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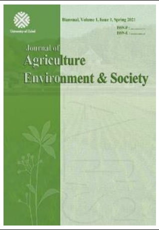

Evaluation of the effect of foliar zinc sulfate application on quality characteristics, yield, and yield components of barley cultivars under irrigation water salinity conditions

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ABSTRACT

In order to evaluate the effect of zinc sulfate fertilizer on quality characteristics, yield and yield components of barley cultivars under irrigation water salinity (salinity over 6 dS/m), this research was conducted as split-plots in randomized complete blocks design with three replicates in Kabutarabad Agricultural Research Station in Isfahan. Foliar application of zinc sulfate concentration at three levels (0, 0.5 and 1%) was considered as main factor and three cultivars of Armaghan (stress sensitivity), Goharan (drought tolerant), and Mehr (salinity tolerant) were considered as sub-factors. The results demonstrated that foliar application of zinc sulfate at concentration of 1% significantly increased the chlorophyll b content by 14.8% compared to a lower concentration (0.5%). The highest chlorophyll a content (1.85 mg/g), leaf content (45.9 mg/kg), and grains/spike (37.2) with foliar application of 1% zinc sulfate was observed in Mehr cultivar. Given foliar application of 1% zinc sulfate, Mehr and Goharan cultivars had 21.3% and 15.3% higher leaf proline than Armaghan cultivar, respectively. Foliar application of zinc sulfate at concentration of 1% in Mehr, Goharan, and Armaghan cultivars significantly increased grain yield by 22.2%, 25.7% and 29.0%, respectively, compared to the non-foliar application of sulfate fertilizer. Generally, the results of the present study suggested that under irrigation water salinity conditions, Mehr cultivar is superior to Goharan and Armaghan cultivars in response to foliar application of zinc sulfate and the photosynthetic pigments produced higher yield and yield components.

Highlights

- Foliar 1% zinc sulfate boosts barley yield by 22-29% under saline conditions.
- Mehr cultivar excels with higher chlorophyll and yield with zinc sulfate.
- Zinc sulfate at 1% increases chlorophyll b by 14.8% vs. 0.5% concentration.
- Mehr and Goharan show 21.3% and 15.3% more proline than Armaghan with zinc.

1. Introduction

Barley, scientifically known as *Hordeum vulgare* L, is an annual grass (belonging to the Gramineae) is the fourth most important cereal after wheat, rice, and corn. Barley needs a less fertile soil than wheat and is more adaptable to different types of soils. It is more salinity tolerant than other cereals, however, some varieties of bread wheat (such as: Narin, Barzegar, …) and durum wheat (Mahan, Sana,…) are more tolerant. The soil should not be drowned and its sandy or acidity should not be lower than 6% (barley is sensitive to acidic soil conditions). Nearly half of the cultivated barley is used as livestock feed. The grains are usually mixed with other foods to produce livestock feed (Winch, 2009). Soil nutrient deficiency, leaching, and drought are the most important factors to reduce barley yield (Tigre et al., 2014).

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Foliar application is another way for rapid supply of nutrients for plants. In this method, nutrients are directly available to air organs and fruit. Given the various effective factors on soil absorption of nutrients, foliar application is an effective method in correcting plant nutrition disorders (Khan et al., 2003). Foliar nutrition is a method to reduce the stability of chemical fertilizers in the soil and as a result decrease environmental hazards, including soil and water contamination, and provides nutrients to the plant in a controlled manner (Kannan, 2010). Nowadays, in addition to macronutrients, micronutrients are also taken into consideration as an important tool to achieve maximum yield per unit area (Mosavi et al., 2007).

Zinc is an essential micronutrient involved in the activity of various enzymes. Carbonic anhydrase, which catalyzes the reversible conversion of carbon dioxide and water to carbonic acid, contains zinc element and needs zinc for activity (Weisany et al., 2012). Zinc plays a role in protein metabolism, gene expression, structural and functional integrity of biological membranes, and photosynthetic carbon metabolism. Zinc is involved in regulating the opening of stomata given its role in keeping membrane integrity. In zinc deficiency, K+ content of stomatal guard cells is reduced (Tester and Davenport, 2003).

Continuous cultivation, annual overuse of phosphorus fertilizers, leaching and other conditions of calcareous soils, including large amounts of calcium carbonate, Alkaline pH, and not using micronutrient-containing and organic fertilizers reduces the storage of this element in the soil and thus its yield (Seyed Sharifi et al., 2015). Zinc deficiency could not be entirely and definitively solved through consuming zinc-containing fertilizers in cases of subsoil constraints, surface soil dryness, and diseases. Therefore, using efficient genotypes for zinc uptake could be an effective and sustainable solution for further production of crops under zinc deficiency conditions (Sadeghzadeh, 2013). Durable and efficient genotypes in absorbing and using zinc can be considered as a complement for soil use and foliar application of zinc, particularly when farmers are not aware of zinc deficiency in their field soil or do not have access to zinc fertilizer. In addition to reducing the use of chemical fertilizers, applying cultivars with high efficiency of zinc element could increase the quantity and quality of the product with the minimum amount of available zinc (Sadeghzadeh and Rengel, 2011).

Salinity of water and soil resources is one of the most important agricultural issues in Iran. Under salinity conditions, the provision of nutrients in the soil solution is reduced due to the high concentration of chlorine, sodium, and also calcium ions and leads to eating disorder and imbalance of plant nutrients. Therefore, the role of proper nutrition is highly important under these conditions to ensure the proper growth and increase plant yield while maintaining the balance of nutrients (Ahmadi et al., 2006). Zinc is one of the most effective micronutrients for plants grown in calcareous, saline, and sodium soils at high pH. Today, treatments that can be used to grow plants in saline soils is of great interest to many researchers. Zinc is one of the significant elements in reducing salinity stress and toxic effects of sodium and chlorine in plants (Vojodi Mehrabani et al., 2018). Therefore, in this regard, this research was conducted with an aim of investigating the foliar application of zinc sulfate fertilizer on morphophysiological properties, yield, and yield components of barley under saline irrigation conditions and also determining the most appropriate cultivar.

2. Materials and methods

This experiment was conducted in a split-plot design with three replications at Kabutarabad Agricultural Research Station in Isfahan (51º40'N, 32º93'E), and an altitude of 1541 meters above sea level with very hot dry climate, arid summers, and semi-cold winters in accordance to Koppen classification. Mean annual precipitation and temperature were 122 mm and 16.1°C, respectively, at the experimental site. Some physicochemical properties of the test site soil are presented in Table 1.

Table 1. Some physical and chemical properties of field soil

Clay	Silt	Sand	O.C	pH	EC	Absorbable phosphorus P (available)	Absorbable potassium K (available)	Absorbable copper Cu (available)	Absorbable zinc Zn (available)	Absorbable manganese Mn (available)	Absorbable iron Fe (available)	Absorbable boron B (available)
%					dS/m	mg/kg						
38	46	16	0.95	7.1	13.2	11.5	304	0.76	0.30	7.64	1.22	1.68

Three foliar application of zinc sulfate concentration [control (0%), 0.5% (2 kg/ha of zinc sulfate or equivalent to 659 g/ha of zinc) and 1% (4 kg/ha of zinc sulfate or equivalent to 1319 g/ha of zinc)] were the main plots, and the barley (*Hordeum vulgare* L.) cultivars [Armaghan (stress-sensitive), Goharan (drought-tolerant), and Mehr (salt-tolerant)] were the subplots. Some physicochemical characteristics of the soil and irrigation water quality are shown in Table.1. Mean annual precipitation and temperature were 122 mm and 16.1°C, respectively, at the experimental site. Seeds were sown with the density rate of 450 seeds m^{-2} on 5 November by a cereal row planting machine (Wintersteiger Plotman, Austria). Each subplot consisted of six rows, 6 m in length, and was spaced 20 cm apart. To irrigate the plots, water was delivered a local well (with water salinity over 6 dS/m). Foliar application of zinc sulfate was conducted at tillering stage with an interval of 7 days and in 3 turns.

2.1. Proline content

Three flag leaves were randomly sampled from each testing unit and the proline content was measured by Bates (1973) technique. In this method, 400 mg of fresh leaf of the plant previously stored at -20 ° C was transferred to a mortar and pounded by adding 10 ml of 3% sulfosalicylic acid. Then, the resulting solution was passed through a filter paper and 2 ml of the filtered solution, 2 ml of ninhydrin solution, and 2 ml of acetic acid solution were poured into a test tube. The solution was stirred and kept in water bath at temperature of 90 ° C for 1 h. Solution-containing tubes were immediately placed on ice to stop the reaction and then 4 ml of toluene was added to the solution and stirred for 15 to 20 s. After being stirred, a two-phase solution was formed and the upper phase contained proline. Toluene solution was used to calibrate the spectrophotometer. After calibration, the samples were read at wavelength of 520 nm. Proline content obtained during this method was obtained based on micromoles of proline per gram of fresh leaf (Bates, 1973).

2.2. Chlorophyll a and b content

The concentrations of chlorophyll a, chlorophyll b and totalchlorophyll were calculated using the following equation (Arnon, 1949):

Total Chlorophyll: $20.2(A_{645}) + 8.02(A_{663})$, Chlorophyll a: $12.7(A_{663}) - 2.69(A_{645})$, Chlorophyll b: $22.9(A_{645}) - 4.68(A_{663})$

2.3. Agronomy measurement and statistical analysis

In order to determine plant height, spike length, grains/spike, 1000-grain weight, biological and grain yield, a number of 10 plants were randomly harvested from plants in testing plot and weighed by a scale with a precision of 0.01 g. Harvest index was also obtained from dividing grain yield by biological yield. Eventually, the data were analyzed using MSTATC after being collected and the means were compared with LSD test at a probability level of 5%. Trait correlation coefficients were also estimated by SPSS software.

3. Results and discussion

3.1. Chlorophyll a

Results of analysis of variance on data indicated that in addition to the main effects of zinc sulfate and cultivar, the interaction of these factors on chlorophyll a was also significant at probability level of 1% (Table 2). Results of comparing the means demonstrated that the highest chlorophyll a content (1.85 mg/g) was observed with foliar application of 1% zinc sulfate in Mehr cultivar, which was significantly different from all treatments (Table 3). This result could be attributed to the superiority of Mehr cultivar under salinity conditions and also to the positive effect of zinc element in improving growth and consequently increasing photosynthetic pigments of the plant. Foliar application of 1% zinc sulfate in Mehr cultivar significantly increased chlorophyll a by 46.8% compared to the control (no foliar application). Under 1% zinc sulfate conditions, Mehr cultivar had 9.4% and 16.3% higher chlorophyll a than Goharan and Armaghan cultivars, respectively. The results of the interaction of the factors indicated that the lowest chlorophyll a content (0.64 mg/g) belonged to Armaghan cultivar and under zinc sulfate fertilizer conditions (Table 3). In this regard, the results of research showed that zinc sulfate uptake increased chlorophyll a, so that foliar application of the largest amount of this substance (1%) increased the aforementioned trait by 22.88% compared to the control (Fallah, 2019). Foliar application of zinc sulfate increased the chlorophyll a content in both safflower cultivars and the lowest chlorophyll a content in both cultivars was observed in the control treatment (Moradi Telavat et al., 2015). In another study, the results indicated that foliar application of zinc sulfate increased the chlorophyll a content in safflower compared to the control treatment (Jamshidi et al., 2017). Zinc synthesis the chlorophyll via protecting the sulfhydryl group. Porphobilinogen is a chlorophyll precursor that is required for forming magnesium and zinc (Cakmak, 2000).

Trait correlation results showed that chlorophyll a content is positively and significantly correlated (0.92**) with grain yield (Table 4). In this regard, the results demonstrated that cantaloupe leaf chlorophyll had a positive and high correlation of 87% with plant yield (Nasiri Dehsorkhi et al., 2020). In a research carried out to investigate the effects of foliar application of zinc sulfate on the mung bean growth and yield under water stress, the results of correlation showed that chlorophyll a and b are positively and significantly related to biological and grain yield (Makarian et al., 2017).

Table 2. Analysis of variance of studied traits in barley cultivars affected by foliar application of zinc sulfate

Source of variation (SOV)	Degrees of freedom (df)	Mean squares (MS)					
		Chlorophyll a	Chlorophyll b	Proline content	Zinc content	Plant height	Spike length
Replication	2	0.31**	0.09ns	8361.48**	29.07ns	4.54ns	0.47ns
Zinc sulfate	2	1.37**	2.05**	12371.7**	397.66**	505.28**	0.10ns
Error (a)	4	0.007	0.01	62.75	4.47	5.35	0.89
Cultivar	2	0.38**	0.17**	2243.51**	30.97**	28.29ns	0.19ns
Zinc sulfate × cultivar	4	0.02**	0.02ns	416.46**	9.62**	6.61ns	0.58ns
Error (b)	12	0.005	0.009	65.37	1.32	8.50	0.23
Coefficient of variation C.V (%)	-	5.10	8.43	3.97	3.23	4.36	10.08

ns, * and ** represent the insignificance and significance at probability levels of 5% and 1%, respectively

Table 2 Continued.

Source of variation (SOV)	Degrees of freedom (df)	Mean squares (MS)					
		1000-grain weight	Grains/spike	Spikes/m^2	Biological yield	Grain yield	Harvest index
Replication	2	17.22ns	5.55ns	2446.17ns	1504331.2**	197428.9ns	0.11ns
Zinc sulfate	2	66.65ns	167.77**	29412.8**	3489440.2**	3378907.2**	61.29*
Error (a)	4	14.97	5.15	597.14	56298.5	41655.4	3.41
Cultivar	2	21.73ns	26.64**	3484.24**	183636.4*	586173.1**	34.99**
Zinc sulfate × cultivar	4	18.06ns	3.09*	788.74*	126331.1*	51030.2*	4.76*
Error (b)	12	6.99	0.94	234.33	36113.9	15325.6	0.88
Coefficient of variation C.V (%)	-	7.43	3.05	3.05	1.24	2.29	2.67

ns, * and ** represent the insignificance and significance at probability levels of 5% and 1%, respectively.

3.2. Chlorophyll b

Results of analysis of variance showed that foliar application of zinc sulfate significantly affect the chlorophyll b content (probability level of 1%) (Table 2). Results demonstrated that chlorophyll b is also increased with increasing levels of zinc fertilizer, so that the highest level of aforementioned trait was observed in foliar application of 1% zinc sulfate. The lowest chlorophyll b content (0.56 mg/g) was observed in the control treatment (no foliar application of zinc sulfate). Foliar application of zinc sulfate at a concentration of 1% significantly increased the chlorophyll b content by 14.8% compared to a lower concentration (0.5%) (Figure 1).

In this regard, the results of research showed that cantaloupe leaf chlorophyll is also increased with increasing levels of zinc fertilizer, so that the highest leaf chlorophyll was obtained from foliar application of 4 g/L zinc sulfate under weeding conditions (Nasiri Dehsorkhi et al., 2020). Hydrolytic activity of cellular organelles such as chloroplasts, mitochondria, cytoplasm. and apoplastic space depend on the presence of zinc (Hellubust and Caraigie, 1978).

Table 3. Results of interaction of zinc sulfate and barley cultivars on studied traits

Levels of zinc sulfat (%)	Cultivars	Traits							
		Chlorophyll a (mg.g^{-1} FW)	Proline content (µg.g^{-1} FW)	Zinc content (mg/kg)	Grains/spike	Spike/m^2	Biological yield (kg/ha)	Grain yield (kg/ha)	Harvest index (%)
0	Armaghan	0.64f	164.5e	27.5e	24.2f	415.7f	14699.9de	4530.5f	30.8e
	Goharan	0.91e	165.4e	28.5e	27.5e	422.4f	14677.8de	4764.0e	32.4e
	Mehr	1.26cd	171.3de	29.1e	29.8d	482.0e	14656.7e	5003.3d	34.1d
0.5	Armaghan	1.24d	183.5d	36.0d	31.8c	501.7de	15701.1bc	5078.6d	32.3e
	Goharan	1.38c	199.0c	36.8cd	32.2c	516.8cd	15393.2c	5508.1c	35.7cd
	Mehr	1.59b	225.5b	37.9cd	34.0b	524.3cd	15012.0d	5865.2b	39.0a
1	Armaghan	1.59b	214.9b	38.5bc	34.7b	535.4bc	15851.9ab	5847.4b	36.9c
	Goharan	1.69b	247.9a	40.0b	35.2b	558.3ab	16104.5a	5989.0ab	37.2bc
	Mehr	1.85a	260.8a	45.9a	37.2a	563.5a	15806.3ab	6118.5a	38.7ab

Based on the LSD test, means with common letter in each column are not significantly different at the probability level of 5%.

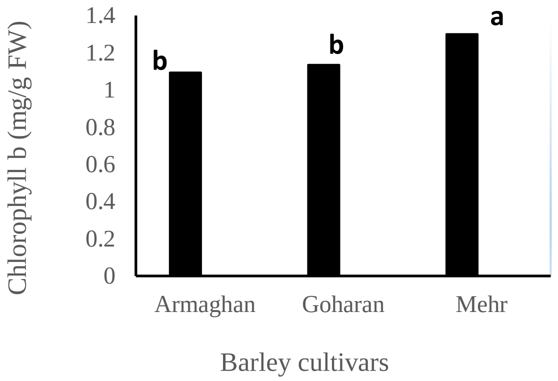
Table 4. Correlation coefficients between the studied barley traits

	1	2	3	4	5	6	7	8	9	10	11	12
1- Chlorophyll a	1											
2- Chlorophyll b	0.86**	1										
3- Proline content	0.88**	0.81**	1									
4- Zinc content	0.70**	0.85**	0.58**	1								
5- Plant height	0.62**	0.72**	0.58**	0.71**	1							
6- Spike length	-0.22ns	-0.10ns	-0.22ns	0ns	-0.06ns	1						
7- 1000-grain weight	-0.68**	-0.57**	-0.60**	-0.43*	-0.41*	-0.22ns	1					
8- Grains/spike	0.84**	0.85**	0.67**	0.86**	0.69**	-0.15ns	-0.58**	1				
9- Spikes/m^2	0.73**	0.80**	0.54**	0.89**	0.65**	-0.12ns	-0.45*	0.85**	1			
10- Biological yield	0.75**	0.74**	0.80**	0.53**	0.69**	-0.22ns	-0.42*	0.60**	0.52**	1		
11- Grain yield	0.92**	0.90**	0.83**	0.80**	0.72**	-0.11ns	-0.65**	0.88**	0.78**	0.67**	1	
12- Harvest index	0.80**	0.78**	0.66**	0.75**	0.56**	-0.03ns	-0.62**	0.82**	0.73**	0.36ns	0.93**	1

ns, * and ** represent the insignificance and significance at probability levels of 5% and 1%, respectively.

According to the results of analysis of variance, barley cultivars also suggested a significant impact ($p \leq 0.01$) on chlorophyll b content of plant leaf (Table 2). The highest (1.21 mg/g) and lowest (0.95 mg/g) chlorophyll b content was found in Mehr and Armaghan cultivars, respectively. However, Mehr and Goharan cultivars were in a statistical group in terms of significance level. Chlorophyll b content in Mehr and Goharan cultivars was 27.3% and 21.0% higher than Armaghan cultivar, respectively (Figure 1). In this regard, the research results suggested that by approaching the final stages of growth, the salinity tolerant genotype of barley showed a higher chlorophyll number, while semi-susceptible genotypes of Morocco and Nosrat were reduced by 7.02 and 5.91, respectively (Mahlooji, 2017). Researchers have said that chlorophyll is less degraded in salinity-tolerant cultivars (Kumar Parida and Bandhu Das, 2005).

Trait correlation study (Table 4) showed that chlorophyll b content was positively and significantly correlated with zinc content in the leaf at the level of 1% (0.85 **). In this regard, results of research showed that zinc content in grape leaf was positively correlated with fruit yield, chlorophyll a at the level of 5%, chlorophyll b, and total chlorophyll at the level of 1% (Vatankhah et al., 2016). Chlorophyll biosynthesis needs zinc element, and while preventing chlorophyll degradation, it increases chlorophyll a and b by producing indole acetic acid, which results in increasing photosynthesis and grain yield (Hemantaranjan and Grag, 1988).



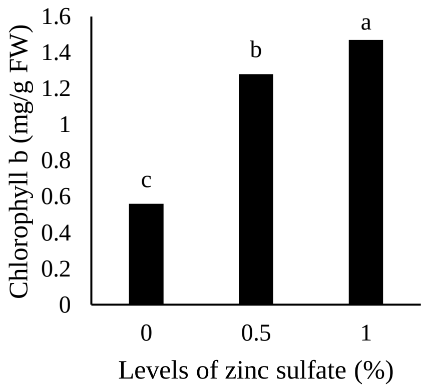


Figure 1. Comparing the means of chlorophyll b content affected by foliar application of zinc sulfate (Right) and barley cultivars (Left)

3.3. Proline leaf

Results of analysis of variance (Table 2) indicated that the main effects of fertilizer, cultivar, and also interaction of these two factors on leaf proline content were significant at the probability level of 1%. Results of the interaction of the studied factors showed that the highest leaf proline content (260.8 μg/g) is belonged to Mehr cultivar with foliar application of 1% zinc sulfate, however, as shown in Table 3, Mehr and Goharan cultivars are in a statistical group. At foliar application of 1% zinc sulfate, Mehr and Goharan cultivars had 21.3% and 15.3% higher leaf proline content than Armaghan cultivar, respectively. (Table 3). In this regard, the research results showed that the difference between barley cultivars for flag leaf proline content was significant at probability level of 1% and leaf proline content in salinity tolerant and semi-tolerant cultivars was higher than semi-salinity sensitive cultivar (Mahlooji, 2017). The researchers said that barley cultivars with high Fv/Fm ratios and the highest potential for proline production under stress conditions could have lower yield reduction (Mamnoei and Seyed Sharifi, 2010).

Results of the present research indicated that the lowest leaf proline content was observed in absence of zinc sulfate fertilizer, and with foliar application of zinc fertilizer, in particular at higher concentration (1%), leaf proline content in all three cultivars was significantly increased. Foliar application of 1% zinc sulfate in Mehr, Goharan and Armaghan cultivars significantly increased leaf proline content by 52.2%, 49.8% and 30.6%, respectively, compared to no foliar application of zinc fertilizer (Table 3).

Increasing proline content in the plants under salinity stress is in fact a reaction of the plant to dehydration in the root environment. Proline helps to regulate osmosis during stress and retain the basic structure of macromolecules and membranes during increased dehydration. In addition to osmotic regulation, proline has other tasks such as protecting plasma membranes and eliminating hydroxyl and reactive oxygen radicals (Sun et al., 2013). On the one hand, using zinc element with impact on production of osmolytes such as proline leads to a discount on stress effects, and on the other hand, indirect prevention of degradation of chlorophyll leads to continued growth and optimal distribution of osmolytes in the plant (Abbasi and Shekari, 2016). Results of the research demonstrated that highest proline content was obtained in the severe stress treatment with foliar application of 1% zinc sulfate (Fallah, 2019). In a research conducted to investigate the foliar application of zinc element on mung bean under drought stress conditions, the results showed that foliar application with 10 g zinc nano-oxide had the greatest impact on leaf proline content by 32% increase compared to the control (Makarian et al., 2017).

3.4. Leaf zinc content

Results of analysis of variance demonstrated that in addition to the main effects of the studied factors (fertilizer and cultivar), the interaction was also significant at probability level of 1% on the leaf zinc content (Table 2). Results showed that in the absence of zinc fertilizer, there was no significant difference between cultivars in terms of leaf zinc content and all three cultivars were in a statistical group. However, leaf zinc content was significantly increased with foliar application of zinc sulfate, in particular at higher concentrations (1%). Foliar application of 1% zinc sulfate in Mehr, Goharan and Armaghan cultivars increased the leaf zinc content by 57.7%, 40.3% and 0.40%, respectively, compared to the absence of fertilizer (Table 3). Increasing zinc concentration in leaf is due to direct effect of foliar application of this element, which is easily absorbed by leaf (Vatankhah et al., 2016). Results of a research showed an increasing trend with increasing concentration of zinc sulfate fertilizers and zinc nanoclates of zinc concentration in Abujahl watermelon leaf (Nikbakht et al., 2021). In another research, the highest concentration of zinc in grape leaf (49.1 mg/kg) was obtained from foliar application of 0.2% zinc sulfate, which was significantly different from the control treatment (Vatankhah et al., 2016). In a research conducted to investigate the effect of zinc fertilizer on grain corn under salinity stress, the results showed that the highest use of zinc increased the zinc and potassium in plant air organs by 27.7% and 5%, respectively, compared to the absence of zinc (Karmollachaab and Gharineh, 2013).

Results of the present research showed that the highest leaf zinc content was observed with foliar application of 1% zinc sulfate, which was significantly different from all treatments. In foliar application of 1% zinc sulfate, Mehr cultivar had 14.7% and 19.2% higher leaf zinc content than Goharan and Armaghan cultivars, respectively (Table 3). In studying the effect of irrigation water salinity and foliar application of zinc fertilizer on barley genotypes, the results indicated that reaction of barley cultivars to zinc element in air organs was significant at the probability level of 1%, so that the highest concentration of zinc element was observed in the four-salt genotype (salinity tolerant) (Mahlooji, 2017). Results of correlation showed that leaf zinc content had a positive and significant correlation with grain yield (0.80**) at probability level of 1% (Table 4). In this regard, researchers said that adding zinc fertilizer under salinity conditions might lead to further growth and increased wheat yield by improving the nutrient status in plants and reducing the effects of salinity (Ahmadi et al., 2006). In a research conducted to investigate the effect of humic acid and zinc sulfate on fruit yield and concentration of elements in grape leaf, the results showed that grape leaf zinc content had a positive correlation with fruit yield at the level of 5% (Vatankhah et al., 2016).

3.5. Plant height

Results showed that among the sources of variation, merely the foliar application of zinc sulfate could affect the plant height at probability level of 1% and the cultivar factor as well as fertilizer and cultivar interaction had no significant effect on this trait (Table 2). Results of comparing the mean levels of zinc fertilizer showed that the highest (74.8 cm) and lowest (0.60 cm) plant height were related to 1% zinc fertilizer and control (no fertilizer), respectively (Figure 2). Foliar application of zinc sulfate at concentration of 1 and 0.5% significantly increased the plant height by 24.6% and 9.3%, respectively, compared to the control. Plant height with foliar application of 1% zinc sulfate also showed a 14% increase compared to 0.5% (Figure 2).

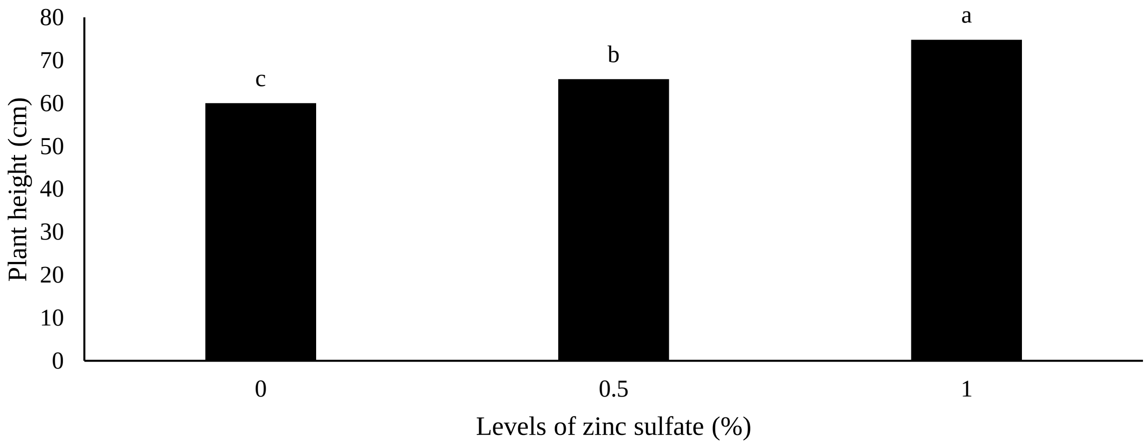


Figure 2. Comparing the means of plant height affected by foliar application of zinc sulfate

Zinc element plays a basic role in the growth, height, and yield of crops as well as in the synthesis of the hormone auxin, nitrogen metabolism processes, and the activity of enzymes. Effect of zinc application in increasing plant height could be mostly associated with effect of this factor on synthesis of tryptophan as a constituent of indole acetic acid (IAA) or plant growth hormone (Brennan, 2007). Research results demonstrated that the highest wheat height was observed at foliar application of zinc sulfate at a concentration of 1%, which was increased by 0.5% compared to foliar application and by 14.3% and 5.6% compared to control, respectively (Fallah, 2019). In another research, consuming 10 and 20 mg of Zn/kg soil under severe salinity stress increased the corn plant height by 8.1 and 12.1% (Karmollachaab and Gharineh, 2013).

Results of trait correlation showed that plant height is positively correlated (0.72**) with grain yield (Table 4). The higher height referred to better light reception by the flag leaf and second upper leaf (which play the most significant role in providing photosynthetic substance to fill the forming grains), which is associated with fertility and formation of more grains per spike (Hoseini Ebrahimi et al., 2016). A positive and significant correlation of grain yield with plant height is reasonable, due to possible increasing height by providing optimal growth conditions and a greater green area that increased CO_2 uptake and production of photoassimilates, which led to production and accumulation of substances in fertilization, grain formation, and filling and largely increased the yield (Dadashi et al., 2010). In this regard, the research results suggested that height of red bean plant is positively and significantly related (0.89**) to grain yield (Varnaseri Ghandali et al., 2020). Study of correlation of traits showed that cumin plant height had a positive and significant relationship with grain yield; so that the highest correlation was related to plant height and grain yield (Nasiri Dehsorkhi et al., 2018). Results of estimating correlation coefficients also showed that plant height is positively and significantly correlated with biological yield by 69% (Table 4). Research results showed that leaf uptake of iron, zinc, and manganese micronutrients increases dry matter yield in corn with increasing plant height (Whitty and Chambliss, 2005).

3.6. Yield components

Results indicated that in addition to the main effects of the studied factors (at probability level of 1%), their interaction at probability level of 5% had a significant effect on grains/spike (Table 2). Results of comparing the mean interaction of factors showed that the highest grains/spike belongs to foliar application of 1% zinc sulfate in Mehr cultivar and the lowest mean grains/spike was observed in Armaghan cultivar and the absence of zinc fertilizer (Table 3). Results showed that grains/spike was increased with increasing levels of zinc fertilizer, so that the highest mean grains/spike in all three cultivars was related to zinc fertilizer concentration of 1%. Foliar application of 1% zinc sulfate in Mehr, Goharan and Armaghan cultivars significantly increased grains/spike by 24.8%, 28.0% and 43.3% compared to no foliar application (Table 3). In this regard, the research results showed that the difference between the studied barley cultivars was statistically significant on grains/spike, so that the highest grains/spike belonged to the four-salt genotype (stress tolerant) (Mahlooji, 2017). Plant nutrition with zinc, due to increasing carbohydrate storage of pollen grains, has increased the lifetime of pollen grain, as a result, it increased pollination and formation of more grains in the plant (Hafeez et al., 2013). Researchers said that sterilization of spike flowers in plants growing in zinc-deficient soils is more severe and adding zinc reduces the spike sterility problem (Bagci et al., 2007). In a research, the highest grains/spike in barley was obtained from the treatment of 60 kg/ha of zinc sulfate fertilizer and the lowest grains/spike was obtained from no fertilizer treatment (Seyed Hayat Gheyb et al., 2019).

Results of estimating the correlation of traits showed that the grans/spike had a negative and significant correlation (level of 1%) with 1000-grain weight (Table 4). In this regard, research results showed that the correlation between 1000-grain weight and grains/spike of barley was negative and significant (Nikkhah et al., 2015). In another research, researchers found that grains/spike in barley showed a significant and negative correlation with 1000-grain weight and number of plants. Therefore, it can be concluded that with increasing number of plants, 1000-grain weight is increased but the grains/spike was reduced (Soleimani et al., 2017). The study of correlation of traits showed that grains/spike had a significant and positive correlation (0.88**) with grain yield (Table 4). Grains/spike determines the capacity of the plant's reservoirs. The higher number of grains, there are more reservoirs for processed substances and any factor that can increase this component will increase the yield.

Results of analysis of variance (Table 2) showed that the main effects of fertilizer and cultivar at probability level of 1% and their interaction at probability level of 5% affected spikes/m^2. According to the results of comparing the means, the lowest spike/m^2 belonged to Armaghan cultivar in the absence of zinc fertilizer, although as shown in Table 3, Armaghan and Goharan cultivars are in a statistical group in terms of significance. Results demonstrated that no significant difference was observed in terms of spikes/m^2 at lower concentrations of zinc sulfate fertilizer (0.5%), however, Mehr cultivar produced more spikes compared to Armaghan at higher concentrations (1%). In foliar application of 1% zinc sulfate, Mehr cultivar produced 5.2% more spikes/m^2 compared to Armaghan cultivar (Table 3).

Different mechanisms are involved in response of various plant cultivars to utilization of nutrients (Baligar et al., 2001; Erenoglu et al., 2002; Karimian and Moafpouryan, 1999). Such mechanisms include root-related interactions to increase the usability of soil zinc to be absorbed by root, increased uptake and transfer of zinc from root to air organs, zinc intracellular meronomy variation in plant air organs to have a larger part of zinc in the cytoplasm, and increased efficiency of biochemical use of zinc in plant cells (Malian et al., 2014).

It seems that zinc fertilizer in the plant with increasing photosynthesis, photosynthetic substances, and auxin hormone increases vegetative growth and improves fertile spikes in the plant. This is also related to the absence of malnutrition in the plant (Seyed Hayat Gheyb et al., 2019). Research results demonstrated that the highest spikes/m^2 in barley belonged to 60 kg/ha treatment and the lowest level of traits belonged to non-zinc fertilizer treatment (Seyed Hayat Gheyb et al., 2019).

3.7. Biological yield

Results of analysis of variance (Table 2) indicated that in addition to the main effect of cultivar (probability level of 5%) and zinc fertilizer (probability level of 1%), their interaction was also significant on biological yield (probability level of 5%). Results of comparing the means showed that the biological yield is also increased with increasing zinc fertilizer levels, so that the highest biological yield was related to the concentration of 1% zinc fertilizer. Foliar application of 1% zinc sulfate in Mehr, Goharan, and Armaghan cultivars significantly increased the biological yield by 7.8%, 9.7% and 7.8%, respectively, compared to the control (no foliar application of zinc fertilizer) (Table 3). The lowest mean biological yield was also seen in the absence of fertilizer, so that there was no significant difference between cultivars at this level of fertilizer (Table 3).

Improving biological yield followed by foliar application of zinc sulfate can be attributed to increased yield components and significant and positive correlation of these characteristics with biological yield. Results showed that there was a significant difference between barley genotypes in regard of biological yield, so that the highest biological yield belonged to the fourth line of salinity tolerant and the lowest belonged to Morocco (stress sensitivity) (Mahlooji, 2017). Researchers found that foliar application of 1% zinc sulfate increased the biological yield of wheat by 12.35% and 23% compared to 0.5% treatment and control treatment, respectively (Fallah, 2019). Positive effect of zinc application on biological yield can be attributed to the role of zinc in the biosynthesis of tryptophan amino acid, participation in structure of active enzymes in carbon metabolism, such as carbonic anhydrase, ribulose-1,5-bisphosphate, fructose-1,6-diphosphate, increased chlorophyll synthesis, followed by increased photosynthesis and thus improved plant growth and yield (Akay, 2011; Hafeez et al., 2013).

Results suggested that there was a positive and significant correlation between biological yield and grain yield at probability level of 1% (Table 4). In order to achieve a high yield, there is a need for proper chlorophyll growth and plants with suitable vegetative power. Proper vegetative growth increases weight, length, and yield of spike and thus increases grain yield (SeyedAghamiri et al., 2012).

Researchers found that the correlation between barley grain yield and biological yield was more than the correlation between grain yield and other traits, and this means that although traits, such as straw yield, spikes/m^2, and grain filling rate have been effective in increasing grain yield, the role of biological yield in increasing grain yield is more than all other traits, It seems that cultivars with higher biological yield could use photosynthetic sources in a more favorable way by producing more foliage and provide the conditions for increasing grain yield (Ahmadi et al., 2014).

3.8. Grain yield

Results of analysis of variance indicated that in addition to the main effects of zinc fertilizer and cultivar ($p \leq 0.01$), their interaction was also significant on grain yield at the probability level of 5% (Table 2). The highest grain yield of 6118.5 kg/ha belonged to Mehr cultivar in foliar application of 1% zinc sulfate, although as shown in Table 3, Mehr and Goharan cultivars are in a statistical group. It seems that greater grain yield in Mehr cultivar is due to higher grains/spike and more spikes and a significant and positive correlation between the aforementioned traits and grain yield. Results of the yield comparison tests in territories under salinity stress at stations in temperate regions of the country showed the superiority of Mehr cultivar over Khatam cultivar, so that this cultivar with mean grain yield of 4751 kg/ha and 655 kg/ha (16%) had an increased yield compared to the mean cultivar (Nikkhah et al., 2019). In studying the effect of irrigation water salinity and foliar application of zinc fertilizer on barley genotypes, the results showed that the highest grain yield was related to fourth line of salinity tolerant, which was increased by 100.5% compared to Morocco genotype (stress sensitivity). Research results showed that various wheat cultivars had different response to zinc fertilizer. Some cultivars were more responsive to zinc fertilizer application compared to other cultivars and grain yield in fertilizer treatments was significantly increased compared to the control. In contrast, some cultivars were less responsive to fertilizer application or fertilizer application did not significantly affect the grain yield compared to the control (Malian et al., 2014).

Lowest grain yield of 4530.5 kg/ha was found in Armaghan cultivar and in the absence of zinc sulfate fertilizer, which was significantly different from all combined treatments of fertilizer and cultivar. Foliar application of 1% zinc sulfate in Mehr, Goharan, and Armaghan cultivars significantly increased the grain yield by 22.2%, 25.7% and 0.29%, respectively, compared to the absence of foliar application of zinc sulfate fertilizer (Table 3). Increasing yield with zinc sulfate fertilizer could be due to various reasons, including increased auxin biosynthesis in the presence of zinc, increased chlorophyll concentration, increased phosphoenolpyruvate carboxylase and ribulose bisphosphate carboxylase, reducing sodium accumulation in plant tissues and increasing efficiency of nitrogen and phosphorus uptake in the presence of the zinc element (Khan et al., 2003). Results of trait correlation showed that among the yield components, 1000-grain weight is negatively and significantly correlated with grain yield at the probability level of 1% (Table 4). It should be noted that there is a negative correlation between the yield components, and with increasing number of grains due to the increased reservoir capacity against a fixed content of storage substance, it is natural to store lower content of substance in each reservoir capacity. It is noteworthy that the essence of correlations between components is not merely genetic and varies from environment to environment, and hence different and contradictory results are seen in tests (Ahakpaz et al., 2020). Researchers said that 1000-grain weight was negatively and significantly correlated with barley yield. Given that the yield is derived from the cereal yield formula, it can be justified that with increasing 1000-grain weight, grains/spike is reduced as one of the yield formula components, which will be consequently effective in reducing yield (Baraty et al., 2014).

3.9. Harvest index

Results of analysis of variance (Table 2) showed that the main effect of cultivar at the probability level of 1%, main effect of zinc fertilizer, and interaction of fertilizer and cultivar at the probability level of 5% were significant on harvest index. Results of the interaction of the studied factors indicated that the highest harvest index belonged to Mehr cultivar in both levels of zinc sulfate fertilizer (0.5 and 1%), which were statistically in a significant group. In the absence of zinc fertilizer, Mehr cultivar had a higher harvest index by 5.2 and 10.7%, respectively, compared to Gohran and Armaghan cultivars (Table 3). In this regard, in investigating the effect of irrigation water salinity and foliar application of zinc fertilizer on barley genotypes, the results suggested that the difference was significant between genotypes in terms of harvest index, so that the highest harvest index (30.6%) belonged to the fourth line of salinity tolerant and the lowest harvest index belonged to Morocco genotype (stress sensitivity) (Mahlooji, 2017).

According to the results of comparing the means, foliar application of 1% zinc sulfate in Mehr, Gohran and Armaghan cultivars significantly increased the harvest index by 13.4%, 14.8% and 19.8%, respectively, compared to the absence of foliar application of zinc sulfate fertilizer (Table 3). In a research conducted to investigate the effect of zinc sulfate on wheat cultivars, the results demonstrated that the highest harvest index belonged to 60 kg/ha fertilizer level and the lowest index belonged to 0 kg/ha zinc sulfate (Mirtalebi et al., 2012). In studying the effect of irrigation water salinity and foliar application of nano-fertilizers and zinc plots on barley genotypes, the results indicated that the highest harvest index belonged to zinc nano oxide (30.5%) and the lowest index (25.6%) belonged to the absence of foliar application (Mahlooji, 2017). Results of trait correlation showed that harvest index had the highest positive and significant correlation (0.93**) with grain yield (Table 4). In this regard, research results showed that cumin grain yield had a positive and significant correlation with harvest index and biological yield (Nasiri Dehsorkhi et al., 2018). In the absence of stress, grain yield had a positive and significant correlation with biological yield (r = 0.777**) and harvest index (r = 0.698**) (Nikkhah et al., 2015).

4. Conclusion

Results of the present research demonstrated that the interaction of zinc sulfate fertilizer and barley cultivars was significant on traits such as chlorophyll a, grains/spike, spikes/m^2, biological yield, grain yield, and harvest index. The highest growth rate, photosynthetic pigments, yield, and yield components were observed with foliar application of 1% zinc sulfate in Mehr cultivar. This could be attributed to superiority of Mehr cultivar under salinity conditions as well as the positive role of zinc element in improving plant growth. Therefore, this level of zinc sulfate fertilizer in this cultivar is appropriate and suggested for barley production in similar conditions to the present research. Generally, given the positive effect of zinc fertilizer on improving barley yield and also with respect to the lack of this element in most territories where barley is grown, this micronutrient should be particularly considered in plant nutrition programs.

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