses of which to Zn nutrition have not been studied. Consequently, considering the socio-economic importance of pomegranate and the widespread Zn deficiency in pomegranate orchards of arid areas, this study was conducted to evaluate the effects of Zn fertilization on fruit yield and quality of four commercial pomegranate cultivars. In addition, differences or similarities in response of different cultivars to Zn fertilization were studied.

MATERIALS AND METHODS

Field experiments were carried out during 2002 and 2003 on a sandy loam soil at Yazd Agricultural and Natural Resources Research Center (YANRC), Yazd Province, Iran. The soil moisture and temperature regimes at the site were

Aridic and Thermic, respectively. The experiment was factorial with randomized complete blocks design and four replications. The pomegranate cultivars studied were Togh Gardan (TG), Shahvar Dane Ghermez (SDG), Malas Yazdi (MY) and Zagh Yazdi (ZY). These cultivars are sweet-sour, sweet, sweet-sour and sour, respectively and based on their taste and color, have their particular markets.

The area of the experimental field was 5000 m^2. The fruit trees were all planted at the same time and at the start of the experiment, they were 18 years old. The distance between trees was 4 m in row and 6 m between rows. The irrigation method was border irrigation and the irrigation depth was 180 cm (18,000 m^3 ha^{-1}) in each year of the experiment. Chemical analysis of the irrigation water indicated relatively high salinity of the irrigation water with an EC_{iw} of 3.99 dS m^{-1}. However since pomegranate is moderately salt tolerant (Maas, 1996) and the soil texture was sandy loam throughout the profile (good natural soil drainage), fruit production generally has been economical.

Soil analysis of the experimental field indicated Zn deficiency (Table I). Based on the recommendations of the plant nutrition specialists at YANRC, the type and amount of fertilizers applied per tree were potassium sulfate (450 g), triple super phosphate (375 g), urea (twice, 300 g each time), iron sulfate (200 g), manganese sulfate (80 g) and copper sulfate (50 g). The required fertilizers were deep placed about 1 m from the tree trunks at a depth of 50 cm, except urea, which was surface applied.

There is no clear recommendation for Zn nutrition of pomegranate in the area and there is uncertainty about its effectiveness under saline conditions. Zn was foliar applied twice (April 15 & May 15), using a pesticide application machine at a rate of 0.4%, when the branches had produced young leaves, in both years of the experiment. The source of Zn was dry zinc sulfate ($ZnSO_4$; 34% Zn). At each foliar application, 5 kg Zn ha^{-1} was foliar applied, for a total of 10 kg Zn ha^{-1} (30 kg $ZnSO_4$ ha^{-1}).

The fruits were harvested on 7-10 of September of each year. The total and unmarketable fruit yields were measured. Unmarketable yield was the amount of rotted fruits per tree, which were due to environmental factors, physiological disorders and damages by pests and diseases. Before harvest, eight fruits from the four sides of each tree were randomly picked and were used for determination of fruit and fruit juice quantitative and qualitative characteristics in the laboratory. These characteristics were dry weights of peel, aril and fruit juice; fruit juice density, total soluble solids (TSS) and vitamin C concentration; and Zn concentrations of leaves, fruit juice and seed. To determine the dry weights, 100 g of fresh peel and 20 mL of fruit juice were oven dried at 80°C for 72 h and dry weights calculated. The fruit juice density (g cm^{-3}) was calculated by weighing 20 mL of fresh fruit juice. The percent of TSS in fruit juice was measured by using an Abbe Refractometer (2WAJ, SIONTECH, Germany) (Saini *et al*., 2001). The fruit juice vitamin C concentration (mg 100 mL^{-1} fruit juice) was determined by indophenols method (Saini *et al*., 2001). Zn concentrations of leaves, fruit juice and seed were determined by dry ash method as described by Saini *et al*. (2001), using Atomic Absorption Spectrometer (5100ZL, Perkin Elmer, USA).

The data were statistically evaluated by analysis of variance procedures, using SAS software (SAS, 1989). Duncan's multiple range test at 5% level of probability was used for comparison of means.

RESULTS AND DISCUSSION

Quantitative characteristics. The effect of year on total yield was not significant, while it was highly significant on unmarketable yield (data not shown). This indicated the importance of environmental conditions on yield characteristics. The average temperature was warmer than the 50-years average in both years of the experiment (data not shown). The average yearly rainfalls were also less than the 50-years average by 24 and 12% in the years 2002 and 2003, respectively. The 2003 season was relatively cooler than 2002 season and had more rainfall, particularly during the fall and winter months. Cooler temperatures indicated less evapotranspiration in 2003 than 2002 and since the rainfall was also more, the fruit trees were under less water and heat stresses.

The total fruit yield did not significantly increase in any of the cultivars due to Zn fertilization (Table II). In addition, the total yields among cultivars were not significantly different, although ZY cultivar had the highest total fruit yield in both Zn fertilized and unfertilized treatments (Table II). The amount of cracked fruits was not significantly different among cultivars in both Zn treatments and there was no significant effect of Zn in any year of the experiment (data not shown).

Zn fertilization significantly decreased unmarketable fruit yields (Table II). There were also significant differences among cultivars either in control or Zn fertilized (Table II). Among cultivars, TG had the lowest unmarketable yield, but it was not significantly different than ZY cultivar in control and ZY and MY in Zn treatment. SDG had the highest amount of unmarketable yield in both treatments, but it was not significantly different than MY cultivar (Table II).

Unmarketable yields were lower in 2003 than 2002 in both control and Zn fertilized treatments (Table II). This was due to better weather condition and less heat and water stresses in 2003. Also, the % reductions in unmarketable yields due to Zn fertilization were greater in 2003 (Table II). Therefore in addition to a more favorable weather condition, the beneficial effects of first year Zn application on general tree health was another reason for lower production of unmarketable yield in the second year. In other words, Zn may have increased the ability of the pomegranate trees to resist diseases and environmental stresses. Graham (1983) has reviewed evidences for linkages between Zn nutrient

Table I. Selected properties of the soil before the start of experiment

Depth (cm)	Texture	EC_e (dS m^{-1})	pH	$CaCO_3$ (%)	OC (%)	P	K	Cu	Mn	Fe	Zn
						(mg kg^{-1} soil)					
0-30	SL	3.85	7.9	23.2	0.19	9.8	110	0.34	1.8	4.2	0.64
30-60	SL	4.90	7.8	22.6	0.09	11.3	150	0.86	3.4	5.8	0.70
60-90	SL	6.18	7.8	21.7	0.17	11.7	165	0.87	3.8	5.8	0.76

OC = Organic Carbon **SL** = Sandy loam **EC_e** = Saturated soil paste electrical conductivity

stress and plant diseases. Zn efficient wheat genotypes were less susceptible to crown rot disease (Crewal *et al*., 1996) and *Rhizoctonia* root rot (Thongbai *et al*., 2001).

Qualitative characteristics. The effect of year on dry peel weight was significant and on fruit juice dry weight and density, TSS, vitamin C and Zn concentrations was highly significant (Table III). The effect of Zn fertilization was not significant on dry peel weight (Table III). It also varied considerably among pomegranate cultivars (Fig. 1A). This property is important for carpet and tanning leather industries, as well as for shelf life and storage capability of fruits. As dry peel weight increases, more natural dye and tannin can be extracted and the shelf life of the fruits is expected to increase. TG and SDG cultivars had the highest and lowest dry peel weights, respectively in both Zn fertilized and unfertilized treatments (data not shown). These two cultivars also had the lowest and highest incidence of unmarketable yields, respectively (Table II). Thus it seems that thinner skin may increase the susceptibility of the fruit to spoilage.

The effects of Zn fertilization on fruit juice dry weight, density and TSS was highly significant (Table III). These characteristics were not significantly different among cultivars (Table III), with or without Zn fertilization (Fig. 1B-D). These results indicate that Zn application improved fruit quality for paste, concentrated fruit juice and fruit roll purposes, as well as fresh fruit consumption.

Zn fertilization did not significantly increase vitamin C concentration of the fruit juice. In addition, it was not affected by year, but was significantly different among cultivars (Table III). The average vitamin C concentration of pomegranate juice in this experiment was between 14.3-24.6 mg 100 mL^{-1} in the control, and between 17.2-24.7 mg 100 mL^{-1} in the Zn fertilized trees. Raw pomegranate pulp (arils without the seeds) has been reported to contain 6.1 (± 0.71) mg vitamin C 100 g^{-1} fresh weight (USDA-NDB, 2006). All four Iranian cultivars studied here seemed to have considerably greater vitamin C content than the above value. MY cultivar had the highest vitamin C concentration among the four pomegranate cultivars, either with or without Zn fertilization (data not shown). This cultivar was rich in vitamin C and had about 43-72% more vitamin C than the other cultivars.

Zinc concentrations. The effect of year on Zn concentrations of leaf, fruit juice and seed was not significant (data not shown). Also, they were not significantly different among cultivars in neither of the Zn treatments (Fig. 2). Zn application significantly increased leaf Zn concentration in all four pomegranate cultivars (Fig. 2A).

Table II. Mean unmarketable fruit yields of the pomegranate cultivars

Year	Cultivar	Fertilizer Treatment - Zn		+ Zn		Reduction in Unmarketable Yield (%)	
2002	TG	3.98	ab†	1.85	d†	47.4	C†
	SDG	4.75	a	3.50	b	26.7	D
	MY	4.15	ab	2.20	cd	49.3	C
	ZY	4.18	ab	1.93	d	54.5	BC
2003	TG	1.38	def	0.38	f	73.5	AB
	SDG	3.55	b	0.63	ef	83.1	A
	MY	3.05	bc	0.68	ef	77.1	A
	ZY	1.70	de	0.48	f	69.8	AB

†Means with the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test

Table III. The ANOVA *F* values for some of the measured qualitative characteristics of pomegranate cultivars, for the two-year experiment

Treatment	Peel Dry Wt. (%)	Fruit Juice Dry Wt. (%)	Density (g cm^{-3})	TSS (%)	Vitamin C (mg L^{-1})
Year (Y)	4.12*	28.49**	28.07**	12.65**	NS
Cultivar (C)	6.06**	NS	NS	NS	5.80**
Y x C	NS	NS	NS	NS	NS
Fertilizer (Zn)	NS	25.36**	23.70**	4.93**	NS
Zn x C	NS	NS	NS	NS	NS
Zn x Y	NS	NS	NS	NS	NS
Zn x C x Y	NS	NS	NS	NS	NS

*, ** significant at 5% and 1% probability levels, respectively
NS not significant at 5% probability level

Normal range of Zn in most plants (mg Zn kg^{-1} leaf dry weight) is 20-100 and below 15 is considered Zn deficiency (Plank, 1989). Leaf Zn deficiency threshold values (mg Zn kg^{-1} leaf dry weight) has been reported to be 14 for apple (Shear & Faust, 1980), 30 for pecan (Plank, 1989) and 20 for avocado (Goodall *et al*., 1979). Also, Zn sufficiency range (mg Zn kg^{-1} leaf dry weight) has been reported to be 30-75 for woody ornamentals (Plank, 1979), 30-150 for avocado (Goodall *et al*., 1979) and 20-50 for apple and pear and 15-50 for peach (Plank, 1989). Sufficiency range of Zn in pomegranate leaves (mg Zn kg^{-1} leaf dry weight) has been reported to be 38-45 (Raghupathi & Bhargava, 1998) and 14-72 (El Kassas *et al*., 1993). Daryashenas and Dehghani (2006) reported that leaf Zn concentration in high (>14 t ha^{-1}) and low (<14 t ha^{-1}) yielding pomegranate orchards of Yazd were between 11-24 and 10-25 mg kg^{-1}, respectively. In this experiment, the average Zn concentrations of leaf in four pomegranate cultivars were also between 12.0-19.8 mg kg^{-1} in the control (Fig. 2A). Thus, pomegranate trees had Zn deficiency. Zn foliar application significantly increased average leaf Zn

Fig. 1. Peel dry weight (A), fruit juice dry weight (B), fruit juice density and total soluble solids of four pomegranate cultivars as affected by Zn treatment (0 & 0.4%) for the combined data of the two study years

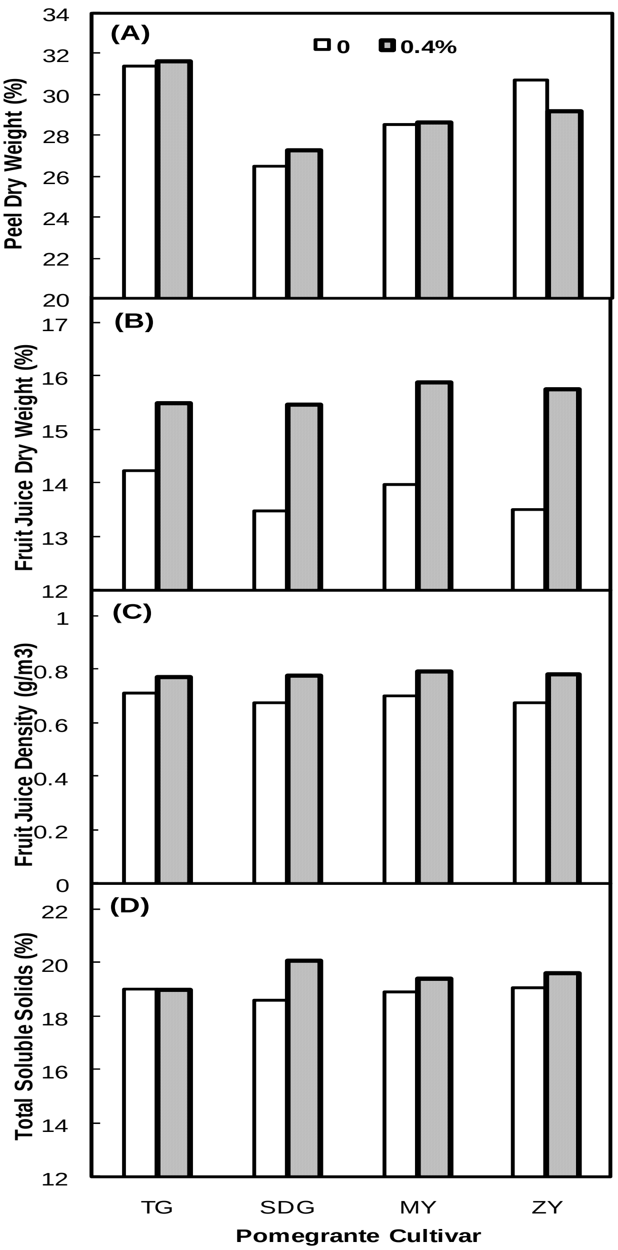
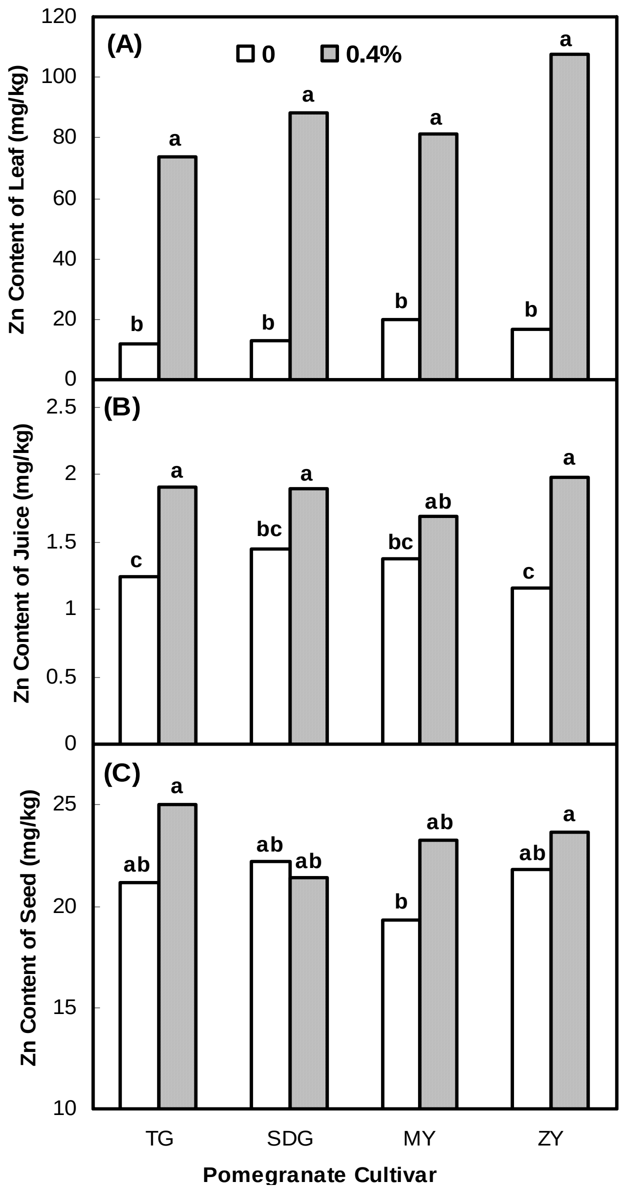


Fig. 2. Zinc concentration (mg kg^{-1} dry weight) of leaf (A), fruit juice (B) and seed (C) as affected by Zn treatment (0 and 0.4%) for the combined data of the two study years. Bars with the same letters at each graph are not significantly different at *p*<0.05 according to Duncan's multiple range test



concentrations to 73.5-107.4 mg kg^{-1} and corrected Zn deficiency of the trees, which was evident in highly significant reduction in unmarketable (rotted) fruit yields (Table II).

Foliar application of Zn significantly increased Zn concentration of pomegranate juice in three out of four cultivars (Fig. 2B). The average Zn concentration of fruit juice in control was between 1.16-1.45 mg kg^{-1} juice dry weight (Fig. 2B). Pomegranate pulp (arils without the seeds) has been reported to contain 1.2 mg Zn 100 g^{-1} fresh weight (USDA-NDB, 2006). Mirdehghan and Rahemi (2007) studied the seasonal changes of mineral nutrients in pomegranate (Malas Yazdi cv., one of the four cultivars studied in this experiment) and reported Zn concentration of the aril (pulp & seed) at harvest to be about 11.75 mg Zn kg^{-1} aril dry weight. The reason for differences in our results and the results of Mirdehghan and Rahemi (2007) was that they measured Zn concentration in the whole dried aril (pulp & seed), while we measured Zn concentration in only the juice (pulp) fraction of the aril. The average Zn concentration of fruit juice in Zn foliar application treatment was between 1.69-1.98 mg kg^{-1} juice dry weight (Fig. 2B). It was increased significantly in TG, SDG and ZY cultivars and although it was increased in MY cultivar by more than 23%, the increase was not significant (Fig. 2B). The results showed that fruit juice nutritional value in terms of Zn has been improved by foliar application of Zn to the pomegranate trees.

Foliar application of Zn did not have a significant effect on seed Zn concentration in any of the four pomegranate cultivars (Fig. 2C). The average Zn concentrations of seeds in control and Zn treatment were between 19.3-22.3 and 21.4-25.0 mg kg^{-1} seed dry weight (Fig. 2C). These values were higher than the ones reported by Mirdehghan and Rahemi (2007) for the whole aril. Considering our Zn concentrations in dry weights of fruit juice (Fig. 2B) and seed (Fig. 2C), the results of Mirdehghan and Rahemi (2007) seems reasonable, since they analyzed the whole aril (pulp & seed fractions) for Zn concentration, while we analyzed each fraction separately. In control treatment, Zn concentration of seeds was higher than Zn concentrations of leaf and juice (Fig. 2). However in Zn fertilized trees the order of Zn concentration from highest to the lowest was leaf>seed>juice (Fig. 2). In both Zn treatments, fruit juice had the lowest concentration of Zn in the three fractions studied. The main reason is that metabolic activities in fruit juice are less than leaves and seeds. Nutrients within the plants tend to move more to the sites, where metabolic activities are for any reason high (Faust, 1989). Pomegranate seed is a rich source of phytoestrogens, a group of naturally occurring phenolic compounds (Moneam *et al*., 1988) and Zn may enhance their concentrations in the seeds. This is the subject of another part of this experiment.

CONCLUSION

Although with different responses, zoliar Zn spray significantly reduced unmarketable fruit yields (rotted fruits) of all commercial pomegranate cultivars, which indicated possible role of Zn in improving the ability of pomegranate to resist unfavorable environmental factors and diseases. Some fruit quality characteristics for various pomegranate food processing purposes and nutritional values in terms of Zn were also affected positively by Zn fertilization. Therefore there is a need for further researches to differentiate differences among cultivars.

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