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Investigation Effect of Different Levels of Zinc Element on Seed Yield and Its Components of Various Barley (*Hordeum vulgare* L.) Cultivars

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RESEARCH ARTICLE

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ABSTRACT

BACKGROUND: Fertilizer management is one of the most important factors in successful cultivation to improve quality and quantity of crop production.

OBJECTIVES: In order to examine the effects of different levels of zinc fertilizer on yield of different barley cultivars, this study was done in the agricultural year 2020-21 in Susangerd County.

METHODS: Current research was conducted by using split plots within a randomized complete block design with three replications. The main plots consisted of three barley cultivars (13 Sarasari, 10 Sarasari and local Susangerd), and the subplots included different levels of zinc fertilizer (Z_1=0, Z_2=20, Z_3=40, and Z_4=80 $ZnSO_4$ kg.ha^{-1}).

RESULT: The results indicated that the highest number of spikes belonged to the local Susangerd cultivar (375.2) and 10 Sarasari (277.6), and also the highest number of grains per spike and 1000 grain weight were attributed, in order, to the 10 Sarasari and 13 Sarasari cultivars (40.17) and (53.6). The highest number of spikes, number of grains, and 1000 grain weight were achieved with the consumption of 80 kilograms of zinc per hectare. The interactive effects of treatments were not statistically significant for any of the examined traits.

CONCLUSION: Overall, considering the environmental conditions of the southern Khuzestan province and the deficiency of zinc in the soils of this region, the use of zinc fertilizer can be effective in improving the grain yield of cereals in the province.

KEYWORDS: *Cereal, Fertilizer, Grain yield, Harvest index, Nutrient.*

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1. BACKGROUND

The world's population is continuously increasing, and the global standard of living is on the rise. This trend necessitates an inevitable increase in the production of agricultural products and derivatives. Grains play a crucial role in supplying 70% of the world's food. Among the plants in this category, wheat, rice, corn, and barley are the most important food sources. More than three-quarters of the energy and half of the required protein for humans come from grains (Azizi and Dehaghi, 2008), making grains the fundamental basis for human nutrition and life. Out of 150 food species, only 15 are commercially produced, and half of these 15 species are grains. Despite the prominent characteristics of these plants, it seems that grains have no substitute in the future, and their importance will only increase. Improving the cultivation environment through the proper use of agricultural inputs such as water, fertilizer, machinery, pesticides, and modified seeds is feasible. One of the most important agricultural inputs is the proper use of chemical fertilizers, known to have a significant impact on increasing the yield of the agricultural products (Kholdbarin and Islam Zadeh, 2001). Increasing fertilizer consumption has led to the growth of food production, and scientific sources have shown that by increasing one or more of the 16 essential nutrients, the yield has also increased. The 16 chemical elements primarily recognized as essential for plant growth include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, zinc, copper, manganese, molybdenum, boron, and chlorine (Sharafizadeh, 2001). In agriculture, zinc deficiency is common and widespread. This phenomenon arises due to the intense uptake of usable zinc from the root penetration zone in the soil and, in some cases, due to the beneficial effect of soil organic matter in zinc absorption by plants and surface erosion leading to zinc deficiency. Additionally, in calcareous and alkaline soils, zinc deficiency occurs due to the high soil acidity (Koochaki and Sarmadian, 1994). It appears that while foliar Zn spraying is more effective than soil N or Zn application to enrich wheat grains with Zn, the grain Zn bioavailability is influenced more by cultivar selection (Xia *et al*., 2018). The results of the research of Al-Murshidi and Halool Jassim (2023) showed that the superiority of nano-zinc at the level of 300 ppm on the flag leaf area and the number of grains in the spike, as the highest averages, while zinc sulfate at the level of 200PPM outperformed in the trait of plant height, as it recorded the highest average, as well as the superiority of zinc sulphate at the level of 300 ppm in the trait of spike length, number of branches, and grain yield, which recorded the highest averages. Experiments conducted at 25 locations with treatments involving zinc, iron, manganese, and copper showed that zinc treatments significantly increased wheat grain yield, 1000 grain weight, number of grains per spikes, and the amount of protein and zinc in the grain. The critical extractable zinc concentration by DTPA was observed to be around 9.0

$mg.kg^{-1}$ of soil. Regression analysis indicated that a combination of high soil pH, high salts, $CaCO_3$ content, clay, and low annual rainfall are the main factors contributing to zinc deficiency and other micronutrient deficiencies. In this experiment, the response to zinc treatment was higher compared to other elements, and after that, grain yield increased with manganese treatment (Ziaeian and Malakouti, 2001). In a comprehensive study conducted by Seyed Sharifi *et al*. (2008), the influence of zinc sulfate on growth analysis, yield metrics, and the protein and zinc content in the grains of various wheat cultivars was investigated. The research revealed a noteworthy augmentation in grain yield, protein percentage, and zinc concentration in grains with an escalating application of zinc sulfate. Furthermore, an examination of the growth trajectory of the wheat cultivars showcased an increase in total biomass and product growth rate with elevated fertilizer usage. While the total biomass and product growth rate were comparable for the application of 40 and 80 kilograms of zinc sulfate per hectare, both significantly surpassed the outcomes of non-fertilized conditions. Consequently, for optimizing protein and zinc attributes in grains under experimental conditions, the judicious application of 40 kilograms of zinc sulfate per hectare is recommended. In a parallel experiment conducted by Mirzavand (2008) focusing on the evaluation of soil-applied zinc sulfate and root immersion in zinc oxide, the study investigated their impact on the yield and chemical composition of Qasr-Dashti rice cultivar in the rice paddies of Fars province. The variance analysis over two years underscored the significant effects of zinc sulfate on grain yield, the number of grains per spike, nitrogen and phosphorus percentages in grains at different levels, and grain protein percentage. The combined results of the two-year analysis also demonstrated the substantial impact of zinc oxide on 1000 grain weight and grain protein percentage in grains at specific levels. These findings suggest the indispensability of zinc application in calcareous soils similar to those scrutinized in the study. Nevertheless, further research is imperative to delve into fertilizer sources, consumption methods, and quantities across diverse soils in Fars province. Mahmoodi *et al*. (2004) conducted a study to investigate the effect of zinc sulfate on the yield of two rice cultivars, Neda and a local cultivar called Tarom, in East Mazandaran. Considering the long-term cultivation in paddy fields, coupled with the use of other essential plant nutrients and inherent soil limitations, the study aimed to address the increased accumulation of absorbable phosphorus and the decreased amount of absorbable zinc in the soil. The research was motivated by the extended cultivation history of these cultivars in other countries, which revealed sensitivity to zinc deficiency, particularly in the case of Neda, a cultivar known for its high yield. The results of this study indicated that the Neda cultivar exhibited a significant and economically viable response to zinc sulfate application, highlighting the nutritional necessity for this particular cultivar. However, the local Tarom cultivar did not show a similar positive and economical response to zinc sulfate supplementation. This underscores the importance of understanding the specific nutritional needs of rice cultivars, with Neda being particularly sensitive to zinc deficiency, emphasizing the necessity of addressing this nutritional aspect for optimal yield.

2. OBJECTIVES

In order to examine the effects of different levels of zinc fertilizer on crop production of different barley cultivars, this study was done in the agricultural year 2020-21 in Susangerd County.

3. MATERIALS AND METHODS

3.1. *Field and Treatments Information*

This research was conducted in Susangerd, located 55 kilometers south of Ahvaz in the southern Khuzestan province. The geographical coordinates are approximately 48 degrees and 17 minutes east longitude and 31 degrees and 55 minutes north latitude. Based on 20 years of meteorological data, the average annual precipitation in the region is 150 mm, with an average maximum temperature of 36.8 degrees Celsius and an average minimum temperature of 8.6 degrees Celsius, occurring in August and January, respectively. The research utilized a split-plot design within a randomized complete block design with three replications. The main factor consisted of three barley cultivars (C_1: 13 Sarasari, C_2: 10 Sarasari, C_3: Local Susangerd). The sub-factor included four levels of zinc fertilizer labeled as Z_1 to Z_4 (Z_1= 0 kg.ha^{-1}, Z_2= 20 kg.ha^{-1}, Z_3= 40 kg.ha^{-1}, Z_4 = 80 Kg.ha^{-1}), resulting in a total of 12 treatments.

3.2. Farm Management

Field operations started in December 2020 and continued until April 2020. The weather statistics during the experimental period indicate that the total precipitation was 110 mm. The highest precipitation occurred in December with 35 mm, while the lowest was in April with 1.0 millimeter. The monthly average temperature was 21.7 degrees Celsius, with May 2020 being the warmest (average of 31.3 degrees Celsius) and December 2020 being the coolest (average of 15.8 degrees Celsius). To assess the physical and chemical properties of the soil before the experiment the fieldwork and soil sampling were carried out in December 2020 (Table 1).

Table 1. Chemical and physical characteristics of the experimental soil

Soil depth (cm)	**Soil texture**	**Clay (%)**	**Silt (%)**	**Sand (%)**	**EC (dS.m^{-1})**	**pH**
0-30	Clay loam	35	39	26	3.33	7.48
Soil depth (cm)	**OM (%)**	**N (%)**	**K (ppm)**	**P (ppm)**	**S (ppm)**	**ρb (gr.cm^{-3})**
0-30	0.67	0.04	113.88	13.5	45	1.55

Zinc sulfate fertilizer was uniformly applied to all plots. Each subplot had an area of 9 square meters (5.2 × 6.3), and the distance between two subplots was 60 centimeters. The main plot covered an area of 8.1 square meters, with 1-meter spacing between two main plots and a 2-meter distance between blocks. Each subplot contained 12 rows of crops with a 15-centimeter spacing between rows. According to soil analysis, nitrogen fertilizer (200 $kg.ha^{-1}$) was used as a basal application, and the remaining amount was split between the tillering and stem elongation stages. Potassium fertilizer (K_2O) at a rate of 150 $kg.ha^{-1}$ from potassium sulfate and phosphorus fertilizer (P_2O_5) at a rate of 100 $kg.ha^{-1}$ from triple superphosphate were also used as basal applications. The planting was conducted on 11.30.2020. Manual weed control was performed throughout the crop growth period.

3.3. Measured Traits

Harvesting operations were carried out at the final harvest surface (4.2 m^{-2}) of each subplot. Several parameters were measured to assess the barley yield.

3.3.1. *Number of grains per spike*

The number of grains in 10 individual spikes was counted separately, and the average number of grains per spike was calculated.

3.3.2. *Number of spikes per unit area*

Before the final harvest, the number of spikes in each subplot was counted, and the number of spikes per unit area was determined by dividing the total number of spikes by the final harvest area.

3.3.3. *1000 grain weight*

To calculate the 1000 grain weight, 10 separate samples of 500 grains each were counted and weighed using a precise scale after the final harvest.

3.3.4. *Biological and grain yield*

The biological yield of each subplot was separately harvested, and the harvested grain was stored in labeled plastic bags.

3.3.5. *Harvest index*

The harvest index, representing the ratio of grain yield to biological yield, was calculated and expressed as a percentage by multiplying the result by 100.

3.4. Statistical Analysis

Analysis of variance and mean comparisons were done via SAS (Ver.8) software and Duncan multiple range test at 5% probability level.

4. RESULT AND DISCUSSION

4.1. *Number of spikes per unit area*

The number of spikes per unit area (m^2) indicates the transformation of suitable seedlings into desirable spikes. The desired establishment of plants is primarily contingent on achieving the desired number of spikes per unit area, and this is facilitated by sowing an appropriate number of seed per unit area.

Table 2. Result analysis of variance of measured traits

S.O.V	df	No. spike per m^{-2}	No. grain per spike	1000 Grain weight	Grain yield	Biological yield	Harvest index
Replication (R)	2	514.89	1.87	0.89	43.18	13227.61	2.94
Cultivar (C)	2	79855**	153.09**	950.55**	14994222**	15267962**	644.24**
Error I	4	1069	10.31	3.5	4014396	2870960	189.72
Zinc (Z)	3	16037**	186.63**	88.45*	1898227**	3892735*	38^{ns}
C×Z	6	2592.5^{ns}	2592.5^{ns}	17.25^{ns}	394482^{ns}	776099^{ns}	47.49^{ns}
Error II	18	4050	56.4	55.65	625950	3162411	214.5
CV (%)		4.86	3.49	5.19	4.68	4.64	7.86

The results of the analysis of variance for the number of spikes per unit area in three cultivars indicate a significant difference at the 1% probability level. The results show that cultivar and zinc fertilizer had a significant effect on the number of spikes per unit area (Table 2). The local barley cultivar had the highest average of 375 spikes, followed by the 13Sarasari cultivar with an average of 273 spikes, and the 10Sarasari cultivar with an average of 277 spikes, having the highest and lowest numbers of spikes, respectively (Table 3). The local barley cultivar quickly reached the tillering stage and was able to utilize favorable environmental conditions to produce more spikes compared to the 10 Sarasari and 13Sarasari cultivars, which reached the tillering stage later. The variation in the number of spikes among barley cultivars is mainly attributed to their genetic potential. However, environmental and agricultural factors also influence this potential. Treatment without fertilizer and treatment with 20 $kg.ha^{-1}$ zinc sulfate had the lowest numbers of spikes per unit area, with 281 and 295 spikes per unit area, respectively. Treatments with 40 and 80 $kg.ha^{-1}$ zinc sulfate also produced the lowest numbers of spikes per unit area, with 322 and 334 spikes, respectively. The considerable effect of iron and zinc fertilizers on the number of spikes per unit area has also been reported by Malakouti and Taherani (2000). Additionally, studies by Pahlavan *et al*. (2005), Khalili Mahaleh *et al*. (2004), and Sattar *et al*. (2022) highlighted the emergence of genetic potential in wheat and barley cultivars in terms of the number of spikes when provided with suitable nutritional resources, especially zinc and iron.

4.2. *Number of grains per spike*

The results of the analysis of variance for the number of grains per spike in different barley cultivars showed a significant difference among cultivars at the 1% probability level (Table 2). The 10 Sarasari cultivar had the highest average of 5.53 grains per spike, followed by the 13 Sarasari cultivar with an average of 49.7 grains per spike.

Table 3. Mean comparison effect of different level of cultivars and fertilizer combination on studied traits

Treatments	No. Spike per m^{-2}	No. Grain per spike	1000 Grain weight (gr)	Grain yield ($gr.m^{-2}$)	Biological yield ($gr.m^{-2}$)	Harvest index (%)
Cultivar (C)						
C_1	277*b	40.17a	40.17a	4591.7a	9390a	45a
C_2	273b	33.91b	33.91a	4275b	9589a	48a
C_3	375a	27.58b	27.58c	3092c	8119b	38b
Zinc (Z)						
Z_1	281.6c	47c	31.56c	3676c	8524b	42a
Z_2	295.3b	50b	33.59b	3870b	9028a	43a
Z_3	322.7a	52a	34.56ab	4127a	9145a	44a
Z_4	344.6a	53a	35.86a	4271a	9434a	45a

C_1: 13 Sarasari cultivar, C_2: 10 Sarasari cultivar, C_3: Susangerd local cultivar, Z_1: 0 (kg Zn ha^{-1}), Z_2: 20(kg Zn ha^{-1}), Z_3: 40 (kg Zn ha^{-1}) and Z_4: 80(kg Zn ha^{-1}).
*Means with similar letters in each column are not significantly differentt by Duncan's test at 5% probability level.

Also, the local barley with an average of 48.8 grains per spike, having the highest and lowest numbers of grains per spike, respectively (Table 3). The application of 80 $kg.ha^{-1}$ zinc sulfate with an average of 53.5 grains per spike resulted in the highest, and the treatment without zinc fertilizer with 47.14 grains per spike had the lowest number of grains per spike. Additionally, treatments with 80 and 40 $kg.ha^{-1}$ zinc sulfate had the highest average of 53.5 and 52.5 grains per spike, respectively, while the treatment with 20 $kg.ha^{-1}$ zinc sulfate had an average of 50.3 grains per spike, and the treatment without fertilizer had an average of 47.14 grains per spike, producing the highest and lowest numbers of grains per spike, respectively. The increase in the number of grains per spike may be attributed to the treatment of the plant with zinc, which was characterized by its physiological role in increasing the work of the leaf and its efficiency and reducing its aging in terms of photosynthesis and chlorophyll formation and increasing the production of dry matter and this is what was indicated by Ali and Sharqi (2010), accounted for the effect of zinc during the flowering period, spraying reduces competition between the flowers to absorb zinc, and this increases the percentage of pollinated flowers that develop into grains. The increase in the number of grains per spike is due to the role of zinc in increasing root depth, leaf area, dry and total weight, including the number of grains per spike (Dapkekar *et al*., 2018), and also the role of zinc in stimulating auxin control, which increases cytokinin concentrations, which is important in increasing the length of the spike axis and thus increasing the number of grains in one spike (Xia *et al*., 2020), and these results agree with Al-Toki

(2022), which showed a significant increase in this characteristic is due to the treatment of wheat with nano and chelated zinc. In the studies conducted by Karimian and Yasrebi (2005), Mahmoudian *et al*. (2002), and Kumar *et al*. (2001), the positive effect of zinc on the number of grains per spike in cereals has been reported. The considerable impact of zinc, iron, and copper on grain yield has also been demonstrated in studies conducted by Khalili Mahaleh *et al*. (2004) on maize.

4.3. 1000 grain weight

The analysis of variance results indicated significant differences in 1000 grain weight among different cultivars and different levels of fertilizer application, although the interactive effects of treatments were not significant for this trait (Table 2). The highest 1000 grain weight (with an average of 35.85 g) belonged to the treatment with 80 $kg.ha^{-1}$ zinc sulfate, while the treatment without fertilizer had the lowest weight with an average of 27.58 g (Table 3). Cultivar 10 (with an average 1000 grain weight of 40.17 g) had the highest weight, followed by 13 cultivar (33.91g) and the local cultivar (27.58 g). The longer grain-filling period of 10 cultivar compared to the other cultivars contributed to its higher 1000 grain weight. 1000 grain weight is one of the most critical factors determining grain yield, ensuring adequate grain weight is essential for proper seed production. Additionally, zinc plays a role in starch metabolism, a significant component of barley grain weight. Adequate zinc supply increases the activity of the starch synthase enzyme, contributing to an overall increase in 1000 grain weight. The results of this experiment are consistent with the findings of Azizi and Dehaghi (2008) and Kumar *et al.* (2009) regarding the positive impact of zinc on yield components, especially 1000 grain weight.

4.4. Grain yield

The analysis of variance results revealed significant differences in grain yield among different barley cultivars at a 1% significance level. Also, there was a significant difference in grain yield among various levels of zinc fertilizer application, although the interaction effects of cultivars and zinc levels were not statistically significant for this trait (Table 2). The highest and lowest grain yields were attributed to 10 cultivar (with an average of 4591 $kg.ha^{-1}$) and the local cultivar Susangard (with an average of 3092 $kg.ha^{-1}$), respectively (Table 3). 10 Cultivar, despite having fewer spikes per unit area compared to the other cultivars, outperformed in grain yield due to a higher number of grains per spike and a higher 1000 grain weight (with an average of 53 grains per spike and 40.1 gr 1000 grain weight). The study of yield components indicated that 10 cultivars, with its superior grain yield, benefited from favorable environmental conditions. The genetic potential of 10 cultivars and 13 in utilizing environmental conditions and input resources was evident in results. However, it's important to note that potential may vary in different experiments due to essential nutritional factors and soil moisture availability for barley.

The highest grain yield, with an average of 4271 $kg.ha^{-1}$, was associated with the treatment receiving 80 $kg.ha^{-1}$ of zinc fertilizer, while the treatment without zinc fertilizer had the lowest grain yield with an average of 3676 $kg.ha^{-1}$. The increase in grain yield may be attributed to an increase in vegetative growth indicators and a number of yield components such as the number of grains per spike and the 1000 grain weight (Abboud *et al*., 2011). The increase in grain yield is due to the role of zinc in the production of pollen with high vitality, which drives the chance of fertilization and indicators of vegetative growth and is reflected in the increase in yield (Fayyadh and Al-Hadithi, 2011). Goborah *et al*. (2015) reported a significant increase in grain yield and yield components of barley by examining the application of the micronutrient zinc compared to the control treatment. Woldesenbet and Tana (2014) also reported that the highest grain yield was obtained from the treatment receiving the micronutrient zinc. The use of micronutrients, considering their impact on chlorophyll synthesis and the increase in growth regulators, enhances the photosynthesis of young leaves, increases the transport of substances to storage sites, and consequently increases grain weight. Therefore, it directly influences grain yield. In studies by Karimian and Yasrebi (2005), Mahmoudian *et al*. (2002), Al-Murshidi and Halool Jassim (2023), and Sattar *et al.* (2022), the positive impact of micronutrients on grain yield of cereals has also been reported.

4.5. Biological yield

Based on the analysis of variance results, there was a significant difference in biological yield among different barley cultivars and different levels of zinc application. However, the interactive effects of treatments on this trait were not statistically significant (Table 2). 10 Sarassari cultivar with an average biological yield of 9589 $kg.ha^{-1}$ had the highest, and the local cultivar Susangard with an average biological yield of 8119 $kg.ha^{-1}$ had the lowest biological yield (Table 3). The cultivar with higher biological yield maximized both the weight of a thousand grains and the number of grains per spike, consequently leading to a higher grain yield. It seems that these three barley cultivars had comparable leaf and stem production, but 10 Sarasari and 13 Sarasari exhibited a more efficient process of nutrient transfer towards the grains compared to the local cultivar Susangard. This enhanced nutrient transfer contributed to higher yield indices in cultivars 10 Sarasari and 13 Sarasari. The application of 80 $kg.ha^{-1}$ zinc sulfate resulted in the highest biological yield with an average of 9434 $kg.ha^{-1}$, while the untreated control (without zinc sulfate) had the lowest biological yield with an average of 8524 $kg.ha^{-1}$ (Table 3). The expression of potential in barley cultivars and the accumulation of dry matter become feasible in the presence of nutritional resources. The increase in dry weight of maize plants with the simultaneous use of iron and zinc fertilizers was also reported in the studies of Ebrahimi and Hassanpour (2002) and Zarea and Karimi (2023).

In this regard, the utilization of micronutrients leads to an increase in dry matter accumulation, and under nutrient deficiency conditions, the enhancement of biological yield in plants will be restricted.

4.6. *Harvest index*

Is defined as the ratio of economic yield to biological yield. This index is influenced by climatic conditions, soil, and the plant itself. The analysis of variance results indicates a significant difference among barley cultivars at the 1% level. However, there is no significant difference in the harvest index among different levels of zinc fertilizer treatments (Table 2). 10 Sararsari Cultivar with an average of 48.06% shows the highest harvest index, while the local cultivar Susangard with an average of 38.11% has the lowest harvest index (Table 3). The variation in the harvest index among barley cultivars is attributed to the fact that the straw yield was the same among the three tested cultivars, but their grain yield was different. There is no significant difference in the harvest index among different levels of zinc fertilizer treatments and the interactive effects of treatments concerning the harvest index are not significant.

5. CONCLUSION

Based on the findings of this study, among the investigated barley cultivars, cultivar 10 Sararsari exhibited a more favorable potential for grain yield. It is recommended to apply zinc fertilizer in the soil for barley cultivation. The highest number of spikes, the number of seeds per spike and the 1000 seed weight were obtained with the consumption of 80 kg.ha^{-1} of zinc. To optimize production costs, it is advisable to use 40 kilograms per hectare of zinc sulfate, as there was no significant difference compared to the use of 80 kilograms per hectare.

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