

The effect of the application method of iron, zinc and manganese on the yield and quality of barley grain

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Abstract: To evaluate the methods of uses microelements of iron, zinc and manganese on yield and quality of barley, this research was conducted at Ahar agricultural research station of East Azerbaijan based on of randomized complete blocks design with 3 replications and 15 treatments. The characteristics of experimental treatments are: T1: no use of micro elements (as a control), T2: Fe soil application, T3: Mn soil application, T4: Zn soil application, T5: T2+T3, T6: T2+T4, T7:T3+T4, T8:T2+T3+T4, T9: foliar spraying of Fe, T10: foliar spraying of Mn, T11: foliar spraying of Zn, T12: foliar spraying of Fe+Mn, T13: foliar spraying of Fe+Zn, T14: foliar spraying of Mn+Zn, and T15: foliar spraying of Fe+Mn+Zn. Soil application of Fe, Mn and Zn was from ferrous sulphate, manganese sulphate and zinc sulphate, as dosage of 100, 60 and 100 kg ha⁻¹, respectively and rates of foliar spraying was 0.005 mgL⁻¹ from the same of soil application sources. Analysis of variance showed that the effect of foliar application of Mn, Iron, Zinc was significant for protein in grain. The maximum yield of grain (3587 kg ha⁻¹) acquired from the soil application of Mn and Zn, while the maximum amount of Fe and Mn in grain were obtained from foliar application of Fe, Mn and Zn. There was a significant effect between experimental treatments and all of studied traits. The soil application of microelement fertilizer was effective in increasing grain yield and biomass, but the foliar spraying has operated better than the soil application for quality of grain yield and protein content. In general, the use of microelements improved the quantitative and qualitative characteristics of barley such as, grain yield, protein content and Fe, Mn and Zn content in grain. In conclusion, the use of microelements is a suitable method to increase the yield of agricultural products. Also, according to the results of this research, foliar application of micro elements was better than soil application in improvement the studied traits.

Keywords: Barley, microelements, protein, yield

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1 Introduction

Barley (*Hordeum vulgare* L.) is one of the small grain cereals which has a broad range of compatibility among other crops. Following wheat, rice and maize barley is the fourth main grain in the world. Recent decades have seen increased interest in non-bread cereals, particularly barley and oats (Klikocka et al., 2016). Barley is one of the most important grains that

human have cultivated since ten thousand years ago. Due to having more protein, minerals, ash and raw fiber, this grain has the same nutritional value as 80%-90% of corn, with 5.7% to 15% protein, 50% to 65% starch, easy cooking, high quality, and relatively low price, barley is an energy source for humans and animals (Hejcman et al., 2013; Sakellariou and Mylona., 2020). Soils with high pH and bicarbonate, when using unbalanced fertilizers, make it challenging

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to achieve optimal yield as nutrient absorption will be impaired due to unfavorable soil conditions, and hence will cause signs of nutrient deficiency in the plant (Prasad et al., 2014). In such situation, foliar application is an excellent way to use chemical fertilizers and reduce the environmental risks of fertilizers (Dola et al., 2022). Fe and Zn deficiency in humans and soil is widespread in the world, especially in developing and under development countries and has also drawn considerable attention globally (Babaeian et al., 2012). These micro elements are required by various metabolic and other processes in human body (Prasad et al. 2014). A large portion of the human population does not take in enough of micro elements with food because their diet is insufficiently varied and consists primarily of cereals. Among the widely available methods of supplementing microelement-deficit diets, one of methods is foliar application of microelement (Welch and Graham, 2005). Thus, foliar application is the easiest and fastest way for fortification of cereal grains with Fe, Zn, or other micro elements in developing Asian and African countries, where cereals are the main food (Ram et al., 2015). Micro elements play an essential role in cell differentiation, growth and cell wall strength and in most cases make plants resistant to pests and diseases (Welch and Graham, 2005). However, soil conditions at Azerbaijan province face challenges for the uptake of Fe, Zn and Mn (Sadeghi et al., 2021). Therefore, the insufficient absorption of these micro elements, may result in, a decrease in the quantity and quality of the product. In such cases, foliar application will be more effective and more economical than using iron and zinc chelates in the soil (Sharma et al., 2023).

Nawaz et al. (2015) reported that with zinc foliar application, grain yield, dry matter yield, thousand seed weight, the number of claws, height, amount of protein, zinc and iron in seeds increased. Sabaghnia and Janmohammadi (2023) showed that fertilizing feed barley plants with a concentration of 90-180 micrograms of zinc with a source of zinc sulfate significantly increased the number of germinated seeds.

Although, micro elements are needed in relatively

very small quantities for adequate plant growth and production, their deficiencies cause a great disturbance in the physiological and metabolic processes in the plant (Jákobsone et al., 2018). The study conducted by Goswami, et al. (2023) showed that the addition of low-use nutrients to the soil solution led to the formation of chelates and significantly increased their absorption by plants, so that low concentrations of elements cause zinc deficiency in corn and barley, biomass and zinc absorption in wheat also decreased. Barczak et al. (2019) in a study concluded that the increase in the amount of manganese in barley grain was accompanied by a decrease in the amount of seed protein, this issue could indicate that the amount of manganese can change independently of the yield of the grain. Ramzan et al. (2020) reported that foliar application with nitrogen, zinc and iron sulfate in the last stages of growth increased the amount of protein, zinc and iron in the grain. They also stated that in order to improve the quality of grain in terms of nutritional value, especially increasing the amount of zinc and iron in the late growth stage. Thus, foliar application of micro elements is necessary in order to increasing of quality and quantity of barely. Saady et al. (2022) by studying the transfer and storage of micro elements in barley grain concluded that the increase in barley nutrition with high levels of iron has led to a decrease in the absorption and storage of zinc. Goswami et al. (2022) concluded in an experiment that foliar application with a nutrient solution containing 2% of iron, manganese, zinc and magnesium elements, significantly increased grain and straw yield as well as carbohydrate content in wheat grain. Since there is little research on the nutritional needs of barley and mainly the results of wheat research are used to determine the nutritional needs of barley, so this research was conducted to investigate the effect of micro elements iron, zinc and manganese on the yield and quality of barley grain.

2 Materials and methods

2.1 Study area

To evaluate the methods of uses micro elements of

iron, zinc and manganese on yield and quality of barley, this research was conducted at Ahar agricultural research farm of East Azerbaijan province. The geographical coordinates were 47° 4' 35'' of east longitude and 38° 28' 48'' north latitude. The experiment was conducted under the randomized complete block design with 3 replications and 15 treatments. The experimental treatments included: T1: no use of micro elements (as a control), T2: Fe soil application, T3: Mn soil application, T4: Zn soil application, T5: T2+T3, T6: T2+T4, T7:T3+T4, T8:T2+T3+T4, T9: foliar spraying of Fe, T10: foliar spraying of Mn, T11: foliar spraying of Zn, T12: foliar spraying of Fe+Mn, T13: foliar spraying of Fe+Zn, T14: foliar spraying of Mn+Zn, and T15: foliar spraying of Fe+Mn+Zn. Soil application of Fe, Mn and Zn from ferrous sulphate, manganese sulphate and zinc sulphate, At the dose of 100, 60 and 100 kg ha⁻¹, respectively and concentration of foliar application 0.005 mg L⁻¹ from the same of soil application sources. Before starting the experiment, a combined sample of the soil was prepared and tested. The results of soil analysis are shown in Table 1. According to the results of soil analysis, the amounts of P, K and Cu are sufficient but the amounts of Fe, Mn and Zn are insufficient.

2.2 Data collection

Based on the results of the soil test, fertilizers containing macro elements of NPK were used using the formula of 100-100-200 kg. ha⁻¹. Phosphorus was from the source of triple superphosphate, potassium was from the source of potassium sulfate, and nitrogen was from the source of urea. All potassium and phosphorus and half of nitrogen was used during

planting date and the rest during the stem stage. Before harvesting, the stem length with centimeter and the number of claws per square meter were measured, and after harvesting of crop in summer, variables such as the weight of one thousand seeds, biological yield, grain yield, protein percentage, iron, zinc, and manganese percentage in the grain were determined. In order to measure zinc, iron and manganese nutritional elements, the extract was prepared by wet digestion method and its amount was measured using atomic absorption device (Wiegmann et al., 2019). With harvesting of all plant in 2×2 m² area, biological yield obtained and after separate grain in this area, grain yield was measured.

2.3 Data analysis

Data were analyzed by analysis of variances (ANOVA) using SPSS software and comparison of mean values was done with Duncan's multi-range test at 5% probability level.

3 Results and discussions

3.1 plant height and weight of 1000 grain

An analysis of variances shows that there is no statistically significant difference between the effect of micro elements to the weight of 1000 seeds (Table 2). However, the use of micro elements compared to the control treatment (no consumption of micro elements) has increased, but this increase it was not statistically significant. Sakellariou and Mylona (2020) reported during their research that the application of zinc sulfate increased the weight of 1000 seeds by 2.8% compared to the control in soybean, but this increase was not statistically significant.

Table 1 Specifications of the soil used

Soil texture class	Soil texture (%)			Mental (mg kg ⁻¹)						N (%)	Total neutralizing substances (%)	OC (%)	pH	Electrical conductivity (dS m ⁻¹)	Sampling depth (cm)
	Clay	Silt	Sand	Cu	Mn	Zn	Fe	K	P						
clay loam	32	27	41	0.84	3.14	0.36	2.2	305	13	0.063	17	0.63	7.8	2.7	0-30

Table 2 Variance analysis of studied traits

S.o.V	df	Plant height	1000 grain weight	Grain yield	Biological yield	Protein	Fe	Zn	Mn
Rep.	2	243.16	6.06	552808.89	3069828.89	1.98	8.817	215.16	9.98
Treat.	14	30.26 ^{ns}	3.14 ^{ns}	194940.32*	654173.65 ^{ns}	11.46**	4444.76**	371.77**	113.69**
Error	28	77.539	3.87	94685.08	417376.08	0.04	287.102	109.11	13.04
CV (%)		12.98	3.85	9.64	9.43	1.82	19.69	23.36	12.22

Note: * and ** are significant at the five and one percent probability levels, respectively

Table 3 Duncan's Multiple range test of the mean values

	Plant height (cm)	1000 grain weight (kg ha ⁻¹)	Grain yield (Kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Protein (%)	Fe (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Mn (mg kg ⁻¹)
Non-use of elements (control)	64.4	49.3	2703 d	5983	7.3 j	49.5 e	32.5 cd	20.2 h
Soil application of Fe	69.5	50.9	3237 abcd	6057	9.3 g	100.0 cd	38.2 bcd	27.7 defg
Soil application of Mn	58.8	51.0	3293 abcd	7253	9.6 fg	62.5 e	34.0 cd	31.7 bcde
Soil application of Zn	68.5	49.9	3293 abcd	7290	8.3 i	47.5 e	42.5 bcd	24.5 fgh
Soil application of Fe+Mn	68.9	50.6	3243 abcd	7047	11.2 d	93.5 d	39.7 bcd	30.9 cdef
Soil application of Fe+Zn	68.0	49.8	3303 abcd	7273	12.6 b	105.0 cd	52.7 abc	25.2efgh
Soil application of Mn+Zn	73.1	51.7	3587 a	7507	12.7 b	53.5 d	43.2 bcd	33.2 abcd
Soil application of Fe+Mn+Zn	68.4	52.2	3437 abc	7490	13.4 a	137.5 b	47.3 bcd	33.5 abcd
Foliar application of Fe	69.4	50.6	2843 cd	6357	10.4 e	130.0 bc	39.0 bcd	21.0 gh
Foliar consumption of Mn	68.9	52.0	2883 cd	6613	8.9 h	49.0 e	28.0 d	31.2 bcde
Foliar application of Zn	67.7	53.3	3177 abcd	6323	9.6 f	40.0e	56.7 ab	24.5 fgh
Foliar application of Fe+Mn	70.8	50.8	2943 bcd	6563	11.4 d	102.5 cd	37.5 bcd	38.0 ab
Foliar application of Fe+Zn	65.7	51.2	3283 abcd	6800	12.1 c	92.5 d	69.3 a	24.5 fgh
Foliar application of Mn+Zn	68.9	51.3	3123 abcd	6423	12.6 b	60.0 e	54.5 ab	37.5 abc
Foliar application of Fe+Mn+Zn	67.7	51.5	3547 ab	6823	13.3 a	167.5 a	55.5 ab	39.5 a

Note: Averages with common letters in each column have no significant difference at the five percent probability level with Duncan's test

3.2 Grain yield

Analysis of variances showed that the effect of microelements on grain yield is statistically significant at the 5% probability level (Table 2). Comparison of averages using Duncan's method showed that there is a statistically significant difference between different levels of foliar application of micro elements. So that the highest grain yield with an average of 3587 kg ha⁻¹ is related to the treatment of soil application of manganese and zinc, and the lowest grain yield is related to the control treatment. There was a significant increase in yield, and soil application of micro elements is better than foliar application this element.

Saquee et al. (2023) reported the increase in grain yield with soil application and foliar application of manganese sulfate in wheat. Moitazedi et al. (2023) stated that foliar application of iron, zinc and copper elements can be effective in increasing plant yield better than soil application and treatment. Among the advantage of foliar application can be mentioned: low consumption of fertilizer per unit area, non-stabilization of nutrients in the soil, high efficiency of fertilizer uses and use this method in water shortage conditions. Therefore, in this situation, foliar application is the best and most economical method of using fertilizer.

3.3 Biological yield

Analysis of variances showed that there is no statistically significant difference between the effects of micro elements in terms of biological yield. But all the treatments have a significant increase compared to the treatment of not using micro elements. So that the highest biological yield with an average of 7507 kg. ha⁻¹ is related to the treatment of soil application of manganese and zinc, and the lowest amount with an average of 5983 is related to the treatment of no application of micro elements. Increased auxin biosynthesis in the presence of low consumption elements and increased photosynthesis as a result of increased chlorophyll concentration, increased activity of phosphoenol pyruvate carboxylase and ribulose phosphate carboxylase (Prasad and Shivay, 2020). Decreased accumulation of sodium element in plant tissues, increased on the amount of iron and its positive role in photosystems one and two, addition to other metabolic activities of the plant and other factors can justify the increase of dry matter yield to a significant extent in the presence of iron, zinc and boron elements (Taliman et al., 2019). Considering the lack of significant effects of micro elements in increasing biological yield, it is concluded that the amount of this elements was not enough to increasing of this trait.

3.4 Protein content

Analysis of variances showed that there is a statistically significant difference in the effect of micro elements in terms of the amount of seed protein at the probability level of one percent (Table 2). Comparison of the averages showed that there is a statistically significant difference between different levels of foliar application of micro elements. So that the highest amount of seed protein with an average of 13.42% was related to the treatment of soil application of iron-manganese and zinc, and the lowest amount of grain protein with an average of 7.27% was related to the treatment of not using low-use elements (control). In this experiment, all the treatments had a significant increase compared to the control, i.e. (no consumption of low consumption elements). Also, the use of leaves

in general has worked better than the use of soil. It seems that in order to increase the amount of protein, all low consumption elements should be provided to the plant sufficiently. So that the plant can produce protein better (Thomas et al., 2019). It seems that the dominance of calcareous conditions and alkaline pH has led to better efficiency of foliar application than soil application of micro elements in this experiment.

3.5 Fe content

Analysis of variances showed that the effect of micro elements on the amount of iron in the grain has caused a significant difference at the level of one percent probability (Table 2). Comparison of average data showed that there is a statistically significant difference between different levels of consumption of micro elements. So that the highest amount of iron content in the grain with an average of 167.50 mg. kg⁻¹ is related to the foliar application of iron, manganese and zinc and the lowest amount of iron is related to the treatment of foliar application of zinc with an average of 40 mg. kg⁻¹. But in general, most of the treatments have increased compared to the control, and foliar application has worked better than soil application.

All treats significantly affected the content of all elements, generally increasing their content of Fe compared to the grain of plants not used with microelements. It seems that balanced foliar application of micro elements not only does not have a negative effect on each other, but the presence of different micro elements has a positive effect to absorb each other, that is, if the plant is placed in an ideal state in terms of nutrients, the required nutrients will be better can absorb but if a food element is lacking in the diet, the balance of the plant will be disturbed. These results agree with the results of other researchers such as Nawaz et al. (2015). Yousefipor et al. (2019) summarized data on Fe concentration in various grains and roots. Fe concentrations in barley grains were in the range 33–218 mg· kg⁻¹. The state of iron balance in the plant is one of the important factors determining the quality of human food (Barczak et al., 2019). During iron deficiency, symptoms of manganese

toxicity can be observed in plants, whereas manganese deficiency can result from excess iron in the soil. This is why the right balance between these elements is important. The correct Fe:Mn ratio in cereal grain is in the range from 1.5:1 to 2.5 :1 (Yousefipor et al., 2019).

3.6 Zn content

Zinc is a component of about 200 enzyme systems and is essential for normal human growth and development, as it participates in metabolism of carbohydrates, proteins, and phosphates. The results of the analysis of variance of the data show that the micro elements had a significant effect on the zinc content of the grain at the probability level of one percent (Table 2). There is a statistically significant difference, so that the highest amount of zinc in the seed with an average of 69.33 mg. kg⁻¹ is related to the foliar application of iron with zinc and the lowest amount is related to the treatment of foliar application of manganese with an average of 28 mg kg⁻¹. Most of the treatments had an increase in yield compared to the control, but in general, foliar application of micro elements worked better than their soil application. This is perhaps because in foliar application, there is less negative interaction of elements and also less competition for absorption, which has made foliar spraying work better than soil application. In this research, foliar application of iron-zinc showed the highest absorption rate, but in soil application of iron-zinc, due to the prevailing antagonistic relationships between phosphorus and zinc in the soil, its absorption rate is lower. This research is consistent with the reports of other researchers such as Alikhani et al. (2023). Due to the mutual effects that exist between nutrients, especially microelements, the increase of one element causes in the absorption of one other element. So, in this research, the use of Fe increased the amount of Zn in the grain.

3.7 Mn content

Mn is one of the most abundant micro elements in the lithosphere. Several soil factors influence Mn availability to plants. The solubility of soil Mn is of significance since the plant supply of Mn depends

mainly on the soluble Mn pool in the soil (Yousefipor et al., 2019). The results of variance analysis of the data show that there is a statistically significant difference in the effect of micro elements on the amount of manganese in the grain (Table 2). The comparison of averages by Duncan's method showed that there is a statistically significant difference between the different levels of consumption of micro elements, so that the highest amount of manganese in the seed with an average of 39.5 mg. kg⁻¹ is related to the foliar application of iron, manganese and zinc, and its lowest amount, with an average of 20.23 mg. kg⁻¹, is related to not consuming low consumption elements. Among the micro elements used in total, foliar application has performed better than their soil application in terms of manganese content. These results are consistent with the results of Hejzman et al. (2013). Compared to optimal microelement concentrations in feeds, which are 40–70 mg·Mn·kg⁻¹, 40–80 mg·Fe·kg⁻¹, 50–100 mg·Zn·kg⁻¹ (Babaeian et al., 2012). In foliar application traits the Fe, Mn and Zn contents in the grain can be considered to be in the optimal range, thus Significantly higher content of Fe, Zn and Mn was obtained in the barley grain with treated on foliar application of these elements.

In conclusion, the use of microelements is a suitable method to increase the yield of agricultural products, and increasing the productivity of resources and the efficiency of production factors requires their optimal use (Azam et al., 2022). In the meantime, preventing harmful intra-species competition in the plant community to obtain food and maximum benefit from environmental factors and inputs has a special place in production management, crops have been appropriated. If the applied fertilizer treatments were on plant height, number of tillers, thousand seed weight, biological yield, harvest index, grain manganese content, grain iron content, grain zinc content, grain protein content and grain yield. The highest seed yield and biological yield are related to the soil application of Zn + Mn, thus in this traits, soil application of micro elements had better than foliar

application of microelements. And the highest amount of seed manganese and seed iron and the percentage of protein are related to the foliar application of Fe+ Mn+ Zn, and the highest amount of grain zinc is also related to the treatment of foliar application of Fe + Zn, thus in this traits, foliar application of micro elements had better than soil application of microelements. In the general case of using fertilizers containing micro elements, the concentration of these elements in the grain is increased.

4 Conclusion

The use of micro element has been effective on most of the studied traits. Comparing the two-methods fertilizer use, foliar application has performed better in improving the studied traits. It seems that the dominance of calcareous conditions and alkaline pH has led to better efficiency of foliar application than soil application of micro elements in this experiment. Therefore, in order to improve the quantitative and qualitative characteristics of barley, foliar application of micro elements is suggested on the condition of this experiment.

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References

- Alikhani, M., A. Mirbolook, J. Sadeghi, and A. Lakzian. 2023. Effect of a new slow-release zinc fertilizer based on carbon dots on the zinc concentration, growth indices, and yield in wheat (*Triticum aestivum* L.). *Plant Physiology and Biochemistry*, 200:107783.
- Azam, M., H. N. Bhatti, A. Khan, L. Zafar L, and M. Iqbal. 2022. Zinc oxide nano-fertilizer application (foliar and soil) effect on the growth, photosynthetic pigments and antioxidant system of maize cultivar. *Biocatalysis and Agricultural Biotechnology*, 42:, 102343.
- Babaeian, M., Y. Esmaeilian, A. Tavassoli, and A. Asgharzade . 2012. Efficacy of different iron, zinc and magnesium fertilizers on yield and yield components of barley. *African Journal of Microbiology Research*, 6(28): 5754-5756.
- Barczak, B., M. Jastrzębska, and M. K. Kostrzevska. 2019. Research Article Biofortification of Spring Barley Grain with Microelements through Sulfur Fertilization. *Journal of Chemistry*, 2019(1): 8214298.
- Dola, D. B., M. A. Mannan, U. Sarker, M. A. A. Mamun, T. Islam T, S. Ercisli S, M. H. Saleem, B. Ali B, O. L. Pop, and R. A. Marc. 2022. Nano-iron oxide accelerates growth, yield, and quality of Glycine max seed in water deficits. *Frontiers in Plant Science*, 13: 992535.
- Goswami, S., S. K. Singh, A. Patra, A. Dutta, and K. K. Mohapatra. 2022. Residual effects of nickel and its interaction with applied zinc and npk improve the growth, yield, and nutritional quality of cowpea and urease activity of soil grown in Vertisols. *Journal of Soil Science and Plant Nutrition*, 22(4): 4262-4272.
- Goswami, V, S. Deepika, S. Diwakar, and D. Kothamasi. 2023. Arbuscular mycorrhizas amplify the risk of heavy metal transfer to human food chain from fly ash ameliorated agricultural soils. *Environmental Pollution*, 329: 121733.
- Hejcman, M., M. Berkováa, and E. Kunzováa. 2013. Effect of long-term fertilizer application on yield and concentrations of elements (N, P, K, Ca, Mg, As, Cd, Cu, Cr, Fe, Mn, Ni, Pb, Zn) in grain of spring barley. *Plant Soil and Environment*, 59(7): 329-334.
- Jâakobson, I., S. Zute, M. Bleidere, I. Kantāne, and V. Bartkevičs. 2018. March. Macro and trace elements in barley (*Hordeum vulgare* L.) breeds in latvia depending on variety, environment, and agricultural practice. *Proceedings of the Latvian Academy of Sciences*, 72(2): 54-64.
- Klikocka, H., M. Cybulska, B. Barczak, B. Narolski, B. Szostak, B. Kobiałka, A. Nowak, and E. Wójcik. 2016. The effect of Sulphur and nitrogen fertilization on grain yield and technological quality of spring wheat. *Plant Soil and Environment*, 62: 230-236
- Moitazed, S, S. Sayfzadeh, R. Haghparast, H. R. Zakerin, and H. Jabari. 2023. Mitigation of drought stress effects on wheat yield via the foliar application of boron, zinc, and manganese nano-chelates and supplementary irrigation. *Journal of Plant Nutrition*, 46(:9): 1988-2002.
- Nawaz, F., M. Y. Ashraf, R. Ahmad, E. A. Waraich, R. N. Shabbir, and M. A. Bukhari. 2015. Supplemental selenium improves wheat grain yield and quality through alterations in biochemical processes under normal and water deficit conditions. *Food Chemistry*, 175: 350-357.
- Prasad, R., and Y. S. Shivay. 2020. Agronomic biofortification of plant foods with minerals, vitamins and metabolites with chemical fertilizers and liming. *Journal of Plant Nutrition*, 43(10):. 1534-1554.

- Prasad, R., Y. S. Shivay, and D. Kumar. 2014. Agronomic biofortification of cereal grains with iron and zinc. *Advances in Agronomy*, 125: 55-91
- Ram, H., V. S. Sohu, I. Cakmak, K. Singh, G. S. Buttar, G. P. S. Sodhi, H. S. Gill, I. Bhagat, P. Singh, S. S. Dhaliwal, and G. S. Mavi. 2015. Agronomic fortification of rice and wheat grains with zinc for nutritional security. *Current Science*, 109(6): 1 171–1176.
- Ramzan, Y., M. B. Hafeez, S. Khan, M. Nadeem, S., Batool, and J., Ahmad. 2020. Biofortification with zinc and iron improves the grain quality and yield of wheat crop. *International Journal of Plant Production*, 14(3): 501-510.
- Sabaghnia, N., and M. Janmohammadi. 2023. Influence of some nano-fertilizers on chickpeas under three irrigation strategies. *Plant Nano Biology*, 4: 100037.
- Sadeghi, F., A. Rezeizad, and M. Rahimi. 2021. Effect of zinc and magnesium fertilizers on the yield and some characteristics of wheat (*Triticum aestivum* L.) seeds in two years. *International Journal of Agronomy*, 2021: 8857222.
- Sakellariou, M., and P. V. Mylona. 2020. New uses for traditional crops: the case of barley biofortification. *Agronomy*, 10(12): 1964.
- Saquee, F. S., S. Diakite, N. J. Kavhiza, E. Pakina, and M. E Zargar. 2023. The efficacy of micronutrient fertilizers on the yield formulation and quality of wheat grains. *Agronomy*, 13(2): 566.
- Saudy, H. S., G. A. A. El-Samad, M. E., El-Temsah, and Y. A. E. G. El-Gabry. 2022. Effect of iron, zinc, and manganese nano-form mixture on the micronutrient recovery efficiency and seed yield response index of sesame genotypes. *Journal of Soil Science and Plant Nutrition*, 22(1): 732-742.
- Sharma, A., S. Kumar, and R. Singh. 2023. Formulation of Zinc oxide/Gum acacia nanocomposite as a novel slow-release fertilizer for enhancing Zn uptake and growth performance of *Spinacia oleracea* L. *Plant Physiology and Biochemistry*, 201: 107884.
- Taliman, N. A., Q. Dong, K. Echigo, V. Raboy, and H. Saneoka. 2019. Effect of phosphorus fertilization on the growth, photosynthesis, nitrogen fixation, mineral accumulation, seed yield, and seed quality of a soybean low-phytate line. *Plants*, 8(5):119.
- Thomas, C. L., G. E. Acquah, A. P. Whitmore, S. P. McGrath, and S. M. Haefele. 2019. The effect of different organic fertilizers on yield and soil and crop nutrient concentrations. *Agronomy*, 9(12): 776.
- Welch, R. M., and R. D. Graham. 2005. Agriculture: the real nexus for enhancing bioavailable micronutrients in food crops., *Journal of Trace Elements in Medicine and Biology*, 18(4): 299–307.
- Wiegmann, M., W. T. B. Thomas, H. J. Bull, A. J. Flavell, A. Zeyner, E. Peiter, K. Pillen, and A. Maurer. 2019. Wild barley serves as a source for biofortification of barley grains. *Plant Science*,. 283:83-94.
- Yousefipor, M., S. Lack, and K. Payandeh. 2019. Evaluation of the Combined Effect of Biological and Chemical Phosphorous Fertilizers and Micronutrient on Seed and Protein Yield of Barley (*Hordeum vulgare* L.). *Journal of Crop Ecophysiology*, 13(1): 103-120.