Hindawi
International Journal of Agronomy
Volume 2021, Article ID 8857222, 6 pages
https://doi.org/10.1155/2021/8857222

Research Article

Effect of Zinc and Magnesium Fertilizers on the Yield and Some Characteristics of Wheat (*Triticum aestivum* L.) Seeds in Two Years

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Received 12 September 2020; Revised 8 March 2021; Accepted 25 March 2021; Published 5 April 2021

Academic Editor: Othmane Merah

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In order to study the interaction effects of zinc and magnesium fertilizers on wheat (cv. Sivand) yield and other characteristics, a factorial experiment was carried out based on a randomized complete block design (RCDB) using four replications. Four levels of zinc sulfate (0, 20, 40, and 60 kg ha^{-1}) and four levels of magnesium sulfate (0, 70, 140, and 210 kg ha^{-1}) were used in this study. The parameters studied included germination, plant height, tillering, 1000-seed weight, hectoliter weight, concentrations of zinc and magnesium in seeds, protein content, and yield. The effects of zinc sulfate and magnesium sulfate for most traits were significant ($p < 0.01$). The highest grain yield (7.68 Ton ha^{-1}) was obtained by applying 60 kg ha^{-1} of zinc and consuming 140 kg of magnesium per hectare. The maximum magnesium amount in seed was shown in treatment with 60 kg ha^{-1} of zinc × 210 kg ha^{-1} magnesium, which was 0.352 mg kg^{-1}. Treatments with the best economic aspects were 20 kg ha^{-1} of zinc sulfate × 70 kg ha^{-1} magnesium sulfate and 40 kg ha^{-1} of zinc × 140 kg ha^{-1} magnesium, in terms of using less zinc and magnesium fertilizers and having a favorable impact on the attributes. The application of these treatments on wheat can ultimately increase zinc and magnesium in wheat grain. Because these elements play a role in human health, the use of these treatments in wheat can increase zinc and magnesium in wheat grains, and therefore, an effective step can be taken in human health by producing these wheat. According to the test results, the application of 60 kg ha^{-1} of zinc sulfate along with 140 kg ha^{-1} of magnesium sulfate can play an important role in increasing wheat yield with reduced costs.

1. Introduction

Bread wheat is one of the major sources of proteins and carbohydrates in Iran; it contributes to food security of the population. In fact, Iranians are the second biggest consumers of bread in the world with a per capita of 160 kg, which is six times higher than the global average [1, 2]. Bread and bakery products obtained from wheat (*Triticum aestivum* L.) are considered worldwide an essential source of protein, dietary fiber, vitamins, micronutrients, and antioxidants [3, 4]. However, dietary deficiency of essential micronutrients, such as zinc, affects more than two billion people worldwide [5]. Zinc, iron, and vitamin A deficiencies are one of the most common problems in developing countries. Zinc deficiency is the fifth leading cause of illness and death [6]. Micronutrient deficiency is widespread in many Asian countries due to the calcareous nature of soils, high pH, low organic matter, salt stress, continuous drought, high bicarbonate content in irrigation water, and imbalanced application of NPK (the amount of nitrogen, phosphorus, and potassium in a fertilizer) fertilizers [7]. Foliar nutrition is an option when nutrient deficiencies cannot be corrected by application of nutrients to the soil [8, 9]. Zinc is known to have an important role either as a metal component of enzymes or as a functional, structural, or regulatory cofactor of a large number of enzymes [10]. Zinc is an essential plant micronutrient; it is involved in their growth and metabolism, such as enzyme activation, protein synthesis, metabolism of carbohydrate, lipid, and nucleic acid, gene expression and regulation, and reproductive development [11]. Moreover, magnesium is an important micronutrient; it is required for biological redo system, enzyme activation, and carrying oxygen in nitrogen fixation [12]. Magnesium also plays an eminent role in the growth and development of plants [13]. According to Li et al. [13], both of zinc and magnesium are highly effective in increasing the quantity and quality of wheat grain yield.

Sarkar et al. [9] showed that a small amount of nutrients, particularly Zn, Fe, and Mg, applied by foliar spraying significantly increases the crops yield. Potarzycki and Grzebisz [14] reported that zinc exerts a great influence on basic plant life processes, such as (i) nitrogen metabolism and uptake of nitrogen and protein quality; (ii) photosynthesis–chlorophyll synthesis and carbon anhydrate activity. It was reported that Zn-deficient plants reduce the rate of protein synthesis and content drastically. Chattha et al. [15] tested three wheat cultivars, Faisalabad-2008, Punjab-2011, and Millet-2011 with five different methods of zinc application: control, seed priming, soil application, foliar application, and soil + foliar application. The results showed that grain yield and grain zinc were positively correlated, whereas grain phytic acid and grain zinc were significantly negatively correlated. The results showed that the simultaneous application of zinc in the soil and foliar application significantly increased the grain yield, while the application of zinc for seed priming only slightly increased grain yield [15]. Moreover, foliar zinc application on agronomic traits and grain quality parameters of wheat were investigated, and the results showed that foliar spray of zinc sulfate at different growth stages increased grain yield, number of grains per spike, fertile spikelet per spike, and plant height [16]. The effect of seven different amounts of zinc fertilizer on two wheat cultivars was studied, and the results showed that spraying of zinc sulfate increased thousand kernel weight, economic yield, harvest index in the milky, and grain zinc concentration in the booting stage, while Arta cultivar was further affected by the spraying compared to Shiroodi cultivar [17]. The effects of different amounts of magnesium fertilizer on wheat were investigated by Ceylan et al. [18], and the results showed that the low Mg supply did not affect the vegetative biomass production but substantially reduced the grain yield. Postanthesis foliar Mg spray significantly minimized yield losses caused by Mg deficiency [18]. Moreover, zinc and magnesium fertilizations could improve wheat kernel composition [19], wheat milling stage [20–22], flour quality [23], dough rheology and kneading [3, 24], and, finally, bread characteristics.

This research aimed to study the effect of magnesium and zinc elements on yield and yield components of bread wheat.

2. Materials and Methods

In order to investigate the interaction effects of zinc and magnesium fertilizers on wheat (cv. Sivand) yield and other characteristics, a factorial experiment was conducted based on a randomized complete block design with four replications. Each experiment was performed separately each year, and these tests were performed in 2012 and 2013 at the Agricultural Research Station of Mahidasht (Kermanshah). The two factors tested were zinc and magnesium fertilizers, and different amounts of these fertilizers were considered as levels of these factors. Treatments consisted of four levels of zinc, which was provided from the source of zinc sulfate (0, 20, 40, and 60 $kg\,ha^{-1}$ of zinc sulfate), and four levels of magnesium, which was provided from the source of magnesium sulfate (0, 70, 140, and 210 $kg\,ha^{-1}$ of magnesium sulfate). The plot spacings were 6 m long and 4 m wide with a between-row spacing of 10 cm and within-row spacing of 4 cm. The replications (blocks) were 2 m distant from each other, and also, the plots were 1 m distant from each other. Soil test was carried out before cultivation.

The measured parameters included germination, plant height, tillering, 1000-seed weight, hectoliter weight (hectoliter weight is a measure of the volume of grain per unit and shown as kilogram per hectoliter), concentrations of zinc and magnesium in seeds, protein content, and yield [25]. The protein content was measured by the Kjeldahl method using a conversion factor of 6.25. At first, the samples were digested and then distilled with Kjeldahl system, and finally, the protein content of each wheat sample was obtained from the total volume of nitrous acid [26]. Zinc and magnesium contents of seeds were obtained by dry ashing method of samples and readings in atomic absorption system.

The essential cares such as fertilizers based on soil test crop, irrigation, and weed control were done during the growing season. All of the phosphate, zinc, magnesium sulfate, and one-third of nitrogen fertilizers were applied before planting, and the remaining nitrogen (one-third at the stem elongation and one-third of heading) was applied. The experimental plots were 15 m2, and after removing the marginal effect, harvesting was done manually in the field.

Variance analyses of the data were based on combined analysis and were performed based on a randomized complete block design (RCBD). LSD test was used to compare the means. The datasets were first tested for normality by the SPSS software ver. 19.0 [27], and combined analysis was done using the SAS software ver. 9.2 [28].

3. Results and Discussion

The main effect of the year was significant for all studied traits at the level of one percent probability, and the variability of the years and their effect on traits were shown, which could be due to differences in climate and environmental conditions in two years (Table 1). The main effect of zinc sulfate and magnesium sulfate for most traits were significant ($p < 0.001$). The interaction effects of zinc and magnesium and also effects of these two factors with the year were not significant for most traits, indicating the parallelism of zinc and magnesium effects on the studied traits. All traits had a low coefficient variation (Table 1).

The mean comparison showed that the effects of two years had significant differences for most traits. The second

TABLE 1: Combined analysis of the traits measured in the examination of different levels of zinc and magnesium, years 2012–2013.

Sources of variation	df	Mean square of traits								
		GER	PLH	TIL	ZNC	MNG	PRC	HEC	TKW	YLD
Year	1	1289.6^{**}	1390.29^{**}	3.63^{*}	22.74^{ns}	11.14^{ns}	11.99^{**}	1.37^{**}	2677.59^{**}	28.78
R (year)	4	136.5	123.852	0.17	37.17	17.96	1.07	0.004	35.51	13.10
Zinc (factor A)	3	30.41^{**}	87.26^{*}	0.28^{**}	31.74^{**}	47.24^{**}	0.48^{**}	0.02^{**}	52.97^{*}	0.893^{*}
LA	3	8.2^{ns}	6.74^{ns}	0.02^{ns}	2.36^{ns}	13.02^{*}	2.92^{**}	0.008^{*}	11.97^{ns}	0.09^{ns}
Magnesium (factor B)	3	4.85^{ns}	10.48^{ns}	0.02^{ns}	74.23^{**}	43.40^{**}	0.20^{ns}	0.008^{*}	77.47^{**}	4.996^{**}
LB	3	2.17^{ns}	8.13^{ns}	0.01^{ns}	0.36^{ns}	1.40^{ns}	0.79^{**}	0.001^{ns}	35.75^{*}	0.077^{ns}
AB	9	2.36^{ns}	11.82^{ns}	0.03^{ns}	0.71^{ns}	2.15^{ns}	0.33^{*}	0.001^{ns}	12.05^{ns}	2.222^{*}
LAB	9	2.12^{ns}	4.82^{ns}	0.05^{ns}	0.25^{ns}	0.84^{ns}	0.71^{**}	0.002^{ns}	6.85^{ns}	0.016^{ns}
Error	60	4.00	5.97	0.028	1.27	3.91	0.08	0.002	10.97	0.225
CV%-		2.10	3.04%	5.82%	2.48	2.29	7.59	13.24	12.80	6.99

Symbols ^{ns,*}, and ** denote nonsignificant and significant at the 5% and 1% probability levels, respectively. GER: germination, PLH: plant height, TIL: tillering, ZNC: concentrations of zinc, MNG: magnesium in seeds, PRC: protein content, HEC: hectoliter weight, TKW: 1000-seed weight, and YLD: yield.

TABLE 2: Comparison of the traits measured in the examination of different levels of zinc and magnesium in bread wheat based on combined analysis.

Main effects	Traits								
	GER (%)	PLH (cm)	TIL (#)	ZNC ($mg\,kg^{-1}$)	MNG ($mg\,kg^{-1}$)	PRC (%)	HEC ($V\ kg^{-1}$)	TKW (gr)	YLD (Tha^{-1})
First year	97.5a	75.3b	2.6b	20.6b	0.77a	11.8a	74.6b	42.0b	6.3a
Second year	98.3a	85.4a	3.1a	31.2a	0.81a	11.9a	75.9a	43.7a	6.9a
LSD5%	2.1	8.4	0.3	3.3	0.32	0.3	10.7	1.3	2.7
Zero	97.3ab	77.1b	2.8b	24.1a	0.30a	11.8b	83.9a	43.5c	6.2c
20 kg/ha	98.4ab	78. 7b	2.8b	26.2ab	0.29a	11.8ab	87.2a	45.4ab	6.9a
40 kg/ha	96.3b	80.9ab	2.9b	26.9ab	0.31a	11.9ab	86.6a	44.8b	6.8b
60 kg/ha	98.8a	81.7a	3.0a	27.8a	0.32a	12.1a	87.1a	45.7a	7.1a
Zero	97.3a	77.9b	2.8a	18.7b	0.39b	11.7c	85.5b	43.9c	6.3c
70 kg/ha	97.8a	79.9ab	2.8a	20.5ab	0.41ab	11.9a	86.4ab	45.3b	6.6b
140 kg/ha	98.3a	81.0ab	2.9a	21.3ab	0.43ab	11.8b	86.9a	45.9ab	6.9b
210 kg/ha	98.4a	80.3a	2.8a	21.8a	0.47a	11.8a	87.2a	46.2a	7.8a
LSD 5%	3.3	2.3	0.2	2.3	1.9	0.03	1.1	0.7	0.5

Means, in each column, followed by at least one letter in common are not significantly different at the 5% probability level. GER: germination, PLH: plant height, TIL: tillering, ZNC: concentrations of zinc, MNG: magnesium in seeds, PRC: protein content, HEC: hectoliter weight, TKW: 1000-seed weight, and YLD: yield.

year showed better distribution of rainfall than the first year, leading to an increase in the yield and most traits (Table 2). The maximum amounts of germination, growth rate, plant height, and tiller number were shown in treatment with $60\,kg\,ha^{-1}$ of zinc × $240\,kg\,ha^{-1}$ magnesium, which were 98, 45, 3.00 and 29.17, respectively. However, treatment with $20\,kg\,ha^{-1}$ of zinc × $140\,kg\,ha^{-1}$ magnesium showed a suitable growth rate and seed germination and had better economic conditions (Table 3). The maximum amount of zinc in the seed was shown in treatment with $40\,kg\,ha^{-1}$ of zinc × $140\,kg\,ha^{-1}$ magnesium, which was $29.17\,mg\,kg^{-1}$.

The maximum amount of magnesium in the seed was shown in treatment with $60\,kg\,ha^{-1}$ of zinc × $210\,kg\,ha^{-1}$ magnesium, which was $0.352\,mg\ kg^{-1}$. However, treatment with $20\,kg\,ha^{-1}$ of zinc × $70\,kg\,ha^{-1}$ magnesium was very frugal and economical (Table 3). The effects of zinc sulfate (zero, 20, 40, and $60\,kg\,ha^{-1}$) and magnesium sulfate levels (zero, 70, 140, and $210\,kg\,ha^{-1}$) on the traits were different and significant. The highest germination was shown in treatment with $60\,kg\,ha^{-1}$ zinc sulfate (98%).

Increasing zinc and magnesium in the soil can also help plant growth, germination, and development because these elements are among the microelements needed for plant growth [29]. Ajouri et al. [30] reported improved germination and seedling development in barley after seed priming with zinc. The effect of zinc was increased plant height, and the effect of $60\,kg\,ha^{-1}$ of zinc sulfate was superior on plant height, 81.67 cm. This finding was consistent with the results of Prasad [31]. Moreover, zinc increased plant height by increasing internodes distances [32]. High seed zinc concentrations ensure good root growth and contribute to better protection against soil-borne pathogens [8]. These nutrients play a vital role in germination and healthy seedling establishment in carrot [33].

The effects of zinc and magnesium were not observed on the tiller. This trait was probably influenced by genetic factors. Zinc and magnesium treatments showed similar effects on zinc and magnesium levels in the seed. The highest zinc concentration in the seed, which was $27.78\,mg\,kg^{-1}$, and the highest protein concentration in the seed, which was

Table 3: Comparison of the traits measured in the examination of different levels of zinc and magnesium in bread wheat based on combined analysis.

Interaction effects	Traits								
	GER (%)	PLH (cm)	TIL (#)	ZNC (mil kg^{-1})	MNG (mil kg^{-1})	PRC (%)	HEC (V kg^{-1})	TKW (gr)	YLD (t ha^{-1})
0 × 0	96ab	77.50b	2.717a	23.22c	0.275b	11.93cd	85.28bc	43.00d	6.21de
0 × 70	95a–c	78.01b	2.621a	27.28ab	0.267b	11.74g	85.12bc	44.17cd	6.32de
0 × 140	94a–c	77.08b	2.345a	24.55bc	0.303ab	11.53i	85.35bc	45.05bc	6.09e
0 × 210	96ab	78.22b	2.539a	27.17ab	0.293ab	11.50ij	85.72a–c	45.7ab	6.45de
20 × 0	96ab	79.03b	2.433a	24.67a–c	0.305ab	11.82ef	86.35a–c	44.15cd	6.21de
20 × 70	96ab	80.17ab	2.800a	27.08ab	0.277ab	11.91d	87.23a–c	46.22ab	6.53cd
20 × 140	97a	78.33b	2.733a	26.25a–c	0.297ab	11.50ij	87.17a–c	46.42ab	6.60cd
20 × 210	97a	81.25ab	2.754a	28.8 ab	0.327a	11.97c	87.67a–c	46.27ab	6.57cd
40 × 0	93bc	80.73ab	2.644a	25.1a–c	0.317ab	11.47j	84.98c	43.55d	6.26de
40 × 70	92c	82.00a	2.967a	26.42a–c	0.302ab	11.86e	86.3a–c	45.17bc	6.78b–d
40 × 140	95ab	81.00ab	2.833a	29.17a	0.303ab	11.93cd	87.78ab	45.88ab	6.72b–d
40 × 210	95a–c	79.67b	2.883a	26.00a–c	0.308ab	11.80f	87.37a–c	46.18ab	7.02bc
60 × 0	96ab	80.12ab	2.688a	25.00a–c	0.307ab	11.63h	85.32bc	45.05bc	6.36de
60 × 70	97a	80.33ab	2.850a	26.08a–c	0.322a	12.06b	87.1a–c	45.7ab	7.20ab
60 × 140	96ab	81.83a	3.000a	27.92ab	0.340a	12.06b	87.6a–c	46.32ab	7.68a
60 × 210	98a	82.83a	2.883a	29.17a	0.333a	12.28a	88.22a	46.77a	7.25ab
LSD 5%	3.30	2.87	0.644	3.82	0.050	0.051	2.28	1.30	0.55

Means, in each column, followed by at least one letter in common are not significantly different at the 5% probability level. GER: germination, PLH: plant height, TIL: tillering, ZNC: concentrations of zinc, MNG: magnesium in seeds, PRC: protein content, HEC: hectoliter weight, TKW: 1000-seed weight, and YLD: yield.

12.05%, were shown in treatment with 60 kg ha^{-1} zinc sulfate. The increased consumption of zinc and magnesium increased seed protein contents.

The yield component traits, such as hectoliter weight, seed weight, and yield, were affected by zinc and magnesium micronutrients. The effect of zinc was not significant on hectoliter weight. The maximum amount of seed weight and yield were shown in treatment with 60 kg ha^{-1} of zinc sulfate treatment, which were 45.74 g and 7.100 t ha^{-1}, respectively.

The maximum germination rate, which was 43.62, was shown in treatment with 210 kg ha^{-1} magnesium sulfate. The maximum plant height, which was 81.00, was shown in treatment with140 kg ha^{-1} magnesium sulfate. The yield component traits, such as hectoliter weight, seed weight, and yield, were affected by magnesium sulfate micronutrients. The maximum hectoliter weight, seed weight, and yield were shown in treatment with 210 kg ha^{-1} of magnesium sulfate, which were 87.24, 46.23 g, and 7.839 t ha^{-1}, respectively. This result was consistent with that of Humphries et al. [34]; Li et al. [13]; Sawan et al. [35]. Zeidan et al. [36] reported that yield components in lentil are enhanced by foliar application of micronutrients. Due to the enzymatic activity enhancement, microelements effectively increased photosynthesis and translocation of assimilates to the seed.

Treatment with 60 kg ha^{-1} of zinc sulfate × 210 kg ha^{-1} magnesium sulfate had produced maximum hectoliter weight, 1000-grain weight, and grain yield, which were 88.22 V kg^{-1}, 46.77 gr, and 7.250 t ha^{-1}, respectively. The treatment with the best economic aspects was 20 kg ha^{-1} of zinc × 140 kg ha^{-1} magnesium. Treatments with 20 kg ha^{-1} of zinc × 70 kg ha^{-1} magnesium and 40 kg ha^{-1} of zinc × 140 kg ha^{-1} magnesium, which used less zinc and magnesium fertilizers and had a favorable impact on the attributes, are recommended (Table 3). Similar results were also reported by Abbas et al. [37], who found that application of zinc had a significant positive effect on all the growth and yield contributing parameters of wheat. The results are strongly supported by Asad and Rafique [38], who indicated that application of zinc increased wheat dry matter, grain yield, and straw yield significantly compared with control. Similarly, Zeidan et al. [39] study showed that wheat grain yield, straw yield, 1000-grain weight and number of grains spike, Zn concentration in flag leaves and grains, and protein content in grain were significantly increased by the application of zinc.

4. Conclusion

Zinc and magnesium are essential elements for crop growth and production. They play an important role in the performance of crops such as wheat. They also interfere in the metabolism of various materials, such as carbon, proteins, and fats. In this study, the application of zinc and magnesium fertilizers in comparison with not consuming any of the elements significantly increased yield and yield components of the product. The role of consumption of each element depends on the amount of deficiency that is observed in the plant growth environment, and of course, the amount of need and ability to use each plant and its cultivar should also be considered. This study showed that increased consumption of zinc and magnesium in the field raised the absorption of both elements in the plant and had a positive impact on traits such as grain weight, hectoliter weight, and yield. Zinc and magnesium did not only facilitate their own absorption, but they also resulted in better absorption of other nutrients in the plant. Although increasing the use of the fertilizer has improved some of the traits, it is important to detect the fertilizer levels that have improved yields better because wheat is grown to produce flour and bread, and it is the yield that ultimately increases the production of flour and bread. Therefore, according to the results, the application of 60 kg ha^{-1} of zinc sulfate along with 140 kg ha^{-1} of magnesium sulfate can play an important role in increasing wheat yield and consequently the production of flour and bread with reduced costs.

Data Availability

The field raw data and code used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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