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Integrated Soil and Foliar Zinc Management Improves Yield Formation and Grain Productivity of Bread Wheat

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ABSTRACT

Evidence of the contribution of soil rate and foliar concentration and time to the formation of yield is needed to optimize zinc management. Wheat (Wadan-17) was used in a field experiment at The University of Agriculture, Peshawar, Pakistan in 2021-2022. Three soil Zn rates (5, 10 and 15 kg ha^{-1}), three foliar Zn concentration (0.2, 0.4 and 0.6%) and two spray timings (booting and anthesis) were combined in 18 treatments, with an untreated control. The treatments were laid out in a randomized complete block design with 3 replications. Soil Zn, foliar Zn and timing had significant effect on spike-1 and thousand-grain weight, BY and grain yield of grains while the harvest index remained unaffected. Grain yield increased from 3180 kg ha^{-1} at 5 kg soil Zn ha^{-1} to 4164 kg ha^{-1} at 15 kg ha^{-1}, from 3389 kg ha^{-1} at 0.2% foliar Zn

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to 3904 kg ha^{-1} at 0.6%, and from 3525 kg ha^{-1} with anthesis spraying to 3803 kg ha^{-1} with booting spraying. The average of treated plots was 3664 kg ha-1, and the control was 2136 kg ha-1. The maximum treatment combination mean of 4702 kg ha-1 was observed under 15 kg soil-Zn ha^{-1} + 0.6 % foliar-Zn at booting. The interactions among the factors were not significant suggesting additivity of the yield responses. The yield advantage was due to higher grain number, grain weight, and spike density, and was not statistically detectable harvest index. The findings are confirmatory of using 15 kg soil Zn ha^{-1} along with 0.6 % of foliar Zn at booting for optimum wheat yield under the above conditions.

Keywords: Agronomic Biofortification; Grain Yield; Micronutrient Management; Spike Fertility; Triticum Aestivum; Zinc Sulphate

Introduction

Proper wheat production requires well-balanced nutrition, covering both source development and grain sink formation. The requirement for zinc is relatively low, but deficiency may affect the activity of enzymes, the function of pollen grains, fertilization, transport of assimilates and formation of grains. These effects are especially important in alkaline and calcareous soils where the total amount of Zn is present but the plant available Zn is low (Alloway, 2009; Cakmak, 2008). Remedies can thus be identified for Zn deficiency which can enhance yield components as well as biofortification agronomically.

Both soil and foliar applications have different agronomic purposes. Soil applied Zn can have a long term effect on root growth and nutrient acquisition over the season, while foliar applied Zn can quickly provide canopy with its nutrients during reproductive development. Foliar application may be particularly beneficial under conditions of high pH that inhibit root uptake of the nutrient, however the effectiveness of this will depend on foliar concentration and spray timing and canopy retention. Recent field trials (Nayak et al., 2023) have shown improvements in wheat yield and grain Zn content using integrated soil and foliar applications, and genotype-by-Zn studies have shown significant yield and biofortification trait differences (Azeem et al., 2023).

Supplies of foliar Zn are important for yield formation. The timing of the application is related to the time of rapid spike development and before anthesis; late application may have a greater opportunity for deposition of Zn in developing grain, but may have reduced time to affect spike number and biomass. Previous field trials have shown that foliar micronutrient application has achieved better wheat yield components (Gul et al., 2011; Zeidan et al., 2010). Foliar application of Zn at booting, flowering and post flowering stage has also been reported to improve the yield of the crop (El-Dahshouri et al., 2017; Sultana et al., 2016; Zarea & Karimi, 2023). Therefore a factorial design is required to determine the independent effects of soil rate, foliar concentration and application stage.

Add to this context sustainable intensification via regional resource-quality assessments. Khan et al. (2025) and Khan and Khan (2026) found significant difference in the physicochemical and biological water-quality parameters of Peshawar and Mohmand. The papers do not focus on crop Zn nutrition but their

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messages as a whole highlight the importance of enhancing food production while simultaneously avoiding a separation of fertilizer decisions from local soil and water resources.

Regional evidence also supports a wider, site-specific approach to crop productivity. Biochar combined with phosphorus or beneficial bacteria has improved maize productivity, nutrient-use efficiency, and crop performance under contaminated-soil conditions (Farooq et al., 2026; Jalal et al., 2026; A. Khan et al., 2026). Although focused on different crops, local field studies further show that yield protection depends on varietal resistance and targeted pest management (Anees et al., 2026; Rehman et al., 2026). Water-quality assessments from Peshawar and Mohmand likewise highlight the need to align fertilizer and crop-management decisions with local soil and water conditions (Khan et al., 2025; Khan & Khan, 2026).

In this study, effect of soil Zn rate, foliar Zn concentrations, foliar timing and grain yield on grains per spike, thousand grain weight, biological yield, grain yield and harvest index of wheat were evaluated. The study also examined if there was a dependency of the responses to the two Zn factors and compared the full Zn treatment with a control that was not treated. We predicted that the highest soil rate and foliar concentration, especially at booting, would enhance yield both through an increase in the number of grains and in individual grain size.

Materials and Methods

Field experiment and crop management

The experiment was carried out at the Agronomy Research Farm, The University of Agriculture, Peshawar, Pakistan in winter season 2021-2022. Wadan-17 wheat was sown on 5 November 2021 at 120 kg seed ha-1 in 2.4 x 2.4 m plots with 0.30 m row spacing. There are five irrigations after establishment and tillering, heading, anthesis and grain filling. All crops were treated for the same and other agronomic aspects, and the experiment was picked in May 2022.

The experiment was designed as randomized complete block design, three replications. The factorial treatments comprised application of soil Zn at 5, 10 or 15 kg ha-1, foliar Zn at 0.2, 0.4 or 0.6%, and foliar application time at booting or anthesis. These factors yielded 18 treatments. Projections were made of these to 57 plots, including one no-Zn control for each replications. Zinc sulphate was used as a source of zinc, and soil treatments were done at sowing and foliar solutions were applied at the specified crop stage.

Yield and yield-component measurements

At harvest, 5 representative spikes were harvested from each plot, threshed individually and grains per spike counted. A clean-grain sample was used to get a random sample of 1,000 grains for measurement of thousand-grain weight. Four central rows of plants were cut off and the biological yield calculated as fresh mass/ha, based on harvested area. The same grain was threshed and grain mass was expressed in kg ha-1. Harvest Index was defined as grain yield/bloom yield x 100.

Spike density was used in order to interpret yield formation and measured in a defined row length to be converted to spikes m-2. The entire spike-density data set is examined in the companion growth manuscript; the present paper deals with the

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formation of final yields.

Statistical analysis

The randomized complete block design (RCBD) was used for analysis of variance. The factorial treatment variation was split into the three main effects and two and three way interactions. All the plots treated with Zn were compared with a plot that was not treated. Mean separation was done using the least significant difference test at P <= 0.05 (Steel et al., 1996). Means were independently re-calculated from the three plot-level replications in the thesis appendices.

Results

Grain number and grain mass

Grains per spike was significantly affected by all three Zns. Zn application at the rate of 15 kg ha-1 over 5 kg ha-1 of soil resulted in a significant increase in mean grains spike-1 from 48.22 to 54.50 grains spike-1, which is a 13.0%. The grain number of the plants treated with foliar Zn has increased from 49.39 at 0.2% to 53.61 at 0.6% and spraying at booting stage resulted in a grain number of 52.78 grains spike-1 while spraying was performed at anthesis stage resulted in 50.33 grains spike-1. Average grain per spike was 51.56 grains in the treated rows as compared to 43.13 grains in the control rows.

A similar response was seen for thousand-grain weight. Means rose from 44.37 to 49.24 g in soil rates and 45.37 to 48.60 g in foliar concentrations. The application at the time of booting yielded 48.16 g while anthesis yielded 45.95 g. The untreated control has an average of 39.40 g, which is 16.3% less than the treatment average. No interactions were significant for either of the grain traits except for soil x foliar, soil x timing, foliar x timing and three-way interactions.

Biological yield, grain yield and harvest index

Each component of the Zn management led to an increase in the biological yield. The response to soil Zn was approximately linear over the tested range, rising from 11,263 kg ha-1 at 5 kg Zn ha-1 to 12,446 kg ha-1 at 10 kg ha-1 and 13,672 kg ha-1 at 15 kg ha-1. Foliar Zn at 0.6% produced 12,938 kg ha-1, compared with 11,941 kg ha-1 at 0.2%. The slight advantage of 411 kg ha-1 obtained with the booting-stage application was significant compared with anthesis-stage application. The treated mean was significantly higher than the control by +4,684 kg ha-1.

The yield of grain was very sensitive to soil Zn. Increasing soil Zn from 5 to 15 kg ha-1 raised yield from 3,180 to 4,164 kg ha-1, a 30.9% increase. Yield increased by 514.6 kg ha-1 as foliar concentration increased from 0.2% to 0.6%, and booting-stage applications were 277.9 kg ha-1 higher than anthesis-stage applications. Mean yield of Zn treated plots was 3,664 kg ha-1 which is 71.5% better than the control which gave 2,136 kg ha-1.

There were no significant differences of harvest index with soil rates, foliar concentrations or spray timings but ranged between 28.31 and 30.42%. None of these differences was statistically significant, nor was it for the control versus rest comparison. Yield gains were therefore due more to increased biomass and yield components than to a statistically confirmed biomass reallocation to grain.

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Table 1 Main-effect means for wheat yield and yield components.

Factor	Level	Grains spike-1	1000-grain wt. (g)	Biological yield	Grain yield	Harvest index (%)
Soil Zn (kg ha-1)	5	48.2	44.4	11263	3180	28.31
	10	51.9	47.6	12446	3646	29.33
	15	54.5	49.2	13672	4164	30.42
Foliar Zn (%)	0.2	49.4	45.4	11941	3389	28.41
	0.4	51.7	47.2	12502	3698	29.56
	0.6	53.6	48.6	12938	3904	30.10
Timing	Booting	52.8	48.2	12666	3803	29.97
	Anthesis	50.3	46.0	12255	3525	28.74
Planned contrast	Control	43.1	39.4	7777	2136	27.57
	Treated mean	51.6	47.1	12460	3664	29.35

Yield units are kg ha-1. All main effects were significant for grains spike-1, thousand-grain weight, biological yield and grain yield. Harvest index was non-significant for all effects and the planned contrast. All interactions were non-significant.

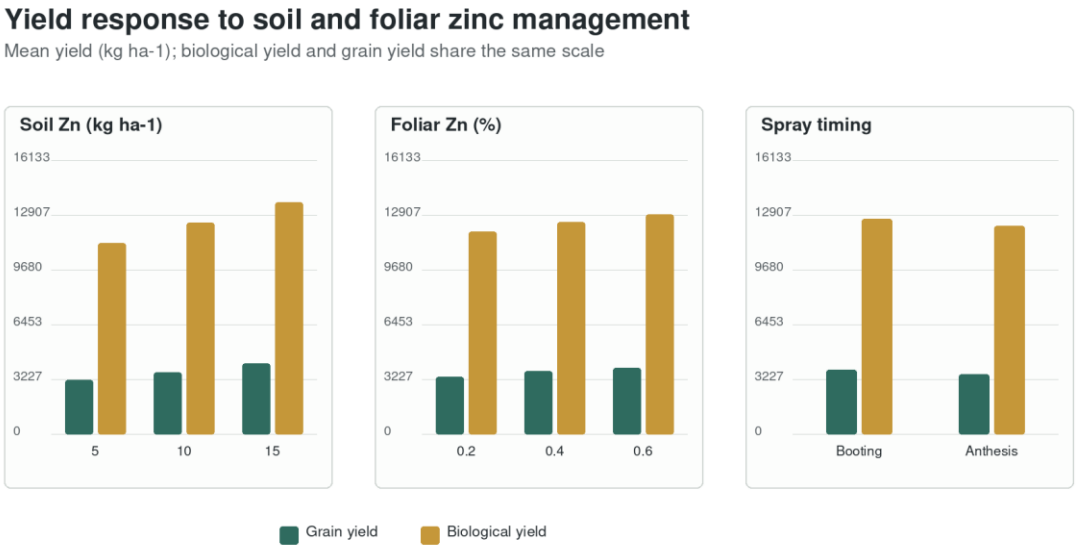

Figure 1 Biological and grain yield response to soil Zn rate, foliar Zn concentration and foliar application timing.

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Performance of individual treatment combinations

Treatment-combination means show the additive pattern, but not interactions were significant. The highest grain production (4,702 kg ha-1) was obtained at soil Zn rate of 15 kg ha-1 and foliar Zn application rate of 0.6%. The anthesis treatment gave 4,340 kg ha-1. At the lowest soil rate, grain yield was between 2708 kg ha-1 (for 0.2% Zn at anthesis) and 3416 kg ha-1 (for 0.6% Zn at booting).

If there is no significant interaction, then the treatment ranking must not be considered as evidence of a special synergistic combination. However, the heatmap reveals that yield tended to rise with increasing soil Zn and foliar Zn concentration, with the consistently higher numerical benefit for application at the boot stage. This pattern is compatible with an additive management interpretation.

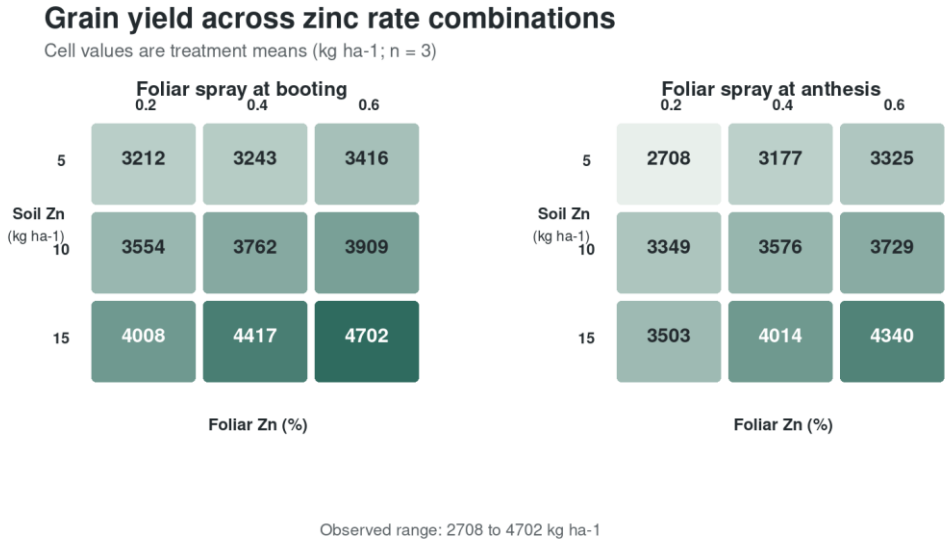

Figure 2 Grain-yield means for all 18 factorial Zn treatment combinations.

Table 2 Significance summary for final yield variables.

Variable	Soil Zn	Foliar Zn	Timing	Soil x foliar	Control vs. rest
Grains spike-1	***	***	**	NS	***
Thousand-grain weight	***	***	***	NS	***
Biological yield	***	***	**	NS	***
Grain yield	***	***	**	NS	***
Harvest index	NS	NS	NS	NS	NS

**** P <= 0.001; ** P <= 0.01; * P <= 0.05; NS, non-significant. All other two-way and three-way interactions were non-significant.*

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Discussion

The yield response was achieved by an increase in the number of grains, in grain mass and also in total biomass. Zinc is involved in reproductive development and function of pollen, and sufficient Zn will increase enzyme activity and assimilated movement during grain formation (Cakmak, 2008). The grains per spike and thousand-grain-weight increase suggests that Zn supply influenced sink establishment in addition to grain filling. The constant harvest index indicates that the crop did not simply allocate a constant amount of biomass to grain, rather Zn expanded the size of the whole production system.

The main effect gradient for soil Zn was the highest. The yield rose by almost one-third for every 5 kg Zn ha-1, with an increase in spike density, grains per spike and grain weight. This is in line with the improved root-zone Zn supply during the vegetative stage and the reproductive stage. The earlier studies conducted in calcareous soils also reported production benefits from soil Zn, but the optimum rate of soil Zn depends on the initial soil Zn and the cost of the fertilizer (Khan et al., 2010; Nawab et al., 2011). This is because no soil-test Zn data were reported in the present study and this rate of 15 kg ha-1 should be used as a best experimental rate rather than a universal recommendation.

The soil-rate response was also larger than the concentration response in the foliage although not as large agronomically. The increase in solution from 0.2 to 0.6% has increased yield of grains by 15.2%. Zinc sulphate sprays had similar positive impacts on wheat yield and grain characteristics in Zn deficiency and water stress (Esfandiari et al., 2016; Sattar et al., 2022). Foliar feeding can provide direct Zn to metabolically active tissues, though the availability of the foliar uptake is influenced by spray volume, weather, use of a surfactant and cuticular properties. Those details should be validated in the future relying on a uniform standard.

Booting was more effective than anthesis for grain yield in this experiment. The advantage in the grains per spike and biological yield was likely due to the time the booting treatment had to influence spike development, canopy function, and biomass before fertilization. Earlier studies did also show the effect of foliar micronutrients on yield was dependent on the stage of plant growth, with some showing yield benefits from foliar micronutrients for booting or pre-anthesis stage (El-Dahshouri et al., 2017; Sultana et al., 2016). If the goal is to enhance the grain Zn level, rather than high yield, then further sprays could be beneficial, since additional Zn can improve grain quality even if yield response is relatively low (Zarea & Karimi, 2023; Cakmak et al., 2010).

ISM resulted in maximum soil and foliar management data with maximum numerical yield, which is in accordance with other data that both types of management can complement each other (Nayak et al., 2023). All interactions were not significant, however. The proper inference is that the factors all acted in the same direction, not that the best combination created synergy in the statistical sense. It is important for recommendation development because farmers can achieve some benefit from the soil application or the lower-cost foliar program, or both, and partial budgeting is necessary in order to determine which program(s) will yield the highest profit.

The contrast with the control and rest was large, with the grain production being 71.5% higher in the treated plots. The magnitude indicates Zn deficiency under the

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experimental conditions but can also be attributed to the fact that all factorial plots were fertilised with both soil and foliar Zn whereas the control was not fertilised with either. The future design should incorporate soil-only, foliar-only and absolute control treatments at similar amounts of Zn to separate route efficiency more clearly. For multi-season experiments, additional measurements of grain Zn concentration, fertilizer recovery, soil residual Zn and economic return should be made to be able to evaluate yield improvement and biofortification together.

Conclusions

The combined effects of soil Zn rate, foliar Zn concentration and foliar timing resulted in improved grain productivity. Application of the highest soil rate increased soil biological and grain yields, the 0.6% foliar treatment resulted in increased grain weight, and grains per spike and strength of the grains, and booting-stage application was more effective than application at anthesis. The harvest index was not changed, indicating that increased biomass production and increased yield components, rather than changing allocation efficiency, caused yield increases. The foliar Zn at booting and soil Zn of 15kg ha^{-1} showed the highest treatment mean and is the best treatment option under the tested conditions, for yield-oriented production of Wadan-17. Before recommending broadly, soil testing, multi-season validation and grain Zn analysis and economic assessment are required.

References

Alloway, B. J. (2009). Soil factors associated with zinc deficiency in crops and humans. Environmental Geochemistry and Health, 31(5), 537-548. https://doi.org/10.1007/s10653-009-9255-4

Anees, M., Saljoqi, A.-U.-R., Shafiq, M., Hayat, H., Farooq, U., Khan, S., & Rehman, Z. U. (2026). Screening of different onion varieties against onion thrips and evaluation of botanical and chemical management strategies in District Charsadda, Khyber Pakhtunkhwa. Annual Methodological Archive Research Review, 4(6), 507–521.

Azeem, A., Ul-Allah, S., Azeem, F., Naeem, M., Sattar, A., Ijaz, M., & Sher, A. (2023). Effect of foliar applied zinc sulphate on phenotypic variability, association and heritability of yield and zinc biofortification related traits of wheat genotypes. Heliyon, 9(9), e19643. https://doi.org/10.1016/j.heliyon.2023.e19643

Cakmak, I. (2008). Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? Plant and Soil, 302, 1-17. https://doi.org/10.1007/s11104-007-9466-3

Cakmak, I., Kalayci, M., Kaya, Y., Torun, A. A., Aydin, N., Wang, Y., Arisoy, Z., Erdem, H., Yazici, A., Gokmen, O., Ozturk, L., & Horst, W. J. (2010). Biofortification and localization of zinc in wheat grain. Journal of Agricultural and Food Chemistry, 58, 9092-9102. https://doi.org/10.1021/jf101197h

El-Dahshouri, M. F., El-Fouly, M. M., Khalifa, R. K. M., & El-Ghany, H. M. A. (2017). Effect of zinc foliar application at different physiological growth stages on yield and quality of wheat under sandy soil conditions. Agricultural Engineering International: CIGR Journal, Special Issue, 193-200.

Online ISSN 3007-3197
Print ISSN 3007-3189

Esfandiari, E., Abdoli, M., Mousavi, S. B., & Sadeghzadeh, B. (2016). Impact of foliar zinc application on agronomic traits and grain quality parameters of wheat grown in zinc deficient soil. Indian Journal of Plant Physiology, 21(3), 263-270.

Farooq, U., Khan, S., Waqas, M., Jalal, F., & Bibi, S. (2026). Effect of different levels of phosphorus applied with biochar and poultry manure on maize yield and phosphorus use efficiency. Annual Methodological Archive Research Review, 4(6), 432–443.

Gul, H., Said, A., Saeed, B., Mohammad, F., & Ahmad, I. (2011). Effect of foliar application of nitrogen, potassium and zinc on wheat growth. ARPN Journal of Agricultural and Biological Science, 6(4), 56-59.

Jalal, F., Mian, I. A., Irfan, M., Hayat, H., Khan, S., Farooq, U., & Bibi, S. (2026). Biochar-assisted Bacillus inoculation reduces cadmium and lead bioavailability and enhances maize growth in contaminated soil. Annual Methodological Archive Research Review, 4(6), 497–506.

Khan, A. A., Khan, Z., Umar, M., Khan, N., Adnan, M., Khan, S., & Hassan, A. (2025). Assessment of physiochemical parameters and biological contamination in drinking water in Danish Abad Peshawar. Annual Methodological Archive Research Review, 3(8), 722-744.

Khan, A., Dawar, K., Jalal, F., Ayaz, M., Khan, S., Bibi, S., & Farooq, U. (2026). Mitigating heavy metal toxicity in maize under contaminated soil using spent mushroom substrate biochar and growth-promoting rhizobia. Annual Methodological Archive Research Review, 4(4), 552–565.

Khan, M. B., Farooq, M., Hussain, M., Shah, N., & Shabir, G. (2010). Foliar application of micronutrients improves the wheat yield and net economic return. International Journal of Agriculture and Biology, 12, 953-956.

Khan, S., & Khan, B. (2026). Assessment of drinking water quality using physicochemical parameters in Durbakheil, Tehsil Halimzai, District Mohmand, Pakistan. Annual Methodological Archive Research Review, 4(3), 443-460.

Nawab, K., Jan, A., Arif, M., Shah, P., Rab, A., & Khan, M. A. (2011). Effect of farmyard manure, potassium and zinc on phenology and grain yield of wheat in rainfed cropping systems. Pakistan Journal of Botany, 43(5), 2391-2396.

Nayak, S., Shivay, Y. S., Prasanna, R., Mandi, S., Parveen, S., Baral, K., & Reddy, K. S. (2023). Soil and foliar application of Zn enhances its biofortification, bioavailability and productivity in both biofortified and non-biofortified wheat varieties. Journal of Food Composition and Analysis, 124, 105691. https://doi.org/10.1016/j.jfca.2023.105691

Rehman, Z. U., Saljoqi, A.-U.-R., Sherin, T., Anees, M., Farooq, U., & Khan, S. (2026). Assessing the seasonal abundance and insecticidal efficacy of synthetic insecticides against the tomato leaf miner (Tuta absoluta). Annual Methodological Archive Research Review, 4(6), 478–496.

Sattar, A., Wang, X., Ul-Allah, S., Sher, A., Ijaz, M., Irfan, M., Abbas, T., Hussain, S., Nawaz, F., Al-Hashimi, A., Al Munqedhi, B. M., & Skalicky, M. (2022). Foliar application of zinc improves morpho-physiological and antioxidant defense mechanisms, and agronomic grain biofortification of wheat under

Online ISSN 3007-3197
Print ISSN 3007-3189

water stress. Saudi Journal of Biological Sciences, 29(3), 1699-1706. https://doi.org/10.1016/j.sjbs.2021.10.061

Steel, R. G. D., Torrie, J. H., & Dickey, D. A. (1996). Principles and procedures of statistics: A biometrical approach (3rd ed.). McGraw-Hill.

Sultana, S., Naser, H. M., Shil, N. C., Akhter, S., & Begum, R. A. (2016). Effect of foliar application of zinc on yield of wheat grown by avoiding irrigation at different growth stages. Bangladesh Journal of Agricultural Research, 41(2), 323-334.

Zarea, M. J., & Karimi, N. (2023). Grain yield and quality of wheat are improved through post-flowering foliar application of zinc and 6-benzylaminopurine under water deficit condition. Frontiers in Plant Science, 13, 1068649. https://doi.org/10.3389/fpls.2022.1068649

Zeidan, M. S., Manal, F. M., & Hamouda, H. A. (2010). Effect of foliar fertilization of Fe, Mn and Zn on wheat yield and quality in low sandy soils fertility. World Journal of Agricultural Sciences, 6(6), 696-699.